Guidelines for all SOLARIS developments

D1.1

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D1.1 – Guidelines for all SOLARIS developments

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Abstract	Deliverable D1.1 establishes comprehensive guidelines for the SOLARIS
Abstract	project, detailing the technical requirements, implementation
	methods, and testing strategies for work packages (WPs) 2 through 5,
	building on the grant agreement. It outlines each task's background,
	data and hardware requirements, implementation specifications,
	validation methods, and key performance indicators (KPIs), along with
	the roles of collaborating project partners. Additionally, it specifies data
	integration and interoperability standards, addressing both the needs
	of demonstration site operators and technology developers. The
	deliverable also provides an overview of the technical specifications for
	the four demonstration sites and their requirements, forming the basis
	for WP6 activities. It contextualizes the project's outcomes through
	nine use cases that link technology developments to real-world
	applications. Finally, it defines the project's KPIs, including their
	significance, calculation methods, required data, evaluation timelines,
	and partner responsibilities, ensuring a structured approach to
	achieving the SOLARIS project goals.





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List of SOLARIS Partners

Organization	Abbreviation
Danish Technical University	DTU
Heliocity	HELIO
Ubimet	UBI
Elliot Cloud	ELLC
emazys	EMA
Air6 Systems	AIR6
Wirtschaftsagentur Burgenland Forschungs- und Innovations GmbH	FIB
Eilat Municipality	EILAT
Public Power Corporation SA	PPC
Tekniker	TEK
Aalborg University	AAU
University of Genova	UNIGE
CIEMAT	CIEMAT
Euroquality	EQY





Table of contents

TABL	CONTENTS	5
LIST (GURES	е
LIST (ABLES	8
EXEC	E SUMMARY	10
1.	INICAL REQUIREMENTS AND SPECIFICATIONS FOR WORK PACKAGES 2, 3, 4, AND 5	11
1.1	TASK 2.1: ENHANCEMENT OF A WEATHER PREDICTION MODEL (INCL. SEVERE EVENTS) [UBI]	11
1.2	Task 2.2: Enhancement of a power prediction model [UBI]	
1.3	TASK 2.3: ENHANCEMENT OF A SEASONAL FORECASTS MODEL [UBI]	
1.4	Task 2.4: Enhance lifetime prediction using online condition monitoring in power electronics inverters [AA	
	19	
1.5	TASK 3.1 DUST AND WIND SMART SENSORS DEVELOPMENT AND OPTIMIZATION [TEK]	23
1.6	TASK 3.2 DEVELOPMENT OF STRATEGIES FOR DELAYED SOILING [TEK]	
1.7	TASK 3.3.1: DRONE IMAGING SOLUTIONS [DTU]	
1.8	TASK 3.3.2: DRONES PATH PLANNING AND OPTIMISATION, CONTROL AND COORDINATION [UNIGE]	52
1.9	TASK 3.4 DESIGN OF AN IMPEDANCE SENSOR DEVICE FOR RETROFITTING TO EXISTING POWER CONVERTERS [EMA]	70
1.1	TASK 3.5: DEVELOPMENT OF A NOVEL INVERTER DESIGN FOR RECONFIGURATION TO ENHANCE THE MAINTENANCE A	N[
INV	R AVAILABILITY [AAU]	75
1.1	TASK 4.1: DEVELOPMENT OF THE SMART IOT CONNECTIVITY FOR AUTOMATED MONITORING, INSPECTION AND MAINTENAN	۱CI
[EL	78	
1.1	TASK 4.2: DEVELOPMENT OF REDUCED ORDER MODELS FOR SELF-PROTECTION MECHANISMS [TEK]	85
1.1	TASK 4.3: DEVELOPMENT OF A FIELD CONTROL APP IN THE CONTEXT OF RECONFIGURABLE TOPOLOGIES [HELIO]	90
1.1	TASK 4.4: DEVELOPMENT OF THE FLEET MANAGEMENT TOOL BASED ON PREDICTIVE MAINTENANCE [HELIO]	93
1.1	TASK 4.5: DEVELOPMENT OF MODELS FOR STORAGE SIMULATION [TEK]	96
1.1	TASK 5.1: INTERCONNECTION AND INTEGRATION INTO A COMPREHENSIVE FORECASTING TOOL [UBI]	99
1.1	TASK 5.2: INTERCONNECTION AND INTEGRATION INTO A PV ASSET MANAGEMENT SOFTWARE [HELIO]1	02
1.1	TASK 5.3: DEVELOPMENT OF AN AI-BASED TOOL FOR THE OPTIMISATION OF THE ENERGY TRADING AT PLANT LEVEL [TEK] 1	07
1.1	TASK 5.4: MANUFACTURING AND PRELIMINARY TESTING OF THE IMPEDANCE SENSOR DEVICE FOR RETROFITTING TO EXIST	
PO	CONVERTERS [EMA]	
1.2	TASK 5.5: MANUFACTURING AND PRELIMINARY TESTING OF THE NOVEL INVERTER FOR RECONFIGURATION TO ENHANCE TO	
MA	NANCE AND INVERTER AVAILABILITY [AAU]	12
2.	A INTEGRATION AND INTEROPERABILITY SPECIFICATIONS1	14
2.1	INFORMATION REQUIRED FROM DEMONSTRATION SITES	14
2.2	INFORMATION REQUIRED FROM DEVELOPERS	17
3.	IONSTRATION SITES 1	24
3.1	Main contacts	24
3.2	DTU DEMO SITE	
	1. PV tracker Facility	
	2. Weather Station	
3.3	PPC DEMO SITE	30
3.4	EILAT DEMO SITE	39





3.4	4.1. Rabin PV Plant	139
3.	4.2. Agrivoltaics site	143
3.5	FIB DEMO SITE	146
3	5.1. General description	146
3	5.2. Energy Storage Competence Center	147
3	5.3. Agricultural College Güssing (LFS Güssing)	148
3	5.4. Living Lab Tobaj	150
3	5.5. Suggested Demonstration Activities for the FIB Demonstration	151
3.6	DATA AND REQUIREMENTS FROM PARTNERS	153
3.	6.1. AAU	153
3.	6.2. EMA	154
3.	6.3. UBI	
3.	6.4. UNIGE	
3.	6.5. HELIOCITY	
_	6.6. AIR6	
_	6.7. DTU	
3.	6.8. TEKNIKER	161
4. SP	PECIFIC USE-CASES TO BE INVESTIGATED IN THIS PROJECT	162
4.1	Her ever #4. [Full viers DV start increasing the province and automates and established	165
4.1 4.2	Use case #1 – [Enhanced PV plant inspection using drones and automated image analysis]	
4.2	Use case #2— [REMOTE PAILURE DETECTION AND QUANTIFICATION (PV ASSET MANAGEMENT SW)]	
4.4	USE CASE #3— [FIELD CONTROL APP (FV ASSET INJANAGEMENT SW)]	
4.5	Use case #5 – [Comprehensive forecasting tool]	
4.6	Use case #6 – [Enhanced PV Inverter availability using smart control for reconfigurable structure A	
_	ITION MONITORING]	
4.7	Use case #7— [Multi-aspect smart sensing for PV systems monitoring - Smart soiling sensors]	
4.8	Use case #8— [Wind smart sensing for PV lifetime and limit the time in defence position]	
4.9	USE CASE #9— [ANTISOILING CLEANING FLUID]	
5. KE	EY PERFORMANCE INDICATORS	1//
5.1	OVERVIEW OF SOLARIS KPIS	177
5.2	DESCRIPTION OF KPIS AND METHODS OF EVALUATION	179
List	of figures	
Figure	1.4-1. Conventional method for lifetime prediction in PV inverters	19
	1.4-2. Online accurate lifetime prediction for the PV inverter	
_	1.5-1. TEK dust sensor illustration and operating principle	
_		
_	1.6-1. Solar panel cleaning methods	
	1.7-1. Example of PV module failures detectable by visual inspection: a) discolora	
& d) d	elamination; c) glass breakage; e) soiling; f) shading	43







Figure 1.7-2. Examples of PV module failures detectable with IR: a) glass breakage;	
c)cell hot spot; d) shading; e) shortcircuited bypass diode; f) PID.	
Figure 1.7-3 Stationary electroluminescence imaging: a) setup for performing EL inclu	_
camera and biasing power supply; b) PV panel/array operating mode during EL imag	
the PV is forward biased beyond the open circuit voltage (Voc).	
Figure 1.7-4 An example of an EL nighttime inspection performed with a stationary EL	
an EL image of a PV module with two shunted cell substrings and b) a PV string a	=
potential induced degradation	
Figure 1.7-5. Principle of Daylight EL inspection using bias modulation and signal	lock in: a)
stationary EL inspection setup for daylight application; b) types of PV bias modulation v	vaveforms
that can be used	45
Figure 1.7-6. Example of drone based EL inspection results: a) raw EL images taken du	ring flight;
b) post processed EL images taken with the drone	46
Figure 1.7-7. Example of daylight EL imaging performed at DTU: a) stationary EL inspect	tion setup;
b) drone EL inspection setup.	46
Figure 1.7-8. Example of daylight PL imaging using inverter modulation performed	at DTU: a)
Daylight PL setup; b) PV biasing principle for performing PL inspection, PL images are to	aken when
the PV is operating at Voc and Pmax or Isc, in quick succession; c) post-pro	47
Figure 1.7-9. Types of equipment used in the visual, IR and EL inspection: a) DJI Mavid	3 VIS and
IR drone; b) Custom DJI Matrice 600 EL drone. c) Airborne Robotics DRSolar drone; d)	DC power
supply for string bias modulation; e) string inverter capable of modulation	=
Figure 1.7-10. Illustration of the Diagnostic Image PV Inspection system develope	
package 3	
Figure 1.7-11. Layout of the DTU PV plant test facility	
Figure 1.8-1. Example images from the Amir database	52
Figure 1.8-2. Schematic of the data processing method in [7]	
Figure 1.8-3. Boustrophedon movement on a segmented PV plant	
Figure 1.8-4. The quadrotor concept. The width of the arrows is proportional to the ang	
of the propellers	-
Figure 1.8-5. Image pre-processing example	
Figure 1.9-1. Installation of the mobile test device in a PV system	
Figure 1.9-2. Schematic of the Emazys mobile test instrument	
Figure 1.10-1. AAU reliability test system and the proposed reconfigurable inverter t	
Figure 1.15-1. Example of California's electrical load curve, due to overproduction of sc	
at midday leading to low electricity prices for produced solar	
Figure 1.15-2. Diagram of the storage selection tool ilustrating inputs and output	
Figure 1.18-1. Diagram of the energy trading tool developed in Task 5.3	
Figure 3.2-1 Layout of the DTILRisk PV plant	125







Figure 3.2-2. Location of sensors in DTU PV plant	128
Figure 3.3-1. Bitakos PV plant located in Thebes, Central Greece.	130
Figure 3.3-2. Ground plan of Bitakos PV plant	131
Figure 3.3-3. Distribution Panel at the Bitakos PV Plant	131
Figure 3.3-4. Closer look at the PV panels of the Bitakos PV plant	132
Figure 3.3-5. Electrical Performance and Temperature Dependance of PV modules	133
Figure 3.4-1. Rabin PV plant located in Eilat, South Israel	
Figure 3.4-2. Ground plan of Rabin PV plant	
Figure 3.4-3. EILAT Agrivoltaics site photo #1	
Figure 3.4-4. EILAT Agrivoltaics site photo #2	144
Figure 3.4-5. EILAT Agrivoltaics site photo #3	145
Figure 3.5-1. Overview of the FIB test sites	146
Figure 3.5-2. Representation of the FIB real-time monitoring system	147
Figure 3.5-3.Picture of BESS1	148
Figure 3.5-4. Picture of BESS2	148
Figure 3.5-5. Overview of the agricultural college campus in Güssing	149
Figure 3.5-6. Layout of the research plan in the agricultural college in Güssing	150
Figure 3.5-7. Scheme of the Living Lab Tobaj demonstration site	151

List of tables

Table 1.6-1. Requirements and specifications of demo-sites for anti-soiling clear	ning fluic
developmentdevelopment	41
Table 1.7-1. Summary of controlled failures in strings 7.1 and 7.2 at the DTU PV Test Fa	cility 49
Table 1.8-1. Aerial drones to be considered in the prototypal stage	62
Table 1.8-2. Requirements of the PC to be used for path-planning and for supporting	g onboard
computations for drone visual servoing	63
Table 1.8-3. Software libraries and other third-party software for optimization, simula	tion, real
time segmentation	63
Table 1.8-4. Data required from SOLARIS partners	64
Table 1.8-5. Algorithm for computing the optimal path on a PV plant using heuristic a	Igorithms
for solving the TSP – even in presence of multiple agents	64
Table 1.8-6. Algorithm for visual servoing over PV panel rows	66
Table 1.17-1. Necessary data input for integration in the HELIO PV Asset management	software
	103
Table 2.1-1. General information from pilot sites	114
Table 2.1-2. Measurements available in the pilot sites	115









Table 2.2-1. Data outputs from the dust sensor	. 117
Table 2.2-2. Data outputs from the wind load sensor	. 117
Table 2.2-3. Data outputs from the novel inverter	. 117
Table 2.2-4. Data inputs from the Comprehensive forecasting tool	. 118
Table 2.2-5. Data inputs from the Energy trading tool	
Table 2.2-6. Data outputs from the Energy trading tool	. 120
Table 2.2-7. Data inputs from the Storage sizing tool	. 120
Table 2.2-8. Data outputs from the Storage sizing tool	. 121
Table 2.2-9.Data inputs from the PV Asset Management Software	
Table 2.2-10. Data outputs from the PV Asset Management Software	. 123
Table 3.1-1 List of Demo Site responsible	. 124
Table 3.2-1. DTU Risø PV plant array distribution	. 125
Table 3.2-2. DTU PV Plant Soltec tracker characteristics	. 127
Table 3.2-3.DTU weather sensors and their measurements	. 129
Table 3.3-1. Technical specifications of PV modules	. 133
Table 3.3-2. Technical specifications of the Inverters	. 134
Table 3.3-3. Environmental sensors of Bitakos PV plant	. 136
Table 3.3-4. Indicative Factors of Energy Production Data	. 136
Table 3.4-1. Environmental sensors of Rabin PV plant	. 141
Table 3.5-1. Demonstrated SOLARIS solutions in the AT Demo-Site	. 151
Table 3.6-1. List of task partners with data and demonstration activities	. 153
Table 3.6-2. Summary of HELIO data and demonstration requirements	. 157
Table 3.6-3. Demo site requirements for DTU and AIR6 Drone inspection demonstration	. 160
Table 5.1-1. KPI revision man	177







EXECUTIVE SUMMARY

Deliverable D1.1 *Guidelines for all SOLARIS developments* is a collaborative effort between all the SOLARIS project partners, and aims to add the necessary context, details on the implementation and methods for testing of the project tasks in work packages 2 through 5, with the grant agreement as basis and starting point.

To this end, in section 1 *Technical requirements and specifications for work packages 2, 3, 4, and 5,* each task leader has provided details at task level regarding the: task *background, data and hardware requirements* of each task, *technical specifications* for implementation of the task, *method for testing and validation* of the task implementation/result, *KPIs* for assessment of the task outcomes, and *role of the other project partners* in the respective tasks.

Section 2 of the deliverable details the *data integration and interoperability specifications* within the project, as they can be estimated at this point, both from the perspective of the demonstration site operators as well as from the perspective of the technology developers in this project.

Section 3 summarizes the main technical specifications of the four demonstration sites (DTU, PPC, FIB, EILAT), as well as specific data and demonstration requirements from the technology developer partners (AAU, EMA, UBI, UNIGE, HELIO, AIR6, DTU, TEKNIKER) from these sites, as they can be foreseen at this point, and which will be used as a basis for WP6.

Section 4 presents the 9 uses cases at the core of the SOLARIS project results and outcomes, putting in context the technology developed by each project partner, with the real-world application and testing of this technology.

Section 5 provides details on the main project key performance indicators (KPI), in terms of description and significance, method of calculation or measurement, necessary data and tools, literature context for the KPI, timelines and demonstration site for evaluation, role of the project partners and eventual contingencies.





1. Technical requirements and specifications for work packages 2, 3, 4, and 5

1.1 Task 2.1: Enhancement of a weather prediction model (incl. severe events) [UBI]

Background

The current state-of-the-art in technological solutions for forecasting, particularly in weather prediction, leverages advanced computational models, data assimilation techniques, and statistical methods. UBIMET's weather forecasting system integrates deterministic and statistical models for highly accurate forecasts across different spatial and temporal scales. The system offers ultra-short forecasts, crucial for applications requiring updates within an hour, as well as extended forecasts covering several days. The core technology involves a consolidated multi-model approach that enhances forecast quality by combining a high-resolution local numerical weather prediction (NWP) model with real-time data assimilation. This NWP model is optimized for phenomena like convection, which is essential for anticipating thunderstorms and precipitation, and integrates physical post-processing for downscaling forecasts to specific topographical regions. For forecasts extending beyond twelve hours, global models such as the ECMWF's IFS and ICON-D2 from Germany complement the NWP model. Together, these models form a robust forecasting system with high spatial (2x2 km) and temporal (hourly) resolution, aiming to outperform traditional numerical models by addressing systematic errors through model output statistics.

Despite significant advancements, the development of high-precision forecasting solutions for PV systems faces several challenges.

- First, the computational demands are significant; forecasting models requiring continuous data cleaning, multi-model cores, and AI-driven nowcasting—demand extensive computing power, which can be costly and resource-intensive.
- Data quality and integration are also hurdles, as high-accuracy forecasts depend on reliable and consistent input from diverse sources, such as radar, satellite, and ground observations. Managing this data with robust quality controls is essential to maintain forecast accuracy.
- Achieving fine-scale accuracy in complex terrains or rapidly changing weather conditions remains challenging, even with advanced downscaling methods aiming for 100 m resolution. Limited access to local observational data can hinder precise forecasting, especially in varied landscapes.







• Finally, self-learning components like Model Output Statistics (MOS) require constant updates to adapt to evolving weather patterns, and maintaining model accuracy through retraining is a resource-intensive process. Balancing local and global data in AI models also demands ongoing refinement for optimal performance.

Data and hardware requirements

The entire system will leverage high-performance computing resources, with 160 server nodes, to support complex processing needs, enabling accurate and timely weather forecasts critical for optimizing PV operations. The data from external global models and radar data is partly purchased or freely available.

Required data inputs from demo partners are:

 Additional weather data from DTU generated by their own weather station (live data and optional also historical data)

Data inputs must align with the requirements defined for the demonstration sites in section 2.2 under section "Comprehensive forecasting tool" and section 3.6.3, "Data and requirements from partners".

Technical specifications

In SOLARIS, the focus is on developing highly precise forecasting methods to support PV asset management. The enhancement of the weather prediction model aims to provide high-resolution, accurate predictions of weather conditions that affect solar power output, enabling better operational decision-making, predictive maintenance, and optimized energy production.

Inputs: The model will utilize a range of meteorological and environmental data to ensure accurate forecasts. Key inputs include current weather observations (temperature, wind speed, precipitation) from ground stations, radar images for short-term predictions, satellite data for cloud formations, and visual data from ground-based cloud cameras (e.g., at DTU). Additionally, historical datasets of observed weather variables will be used for model training and evaluation, alongside environmental factors such as air quality data and parameters like turbidity and sun position derived from NWP models.

Outputs: The model will generate a variety of forecasts tailored for PV systems. This includes short-term forecasts (up to 12 hours) at approximately 15-minute intervals and mid-term forecasts (up to 13.5 days) with hourly updates. Outputs will cover solar radiation forecasts with fine spatial resolution, temperature, wind speed at different heights, and cloud cover information, all essential for effective PV asset management.

The operational methodology will focus on robust data cleaning and quality management using big data analytics to ensure reliable inputs. A consolidated multi-model core will employ







advanced observation-based algorithms and Model Output Statistics (MOS) to improve forecasting accuracy. The model will also implement dynamic and statistical downscaling techniques to enhance spatial resolution, integrating environmental factors to assess their impact on PV performance.

Method for testing and validation

Since the calculation of meteorological models involves particularly complex processes in which minor changes in initial conditions can have a major impact, there is also a great need for a regular and standardized review of the quality of the forecast data output by the models used and calculated. Essentially, this quality control involves comparing the forecasts for various parameters provided by a model provider or calculated by UBIMET itself with the observed data at various locations for different time periods.

KPIs for assessing performance of the developed models, tools and hardware

This task is covered by the following KPI, detailed in section 5.2:

• KPIO1.1: Improvement of weather forecasting accuracy based on verification & skill scores (RMSE, CSI, Brier Score) (vs. Available forecast – GFS, ECMWFS, ICON-D2)

Role of project partners

The technical part of the task will be fully done by UBIMET. No additional input from project partners is needed.





1.2 Task 2.2: Enhancement of a power prediction model [UBI]

Background

UBIMET's power prediction process for PV plants is based on a range of Numerical Weather Prediction (NWP) models, which simulate relevant atmospheric conditions. These NWP models forecast solar irradiance, temperature, humidity, and other key parameters that influence solar energy generation, drawing on meteorological data from diverse sources. Forecasts cover timeframes from two hours up to 10 days, providing an estimate of potential solar power production over different intervals.

To translate weather forecasts into power output estimates, forecasted irradiance and weather conditions are aligned with the specific performance characteristics of the PV panels in each plant. This enables a model of the relationship between solar irradiance and expected power output. Finally, statistical or machine learning-based post-processing techniques refine the raw forecasts to improve accuracy.

Developing a robust PV power prediction solution faces several key challenges:

- Variability and predictability of renewable sources: solar power generation is inherently
 variable due to weather fluctuations, seasonal changes, and long-term climate trends.
 These factors create unpredictability in energy output, often leading to mismatches
 between supply and demand, complicating effective energy forecasting.
- Grid integration and stability: integrating PV power predictions into energy grids requires
 careful management to maintain stability. Challenges include scheduling energy dispatch
 to match fluctuating generation levels, and ensuring forecasts can scale from single PV
 installations to national grids without disrupting grid operations.
- Data quality and availability: reliable predictions depend on high-quality, real-time meteorological and operational data, which can be inconsistent or delayed. Additionally, integrating diverse data sources into a single forecasting model is complex and requires robust data handling to avoid forecast inaccuracies.

Data and hardware requirements

The entire system will leverage high-performance computing resources, with 160 server nodes, to support complex processing needs, enabling accurate and timely weather forecasts critical for optimizing PV operations. The data from external global models and radar data is partly purchased or freely available.

Required data inputs from demo partners are:

 Historical monitoring data: Historical data on the generated electrical power with a resolution of 15 minutes for a period of at least 2 years would be desirable







- Information about master data for PV demonstration site(s): type of PV plant, installed performance, orientation of the panels or information on whether they follow the position of the sun, coordinates of the location of the PV system
- live data or near live data on how much electrical energy is currently being produced (optional)
- Additional weather data from DTU generated by their own weather station (live data and optional also historical data)

Data inputs must align with the requirements defined for the demonstration sites in section 2.2 under section "Comprehensive forecasting tool" and section 3.6.3, "Data and requirements from partners".

Technical specifications

The developed PV power prediction model combines physical models, hybrid approaches, and deep learning to deliver both immediate and seasonal power forecasts tailored to PV plants.

Inputs: It uses weather model outputs—such as solar irradiance, cloud cover, and aerosols—along with the specific characteristics of PV panels like location, orientation, and power curves. These inputs, combined with historical generation data, enable accurate short-term forecasts that update in real time and extend to seasonal predictions spanning up to seven months.

Output: The model outputs are integrated into energy trading tools, supporting strategic trading based on predicted power generation.

Method for testing and validation

The model's performance is continuously validated and benchmarked against observations and reanalysis data.

KPIs for assessing performance of the developed models, tools and hardware

This task is covered by the following KPI, detailed in section 5.2:

 KPI2.2: Improvement of power generation forecasting accuracy (vs. Traditional physical forecast)

Role of project partners

HELIO will focus on forecasting intra-hour power production for the DTU demonstration site, leveraging its digital twin technology. Using weather forecasts provided in T2.1, HELIO's digital twin will model short-term power output with a high degree of accuracy.

The outputs of HELIO's digital twin will be benchmarked against UBIMET's machine learning algorithms to evaluate performance and accuracy. This comparative analysis aims to identify the







strengths of each approach and guide improvements. Results and insights from this benchmarking will be compiled in report D2.1.







1.3 Task 2.3: Enhancement of a seasonal forecasts model [UBI]

Background

State-of-the-art seasonal forecasts, such as those by ECMWF, use ensemble runs—multiple simulations with different boundary conditions. However, due to limited model resolution, they struggle to accurately predict extreme weather events.

UBIMET, however, has made progress in medium-range forecasting with two initial, specialized models. One model estimates the probability of cyclones in Australia, addressing a critical regional weather risk, while another focuses on snow-water equivalent predictions. This second model is used to forecast power output for pumped storage hydroelectric plants, showcasing a practical application of meteorological data in energy forecasting.

Barriers to Development:

- Model Resolution and Computing Power: Higher resolution needed for extreme events requires significant computing resources.
- Data Quality and Geographic Gaps: Accurate extreme event forecasting relies on comprehensive, high-quality data, which can be scarce in remote areas.
- Complexity of Extreme Events: Extreme weather is inherently difficult to predict due to complex, nonlinear dynamics.
- Operational Integration: Implementing these new models into existing systems and ensuring reliable, actionable forecasts remains challenging.

Data and hardware requirements

The entire system will leverage high-performance computing resources, with 160 server nodes, to support complex processing needs, enabling accurate and timely weather forecasts critical for optimizing PV operations. The data from external global models and radar data is partly purchased or freely available.

Required data inputs from demo partners are:

 Additional weather data from DTU generated by their own weather station (live data and optional also historical data)

Data inputs must align with the requirements defined for the demonstration sites in section 2.2 under section "Comprehensive forecasting tool" and section 3.6.3, "Data and requirements from partners".







Technical specifications

The focus is on the development of a seasonal forecasting model that assesses the long-term profitability of PV plants and predicts extreme weather impacts on them using physical downscaling and statistical techniques. For each demonstration site, it will evaluate different climate scenarios up to 2070. Extreme weather events will be modeled with clustering and generative methods, mapping critical weather patterns onto climate projections with hourly resolution to forecast variations in solar power and production.

Inputs include meteorological data (irradiation, turbidity, cloud coverage, aerosols), historical power generation time series, and reanalysis of climate variables.

Outputs will provide seasonal forecasts, risk scenarios for extreme events, and production estimates. These forecasts will feed into asset management for optimized maintenance and into energy trading tools for long-term strategy.

Using hybrid machine learning models that combine historical and real-time data, the forecasts will be updated every six months to capture seasonal and weather-related variability. This information is shared with operators to guide decision-making, enhance site resilience, and improve profitability through risk-informed adjustments in energy production and dispatch planning.

Method for testing and validation

Validation will occur by comparing forecasted versus actual production at set intervals, enabling the model to refine predictions for better accuracy and reliability in asset management and trading.

KPIs for assessing performance of the developed models, tools and hardware.

This task is covered by the following KPI, detailed in section 5.2

 KPIO1.1: Improvement of weather forecasting accuracy based on verification & skill scores (RMSE, CSI, Brier Score) (vs. Available forecast – GFS, ECMWFS, ICON-D2)

Role of project partners

The technical part of the task will be fully done by UBIMET. No additional input from project partners is needed.







1.4 Task 2.4: Enhance lifetime prediction using online condition monitoring in power electronics inverters [AAU]

Background

The inverter lifetime can be predicted in two ways, online condition monitoring and off-line mission profile analysis. In the first option, the state of health is monitored, but it is valid just for the device under test. However, there are various uncertainties over the devices and lifetime parameters. Thus, the reliability and lifetime prediction by condition monitoring cannot show the statistics on inverter failure. This is required for large scale PV power plants with high number of inverters to optimize the maintenance and spare units.

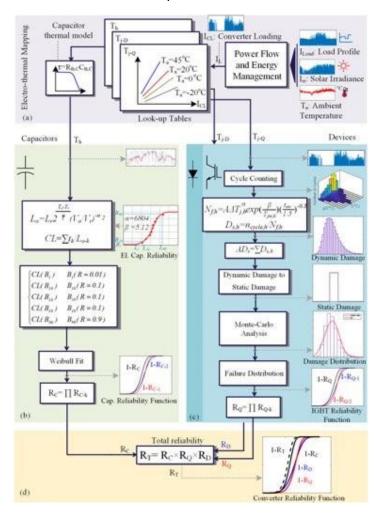


Figure 1.4-1. Conventional method for lifetime prediction in PV inverters

To address this issue, the second solution has been introduced as shown in the figure below. In this approach, the experienced damage over the device is calculated under the given stress level that is called mission profile. In this analysis, the uncertainties of various parameters are modeled







using Monte Carlo simulations. The main issue here is that everything is offline and if the applied stress is changed, that happens in practice, this method cannot capture its impact. In this project, we will develop a hybrid method that will use condition monitoring and mission profile analysis to accurately predict the lifetime of PV inverters as shown in the figure below.

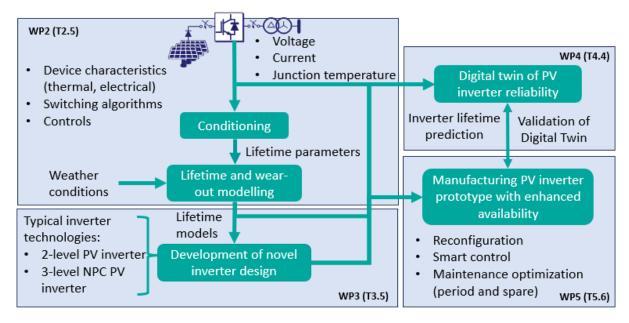


Figure 1.4-2. Online accurate lifetime prediction for the PV inverter.

AAU will develop accurate physics-of-failure-based lifetime prediction models to predict the aging of power inverters prone to wear-out failures using condition monitoring signals in 2 types of commercial PV inverters (2- level H-bridge and 3-level NPC). To do so, AAU will: 1) Develop physics-of-failure-based reliability models for PV inverters using mission profile analysis considering operating conditions, weather conditions, control strategies to predict the lifetime of the inverter; 2) Develop conditioning approaches to predict the state of the health of inverters using power signals including voltage, current, harmonics and directly measured lifetime related signals including on-state voltage of power devices and temperature/voltage of capacitors; 3) Develop reliability models tuning method using condition monitoring signals from the power inverters. The physics-based reliability models will be updated according to the real state of health of individual inverters. These models will serve as basis to T4.4 for the development of the online tool for predictive maintenance.

Data and hardware requirements

- Mission profile:
 - 1. predicted power (we need these data with 1-15 min resolution)
 - 2. seasonal forecast (we need these data with 1-15 min resolution)







Technical specifications

The following measurements are required:

Current sensors: 3

Voltage sensors: 3

• Voltage sensors for VCE: 8/16 depends on selected inverter topology

Provided data	Resolution
DC voltage	40ms window, 2 kHz sampling frequency
DC current	40ms window, 2 kHz sampling frequency
AC voltage	40ms window, 2 kHz sampling frequency
AC current	40ms window, 2 kHz sampling frequency
V_{CEon}	10s window, 1 Hz sampling frequency

Method for testing and validation

The inverter lifetime model will be tested and validated in the AAU reliability lab. The inverter will be run for short period with high stress and manual damage will be implemented in the IGBT to accelerate the aging (due to the time limit in the project) and the IGBT lifetime will be monitored with measuring VCE-on and will be compared to the proposed mathematical model developed in this project.

In practice measurement of the lifetime of the Power Electronics converters (or any devices) require long term operation, that is not practical due to the time limitation. For this reason, in SOLARIS, we will have two methods to measure the lifetime enhancement of the PV inverter lifetime. First, we will use laboratory tests to demonstrate that our advanced control and reconfiguration solution will decrease the thermal stress on the inverter semiconductor devices in short term operation. We will use these test data to validate our lifetime model, and then we will use long term mission profile simulations to demonstrate the lifetime enhancement for long term operation.

KPIs for assessing performance of the developed models, tools and hardware.

This task is covered by the following KPIs, detailed in section 5.2:

• KPI 1.7ii: Prolonged lifetime of inverters







Role of project partners

AAU will develop the enhanced lifetime model with collecting data from DTU and UBIMET.

AAU will develop this task by itself, getting weather prediction data (solar irradiance and ambient temperature) from UBIMET and DTU and power prediction data from UBIMET.







1.5 Task 3.1 Dust and wind smart sensors development and optimization [TEK]

Background

Dust sensors

The efficiency loss of PV panels due to dust accumulation can vary depending on several factors, including the type and amount of dust, environmental conditions, and panel design. Efficient (in performance and in cost-effectiveness) measurement of soiling level is still a topic under research for the PV sector.

Some approaches have been proposed, e.g. by comparing power output from a clean module (periodically washed) to the real output in production modules, by using complex optical integration modules with embedded cameras or through a combination of sensing techniques. Yet, field testing campaigns with data collection and performance analysis are required to enable the evolution of such technologies. Two-panel based systems that follow this concept, with PV modules identical to the ones used in the PV plant and cleaned every day exist, yet they are an expensive and cumbersome solution and more difficult to integrated among the real PV modules, which may result in soiling differences. Also, these approaches suffer from the lack of correlation models between the sensor signals, actual soiling and power output.

Other solutions, such as the market available DustIQ System dust sensors by Kipp & Zonen, are large and are integrated in the PV systems. It means that their calibration needs to be done onsite in not ideal light condition, which can imply some deviations and inaccuracies. This often makes this sensor solution expensive and not easy to deploy in the field. More compact solutions, such as the Mars Soiling Sensor by Atonometrics, are based on image analysis to determine transmission loss due to soiling and require diffuse lighting to operate. This limits their data gathering to sunset. This solution also lacks the option to create daisy chain sensor lines.

TEK has previously developed a soiling sensor prototype within the framework of the H2020 WASCOP (1st design, TRL3/4) and H2020 SOLWARIS (2nd design, TRL3/4) projects. This sensor relies on the projection of a controlled infrared light beam under the dust in a sensitive transparent substrate and the measurement of the scattered light from the particles. Although there were plans to carry out field trials of the second sensor design, these were cancelled due to demo site availability problems, so the sensor prototypes did not go beyond the laboratory testing phase.

TEK's sensor offers the following advantages over the commercial solutions present in the State-of-the-art previously mentioned:

Operation at accurate signal levels under broad environmental conditions







- Autonomous independent operation, does not require independent cleaning, unlike the two-panel based solutions
- More compact design, more integration options and lower estimated cost than the DustIQ System solution
- Does not require the presence of sunlight for operation, its data gathering period is not limited to dusk and is compatible with daisy chain interconnections, unlike the Mars Soiling Sensor.

all this while maintaining some of the advantages present in the commercial sensors, i.e. the absence of moving parts,

As part of the novelty beyond the state-of-the-art, SOLARIS will support new research on efficient low-cost systems for soiling detection through the following main improvements to be brought on TEK's design for soiling detection prototypes:

- Development of easy and non-invasive installation and management procedures for seamless site deployment
- Robust calibration and continuous low-cost operation for soiling measurement
- Analysis of weather effects, of correlation of sensor signals, actual soiling and power output and subsequent definition of soiling detection algorithms

Building on the state-of-the-art, the prototype will be installed in a selection of the demonstration sites available for long-term field testing and validation (>10 months).

Wind smart sensors

Mechanical integrity of Photovoltaic (PV) modules plays an important role in their performance and electrical output. The mechanical integrity is greatly influenced by its design, type of material used, the manufacturing process, and the method of handling during transportation [1]. Furthermore, it is also affected by environmental conditions and the loads applied on it, like the mechanical load due to wind, snow, rain and hail, or the thermal loads due to temperature variation. These loads tend to degrade the performance of the PV module by generating stresses and enhancing micro cracks and defects; finally, this results in increased resistance to the flow of electric current and the reduction of the power output of the modules [2][3]. Furthermore, the degradation of the panel results not only on efficiency issues in the electric power generation but also a reduced lifetime.

Wind can act steadily and transiently, imposing static and dynamic loads on PV modules. Depending on the wind direction, cells may be under compression or tension, being the tension stress the main factor for the degradation of the panels [4].







The preservation of the integrity of the panel is an important issue to maintain the productivity and the lifetime, so methods to protect the panels against wind loads have been investigated and developed. The effect of the wind in flat plates have been studied in the past, experimentally and numerically [5]. In those studies, the static and dynamic effects of the wind for different velocities and tilt angles of the flat plate were studied in detail. The static forces that the wind induces on a solar array are decomposed into drag (parallel to the ground) and lift (perpendicular to the ground) forces, which create a torque about the support bar, also deforming the panel.

The most challenging point in the structural design of solar trackers is to consider the dynamic effects of the wind, as it can produce damage in the structure by different mechanism, such as resonant vibration and the torsional flutter or galloping [5], being the first related to the structural vibration modes and the second to self-excited aerodynamic instabilities.

The damage as a result of the dynamic wind loads has been treated mainly from the frequency of vibration point of view, linking the stress to the modal shapes of the panels and the excitation of the main modes [6][7]. So, strategies to improve the behaviour of the modules normally involve the lowering of the natural frequencies and the increase of the damping, that can be performed by the increase of the tracker length, the reduction of the cord length and the general improvement of the torque tube of the actuation [8], but this measured counteract between leading to non-desired effects and the increased demands in the structural part of the modules.

The wind gusts produce surface loads in the panels and torsional motion in the modules, that lead to vibrations and stress that could damage the modules. Furthermore, the aerodynamic aspects are relevant, as they also affect the way the loads are applied on the module and its behaviour [8]. So, the configuration of the modules, the mechanical structure and the position (i.e. tilting angle) significantly affect the integrity and the lifetime of the modules.

Many studies have analysed the wind loads on solar panels to improve the safety of the design [9]. The first row of solar panels provides a sheltering effect that reduces the wind load on other rows, the individual panel are more exposed to wind load, the wind load on a solar panel is affected by the longitudinal spacing rather than the lateral spacing, the critical incidence angle at low tilting angles, or the use of windbreaks to reduce the wind load. So, the angles of the panels and the wind direction influences the forces applied on the panel [10], being the 0 pitch angle the best orientation for reducing the bending moment, while low tilt angles could reduce the normal force. However, the low angles tend to suffer aeroelastic instabilities producing galloping.

The monitoring of the PV panels and modules has not been treated extensively. The wind pressure in a set of modules can be monitored using pressure sensors in both sides of the panel in a wind tunnel to monitor the drag and lift forces [9]. The current available products estimate the wind load based on coefficients obtained from wind tunnel test [8] and not based on actual







forces acting on the panel or the module structure; but the motor consumption is used to test the torsion of the main torque tube during design phases [8].

The stow management strategies are focused on the definition of positions to minimize the effects of the wind loads and other (snow, hail...), but the optimum is not clear if several effects are present simultaneously. Furthermore, the optimum value for wind loads depends not only on the panel area but on the structure of the module due to the different effects of the static, the dynamic and the aeroelastic loads [8]. The tracker is controlled and sent to the stow position based on the information about the wind speed and direction of the available sensors. Alternatively, this can be commanded manually by the operators. Even in the stow position the wind loads could result in uncontrollable movement due to resonant modes or galloping. So, there could be different stow positions depending on the wind speed and direction, or it could be necessary to change the stow position to break the forced or regenerative vibrations.

- [1] R. M. Gul et al., The impact of static wind load on the mechanical integrity of different commercially available mono-crystalline photovoltaic modules. Engineering Reports. 2020;2:e12276. https://doi.org/10.1002/eng2.12276
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- [5] D. Valentín et al. Failure investigation of a solar tracker due to wind-induced torsional galloping. Engineering Failure Analysis 135 (2022) 106137. https://doi.org/10.1016/j.engfailanal.2022.106137.
- [6] Višniakov N, et al. Low-cost experimental facility for evaluation of the effect of dynamic mechanical loads on photovoltaic modules. Eksploatacja i Niezawodnosc Maintenance and Reliability 2015; 17 (3): 334–337, http://dx.doi.org/10.17531/ein.2015.3.2.
- [7] Bergmann, S., et al. (2020). On a Fast Analytical Approximation of Natural Frequencies for Photovoltaic Modules. Technische Mechanik. 40. 191-203. 10.24352/UB.OVGU-2020-025.
- [8] Trina trackers. Strategies to Mitigate Risks Associated to Wind Loads in Trackers Compatible with Large-Format Modules. Document Nº TDMS-003-V1. May 2021







[9] Seok Min Choi, et al. Effects of wind loads on the solar panel array of a floating photovoltaic system — Experimental study and economic analysis. Energy, Volume 256, 2022, 124649. https://doi.org/10.1016/j.energy.2022.124649.

On-going PV systems initiatives on similar topics

Dust sensors

https://cordis.europa.eu/article/id/442910-solving-solar-panels-dirty-problem

https://www.plumtri.org/Project-DustPV

https://thinkmagazine.mt/maximising-solar-panel-efficiency-the-dustpv-project/

Wind smart sensors

Currently the wind load management is faced by numerical and experimental analysis to improve the PV and tracker design, based on standard weather stations and wind sensors located in specific position of the plant. There is no specific products for directly monitoring the PV panel with low cost sensors and the assistance to the defence control algorithms.

In the scientific journals, some similar approached can be found, like "N. T. Hoa et all; Improved Design of Automatic Solar Tracking System based on Integration of Accelerometer, Compass Sensor, and GPS. Int. J. Com. Dig. Sys. 12, No.1 (Jul-2022)".

Potential barriers to the development of the solutions

Dust sensors

There is no barrier to the technical development of the dust sensor as prototypes are already available. The main barrier lies at the operational level: deploying and collecting data, planning validation tests and timelines, etc. In other words, the need to conduct field studies large enough to generate results and Solaris is the ideal context for this.

In terms of possible market barriers to the deployment and implementation of the technology, for anyone to want to adopt it, these would also be linked to the need to generate results and technical evidence of sensor response.

Wind smart sensors

The main potential barriers are:

- The obtaining of suitable information relating the mechanical behaviour of the panel and the wind loads applied.
- The installation of a set of sensors able to monitor the PV at low frequencies to assess the response against wind loads and the potential damage.







- Depending on the final set of sensors required, the cost could be a potential drawback for industrialization.
- The control algorithm's ability to provide a fast and suitable response to the variable wind loads. i.e. avoiding unstable response, not achieving a fixed defence position.

Data and hardware requirements

Dust sensors

TEK's sensors provide an evaluated percentage value based on a scattering measurement from the sensitive surface of the sensor. This value should be 100% when the sensitive surface is totally clean and 0% when the sensitive surface is covered by a white tile that is used as a reference for the maximum scattering to be measured.

The objective of the tests to be carried out by project partners in the selected sites will be to obtain the required data that will allow to:

- Evaluate on site real dust levels on PV panels in relation to the optical measurements of the sensor
- Define a soiling detection algorithm which allow to correlate the soiling levels provided by the optical measurement of the sensors with the step change/decrease in energy generation of the PV panels

Based on TEK's experience, this data should include at least the following aspects:

- Measurements for the dust sensors (REQUIRED): TEK's sensors can provide measurement data at a rate that is only limited by the communication protocol it uses and the communication speed set in its configuration. Since the accumulation of dust is a slow process such high data gathering frequencies should not be required for just plain monitoring of dirt levels. Still, for the environmental effects filtering (see next point), the evaluation that is planned and correlations that are expected to be extracted from it, a data acquisition frequency of 1 measurement every 5 minutes will be used.
- Environmental / Weather data of the demo site (REQUIRED): temperature and humidity values, wind, rain, fog or snow coming from a local weather station as close to the tested PV lines as possible. Information provided second hand (external weather information provider) could be used but would not be as useful. The reason for this requirement is that dust sensor measurements are sensitive to dew, rain or snow. Values obtained in these conditions should be ignored. Reliable weather information, ideally updated with a similar frequency to that of the data gathered from the sensors, will allow to filter these values.







- Still image data of the demo site (OPTIONAL): ideally from as close to the tested PV lines as possible, as a complement to the weather information. These could include IR still images taken during night periods as long as they are setup in a way that they do not interfere with the line of sight of the sensors in order to prevent any interference in the readings.
- Data regarding the dirt inspection and cleaning process performed on the tested PV lines (REQUIRED): this could include cleaning /inspection dates and still images of the tested PV lines before and after cleaning.
- Power generation data and radiation data of the tested PV lines (REQUIRED): ideally with a similar frequency to that of the dust sensor measurements (1 measure every 5 minutes). Also, both generation and radiation shall be correctly synchronized

Regarding the minimum data collection time that may be required: this time shall not be set by the sensor itself but shall be sufficient to collect data for several fouling and cleaning cycles. It will therefore depend on the tests to be carried out (see section 4) and on the cleaning cycles established at a specific demo site.

Finally, regarding the number of sensors to be used, with a total of 6 to 10 considered for the project, a minimum of 2 sensors will always be necessary in a demo site when considering the tests outlined in section 4. The number and final distribution in the selected demo sites will depend on the working configuration of their PV panels and possible restrictions associated to them. For more information related to sensor requirements (mechanical installation options, communication interface, power consumption, protections, etc.) check the next section.

Wind smart sensors

The wind smart sensor is a set of sensors that provide information about the vibrations and deformations of the PV and relate this information to the wind loads. Two set of sensors are planned in the project: (a) industrial sensors consisting on several precision sensors to obtain quality data in order to stablish the relationships between the wind load and the response of the PV; and (b) low-cost sensors able to provide the suitable information in the required measuring ranges to perform the monitoring to protect the PV against wind loads.

The development will be tested in the DTU demo site, so the information required (partially covered in the corresponding chapter of this deliverable) is related to the following aspects:

 Drawing of the plant identifying the different panels and the information of the building aspects of the panels and their mechanical structure. A preliminary selection for 3 or 4 panels will be made for the development of the monitoring system with both the industrial and low-cost sensors.







The panels selected will represent different situations and positions within the plant (fist row, lateral, central...).

- The data needed is related to the information of the wind (time stamp, speed and direction) and how this is used to adopt the defence position. Probably, it will be needed to monitor the wind near the monitored panels in order to establish the correlation between this and the data of the sensors installed in the PV. For the evaluation of the time spent in defence position (KPI 1.5), the actual data corresponding to this type of event is required, as well as, the causes that drives to adopt the defence position (wind speed and direction and others).
- Information about the **actuation mechanism** to check if it is possible to obtain additional information about the PV behaviour from the monitoring of the actuation and transmission. The expected data is related to the motors and reductions of the different sets, presence of a brake, irreversibility of the transmission.
- Information about the controllers, the Scada and the available communication
 protocols. The objective is to understand the possible ways to send the sensor data and
 the implementation of new control algorithms based on the new data set generated with
 the panel sensors.

Software for data analysis and device drivers (sensors and DAQ) needs to be running in the **Scada** or a computer available in the plant.

- Information about the algorithms to set the target defence position and the data currently used by the PLC program
- Hardware for data acquisition will be installed near the monitored panels. These will be connected via ethernet to the Scada or an additional PC in a suitable location in the plant.
- Regarding the monitoring, the idea is to have some sensors installed in order to record the data and correlate these with the weather/wind data.

Initially, the **industrial sensors include accelerometers**, force sensors and strain gauges. So, suitable installation places for these sensors have to be found in the current structure of the PV and the support. Additionally, the **internal signals of the tracker** (motor consumption...) will be used.

For the vibration analysis, **modal analysis of some panels** will be performed at different positions in the strings to obtain information about the vibration behaviour.

 Information about the loss of efficiency or damage to the PV panel attributed to the wind loads in order to assess potential improvements in this sense, linking this to the evaluation of the KPI 1.8iii.







The data will be collected at least during 4 months in order to record different wind events and the response of the panels for the development of the activity related to WP4 and T4.2.

Regarding the sets of sensors, the industrial sensors are expected to be comprised of 2-3 triaxial accelerometers, 3-4 force sensors and 8-10 strain gauges. The low-cost sensors will be a consequence of the development of the project targeting the use of accelerometers and force sensors.

Technical specifications

Dust sensors

TEK's sensor are designed for online real-time measurement of dust or soling levels on various surface types. Its principle of operation is based on IR light scattering: a controlled IR light beam is projected under the soiling deposited on the surface of a Ø34 mm sensing window and the light scattered back is detected and measured by means of a series of sensitive photodiodes.

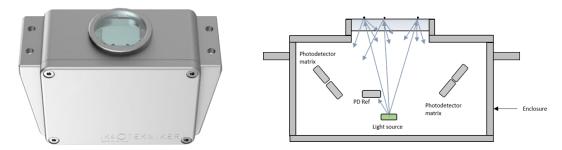


Figure 1.5-1. TEK dust sensor illustration and operating principle.

Its field of application includes solar fields. The internal configuration of the photodetector is designed to minimize direct sun radiation. Still, this effect is highly dependent on the configuration and monitoring orientation of the sensor. It may be possible that part of the daylight measurements are not valid, even reaching the saturation of the photodetectors. For that reason, only night-time operation is necessary and recommended.

The sensors feature a compact design, are easy to install and require no additional on-site adjustments. With a CE-ready construction, they are suitable for aggressive outdoor operating environments (IP65).

TEK's sensor are interconnected through a daisy chain configuration that provides both an RS-485 communication bus and distributed power supply (24 VDC, 40 mA) to all the chained sensors. The daisy chain design also allows disconnecting any sensor from the line without affecting the operation and connectivity of the rest of the line of sensors. Using a suitable datalogger device, several sensor chains or lines can be connected at the same time.







The sensors integrate protections against over-voltages and surges caused by lightning (in both the power line and the RS-485 bus). When installing, it is also important to add protection to power supply lines and the communication bus to the Datalogger.

TEK's sensor are pre-configured for MODBUS-RTU with a fixed 9600 baud speed and MODBUS address. This provides up to 256 devices per line and a maximum theorical distance for each chained line of nodes of 1200 m. In practice, these values are reduced due to various factors such as limitations of the transceiver or the datalogger or voltage drops in the lines. In case the length of a given chained line of sensors exceeds tens of meters suitable terminating resistors might be required at the end of the line of sensors and the Datalogger to prevent distortions caused by reflections, which can produce ambiguous digital signal levels and misoperation of the communication bus.

A total of 9 MODBUS registers are used to access a single measurement information. This information includes, among other values, the evaluation of the detected "scattering" percentage. This value will be 100% when the sensitive surface is totally clean (no scattering) and 0% when the sensitive surface is covered by a white tile that is used as a reference for the maximum scattering to be measured.

Regarding mechanical mounting, TEK's sensors must be installed adjacent and coplanar to the PV surface to be monitored and will be cleaned in the same moment and in the same way as the PV panel.

The design of the housing of the sensors offers two different installation options, either with the sensing window integrated into another surface or with the sensor attached to a structure using a suitable mechanical adapter. This solution will also allow to easily remove and substitute any sensor if a malfunction is detected.

If required, TEK can provide a specific datalogger PC program (Windows 7, Windows 10 or Windows 11) prepared for data acquisition and logging. This application can monitor in real time the measurements provided by a set of sensors distributed in an installation over several independent chained RS-485 lines and save the acquired data into log files.

Even though the sensors can provide real-time measurements at a frequency only limited by the communication bus and protocol used, in practice, since scattering values vary very slowly, only a periodicity of the order of several minutes is required (a sample every 5-10 minutes can be considered valid for further data analysis).

Wind smart sensors

The industrial sensors to be used has the following characteristics:

Triaxial accelerometers, piezoelectric or MEMS.







- Force sensors based on strain gauges or MEMS
- Foil strain gauges

The sensors will be connected to a DAQ system in an electric box with suitable IP protection for working in the PV plant. The DAQ system will be based on National Instruments hardware or similar. The connection of this system to the Scada or PC will be using an ethernet connection. Depending on the existing software, a suitable connection will be evaluated; alternatively, a DAQ and analysis software (running on Windows platforms) can be provided by TEKNIKER.

The data sampling will consist of several data streams with a duration between 1 and 6 seconds and with a sampling frequency of 100 Hz or above. These conditions will be analysed after the characterization tests (see next chapter).

The electric power required is a conventional 240 V AC connection or a 24 V DC power supply.

Method for testing and validation

Dust sensors

In order to broaden the spectrum of the acquired data, and to ensure the possibility of witnessing higher levels of dirtiness, the testing and validation method to be followed in each of the demo sites will include a comparison between cleaned and not cleaned PV lines.

As mentioned in section 2, the exact number of sensors to be deployed at a given site and the number of sensors per monitored PV line will depend on the working configurations of the panels and the possible restrictions associated with them. In any case, sensors will be distributed in order to cover at least two independent PV lines:

- One of those lines will be periodically cleaned following the standard frequency and procedures defined in the own site operation.
- Meanwhile, the other line will not be cleaned at all during the test run.

For each of these lines the data defined in section 2 will be gathered.

Wind smart sensors

The testing and validation will be performed at the DTU demonstration site. This will consist of three stages:

Characterization tests. These cover the analysis and characterization of the selected panel
and the supporting structures in order to assess their behaviour and the way to include
the sensors.







- Monitoring tests. This will consist of at least 4 months of continuous data acquisition with
 events leading to the adoption of defence position in the PV plant. This will be used to
 collect enough data to perform the analysis of the behaviour of the panels attending to
 the monitoring and the occurring events.
- Validation tests. This involves the validation of the low-cost ability to collect the significative data in order to perform the new protection algorithm to adopt the defence position.

TEK and DTU will collaborate to manage the issues depending on the plant and on the sensor sets.

KPIs for assessing performance of the developed models, tools and hardware.

This task is covered by the following KPIs, detailed in section 5.2:

Wind smart sensors

- KPI1. 5: Reduction in time spent in defence position
- KPI 1.7iii: PV system reliability and security

Dust sensors

• KPI 2.1i: Reduction of workforce for dust monitoring

Role of project partners

DTU & PPC

Dust sensors

Handle the installation of the dust sensors following the detailed installation protocol provided by TEK.

Provide the data defined in section "Data and hardware requirements"

Follow the test procedures defined in section "Method for testing and validation"

DTU

Wind smart sensors

Collaboration with TEK for the modifications required for the installation of the sensors.

Provide the data defined in section "Data and hardware requirements". Propose a method to evaluate the damage or loss of efficiency of the PV due to wind loads.







Provide the access to facilities and the support for the methods defined in section "Method for testing and validation".







1.6 Task 3.2 Development of strategies for delayed soiling [TEK]

Background

The performance of photovoltaic panels is affected by the accumulation of dust particles on their surface. Regular cleaning of these photovoltaic panels is required, which increases the overall system cost and solution complexity. Electrical efficiency of PV panel reduces from 16% to 8% over the period of 45 days if the PV panel is not cleaned regularly¹. In Figure 1.6-1 are summarized the current cleaning methods of PV panels.

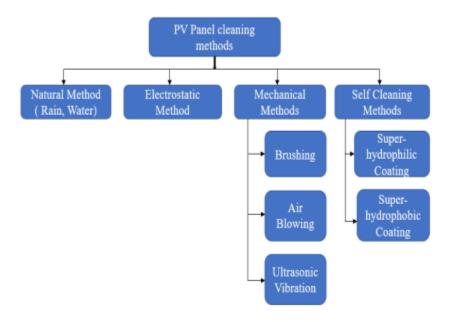


Figure 1.6-1. Solar panel cleaning methods²

It has been found tentatively that utilizing nanocoating on PV panels gives an impressive improvement in light transmission and voltage which is not connected to any load in a circuit because it understands the issue of dust electrical losses. However, the cleaning cost of the solar panel depends on a number of repeated cycles, and moreover, manual cleaning does not give the best shot in cleaning very small dust particulates. In this manner, analysts around the world are advancing the self-cleaning strategies, electrostatic strategy, mechanical strategy and coating strategy for PV surface cleaning. It has been estimated that the cleaning cost by conventional methods is about 2.25€/m²/year. Whereas cleaning cost by nanocoating is about 1.89 €/m²/year

² Jaswal, Ashish & Sinha, Manoj. (2021). A Review on Solar Panel Cleaning Through Chemical Self-cleaning Method. 10.1007/978-981-15-8542-5 73.



¹ M. Al-Housani, Y. Bicer, and M. Koç, —Assessment of various dry photovoltaic cleaning techniques and frequencies on the power output of CdTe-type modules in dusty environments,∥ Sustain., vol. 11, no. 10, 2019





which is equivalent to 18.900€/MW/year. This shows that the production of nano-coated material is beneficial³.

Materials which possess property of cleaning dust from their surface are known as self-cleaning materials. Self-cleaning material surfaces fall under two categories, hydrophilic and hydrophobic. Both of these types are able to clean themselves when water is present. The common case in nature is Lotus effect. Due to hydrophobicity of the lotus leaf water droplets can be seen on the surface of it. Since these surfaces are highly water repellent, water tends to form spherical droplet and roll over on the surface and hence cleans it. Whereas on hydrophilic self-cleaning materials water spreads over the surface forming a thin film and also are based on the photocatalysis. When they are exposed to light, they break downs the impurities⁴.

However, the harsh environment (including strong wind-sand motion, high temperature, great erosion and corrosion by dust particles) easily destroys the micro/nanostructures of superhydrophobic and superhydrophilic surfaces.⁵ This causes the self-cleaning abilities of these surfaces to degrade after the PV glass has been in operation for a long period.

There are several self-cleaning commercial products available specifically for glass surfaces. These products are designed to minimize the buildup of dirt, grime, and water spots on glass, making cleaning easier and reducing the need for frequent manual cleaning. They are grouped in 2 categories

- Glass Coatings: Some glass manufacturers offer specialized coatings that can be applied
 to glass surfaces. These coatings create a hydrophobic layer that repels water and
 prevents dirt from adhering to the surface, or n photocatalytic and hydrophilic coating
 that reacts with sunlight to break down organic dirt and grime. Rainwater then helps to
 wash away the loosened dirt, leaving the glass cleaner.
- Glass Cleaners: There are glass cleaning products available in the market. These cleaners often contain special additives that help prevent the adherence of dirt, grime, and water spots to the glass surface. They provide a protective barrier, but they are not permanent. (Chemitek ⁶).

⁶ Hydrophobic Coating for Solar Panels (chemitek.pt)



³ M. Fathi, M. Abderrezek, and M. Friedrich, —Reducing dust effects on photovoltaic panels by hydrophobic coating, || Clean Technol. Environ. Policy, vol. 19, no. 2, pp. 577–585, 2017

⁴ Deshmukh, Meera & Dongare, Rashmi. (2019). Review on self-cleaning materials and its applications in industries. 8. 252-253.

⁵ Bai, X., Xue, C.H., Jia, S., 2016. Surfaces with sustainable superhydrophobicity upon mechanical abrasion. ACS Appl. Mater. Interfaces 8 (41), 28171–28179. https://doi.org/10.1021/acsami. 6b08672





In this sense, most of the developments for PV panels are based on nanocoating, most of them synthesized by sol-gel technology, due to the low cost and optimal optical properties of the functional thin films. ⁷

Accordingly, the synthesis of superhydrophobic films requires the combination of surface chemical modification and the enhancement of surface roughness. Therefore, particular attention should be paid to controlling the surface roughness size and controlling the surface roughness to an appropriate value is the main task to meet both of requirements. The practical application of superhydrophobic surfaces was limited by some preparation conditions, multi-step processes, expensive low surface energy materials, etc. Sun et al. developed and active PV pannel with self-assembled monolayer silane and fluoropolymer thin film (Cytop). Fabrication processes were established to fabricate these two systems, including patterning Cytop without degrading the original Cytop hydrophobicity. ⁸ Usually organic molecules like stearic acid, fluoroalkyl-silane molecules on the coating surface are used to enhance hydrophobicity. A selection of resins, acrylates, silanes, and siloxanes polymeric structures can be used in the coating formulation. For example, trimethylethoxysilane (TMES) and tetraethylorthosilicates (TEOS) were used to obtain thermally stable, highly durable, and optically transparent hydrophobic coatings.⁹ These formulations can be combined with nanoparticle technology to achieve increased hydrophobic properties. Most of the bare-fluorinated materials have the expensive price and often are vulnerable to environment attacks while causing ozone shield to crack more seriously. Hence, the other hydrophobic group must be replaced for good use. Whereas fluorine-containing bonds (-CF₃) have lower surface tension than -CH₃, replacing -CF₃ with -CH₃ chemistries need introducing more stringent requirements for transparent superhydrophobic surface. It is usually introduced a posttreatment end-capping by means of trimethylchlorosilane (TMCS) and hexamethyldisilazane (HMDZ) for modifying the hydrophilic groups to enhance hydrophobic properties.

As opposed to water-repellent coatings, the hydrophilic effect reduces the angle of water droplets, allowing penetration beneath the contaminant. Deng et al.¹⁰ prepared a hydrophilic surface using feldspar, kaolin and TiO_2 as the main raw materials, and the contact angle was 13.3°. This hydrophilic surface also had a micro/nano hierarchical structure and good wear resistance, which improved the surface wettability and enabled hydrophilic self-cleaning.

¹⁰ Deng, Z., Dong, W., Gu, X., Luo, T., Huang, S., 2020. Effect of titanium dioxide on properties of phase droplet self-cleaning glaze. J. Synth. Cryst. 49 (1), 138–157. https://doi.org/10.16553/j. cnki.issn1000-985x.2020.01.017



⁷ Yanping Zhang, ab Binghai Dong, *ab Shimin Wang, *ab Li Zhao, ab Li Wanab and Erjing Wanga RSC Adv., 2017, 7, 47357-47365

⁸ Sun, D., Böhringer, K.F. An active self-cleaning surface system for photovoltaic modules using anisotropic ratchet conveyors and mechanical vibration. Microsyst Nanoeng 6, 87 (2020). https://doi.org/10.1038/s41378-020-00197-z

⁹ Brophy, B.; Abrams, Z.; Gonsalves, P.; Christy, K. Field performance and persistence of anti-soiling coatings on photovoltaic glass. In Proceedings of the 31st European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC 2015), Hamburg, Germany, 14–18 September 2015; pp. 2598–2602.





However, when superhydrophobic and superhydrophilic surfaces are subjected to external mechanical forces, the hierarchical micro/nanostructures are easily damaged, resulting in a significant decline in, or even loss of, their self-cleaning abilities. Some studies have demonstrated that the hydrophobicity of the coatings degraded more quickly than anticipated.¹¹

The current situation, as the PV panel must be cleaned frequently, is that some companies have developed robots or robotic systems designed to clean solar panels automatically. These robots move along the surface of the panels and use brushes or other cleaning mechanisms to remove dirt, mainly with pressurize water. These cleaners often contain special additives that help prevent the adherence of dirt, grime, and water spots to the glass surface. They provide a protective barrier, making future cleaning easier and more effective without modifying the glass of the PV panel. The composition of the additives is based on surfactants that once they reach the land, can cause environmental contamination. This is an important reason why there is a need to develop new green cleaning additives to be incorporated in the water

On-going PV systems initiatives on similar topics

Solving solar panels' dirty problem

Potential barriers to the development of the solutions

The main barrier lies in the validation process in operational environments using real scaled PV panels which implies excessively time-consuming. In some of the demo sites the PV panels are not cleaned due to the low dust that is accumulated on the glass surface, and this could be an issue for the validation of the solution. Moreover, there is a lack of specialized and advanced know-how on the maintenance of PV systems.

Data and hardware requirements

The antisoiling fluids will be tested on the demo sites. The procedure will consist on cleaning some of the PV panels of one string with water (conventional procedure) and other string with the antisoiling fluids developed in SOLARIS. The data that should be monitored is the following:

- PV power (REQUIRED): This will be the main parameter to monitorize to compare the behaviour of the PV panel cleaned with the antisoiling fluids and the PV panels cleaned with conventional procedures.
- Environmental / Weather data of the demo site (REQUIRED): temperature and humidity values, wind, rain, fog or snow coming from a local weather station as close to the tested PV plant as possible.

¹¹ Lisco, F.; Bukhari, F.; Uličná, S.; Isbilir, K.; Barth, K.L.; Taylor, A.; Walls, J.M. Degradation of Hydrophobic, Anti-Soiling Coatings for Solar Module Cover Glass. *Energies* 2020, *13*, 3811. https://doi.org/10.3390/en13153811







- Data regarding the cleaning process performed on the tested PV strings (REQUIRED): this
 could include cleaning /inspection dates and still images of the tested PV lines before and
 after cleaning. It will be necessary to know the water consumption and composition, and
 the cleaning procedure (manual or spray).
- Image data of the demo site (REQUIRED): The images are very useful for verifying the dust and soiling accumulation on the PV glasses and to compare the coated and uncoated PV panels.

Technical specifications

The new water-based cleaning fluid will provide a long lasting semi-permanent self-cleaning and dust repelling effect on the PV glass. This fluid will optimize the cleaning processes by using additives in the cleaning water for delayed soiling.

For achieving the optimal formulation of these additives, it will be necessary to optimize the precursor types, pH of the synthesis and the type of solvent employed, being preferably water. The additives will be fully characterized by determining their surface tension and the semipermanent hydrophobic or hydrophilic effect in the glass by means of the measurement of the contact angle.

The final water-soluble cleaning fluid will be water based with a composition of water higher than 90% and anti-soiling active additives lower than 10%. It will not include any fluorithated compound. Considering application conditions, the drying time will be lower than 30 min and the ideal viscosity will be of 1cP taking into account the possible need for spraying the fluid. The end of life of the formulation at storage conditions between 5 and 30°C should be at least 12 months

The best formula will be selected based on the above specifications and on transmittance measurements on PV glasses. The cleaned PV glasses should maintain a high transmittance of light during longer time than ones cleaned with conventional methods. The cleaning result will be evaluated at lab depositing soiling and cleaning with the additives in different concentrations.

Method for testing and validation

The procedure for testing the antisoiling semipermanent coatings or fluids at each demo site will consist in:

- 1. TEK will prepare and send 1 to 5 litres of the concentrated formula to the demonstration sites with storage and dilution protocols and with application instructions.
- 2. One of PV string will be cleaned following the standard frequency and procedures defined in the own site operation with water and conventional methods
- 3. Meanwhile, the other PV string will be cleaned with antisoiling fluids developed in the project with the same frequency than in step 2.







For each of these lines the data defined in section "Data and hardware requirements" will be gathered.

KPIs for assessing performance of the developed models, tools and hardware.

This task is covered by the following KPI, detailed in section 5.2:

KPI1. 6: Reduction in <u>cleaning interventions</u>

Role of project partners

Effective demonstration of the efficiency of the anti-soiling cleaning fluid will be carried out in the three demo-sites of the project PPC, EILAT and FIB. If necessary, the pilot plant of DTU could also be used.

The way to apply the cleaning fluid as well as the type of soiling on the PV cells will determine the fluid formulation and its physical-chemical characteristics. The position within the PV plant where the cleaning fluid will be tested is also very important because there will be differences in the fouling of the plates depending on where it is located.

The requirements and specifications for an optimal development of the cleaning fluid for each demo-site are summarized in Table 1.6-1.

Table 1.6-1. Requirements and specifications of demo-sites for anti-soiling cleaning fluid development.

	DEMO SITES			
Requirements and specifications	DTU No demo site (Denmark)	PPC (Greece)	EILAT (Israel)	FIB (Austria)
Actual cleaning procedure	No cleaning (Rain)	Preparation: Cleaning in the early morning with soft wipes Process: Dry cleaning with a dry cloth damping with mineral water	Manual	No regular cleaning (Rain)
Cleaning frequency	None	Once a year or as required	4 times/ year	Once in a while
Additives to the cleaning water	None	None	None	None
Soiling	Mostly pollen	Dust from agricultural activity	Bird droppings sand	Fine gravel stones (rooftop) Polen (spring)
Glass substrate				
PV plant layout and wheatear monitoring	ОК	OK Unable to indicate now specific site (AgriPV, rooftop)	OK 3 sites	OK Roof AgriPV







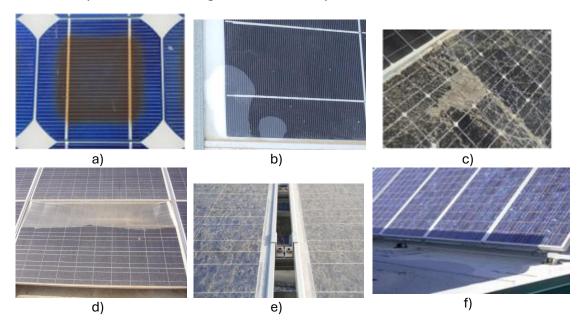
1.7 Task 3.3.1: Drone Imaging Solutions [DTU]

Background

In this task, DTU will develop a drone imaging PV plant inspection process based on combining visual imaging, infrared (IR) imaging, and luminescence imaging, taken with one or multiple drones, including image analysis and failure detection.

Visual inspection is a fundamental method for assessing the condition of PV modules in the field, offering a cost-effective and accessible approach to identifying defects that can impact performance and safety. This method relies on trained inspectors to examine modules for signs of damage, discoloration, and other issues. Images are usually taken with a commercial drone equipped with an HD RGB camera. The main limitation being the human factor in image analysis and failure detection.

Visual inspection serves as a crucial first step in identifying potential problems and can guide the use of more specialized techniques, like EL and IR imaging, to investigate further.¹² This method requires minimal equipment and expertise, making it highly accessible to many users, from manufacturers and installers to system owners. Moreover, many defects, including discoloration, delamination, burn marks, and physical damage, become visually apparent early, enabling timely intervention to prevent further degradation or safety hazards.



¹² Köntges, Marc, et al. "Review of failures of photovoltaic modules." (2014): 1-140



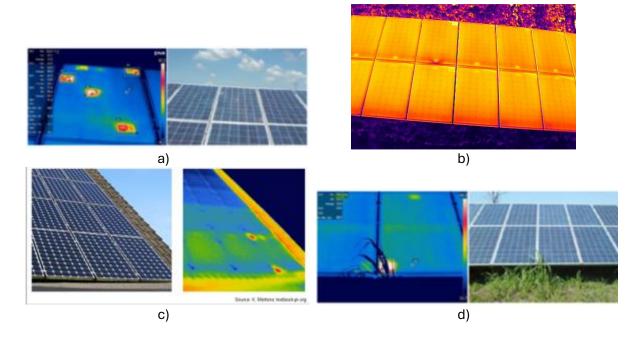




Figure 1.7-1. Example of PV module failures detectable by visual inspection: a) discoloration¹³; b) & d) delamination¹⁴; c) glass breakage; e) soiling¹⁵; f) shading.

However, this method is limited in identifying electrical degradation or failures, unless these leave a visual footprint on the module, such as burn marks or corrosion.

In contrast to visual inspection, **IR thermography** can detect both some of the optical failures that result in a temperature effect on the panel, such as hotspots due to glass breakage (Figure 1.7-2a), soiling (Figure 1.7-2b) or shading (Figure 1.7-2d), as well as electrical degradation or failures characterized by increased Rs (Figure 1.7-2c), disconnected or shunted cells (Figure 1.7-2f), bypass diode short-circuit (Figure 1.7-2e), or other issues causing variations in the temperature distribution of the module. The sensitivity and resolution of IR thermography are more limited than those of EL imaging. Nevertheless, from a field application perspective, IR thermography inspection can be performed on a module or system level, allowing the fast inspection of many modules through aerial drone thermography.



¹⁵ J. Zorrilla-Casanova et al. , "Losses produced by soiling in the incoming radiation to photovoltaic modules.", Prog. In PV, 2013



¹³ J. H. Wohlgemuth et al., "Discoloration of PV encapsulants." pp. 3260-3265

¹⁴ M. A. Munoz el al., "Early degradation of silicon PV modules and guaranty conditions," *Solar Energy, vol. 85, no. 9, pp. 2264-2274, 9//, 2011*





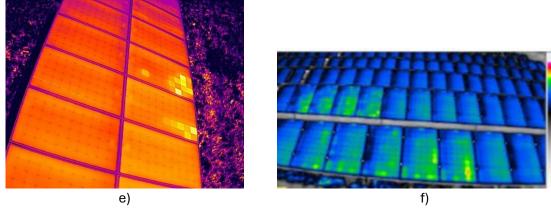
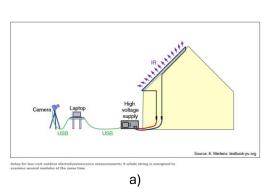


Figure 1.7-2. Examples of PV module failures detectable with IR: a) glass breakage; b) soiling; c)cell hot spot; d) shading; e) short circuited bypass diode; f) PID.

Luminescence imaging is an inspection method specific for photovoltaic solar cells and modules that relies on physical process of radiative recombination of the charge carries in a solar cell, which results in photons being emitted, with a wavelength determined by the energy bandgap of the semiconductor material, in the case of silicon solar cells, 1150 nm. Measuring this light emission required a camera detector sensitive to the near-infrared spectrum (NIR). The luminescence intensity from the solar cells depends on the charge carrier density, and directly correlated to the solar cell material quality, defect and degradation of the solar cells.

Luminescence imaging inspection can be realized in different ways in practice. By forward biasing the PV device with a DC voltage higher than the open circuit voltage of the PV device, as illustrated in the figure below, the average charge carrier density of the device can be "controlled" and "enhanced". And as the luminescence of solar cells is much weaker than sunlight in terms of intensity, these measurements are usually carried out in a dark room or during nighttime.



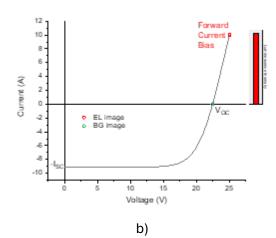


Figure 1.7-3 Stationary electroluminescence imaging: a) setup for performing EL including SWIR camera and biasing power supply; b) PV panel/array operating mode during EL imaging where the PV is forward biased beyond the open circuit voltage (Voc).



In this way several "invisible" module failures (i.e. not visible to the naked eye) can be detected, for example, shunted or disconnected PV module substrings will have no current flowing through the solar cells, resulting in no luminescence emitted, this can be easily detected as in the left figure below. Shunted cells, such as those caused by PID, are invisible to the naked eye as well and difficult to detect from thermal IR images but easily detectable from EL images, as illustrated in the right picture below.

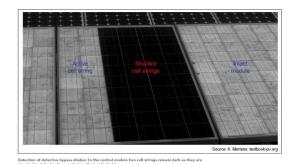




Figure 1.7-4 An example of an EL nighttime inspection performed with a stationary EL setup is a) an EL image of a PV module with two shunted cell substrings and b) a PV string affected by potential induced degradation.

Application of the electroluminescence imaging technique for inspection of PV systems during daylight involves complex technique and more post-processing steps, due to the additional solar light that acts as noise in the EL images. This solar noise can be partly removed by modulating the biasing current of the PV modules between zero and a high forward current, with frequency between 10-30 Hz, whilst images are acquired in sequence with a framerate at least double of the modulation frequency, as depicted bellow. The resulting

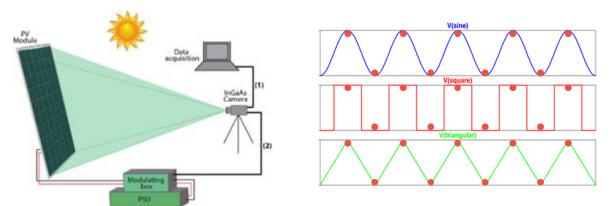


Figure 1.7-5. Principle of Daylight EL inspection using bias modulation and signal lock in: a) stationary EL inspection setup for daylight application; b) types of PV bias modulation waveforms that can be used.

The resulting image sequence (Figure 1.7-6a) requires on average 100-200 consecutive image frames of the same scene of the PV panels, that need to be post-processed using a lock-in or fast Fourier transform technique, and finally processed in a laboratory equivalent EL image (Figure 1.7-6b).







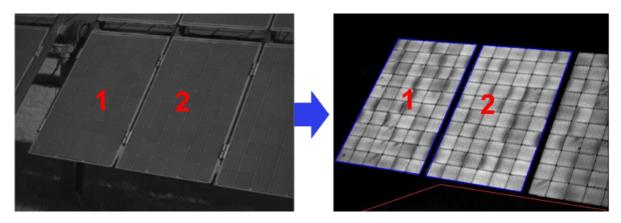


Figure 1.7-6. Example of drone based EL inspection results: a) raw EL images taken during flight; b) post processed EL images taken with the drone.

The daylight EL inspection method can be performed through stationary tripod image acquisition (Figure 1.7-7a), which is the more typical approach, or through a drone equipped with a SWIR camera (Figure 1.7-7b). However, both instances require an external power supply to forward bias the PV modules through modulation.

A viable alternative to EL imaging, that does not have the drawback of requiring an active external power supply, is photoluminescence imaging, where the PV inverter itself is controlled to modulate it's operating point (typically between short circuit or maximum power and open circuit).



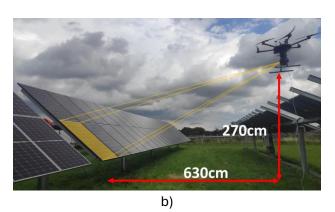


Figure 1.7-7. Example of daylight EL imaging performed at DTU: a) stationary EL inspection setup; b) drone EL inspection setup.

The PL method is illustrated in Figure 1.7-8 and can achieve comparable result to EL under favourable conditions (high solar irradiance and luminescent solar panels. However, the resulting images contain less diagnostic information relating to solar cell crack and series resistance type degradation modes, due to the inherent nature of how photoluminescence is generated.





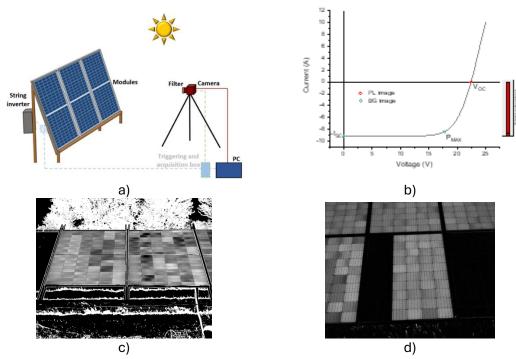


Figure 1.7-8. Example of daylight PL imaging using inverter modulation performed at DTU: a) Daylight PL setup; b) PV biasing principle for performing PL inspection, PL images are taken when the PV is operating at Voc and Pmax or Isc, in quick succession; c) post-pro

Data and hardware requirements

The requirements for performing drone inspection are detailed in section 3.6.7.

The drone inspection will be performed using the DTU and AIR6 drones shown in Figure 1.7-9, as well as equipment capable of biasing and modulating the string current for daylight EL and PL inspections.

Technical specifications

DTU will develop methods for correcting VIS, IR, EL/PL images (perspective, noise, distortion, panel tracking) acquired with the drones into a normalized perspective and format that can be more easily machine analyzed for detecting PV panel failures (disconnected cell sub-strings, severe hotspots, shading, soiling, cell cracks, PID, short-circuited bypass diodes) and assessing their severity (safety risk and risk of power loss).

These methods will be implemented into a cloud image processing and analysis pipeline, in Azure, depicted in Figure 1.7-10. Illustration of the Diagnostic Image PV Inspection system developed in work package 3, giving REST API to the project partners, involved in the PV system inspection process. The drone inspection partners (AIR6 and DTU) will upload raw VIS, IR, EL/PL images, along with inspection metadata, post plant inspection to the image processing pipeline, that will





automatically correct the images, annotate detected issues and failures in the panels, and estimate their severity.

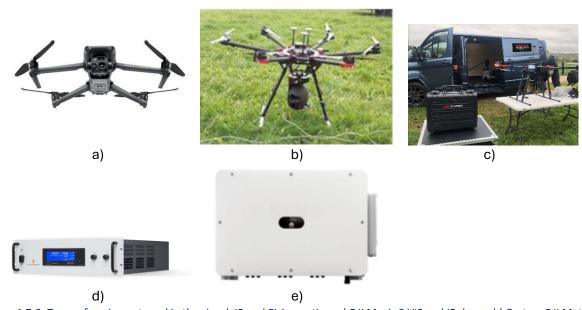


Figure 1.7-9. Types of equipment used in the visual, IR and EL inspection: a) DJI Mavic 3 VIS and IR drone; b) Custom DJI Matrice 600 EL drone. c) Airborne Robotics DRSolar drone; d) DC power supply for string bias modulation; e) string inverter capable of modulation.

Inspection reporting partners (Heliocity) will be able to access the corrected images, annotation and severity estimates for all the panels inspected, using the same REST API framework

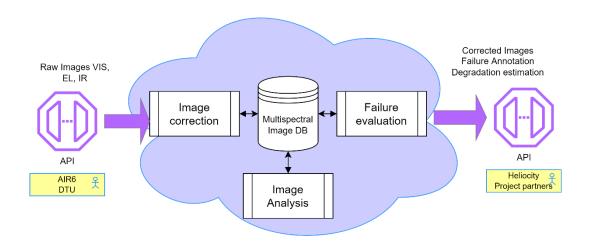


Figure 1.7-10. Illustration of the Diagnostic Image PV Inspection system developed in work package 3.







Method for testing and validation

The drone-based PV inspection system will be tested at three of the demonstrations sites (DTU, PPC and FIB, as described in section 4.1, Use case #1. The methods of validation will be slightly different depending on the data available at each site.

The test performed at the DTU site will aim to quantify the true panel failure detection rate of the inspection system, by inspecting a PV system where the failures and their severity are known a priori, with high confidence. This is achieved by retrofitting existing PV strings at the DTU testing facility (shown in Figure 1.7-11) with PV panels that have been degraded in a controlled manner and which have been characterized in detail in the laboratory. Currently, two strings (7.1 and 7.2) have been retrofitted for this purpose, detailed in Table 1. More strings will be retrofitted, as it will be necessary.

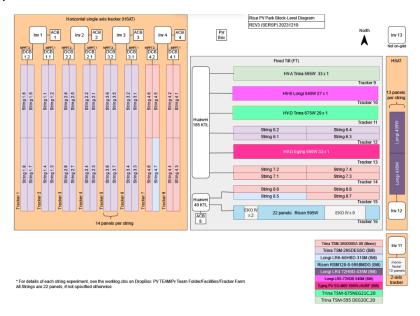


Figure 1.7-11. Layout of the DTU PV plant test facility.

Table 1.7-1. Summary of controlled failures in strings 7.1 and 7.2 at the DTU PV Test Facility

Type of degradation	Number of modules
PID	8 modules
Microcracks	8 modules
Ribbon damage	8 modules
Bypass diode short-circuit failure	2 modules







Bypass diode open-circuit failure

2 modules

A second type of validation test will be performed at one of the PPC utility-scale PV plants, where, upon the availability of O&M inspection reports and logs, the drone-based PV inspection system will be benchmarked to measure its average panel failure detection capability versus previously performed inspections by the O&M team.

The third type of test will be performed at the FIB demonstration site, where the two existing rooftop systems will be inspected. As these are relatively small PV systems, no previous inspections have been performed and the PV failure state of the two PV systems is largely unknown. Therefore, the drone-based PV inspection will be benchmarked against visual and handheld/aerial IR inspection performed on-site, and the images will be evaluated by a human expert and will serve as a baseline for the average failure detection rate of the drone PV inspection system.

KPIs for assessing performance of the developed models, tools and hardware.

The revised KPI 1.2i, applies to this task. It is defined as follows but section 5.2 must be checked for further description:

Average panel failure detection rate=# panel failures detected /# panels inspected

The revised target values of the KPI are:

- Detect at least 90% of existing failures at the DTU-controlled failure test sites
- Double the average panel failure detection rate relative to previous O&M inspection reports
- Double the average panel and string failure detection rate relative to visual and handheld IR inspection

Role of project partners

AIR6 performs drone flights and image acquisition, primarily at the FIB and PPC sites.

PPC provides access to a utility-scale PV plant for inspection, support for inspection, and previous O&M inspection reports for planning and benchmarking

FIB provides access to its two rooftop PV systems for inspection, support for inspection, and previous O&M inspection reports for planning and benchmarking

UNIGE will support the development of optimized flight plants for inspection, as well develop solutions for autonomously moving along PV rows using visual servoing techniques for autonomous navigation as alternative to pre-flight planning.







HELIO will provide information where sub-performances are detected (e.g. depending on monitoring data granularity: string, MPPT, JB, etc.) as useful instruction to the drone. And will collaborate and coordinate on the testing and validation of KPI1.2ii which relates with string-level panel failure detection through electrical performance monitoring.







1.8 Task 3.3.2: Drones path planning and optimisation, control and coordination [UNIGE]

Background

UNIGE will focus on two interrelated problems: computing optimal paths for drones navigating along PV rows in large PV plants and ensuring real-time control of the drones to follow the planned paths using visual servoing and GNSS-based techniques. This effort may also consider the presence of multiple drones, which increases the complexity due to potential conflicts between them.

The required expertise is therefore highly interdisciplinary, necessitating a well-balanced integration of vision-based AI, navigation, and control methodologies.

PV panel segmentation

The first step in extracting PV panel rows from satellite or aerial images is segmentation, a problem usually addressed through deep learning techniques used for image and video analysis. Segmentation techniques aim to assign a semantic label to every pixel in an image, enabling a much more detailed and nuanced understanding of the scene compared to classifying the entire image as a whole. Unlike classic object detection, which only identifies objects by drawing bounding boxes around them, segmentation provides the actual outline of the objects. For localizing PV panel rows, segmentation approaches are far more accurate than bounding box detection, as they allow the precise contours of the panels to be extracted. Additionally, this method can be applied to detect defects on the panels [1].

Once segmentation is complete, the next step is to localize a specific row within the image. This typically involves calculating the minimum bounding rectangle that encloses the segmented panel mask. From this rectangle, the center, median line of a PV panel row and its orientation angle can be determined. The coordinates of the center/median line are then returned to locate the panel within the image [2].

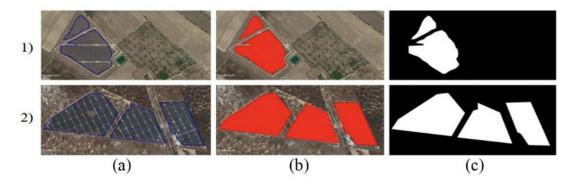


Figure 1.8-1. Example images from the Amir database.







When focusing explicitly on PV plants, segmentation methods are typically used for extracting the boundaries of a PV plant. Two examples are mentioned in the following:

- Fully Convolutional Neural Network (FCN): A Fully Convolutional Neural Network based on a Mask-RCNN deep learning architecture is employed for boundary extraction [3].
- Network-Based Architecture: A semi-automatic approach that combines image processing with a Convolutional Neural Network (CNN) model built on a server. This method efficiently and accurately identifies regions of interest, integrating an image processing layer into the overall process to enhance precision [4].

FCN approach

Identifying the boundaries of a PV plant is essential for creating a precise flight route that ensures complete coverage of the area. FCNs are an efficient method for extracting these boundaries, Figure 1.8-1. The FCN approach modifies the traditional CNN architecture by replacing fully connected layers with convolutional layers. The input for this method is an RGB image of a PV plant, and the output is the predicted mask. In [5], a Mask-RCNN was used with a modified VGG16 backbone. Mask-RCNN is a widely utilized method for segmentation tasks, employing a two-phase approach. The first phase scans the image to generate potential object locations, while the second phase classifies these proposals and produces pixel-level masks. The VGG16 backbone incorporates connections in various directions—upward, downward, and lateral—resulting in diverse feature maps, such as pyramid maps.

Since FCNs are supervised machine learning algorithms, they require a large and diverse dataset for training [6]. For this purpose, the Amir dataset can be used, consisting of 3,580 orthophotos from various large-scale PV plants in 12 different countries. The dataset includes PV plants of varying capacities, providing the necessary diversity for effective training [3].

A typical approach for boundary extraction using the Mask-RCNN method involves down-sampling the input image to create lower-resolution feature maps, which are then up-sampled with transpose convolutions to produce a full-resolution segmentation map. To improve accuracy and reduce losses during training and evaluation, the model weights are initialized using values from ImageNet, a technique known as transfer learning [3].

A comparison was made between traditional image processing techniques and the FCN method for PV plant boundary extraction. This was conducted as part of an effort to develop an autonomous monitoring, aerial photogrammetry, and path-planning system for aerial robots in [3]. The FCN method demonstrated higher efficiency and accuracy compared to traditional image processing techniques. Furthermore, it did not require site-specific tuning parameters, making it more versatile and robust.

Network-Based Architecture







The approach described in [4] explores segmentation as a step towards developing an efficient strategy for coverage path planning over PV plants using aerial drones. This method leverages a semantic segmentation algorithm hosted on a server to identify the region of interest. The process involves the following steps:

- 1. Raw satellite images of PV plants (e.g., from Google Maps) are captured at a predefined altitude from the ground.
- 2. The images are input into the deep learning server, which generates a mask of the PV plant. This step builds on earlier work by the same research group [7].
- 3. A series of OpenCV functions are applied for post-processing. The resulting masks are then tested with a coverage path-planning method (CPP), Figure 1.8-2.

The server-based algorithm segments the PV plant and extracts a mask from the satellite image. For training, samples are collected from the Amir dataset: these samples are converted into images with a resolution of 240×320 and are inputted into the CNN. The chosen model for the CNN server is the U-net network, which features a U-shaped architecture composed of two blocks:

- Decreasing Block: A typical CNN block that reduces spatial information while increasing feature information.
- Increasing Block: Combines feature and spatial information through up-sampling layers and transposed convolution.

Post-processing involves a step-by-step image processing pipeline using OpenCV functions. The procedure includes:

- 1. Applying morphological operators (Erode and Dilate) to the images.
- 2. Using the FindContours function to extract contours.
- 3. Applying the ContourArea function to calculate the area of each contour and filtering out smaller areas that may represent false positives.
- 4. Utilizing the ApproxPolyDP function to approximate the contour to a shape with fewer vertices.
- 5. Applying the Erode operator again to expand the shape, compensating for false positives from the deep learning server.

The U-net model proved more effective in predicting PV plant areas compared to other techniques, such as the FCN method. It offers faster processing and superior performance in







identifying PV plant areas while minimizing false positives. The inclusion of a post-processing refinement step further enhances its overall accuracy and performance.

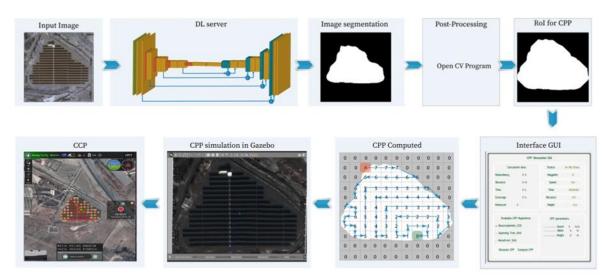


Figure 1.8-2. Schematic of the data processing method in [7].

It is crucial to emphasize that U-Net models are commonly used for satellite image segmentation tasks. They perform effectively across a wide range of image segmentation applications and are specifically designed for semantic segmentation tasks. Satellite images often contain complex and diverse patterns, such as various types of land, structures, roads, and water bodies. The U-Net model is particularly well-suited to handle such complex scenes due to its ability to capture both contextual information and small shapes [7].

Path-planning

The goal of this task is to determine the most efficient route for UAV coverage of a PV plant based on satellite or aerial images. Since UAVs have limited endurance due to their batteries, inspection methods must address this limitation. To achieve this, a path planning system that generates the best possible route in terms of length and time must be implemented, taking into account—when relevant—the presence of multiple drones.

Some works on path-planning focus on computing waypoints (WPs) on the border of the PV plant (possibly after performing segmentation as described in the previous section) and then connecting these WPs to create a boustrophedon movement, Figure 1.8-3. For example, the authors of [8] propose a method for connecting WPs along the borders of a PV plant to ensure complete coverage. In the Figure, it is assumed the drone flies at a relatively high altitude: then, it is not necessary for drones to move along PV rows, and consequently, WPs are not necessarily aligned with the extremities of PV panel rows As already mentioned, under these conditions, finding a path connecting all WPs is simple because there are no constraints deriving from the







geometry and PV rows, and therefore a boustrophedon movement within the segmented plant can suffice.

However, this is not always true. In the SOLARIS project, UNIGE considers the situation that drones are required to fly at much lower altitudes using visual servoing techniques to navigate along PV panels, with the final objective of capturing higher resolution images. To achieve this, WPs can be set at the extremities of each PV row. Under these conditions, defining an optimal connection among the WPs becomes significantly more complex, particularly when the plant structure is irregular. As a result, automatically determining the best possible path is formulated as a Traveling Salesman Problem (TSP).



Figure 1.8-3. Boustrophedon movement on a segmented PV plant.

TSP can be described as follows: "A salesman must visit each of *n* different cities exactly once, starting and ending at a base city. Which path minimizes the total distance traveled by the salesman?" [9]. This classic problem in Operations Research has been extensively studied over the years. Initially focused on determining the optimal route for a single entity, such as a drone, the TSP has since been generalized to multi-drone systems, making it a continuously active area of research [10]. In this scenario, a TSP must be solved by considering all waypoints (WPs) located at the extremities of PV panel rows, with the additional constraint is that the arc connecting a WP at one extremity to the WP at the other extremity of the same PV panel row must necessarily be included in the path.

The TSP is an NP-hard problem in combinatorial optimization. Despite its computational difficulty, various heuristics and exact algorithms have been developed to address it. These approaches allow for the exact solution of instances with tens of thousands of nodes and approximate solutions for instances involving millions of nodes.

There are two main types of TSPs:

- Symmetric TSP: The length of the edges connecting two nodes is the same regardless of the traveling direction.
- Asymmetric TSP: The length of an edge depends on the direction of travel.

The most studied methods for solving the TSP are exact algorithms, which aim to find optimal solutions. However, in the worst case, exact algorithms for NP-hard problems cannot run in







polynomial time. Significant research has focused on developing exact algorithms with exponential running times but low bases. One such method is branch and cut [11], which combines branch-and-bound techniques with cutting planes to reduce linear programming relaxations.

In contrast, heuristic techniques [12] are practical methods that do not guarantee optimal solutions but provide satisfactory approximations in a fraction of the time. Heuristics act as shortcuts to reduce the computational burden. Notable examples include:

- Greedy Method: This method selects the locally optimal path incrementally by consistently choosing the closest unexplored node. While it is one of the fastest approaches, it often gets stuck in local minima and produces sub-optimal solutions. It is commonly used to generate initial solutions for more advanced algorithms.
- Local Search (LS) and Iterated Local Search (ILS): LS methods explore the neighbourhood
 of the current solution to identify improvements. Common moves include two-opt
 (removing two edges and reconnecting them), three-opt (removing three edges), and LinKernighan (adaptive edge removal). These methods are straightforward but improve
 solutions slowly. ILS extends LS by iterating it to escape local minima, often leading to
 better results.
- Simulated Annealing (SA): A probabilistic technique that examines random changes to the solution. It sometimes accepts worse solutions to escape local minima, with a decreasing likelihood of such changes over time. Although slower, SA has proven successful in many applications.
- Memetic Algorithms (MA): These combine LS with strategies like Genetic Algorithms (GA). For TSPs, this involves merging two solutions (via a crossover operator) and refining the result with LS. MAs balance local exploration with global evolutionary strategies, producing high-quality solutions, though they may require many iterations to converge. ε-Approximate Algorithms ensure that the objective function of the solution is at most ε times the minimum. The goal is to achieve an approximation ratio (ε) as close as possible to 1 while maintaining manageable computational complexity. An example is the 3/2-approximate Christofides' algorithm.

In summary, there are numerous algorithms available for solving the TSP, each with unique tradeoffs between solution quality, computational speed, implementation complexity, and theoretical guarantees. Hybrid methods and MAs currently represent some of the most successful approaches [12].

Drone control







The third step involves implementing control mechanisms for guiding drone flights. We start with a quick overview of the model of the drone to be controlled, followed by an analysis of traditional computer vision (CV) and deep learning (DL) models specifically designed for panel segmentation and tracking. These models ensure that drones can accurately identify and track PV panels using various visual servoing techniques. The primary objective is to extract critical visual features that enable the drone to maintain a steady trajectory and execute pre-planned flights with maximum precision and efficiency. This capability becomes particularly crucial when inspecting larger PV installations, where system complexity and the likelihood of errors are significantly higher. The analysis and application of these advanced CV and DL models and visual servoing techniques aim to minimize errors and ensure that drones carry out inspections both efficiently and accurately [13].

Quadrotor modeling

The drones selected for this project are the DJI Mavic 2 Enterprise Duo and the DJI Matrice 350 RTK. In a multicopter configuration, each propeller generates thrust (due to lift), which is orthogonal to the plane of rotation of the blades. During hovering (when the multicopter remains in a fixed position), the total thrust produced by all propellers balances the drone's weight. In stable flight conditions (when the multicopter cruises at a constant altitude and speed), one component of the thrust balances the weight, while the other component drives the motion in the desired direction, counteracting the resistance encountered as the multicopter moves forward.

Each propeller also generates torque due to drag [14]; hence, multicopters typically have an even number of propellers, with half rotating clockwise and the other half counterclockwise. This configuration ensures that when all propellers operate at the same speed, the overall torque is zero, preventing the drone from rotating along the z-axis (yaw). To adjust the yaw angle, the speeds of specific propellers are varied while maintaining sufficient overall thrust to counterbalance the drone's weight, Figure 1.8-4.

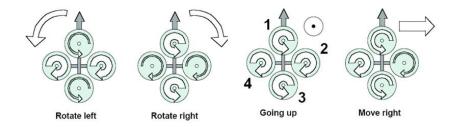


Figure 1.8-4. The quadrotor concept. The width of the arrows is proportional to the angular speed of the propellers.

A quadrotor has six Degrees of Freedom (DoFs): three translational DoFs (forward/backward, left/right, up/down) and three rotational DoFs (roll, pitch, and yaw). However, a quadrotor drone is considered an underactuated robot because it has more DoFs than the number of actuators or







control inputs (specifically, the four rotor speeds). This means it cannot independently control all of its DoFs simultaneously. Despite this limitation, a quadrotor can still execute a wide range of maneuvers by carefully modulating the forces generated by each rotor.

To address the DoF limitations of quadrotor drones, a cascade control system architecture is typically employed. In cascade control, two or more controllers operate in series, with the output of one controller serving as the input for the next. This architecture is commonly used in quadrotor control as it enables separate controllers to manage different aspects of motion, such as position and orientation. This separation makes the control system more flexible and efficient, allowing the quadrotor to respond accurately to a wide range of control inputs and disturbances. Additionally, cascade control simplifies handling nonlinearities in the system and compensates for uncertainties.

The following three control layers are typically required:

- Mixer-Matrix: Computes the rotor velocities based on the torques around the three axes and the quadrotor's thrust force.
- Attitude Controller: Determines the required torques to achieve the desired orientation of the drone.
- Position or Speed Controller: Maintains the desired position or speed by calculating the required angle configuration to pass to the attitude controller.

It is worth noting that, in commercial platforms such as the DJI Mavic 2 Enterprise Duo and the DJI Matrice 350 RTK, the low-level control tasks described above are managed by the onboard flight controller. In these cases, our control tasks are limited to computing the desired speeds or velocities to be provided to the onboard controller, with the objective of making the drone fly along PV panel rows by keeping them in the center of its camera images through visual servoing.

Vision-based inspection strategy

The objective of our drone-based inspection system is to gather data to detect failures (typically, infrared and visible images of solar panels, but other data could be considered as well by changing the drone payload to another sensor). Typically, image acquisition is conducted either manually or via autonomous flight control using predetermined WP and GNSS-based navigation — which may follow, for instance, a boustrophedon path above the PV plant. However, we choose to review vision-based image acquisition strategies that do not rely on GNSS navigation between predefined WPs. To this end, we will consider as a prototypical example the work described in [15]. In this approach, the flight control system is designed to assist the drone in following the lines of panels, adapting to variations in the arrangement of modules within the rows. Please, see also our previous work [16].





The approach proposed in [15] relies on detecting panel edges, which serve as guidelines for computing velocities to be fed to the onboard flight controller. To extract these features, the video from the downward-facing camera is processed. Data extraction can be performed in the Hue-Saturation-Value (HSV) color space, where edges are more distinctly visible. The following preprocessing steps are typically applied to the image:

- 1. Resizing the UAV camera image to a smaller size;
- 2. Applying median filtering to the image;
- 3. Identifying edge pixels in the HSV color space;
- 4. Connecting adjacent panels using morphological methods;
- 5. Using the Canny edge detector to identify all edges [15, 17].

Once the final binary image is obtained, a Hough transform [18] can be applied to identify straight lines in the image. However, a common challenge with this algorithm is the detection of extraneous lines that do not correspond to actual panel edges. A possible rejection strategy exploits the fact that panel edges correspond to the longest lines. Another crucial factor is the line slope, influenced by the tilted positioning of the panels. Consequently, lines are extracted based on thresholds for line length and slope.

Finally, the orientation and distance error between the median line of the camera frame and the extracted line are computed. These values are then used to calculate the required velocities, which are provided to the onboard flight controller to minimize the errors and regulate them to zero, Figure 1.8-5.

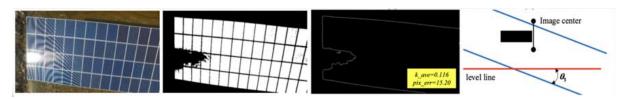


Figure 1.8-5. Image pre-processing example.

When the drone reaches the end of a PV panel row, it must move to the start of the next PV panel row by following a path that has been precomputed, for example, by solving a TSP problem. This task cannot be achieved using visual servoing because the drone lacks visual references when transitioning ("jumping") from one PV panel row to the next. Our previous work [16] demonstrates that this task can be safely accomplished by relying solely on GNSS measurements, even in the presence of significant positioning errors. This is because GNSS errors tend to vary at low frequencies. As a result, the short relative displacement between the end of one PV panel row and the start of the next does not require GNSS measurements to be highly accurate but only necessitates that errors remain stable during the time interval in which the drone is moving.







The presence of multiple drones operating simultaneously in the same PV plant requires solving a multiple TSP [10] to determine paths for all drones that optimize coverage of the entire area. However, this alone is not sufficient, as it is also necessary to address the potential for conflicts or interferences/collisions. These may occur when multiple drones are traveling to or from the takeoff/landing/recharging area, as well as when they are navigating along adjacent PV panel rows. To mitigate these issues, established techniques for real-time coordination of multiple agents operating in the same workspace should be applied [19, 20].

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Data and hardware requirements

The solution developed by UNIGE for planning drone paths and visual servoing along PV panel rows will have the following hardware and software requirements concerning

- The aerial drones to be considered in the prototypal stage
- The PC to be used for path-planning and for supporting onboard computations for drone visual servoing
- The software libraries and other third-party software for optimization, simulation, realtime segmentation

Table 1.8-1, Table 1.8-2 and Table 1.8-3 report these requirements in detail.

Table 1.8-1. Aerial drones to be considered in the prototypal stage

For	tests	DJI Matrice 350 RTK or newer model
with	one	Example configuration:





aerial	DJI Matrice 350 RTK or newer model
drone.	Zenmuse H20T or newer model
	DJI BS65 - Matrice 350 Intelligent Battery Station
	6 Intelligent Flight Battery
	D-RTK High Precision GNSS Mobile Station
	DJI D-RTK 2 Base Station Tripod
For tests with one or multiple aerial drone	DJI Mavic 2 Enterprise Dual (at least 2) or newer model

Table 1.8-2. Requirements of the PC to be used for path-planning and for supporting onboard computations for drone visual servoing

СРИ	>=i7, >=2.60GHz, >=6 Cores (tested on: Intel(R) Core(TM) i7-9750H)
RAM	>=32 GB
Free disk	>=350 GB
space	
OS	Ubuntu 20.04 or higher
GPU	>=4 GB, >=1065 MHz (tested on: Quadro T1000, NVIDIA required)
CUDA	12.2 or higher

Table 1.8-3. Software libraries and other third-party software for optimization, simulation, real-time segmentation

Python	version 3.8.10
ROS	Noetic (Desktop full version) or higher
CPLEX	G0798ML or higher
Concorde	Concorde-03.12.19 or higher







Regarding the requirements from other partners, the activities carried out by UNIGE require input data solely from the demo sites where the tests will be conducted, namely DTU and PPC. Table 1.8-4 outlines the historical data needed from each demo site, along with an estimated timeline for data delivery.

Table 1.8-4. Data required from SOLARIS partners

Partner	Data needed	Purpose	When is it needed?
DTU, PPC	Existing satellite and/or aerial Feed segmentation algorithms that will create a images of the demo plant model of the PV plant for optimal route planning.		Required in January 2025
DTU, PPC	Higher-resolution aerial images of the plant taken at different times of the year and day, under varying sunlight and weather conditions	Train machine learning algorithms for segmentation AND	Required in January 2025
		Provide texture for real-time simulation environments, based on the Robot Operating System and the virtual environment Coppelia. These will be used to model and simulate operations at each site before deployment.	
DTU, PPC	GNSS data collected at the site at different times of the year and day, under various weather conditions	Estimate the dynamics of GNSS data and predict the errors that may occur when moving to the actual site.	Required in March 2025
Any partner	Thermographic images that can be used to train machine learning algorithms for defect recognition on PV panels	ain machine learning algorithms for defect recognition on PV panels. These images can be collected at the selected site or sourced from available datasets that partners may have access to, if they exist	Optional – at any time

Technical specifications

Table 1.8-5 outlines the technical specifications of the algorithms to be developed for optimal path computation.

Table 1.8-5. Algorithm for computing the optimal path on a PV plant using heuristic algorithms for solving the TSP – even in presence of multiple agents.

Phase 1: PV Row Segmentation and Waypoint Computation	Input:







An aerial or satellite image is analyzed using a state-of-the-art neural network for image segmentation (e.g., Detectron2 or a similar model), trained on a dataset specific to solar power plants.

aerial or satellite images of a PV plant. The image resolution, in terms of image pixels per meter, has to be within given limits.

Output:

 CSV file containing geolocated coordinates of the panels (two for each panel).

Phase 2: Path Computation

The set of waypoints to be visited is input to a heuristic-based optimizer, which computes an optimized path for each drone within a reasonably short timeframe. To achieve this, PV panel rows are first divided into clusters using established algorithms such as k-means, ensuring all panels within a cluster are assigned to a single drone for inspection. Subsequently, an optimal control algorithm adjusts the speed of the drones along their paths to prevent collisions or "close calls," where the distance between two drones falls below a user-defined threshold.

Models for optimization

The following models are considered for path optimization:

- 1. CPLEX and Concorde
 - a. Both are deterministic solvers. Given sufficient time, they always find the optimal solution.
 - For CPLEX, a maximum time limit can be set, and within this timeframe, the algorithm produces the same solution consistently (though not necessarily optimal).
- 2. Simulated Annealing and Iterated Local Search
 - a. These are heuristic methods that produce nearoptimal solutions within a reasonably short time.
 - b. They are non-deterministic, meaning that multiple runs may yield different solutions.
- 3. Additional Models
 - a. Gurobi
 - b. Genetic algorithms
 - c. Self-organizing paths

Input:

- CSV File: Contains the geolocated coordinates of the panels (two coordinates for each panel).
- YAML Configuration File: Specifies parameters such as the solver to use, the number of passes per panel, etc.

Output:

- CSV File: Contains the list of waypoints to be visited (in the order of visitation) and their corresponding panels.
- 2. PDF File: Provides a flight map over the panels.
- (If CPLEX was used) MST File: Stores the best solution found so far, which can be further refined by re-running CPLEX using this solution as a starting point.
- Global Log File: Records the optimization problems solved to date, including computation times and the total cost of the solutions found.







- d. Ant Colony Optimization
 - Single-Agent vs. Multi-Agent Optimization
- Single Agent: During optimization, the drone's speed is assumed to be constant along the path, except at trajectory corners where adjustments are required.
- Multiple Agents: For multi-agent scenarios, a separate file is generated for each drone. This file includes:
 - The list of waypoints to be visited.
 - The motion laws between consecutive waypoints.
 These motion laws are optimized to minimize inspection time further while ensuring collision avoidance.

Table 1.8-6 presents the technical specifications of the algorithms to be developed for real-time visual servoing of aerial drones over PV panel rows.

Table 1.8-6. Algorithm for visual servoing over PV panel rows

Phase 3: Flight above PV panels

The waypoints generated in the earlier phases will serve as inputs for aerial drones, which are tasked with flying along PV panel rows to capture high-resolution images for further analysis (not performed by UNIGE).

To achieve this, the drones will rely on two key types of data: real-time images for visual servoing (i.e., maintaining the median of the PV panel row as closely aligned as possible with the median of the image) and GNSS data, which will enable navigation to the next panel by determining the relative position between the waypoint at the end of one PV panel row and the waypoint at the start of the next.

For segmenting PV panel rows, a state-of-the-art neural network for image segmentation, such as Detectron2 or a similar model, will be utilized. This network will be trained on a dataset specifically tailored to the solar power plants where the experiments are to be conducted.

For visual servoing, various control algorithms will be defined and tested, including at a minimum: PID control, Lyapunovbased nonlinear control, and task-stacking control.

Input:

- CSV File: Contains the list of waypoints to be visited (in the order of visitation) and their corresponding panels.
- 2. YAML configuration file: it defines the parameters for the flight, such as the angle of the panels with respect to the horizontal (assumed to be the same for all panels), the coefficients used for the control algorithms, the desired flight height (assumed to be constant) and so on.
- Images: Real-time images (RGB and/or thermal) captured by the drone's camera at a minimum frequency of 5 Hz, using a







The system will also be implemented in simulation using the CoppeliaSim simulator. The drone's flight is simulated in real time, by re-using the same code used to control real drones. During the simulation, the user should be able to visualize:

- Dynamic Plots: Continuously updated plots should display flight parameters, including real and desired flight coordinates, control actions, and errors.
- Simulated Camera Views: separate displays should show the panels as viewed by the simulated camera and as segmented by the neural network.

- sensor such as the Zenmuse H2OT.
- 4. Positioning Data: Real-time positioning data, including GPS or RTK GPS (for enhanced accuracy), compass readings, and onboard IMU data, acquired by the drone.
- For simulation only: a satellite image of a solar plant as a JPG file. This is optional, but it is helpful to provide a realistic background (grass, soil and so on) for the CoppeliaSim simulator.

Output:

- Log File: Contains detailed information about the trajectory followed by the drone, including positions and velocities along the three axes.
- 2. High-Resolution Thermal Images: A sequence of high-resolution thermal images stored on an onboard storage, to be analyzed offline in a subsequent phase.
- Additional Sensor Data: Data potentially collected via a custom sensor used as a drone payload, with specifications to be formalized at a later stage.







Method for testing and validation

The capabilities developed by UNIGE will be tested at two of the demonstration sites (DTU, PPC), as described in section 4.1, Use case #1. The tests will be aimed at evaluating:

- The ability of the UNIGE solution to find an optimal inspection path using satellite or aerial images of the selected site, taking into account constraints such as takeoff/landing/recharging areas and battery capacity. The quality of the solution provided by different optimization algorithms will be assessed on the as well as the optimization time.
- The ability of the UNIGE solution to enable aerial drones to fly along PV panel rows with minimal lateral error, ensuring that the PV panel remains within the boundaries of the collected images, even at low altitudes when the panel occupies most of the image. This will be tested at various navigation speeds, altitudes, and PV panel inclinations, with all related errors being measured.
- The ability of the UNIGE solution to enable aerial drones to navigate from one PV panel row to the next using GNSS data, as visual servoing is not possible in this case. The drone's ability to use GNSS positioning data to reach the start of the new PV row after the previous one has been fully inspected will be measured, along with the related errors.
- The ability of the UNIGE solution to manage multiple drones (e.g., 2 or 3) inspecting the
 plant simultaneously, ensuring they avoid conflicts and collisions when heading to takeoff/landing/recharging sites or inspecting nearby PV rows. The reduction in inspection
 time will be measured.

The DTU site is particularly valuable due to its smaller size, which simplifies initial experiments. The PPC site, in contrast, offers greater size and complexity, providing a more challenging environment for algorithms to find and follow an optimal path during real-time operations.

KPIs for assessing performance of the developed models, tools and hardware.

This task is covered by the following KPI, detailed in section 5.2:

• **KPI O2.6:** Reduction in inspection time through group flight (N number of drones, 5% possible interferences between drones)

Role of project partners

It should be emphasized that UNIGE will focus on enabling aerial drones to carry payloads (e.g., sensors suitable for defect recognition) along PV trackers, but it will not focus on defect recognition itself, as this is not part of their role in the project. Therefore, any partner proposing a defect recognition solution based on data collected by aerial drones will have the opportunity (provided that physical constraints are respected) to use their sensor as a payload that UNIGE's drones will carry during flights.







- UNIGE will develop and test all the required techniques for path optimization starting
 from satellite or aerial images, visual servoing and GNSS-based navigation along PV panel
 rows, and scheduling of multiple aerial drones to improve inspection times. Also, UNIGE
 will provide local technical support during the initial experimental phases at DTU and PPC.
- **DTU** and **PPC** will provide data (images and GNSS data) to train algorithms for image segmentation and navigation, as well as local support for testing at the demo sites, as also described in section 3.6.4.







1.9 Task 3.4 Design of an impedance sensor device for retrofitting to existing power converters [EMA]

Background

Impedance testing on the DC side in solar farm assets is limited in use, so state of the art is the mobile test instrument solution as patented by emazys (DK). The technological solution is a rugged field ready test instrument, that comes with the following measurement functions:

- Open circuit voltage Voc [0-1500V]
- Short circuit current Isc [0-30A]
- Electrical polarity
- Isolation resistance Riso [0 40 MΩ]
- Isolation resistance fault location measurement [Riso < 3MΩ]
- Series resistance Rs
- Tone generator + amplifier probe

The instrument has the following key features:

- Wireless connection between smart device and instrument (Bluetooth)
- Wireless connection between data cloud and controller App (WiFi)
- Controller App available iOS and Android
- Meta data in reports: GPS, timestamp, photo, module, environment data etc.
- Single test report as PDF
- Filter and view data as GPS map or table
- Export data as CSV
- Rechargeable battery with operating time of 8-10 hours

With its capability to test impedance values (essentially Rs) at 1500V DC, and the capability to function as a data-logger, the instruments from emazys are an ideal platform, where we can pick the essential hardware and software components, to design and build an on-site installed monitoring device.

On-Site Impedance Testing for Solar Modules







To our knowledge, SOLARIS is currently the only project using on-site impedance testing as a monitoring solution for solar modules. The mobile testing instrument we are developing is a key part of our approach, allowing us to test our ideas directly in the field rather than in a lab. This hands-on testing gives us real-world data about how solar modules and sensors perform in actual conditions.

Testing on-site is a big advantage, as it lets us spot potential problems early on. Instead of relying only on simulations or theoretical models, we can see how our designs work in practice and adjust before moving forward with the final design. This helps us avoid surprises later on and ensures our solutions are practical and ready for real-world use.

Data and hardware requirements

For the development and validation of the design idea we have a good starting point since we can use our mobile test instrument as a laboratory – see main design in Figure 1.9-2.

The core advantage is that the field test instrument hardware allows us to connect to module string with up to 1500V DC and still be able to test the impedance using a weak test signal, that will not create perturbations in the device under test (DUT). This msr_engine PCB can thus interface to basically any PV system and be used at the connection point.

Technical specifications

MC4 connectors are found between the modules, and at the terminals – see illustration. In this way the EMA sensor is a stand-alone device that can be retrofitted to any PV system in the field with only these technical requirements:

- 1) MC4 connectors
- 2) On-site internet / WiFi





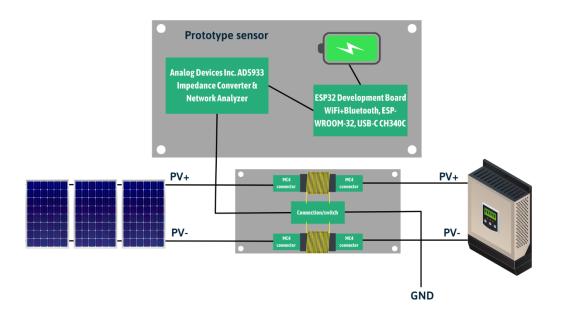


Figure 1.9-1. Installation of the mobile test device in a PV system.





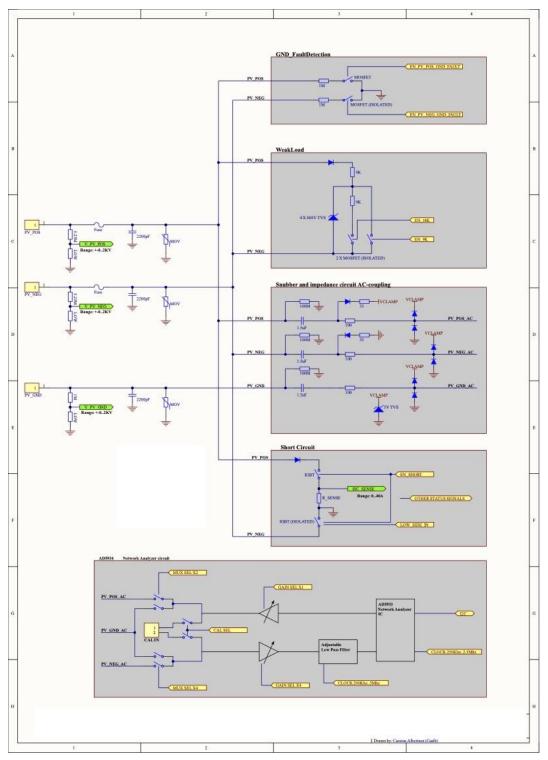


Figure 1.9-2. Schematic of the Emazys mobile test instrument.





Method for testing and validation

The validation of the requirements and specifications of the design is based on field testing first the mobile instrument including data logging, which is ongoing in autumn/winter 2024. In spring and summer 2026 we will install the modified "monitoring ready" versions of the instrument in the field and start to log data i.e. the data to be logged is a subset of full measurement capability for the instrument. The validation is that we collect data to the EMA cloud.

KPIs for assessing performance of the developed models, tools and hardware.

The KPI in question is Revised to be "KPI1.2ii: Average PV string failure detection rate" and the goal is to double the average number of strings faults detected over 1 year of operation, by adding the impedance sensor. Refer to section 5.2 for detailed description

The key issue is that electrical string faults online reported by inverters and energy monitoring equipment, can be highly ambiguous. The root cause of the most frequently observed string faults at the utility scale is loss of electrical isolation or loss of connectivity due to mismatched connectors. In this way the majority of string faults are typically not related to the photovoltaic absorbers/PV cells. Therefore, performance measurements typically do not reveal the root cause of issues, but they highlight that something is wrong.

By using impedance testing, we can narrow down the number of possible root causes to in case of common string faults. The aim is to remove the ambiguity that appears when the energy monitoring is used, for diagnosing a specific fault. The KPI for the sensor is therefore defined as its ability to consistently register a fault before the energy monitoring does, as well as registering faults that energy monitoring does not catch. The sensor is installed as an add on device and it may be integrated in the inverter.

Role of the project partners

EMA will work with AAU on setting up the device at DTU, and we will work together on establishing the 2 monitoring solutions, to measure their effectiveness.







1.10Task 3.5: Development of a novel inverter design for reconfiguration to enhance the maintenance and inverter availability [AAU]

Background

Recent advances in inverter design rely on mission-profile-based reliability analysis using physics-of-failure to design the inverter components for a desired end-of-life criterion under given operating conditions and mission profiles. Furthermore, inverter design based on physical reconfiguration using interleaving concept and redundant operation strategy has been developed to enhance its reliability. However, maintenance and reconfiguration with respect to the state-of-the-health of inverter and active/reactive power control reconfiguration have not been considered so far in PV inverter design optimisation. As PV systems are working in different loading levels according to solar irradiance, maintenance, physical and control reconfiguration in the PV inverter structure will remarkably impact its reliability, availability, and consequently its manufacturing and operational costs.

Going beyond the state-of-the-art, AAU will propose a novel PV inverter design based on current commercial topologies of two-level inverter and three-level NPC inverter with redundant operation to enhance its reliability and decrease its manufacturing and operational costs (see figure below). The main idea is to design a reconfigurable structure for the PV inverter, where the reconfiguration will be smartly applied at physical level (by having non-exclusive redundant and interleaved legs) and at control level (by reactive power routing), according to the state-of-the-health of different power devices and loading conditions. This will not only add physical and non-exclusive redundancy to the inverter to properly operate in case of failure in a power device, but also add inherent redundancy in partial loading conditions in case of failure in more than one power device, high thermal damage in some power devices and reactive power supply. Thus, the inverter's availability will be remarkably increased.

Data and hardware requirements

- Mission profile at DTU demonstration site: resolution of 5 seconds or at least 1 minute:
 - 1. Annual solar irradiance
 - 2. Annual ambient temperature
- PV array characteristics at DTU site.





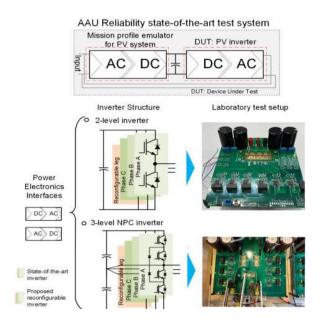


Figure 1.10-1. AAU reliability test system and the proposed reconfigurable inverter topologies.

Technical specifications

Two inverter structures including 2-level inverter and 3-level NPC inverter will be considered and analyzed in this task. According to the mission profile at the DTU site and also the PV array characteristics, the optimum inverter topology will be selected and designed.

Method for testing and validation

The developed inverter will be tested at the reliability lab of AAU Energy. In practice measurement of the lifetime of the Power Electronics converters (or any devices) require long term operation, that is not practical due to the time limitation. For this reason, in SOLARIS, we will have two methods to measure the lifetime enhancement of the PV inverter lifetime. First, we will use laboratory tests to demonstrate that our advanced control and reconfiguration solution will decrease the thermal stress on the inverter semiconductor devices in short term operation. We will use these test data to validate our lifetime model, and then we will use long term mission profile simulations to demonstrate the lifetime enhancement for long term operation.

Furthermore, the junction temperature of the IGBTs will be measured and the lifetime model of the PV inverter will be tuned. Due to the time limitation in the project, fake failures will be implemented in the inverter, and their occurrence will be predicted to reduce the downtime and increase the inverter availability.

KPIs for assessing performance of the developed models, tools and hardware.

This task is covered by the following KPI, detailed in section 5.2:

KPI 1.7ii: Prolonged lifetime of inverters







Role of project partners

AAU will develop this task by itself by getting weather prediction data (solar irradiance and ambient temperature) from UBIMET and DTU.





1.11Task 4.1: Development of the smart IoT connectivity for automated monitoring, inspection and maintenance [ELLC]

Background

Existing solutions for PV plants maintenance include ::

- **Sprinkler**: effective when water is treated to ensure it is pure. The quantity of water is a great disadvantage, especially with the current situation of water scarcity. Current commercial solutions program the sprinklers every night for the right cleaning of panels^{[2],[3]}.
- Manual cleaning: this option can pose a risk for workers, especially on rooftops. In addition, chemicals can be aggressive to solar panel materials and must be controlled for environmental reasons.
- Cleaning robot: they are too heavy and can produce cracks on the PV panels
- Cleaning drone

In recent years, the evolution of reliable condition-monitoring and fault detection techniques based on enabling technologies, namely, artificial intelligence (AI), machine and deep learning, internet of things (IoT), unmanned aerial vehicles (UAVs), big data analytics (BDA), and satellite data, have seen dramatic development to automate PV monitoring [4].

IoT technologies can support the real-time monitoring of PV plants. This data can then be used to develop machine learning (ML) or AI algorithms that predict power generation or identify faults before they occur. Currently, models for fault diagnosis focus on one type of fault. Therefore, further research should focus on dealing with multiple defaults at the same time using the same model or integrating different models^[5]. In addition, they are also not able to make a clear diagnosis to prompt autonomous decisions^[6].

Regarding the application of IoT technologies for the maintenance of PV plants, a previous study has demonstrated a maintenance system consisting of actuators, embedded systems, intelligent devices (with the ability to compute), microcontroller units, transceivers, and sensors. It was highlighted that the IoT and maintenance systems may, in reality, be **complicated and sophisticated**. It is easy to overinvest in such installation and some functions may not be used in all circumstances or only used rarely, which makes their utilisation questionable.

"Machine learning for predictive maintenance of photovoltaic panels: cleaning process application" (2022)

[2] RST Cleantech case study







- Bigwit Energy Cleaning Solution
- 4 "Autonomous Monitoring and Analysis of Photovoltaic Systems" (2022)
- ^[5] "Review on maintenance of photovoltaic systems based on deep learning and internet of things" (2022)
- "Artificial intelligence and internet of things to improve efficacy of diagnosis and remote sensing of solar photovoltaic systems: Challenges, recommendations and future directions" (2021)
- "IoT Solutions for Maintenance and Evaluation of Photovoltaic Systems" (2021)

An example of a commercial solution for IoT PV monitoring is the ABB Ability Aurora Vision Plant Management Platform^[1].

On-going PV systems initiatives on similar topics

A previous EU-funded project (**EASY PV**) presented a solution to automate the process of PV plant maintenance by employing a **Remotely Piloted Aircraft System** (RPAS) equipped with a custom-designed payload that includes a thermal camera and a low-cost GNSS RTK receiver^[2]. Data collected and processed were stored and visualised through a web platform, called Visual Track Energy (VTE) platform. In this tool, the operator could easily visualise the PV modules affected by anomalies, usually hot spots. The main inconvenience is that all **data processing** operations were carried out **manually**^[3].

Potential barriers to the development of the solutions

IoT monitoring for PV industry challenges [4][5] can be summarised as follows:

- Interoperability: lack of standards, complexity in mixed implementations due to the heterogeneity of integrated solutions (both IoT and legacy SCADA systems)
- Management: good communication systems are also needed because the plants are
 usually large and isolated which means that all the monitoring must be done remotely.
 The communications are also required for video surveillance and typically for remote
 access by energy companies to the meter of the plant. The whole network load is quite
 intense, and the quality of the connections tends to be inadequate due to the isolation of
 the plant. Inefficient end-devices
- Cybersecurity
- **Processing**: Data must be collected up to a frequency of 1 s for a good Real-Time analysis
- **Scalability**: Configuration should be simplified and automatized to allow better deployment times.







- Cost: intensive initial effort
- "AI4PV D1.1 Use cases for O&M of solar power plants" (2021)
- (2017).
- (2018). "Operational Validation Report. EASY-DEL-D10.1"
- "An IoT open-source platform for photovoltaic plants supervision" (2021)
- (2021) "Artificial intelligence and internet of things to improve efficacy of diagnosis and remote sensing of solar photovoltaic systems: Challenges, recommendations and future directions"

Data and hardware requirements

The data requirements by both pilots and technical providers in the projects have been gathered in section 2 of this document.

Technical specifications

• Functional requirements for the IoT platform

ID	FUNC.01	
Name	Multiplatform support for accessing the IoT platform	
Requirement Type	Functional	
Description	The user should be able to access the platform using different devices: • Tablet • Computer	
Fit Criterion (Measurable)	The IoT platform is compatible with different devices.	

ID	FUNC.02
Name	GUI for the IoT platform
Requirement Type	Functional
Description	Access to the dashboard of the IoT platform should be provided through a GUI.







Fit Criterion	An interactive User Interface will be provided that will allow users to access	
(Measurable)	the IoT platform, see KPIs perform queries and retrieve information related to the performance of the PV plant.	

• Non-functional requirements for the IoT platform

ID	NFUNC.01	
Name	Containerised deployment of the IoT platform.	
Requirement Type	Non-Functional – Scalability	
Description	The IoT platform must be compatible with a wide range of OS and hardware while being easy to install. For that, it will be provided as containerised applications with no external dependencies needs. The IoT platform will deploy containers with Elliots Apps lowcode.	
Fit Criterion (Measurable)	The IoT platform can be seamlessly deployed using a containerised approach with a given set of minimum technological constraints.	

ID	NFUNC.02	
Name	Security layer in HTTPS for communication to the IoT platform.	
Requirement Type	Non-functional - Security	
Description	All incoming and outgoing traffic will be routed through an Nginx reverse proxy configured with an SSL certificate to use HTTPS, in addition to configuring the redirection of all communications through HTTPS. This also forces the WEB GUI application to only be able to communicate over HTTPS.	
Fit Criterion (Measurable)	Reliability of the data communication security through SSL certificate.	

ID	NFUNC.03
Name	Responsive Angular application
Requirement Type	Non-Functional - Scalability







Description	The IoT platform will be an independent Angular application, which applies accessibility and responsive design standards for correct display on all types of screens. Angular compiles to static files using Webpack, which ensures compatibility with different browsers such as Firefox, Edge, and Chrome.	
Fit Criterion (Measurable)	Compatibility with most common internet browsers to increase the coverage.	

ID	NFUNC.04
Name	Easy to use GUI in line with SOLARIS identity.
Requirement Type	Non-Functional – Usability
Description	The User Interfaces shall have a user-friendly look aligned with the SOLARIS common design and communication guidelines. Each user should be able to act in a well-planned and easy way.
Fit Criterion (Measurable)	All IoT platform UIs will be implemented by employing a User-Friendly approach, and their look and feel should comply with SOLARIS design guidelines.

ID	NFUNC.05	
Name	Management of the consent to public visibility of the data.	
Requirement Type	Non-Functional – Privacy	
Description	Before making data sets publicly available, pilot site owners should explicitly provide their consent to the IoT platform. Pilot site owners have complete control and are free to remove their consent at any time if needed.	
Fit Criterion (Measurable)	Pilot site owners can give and remove their consent to make data publicly available.	

Method for testing and validation

The smart IoT platform will be tested in all demo sites.







KPIs for assessing performance of the developed models, tools and hardware.

This task is covered by the following KPI, detailed in section 5.2:

KPI O2.7: Platform availability:

The platform must be robust and guarantee a high availability. This means that it must not withstand long-term interruptions with the loss of data or management alerts. It is very important that the point of failure is not the central management platform, since it impacts the overall project. As a baseline, we can estimate that current availabilities can be around 90%.

The availability can be calculated as: Availability = (Hours per year – Hours downtime) / Hours per year.

ELLC will need contribution from pilot leaders in order to gather their data in our platform and will be responsible for the correct data processing in order to meet this KPI. ELLC will measure this KPI using tests.

Role of project partners

DTU

Must provide access to the database to collect all the necessary information by means of one or more scripts to read all the data.

Database queries may be predefined by DTU. Otherwise, a document must be provided to ELLC mapping each of the required variables and attributes including how to obtain them.

PPC

Must provide access to the database to collect all the necessary information by means of one or more scripts to read all the data.

Database queries may be predefined by PPC. Otherwise, a document must be provided to ELLC mapping each of the required variables and attributes including how to obtain them.

For the integration of historical data that are not present in the database, PPC will deliver an Excel document with all the measurements. Several Excel can be delivered if the same format is followed.

FIB

The data will be collected through an API Rest provided by FIB. Thus, a user manual must be sent to ELLC, and the corresponding access must also be provided.

EILAT







The data will be collected through an API Rest provided by EILAT. Thus, a user manual must be sent to ELLC, and the corresponding access must also be provided.

Technical Partners

Measurements from other partners' devices will be collected via an MQTT server. ELLC will be responsible for setting up an MQTT broker so that all data can be sent from each of the devices.

At the same time, each partner is responsible for developing an MQTT client that is responsible for sending or receiving messages. It can be an IoT device, or an application in Python, Java, Node.js, etc. ELLC cannot provide this infrastructure.

Popular libraries:

Python: paho-mqtt

Java: Eclipse Paho Client

JavaScript/Node.js: mqtt package

ELLC will define the topics to which each measure should be published.

Another option is for the pilots to incorporate the measurements from the partners' devices into their database so that they can be collected as a plant variable.





1.12Task 4.2: Development of reduced order models for self-protection mechanisms [TEK]

Background

Mechanical integrity of Photovoltaic (PV) modules plays an important role in their performance and electrical output. The mechanical integrity is greatly influenced by its design, type of material used, the manufacturing process, and the method of handling during transportation [1]. Furthermore, it is also affected by environmental conditions and the loads applied on it, like the mechanical load due to wind, snow, rain and hail, or the thermal loads due to temperature variation. These loads tend to degrade the performance of the PV module by generating stresses and enhancing micro cracks and defects; finally, this results in increased resistance to the flow of electric current and the reduction of the power output of the modules [2][3]. Furthermore, the degradation of the panel results not only on efficiency issues in the electric power generation but also a reduced lifetime.

Wind can act steadily and transiently, imposing static and dynamic loads on PV modules. Depending on the wind direction, cells may be under compression or tension, being the tension stress the main factor for the degradation of the panels [4].

The preservation of the integrity of the panel is an important issue to maintain the productivity and the lifetime, so methods to protect the panels against wind loads have been investigated and developed. The effect of the wind in flat plates have been studied in the past, experimentally and numerically [5]. In those studies, the static and dynamic effects of the wind for different velocities and tilt angles of the flat plate were studied in detail. The static forces that the wind induces on a solar array are decomposed into drag (parallel to the ground) and lift (perpendicular to the ground) forces, which create a torque about the support bar, also deforming the panel.

The most challenging point in the structural design of solar trackers is to consider the dynamic effects of the wind, as it can produce damage in the structure by different mechanism, such as resonant vibration and the torsional flutter or galloping [5], being the first related to the structural vibration modes and the second to self-excited aerodynamic instabilities.

The damage as a result of the dynamic wind loads has been treated mainly from the frequency of vibration point of view, linking the stress to the modal shapes of the panels and the excitation of the main modes [6][7]. So, strategies to improve the behaviour of the modules normally involve the lowering of the natural frequencies and the increase of the damping, that can be performed by the increase of the tracker length, the reduction of the cord length and the general improvement of the torque tube of the actuation [8], but this measured counteract between leading to non-desired effects and the increased demands in the structural part of the modules.







The wind gusts produce surface loads in the panels and torsional motion in the modules, that lead to vibrations and stress that could damage the modules. Furthermore, the aerodynamic aspects are relevant, as they also affect the way the loads are applied on the module and its behaviour [8]. So, the configuration of the modules, the mechanical structure and the position (i.e. tilting angle) significantly affect the integrity and the lifetime of the modules.

Many studies have analysed the wind loads on solar panels to improve the safety of the design [9]. The first row of solar panels provides a sheltering effect that reduces the wind load on other rows, the individual panel are more exposed to wind load, the wind load on a solar panel is affected by the longitudinal spacing rather than the lateral spacing, the critical incidence angle at low tilting angles, or the use of windbreaks to reduce the wind load. So, the angles of the panels and the wind direction influences the forces applied on the panel [10], being the 0 pitch angle the best orientation for reducing the bending moment, while low tilt angles could reduce the normal force. However, the low angles tend to suffer aeroelastic instabilities producing galloping.

The monitoring of the PV panels and modules has not been treated extensively. The wind pressure in a set of modules can be monitored using pressure sensors in both sides of the panel in a wind tunnel to monitor the drag and lift forces [9]. The current available products estimate the wind load based on coefficients obtained from wind tunnel test [8] and not based on actual forces acting on the panel or the module structure; but the motor consumption is used to test the torsion of the main torque tube during design phases [8].

The stow management strategies are focused on the definition of positions to minimize the effects of the wind loads and other (snow, hail...), but the optimum is not clear if several effects are present simultaneously. Furthermore, the optimum value for wind loads depends not only on the panel area but on the structure of the module due to the different effects of the static, the dynamic and the aeroelastic loads [8]. The tracker is controlled and sent to the stow position based on the information about the wind speed and direction of the available sensors. Alternatively, this can be commanded manually by the operators. Even in the stow position the wind loads could result in uncontrollable movement due to resonant modes or galloping. So, there could be different stow positions depending on the wind speed and direction, or it could be necessary to change the stow position to break the forced or regenerative vibrations.

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- [9] Seok Min Choi, et al. Effects of wind loads on the solar panel array of a floating photovoltaic system Experimental study and economic analysis. Energy, Volume 256, 2022, 124649. https://doi.org/10.1016/j.energy.2022.124649.

On-going PV systems initiatives on similar topics

The classical wind strategies protects solar trackers based on the wind speed and direction information, sending the tracker to stow position though a sequence of positions that face the wind. Some manufacturers include tracker that avoid facing the wind, being faster to adopt the stow position and the potential damage to the panels. However, this kind of systems works with the general wind data not the particular behavior at panel level. Stow Strategies for PVH Trackers

Other proposal include a first row of panels controlled by the tracker to adopt positions that protect the interior rows of panels, but this again uses conventional wind sensor at plant level to adopt the defence position. <u>US10601364B1 - Solar wind fence for an array of trackers - Google Patents</u>

Potential barriers to the development of the solutions

The main potential barriers are:

- The obtaining of a suitable algorithm to be implemented in the current controllers of the trackers. This is related to open nature of the controller and the possibilities to modify the defence position algorithm.
- The control algorithms' ability to provide a fast and suitable response to the variable wind loads. i.e. avoiding unstable response, not achieving a fixed stow position.







Data and hardware requirements

The reduce order models should lead to a control algorithm based on the wind smart sensor (WP3, T3.1) signals to protect the panels based on their individual behaviour (static and dynamic) against the wind loads. This algorithm and the reduced model is expected to be developed based on the data captured during the characterization and monitoring tests of the wind smart sensors, and the development of the reduced models will be based on data based models or regression models, aiming to obtain model suitable to be implemented in a tracker controller.

The development will be tested in the DTU demo site together with the wind smart sensor (WP3, T3.1), so the information required (partially covered in the corresponding chapter of this deliverable) is related to the following aspects:

- The data needed is related to the information of the wind (time stamp, speed and direction) and how this is used to adopt the defence position. Probably, it will be needed to monitor the wind near the monitored panels in order to establish the correlation between this and the data of the installed the sensors in For the evaluation of the time spent in defence position (KPI 1.5), the actual data corresponding to this type of event is required, as well as, the causes that drives to adopt the defence position (wind speed and direction and others).
- Information about the controllers, the Scada and the available communication protocols. The objective is to understand the possible ways to send the sensor data and the implementation of new control algorithms based on the new data set generated with the panel sensors.
- Information about the algorithms to set the target defence position and the data currently used by the PLC program
- Information about the loss of efficiency or damage to the PV panel attributed to the wind loads in order to assess potential improvements in this sense, linking this to the evaluation of the KPI 1.8iii.

The development of the models and the implementation in the controller will be performed after the initial phases of testing with the wind smart sensor (WP3, T3.1) in order to record different wind events and the response of the panels under different situations.

Technical specifications

The model and the control algorithm will be executed directly in the tracker controller or externally in a PC with communication to the controller to command the tracker stow positions based on the data provided by the wind smart sensor.







The control algorithm is expected to have an active nature, slightly modifying the stow position based on the behaviour of the panels, rather than just adopting a fixed stow tilt angle. So, a direct and continuous communication must be stablished between the tracker controller and this self-protection algorithm.

Method for testing and validation

The testing and validation of the self-protection mechanism based on the wind smart sensors will be performed at the DTU demonstration site. This will consist of a campaign of validation test involving the verification of the control algorithm to bring the panel to a suitable defence position optimizing the energy production and minimizing the damage to the panel, mainly by reducing the deformation of the panels.

TEK and DTU will collaborate to manage the issues depending on the plant and on the sensor sets.

KPIs for assessing performance of the developed models, tools and hardware.

This task is covered by the following KPIs, detailed in section 5.2:

- KPI1. 5: Reduction in time spent in defence position
- KPI1. 7iii: PV system reliability and security

Role of project partners

DTU

- Collaboration with TEK for the communication and modifications required in the tracker controller.
- Provide the data defined in section "Data and hardware requirements".
- Propose a method to evaluate the damage or loss of efficiency of the PV due to wind loads.







1.13Task 4.3: Development of a field control app in the context of reconfigurable topologies [HELIO]

Background

Today onsite inspection and maintenance operations of solar photovoltaic facilities typically fall into the one of the following categories:

- · Acceptance test as part of a site commissioning
- Preventive periodic inspections
- Punctual inspections triggered by the remote detection of a performance issue, or investigate a suspected incident (for example a severe weather episode)
- Curative works following the identification of a performance issue

Innovation in field instrumentation, such as thermographic imaging supported by drones, or portable electroluminescence or UV fluorescence devices, have enabled technicians to collect more detailed and more voluminous measurements during an inspection. However these data are typically not cross-examined with performance analytics, which hinders decision-making regarding faults and typically prevents the effectiveness of actions to be verified until a significant time after the intervention has been completed.

The effectiveness of all the above classes of onsite intervention is enhanced by a detailed knowledge of the facility's performance and condition of components in advance. In the frame of SOLARIS project, Heliocity proposes a remote diagnostics inspection service that provides such analytics that can complement initial assessments, guide technicians to undertake more targeted actions during the operational life of a facility, as well as alert operators of performance issues. Moreover, the quality of information that can be obtained onsite can be improved by putting performance analytics in the hands of technicians during an inspection. For example, junction box open circuit voltage and nominal current measurements are more useful when combined with estimates of expected values derived from local meteorological conditions.

The development of a field control app will demonstrate the value of leveraging remote diagnostics for improved onsite actions. In addition, other digital tools, plus novel measurements to either be made by a technician or that can be made available remotely can be integrated into this tool to even greater effect. Features capitalising simulation and diagnostic information include

- Estimation of expected electrical characteristics with which to compare onsite measurements
- Estimation of changes in electrical characteristics following a maintenance operation







 Pre-identification and localisation of likely faults with instructions for a technician to follow onsite

In addition, the opportunities of reconfigurable topologies will be exposed through the analytic capabilities delivered by the field app connected to the Heliocity platform. The following features will be integrated to this end:

- Dynamic estimation of string re-balancing scenarios to minimise losses resulting from component deterioration (for example, voltage drops along strings due to ageing)
- Prediction of a new operating conditions resulting from the replacement of components including PV modules (that may have different electrical characteristics to initial modules) and inverters (that may introduce different operating ranges)

Beyond the previous lack of remote diagnostic services, another hindrance that is a potential barrier to the development of the field app is the interoperability of and accessibility of the various data sources. This difficulty will be tackled by establishing a suitable data model and leveraging competences for data connectivity within the consortium (IoT platform).

Data and hardware requirements

Since the field control app is a software project, no specific hardware is required for its development. However, for the purpose of testing at the demonstrator site, the field control app with be installed on a smartphone and a laptop for a technician to use during an onsite intervention. The technical requirements of these devices will be confirmed once the app development has reached a sufficient level of completeness. The technician will further need to be equipped with relevant measurement devices to carry out an inspection and/or staged maintenance action. Beyond the smartphone device and laptop, the infrastructure requirements of the application are all cloud-based.

The field control app requires that all necessary historical data are available in ELLC cloud platform, and additionally that the "Remote Failure detection and quantification" service running for the purpose of the test inspection. The ELLC platform must enable data interchange with the other digital services, including the forecast and energy trading services. The data requirements the demo site are listed in section 3.6.5.

Technical specifications

The field control app comprises a frontend application to be developed for the Android operating system that functions as an interface to the Heliocity cloud-based software suite, which will provide a dedicated REST API for the application. The detailed specifications of the app will be elaborated by consulting existing customers of Heliocity who have expressed an interest in such a tool. It will incorporate the following technical functionalities, requiring developments both within the app itself and within the software stack deployed in the cloud:







- Multi-sources data harmonisation and fusion
- Development of pseudo realtime physics-based simulator and human-guided data labelling for robust machine learning and thresholds optimisation.
- Development and integration of field actions recommendations/reconfiguration instructions engine.

The field app will be developed such that it is compatible and ready for integration with the PV asset management software.

Method for testing and validation

The field app will be tested at the DTU demo site as described by the use case 3a. More precisely a technician at the DTU site will undertake a scripted inspection of the facility, taking the relevant data and undertaking a (simulated) maintenance operation, recording data and verifying the works with the app during the operation.

For testing, a fictional scenario or fault detection and remediation will be prepared for the technician to carry out an intervention that involves the complete range of the apps features.

KPIs for assessing performance of the developed models, tools and hardware.

This task is covered by the following KPI, detailed in section 5.2:

• **KPIO3.2:** Field control app demonstrated with >5 on-site features: 5 different features shall be field tested at DTU site

Role of project partners

The ELLC platform will provide a crucial role in connecting the Heliocity platform (which will handle the mobile app backend) to the required data and other services. A common basis must also be established with partners developing other software and hardware tools with which data interfaces must be introduced.







1.14Task 4.4: Development of the fleet management tool based on predictive maintenance [HELIO]

Background

Asset management software for PV systems typically comprise summary tables and visualisations of fleet performance, and in some cases, information relating to major incidents and maintenance interventions. Rather than offering fine analytics, these solutions offer an overview of the PV facilities operational state. The underlying philosophy of these tools is to accompany practices of preventive actions without priori verification of need, curative actions to remedy a major failure, and allow periodic summaries of the assets. The integration of high-quality diagnostic algorithms therefore represents a revolutionary advancement, to enable earlier and targeted preventive interventions, to prioritise between different tasks and even sites in the fleet, and thus develop an optimised maintenance scheduling. For all of these, it is necessary to introduce predictive maintenance.

Today predictive maintenance remains an unattained goal in the field of PV operations. A particular barrier to the development of such tools has been to date the lack of rich labelled performance and fault data needed to train for machine learning and deep learning algorithms. Through its existing services Heliocity has constructed a substantial dataset of labelled performance data, well adapted for the identification of failure pathologies, their precursors and consequences. This dataset will be further enhanced for the purpose of training a predictive maintenance tool.

Data and hardware requirements

There are no specific hardware requirements specific to this task, although the developments are reliant on data sources and interfaces to be made available through parallel actions in the project. The underlying algorithms will be developed within the existing infrastructure of the Heliocity software suite and does not require additional infrastructure, other than a straightforward scaling of already committed resources (disk, virtual machine specifications). Additional data modules will be added to handle the data harmonisation and storage of the various data sources.

Technical specifications

The fleet management tool is a web application comprising frontend, dedicated backend with REST API to retrieve the results of offline computation undertaken by separate applications in a software stack.

Building on Heliocity's algorithms for fault detection and identification based on AI and Big Data analytics, an online tool will be developed to predict upcoming maintenance activities and enhance the bankability of solar installations by matching cost of intervention, expected financial gain and projected losses resulting from the maintenance schedule. These algorithms will be







based on a digital twin of the demonstration installations, modelled by Heliocity. The algorithms will be developed as a python application integrated into the existing software stack and infrastructure of Heliocity which is both deployed on local servers and in the cloud.

Several developments and optimisations will be needed concerning data harmonisation (interpolation, synchronisation), ML on anomaly/fault precursors, multi-objectives optimisation, and recommendation engines (decision tree, including on failure probability). Algorithms will be developed for PV modules ageing, inverter failures, soiling/cleaning schedule, inverter clipping, etc. Weather forecasts developed in the project, as well as data obtained from sensing gathered in the IoT platform will be particularly useful -e.g. soiling sensing will help cleaning scheduling.

The new features to be developed include:

- A risk of module power loss estimator model that takes as input the multispectral (visual, IR, EL/PL) images acquired by drone inspection, and performs automatic image analysis to detect anomalies and potential failures or power loss causes, classify them based on type and severity, estimate power and energy loss over time. This will allow to detect faults/anomalies such as glass breakage, frame and glass/EVA delamination (visual); soiling (IR and visual); potential induced degradation (PID), incipient cell cracking and cell interconnect degradation (EL/PL).
- enhanced data labelling model to allow ML approaches (fault precursors on inverters, module/strings ageing, soiling dynamics), plus the validation of ML algorithms to predict failures/losses before occurrence and failure probability.
- Fleet management actions recommendations engine (cleaning schedule, site inspection, inverter reconfiguration or replacement, etc.);
- Integration of the modules into a comprehensive demonstrator of a PV fleet management tool with maintenance interventions defined and prioritised thanks to a predictive maintenance advisor.

Two separate add-ons will be integrated in this fleet management tool, developed by separate partners: i) DTU: Focus on fault detection and predictive maintenance at the panel level, DTU will integrate the cloud image analysis pipeline, developed in Task 3.3.1 into the API through the use of REST API. If the panels/plant was inspected by VIS, IR, or EL and the image data was uploaded to the cloud image analysis pipeline, then based on panel location request, the add-on will provide the fleet management app with panel condition indicators, detailing detected failures, risk of power loss, and recommended maintenance actions. ii) AAU: Focus on wear-out failure modeling based on physics-of-failure-analysis and online condition monitoring for predictive maintenance.







This solution with integrate developments concerning inverters by **AAU**, and a separate add-on will be developed for this purpose. **DTU** will carry out the development of another add-on model linked to predictive maintenance of solar panels based on automatic analysis of drone images.

Method for testing and validation

The training and validation tests of predictive maintenance algorithm will be undertaken in adopting a stand procedure for data segmentation and verification process for deep learning algorithms in order to quantity the accuracy and reliability of detection and identification in terms of probability of false (negative or positive) results.

End to end testing of the fleet management tool will involve a full deployment of the solution stack with a dataset of demonstrator PV facilities provided by Heliocity. The demonstrator will be used to expose and elaborate on the suite of features for the client.

The dataset for training, testing and demonstration purposes will be sampled from an existing dataset comprising approximately 100 MW of real installed capacity that has be analysed by Heliocity. The dataset comprises a wide variety of system sizes ($^{\sim}100 \text{kW} - ^{\sim}10 \text{ MW}$) and integration classes (building integrated and ground mounted), with labelled monitoring data spanning on average 12 months for each site.

KPIs for assessing performance of the developed models, tools and hardware.

This task is covered by the following KPIs:

- A simulated fleet of PV installation will be used to demonstrate a quantified reduction in maintenance activities, equated to 15-20% in operational costs to meet KPIO 3.1 (refer to section 5.2)
- Similarly, decreases in production losses will be demonstrated with the aid of the simulated fleet to meet KPIO 3.5 (refer to section 5.2)

Role of project partners

This solution with integrate developments concerning inverters by **AAU**, and a separate add-on will be developed for this purpose. **DTU** will carry out the development of another add-on model linked to predictive maintenance of solar panels based on automatic analysis of drone images.







1.15Task 4.5: Development of models for storage simulation [TEK]

Background

Hybrid projects combining PV with storage are starting to become popular in countries with high PV penetration. Storage solutions include, among others, Li-ion batteries (BESS), super-capacitors and/or hydrogen. The most popular approach until now is using Li-ion BESS, due to their competitive prices and adequate characteristics for the purposes that PV plants might need: high energy density, high efficiency, acceptable cycling duration, high response to react against frequency events (FFR, FCR, aFRR...).

Li-ion BESS prices have dropped drastically in the last decade. However, prices are not competitive enough yet to become cost-effective with the current market prices.

Nevertheless, future price cannibalisation scenarios are expected and already seen in countries with high share of renewable generation (specially with high shares of PV), as at noon hours the net load decreases considerably, leading to low electricity prices. At the same time, the low net load implies forced curtailments by grid operators, not allowing PV plants to produce as much power as they could.

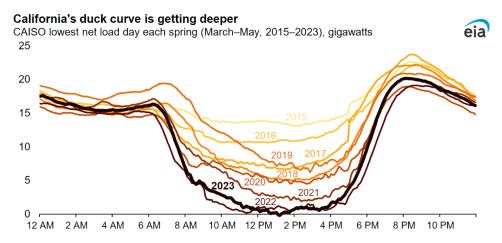


Figure 1.15-1. Example of California's electrical load curve, due to overproduction of solar energy at midday leading to low electricity prices for produced solar.

Under this scenario, storage is expected to become a key part of the future PV power plants, as it will enhance their flexibility to shift the electricity production, allow the plants participate in additional electricity markets, and provide further services to the grid.

Data and hardware requirements

All developments are software related, so no hardware is needed in this task.







Regarding data requirements, some of the models will be presumably developed based on bibliographic information, as no hydrogen storage facilities are included inside the sites of the project.

However, in case any of the project partners (FIB, PPC or DTU) have any supercapacitor or Li-ion BESS system, data from these systems will be used in order to develop and validate the models developed for these technologies. The data needed in this case will be:

- Datasheet of the storage system, including:
 - Rated power
 - Rated energy/capacity at beginning of life
 - Expected lifetime
 - Degradation data (maximum number of cycles allowed per depth of discharge range, calendar ageing curves...)
 - CAPEX and OPEX of the system

The models developed will be later validated together with the AI trading tool developed in Task 5.3, and the idea will be to compare the techno-economic results between the PV plant operating alone, and using each of the systems. The simulations of different scenarios might be improved with real data from storage technologies in case any of the sites have them (FIB, PPC and alternatively DTU).

All the data requirements are detailed in section 2 of this document.

Technical specifications

The models will be developed in MATLAB/Simulink and/or Python, and a previously registered software by Tekniker to size battery energy storage systems will be used as starting point to improve them.

The inputs and outputs of the storage selection tool, which will internally use the models developed in this task are summarized in Figure 1.15-2.





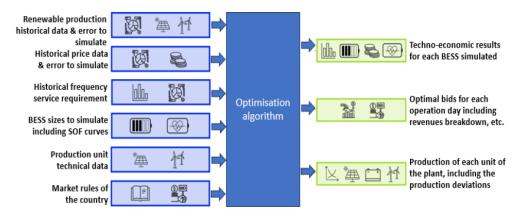


Figure 1.15-2. Diagram of the storage selection tool illustrating inputs and output.

In addition, these models will also be used inside the energy trading tool developed in Task 5.3, illustrated in Figure 1.18-1.

Method for testing and validation

All the validation will be done based on long term simulations using historical and real data, and pre-defined market/generation scenarios, and the results will be provided in the deliverable *D4.4* – Storage models: used to later conduct sensitivity studies of using storage with PV.

KPIs for assessing performance of the developed models, tools and hardware.

The models developed in this task will not have any KPIs associated, but they will be used to address the performance of the energy trading tool developed in Task 5.3. Therefore, please refer to the description of this task to get further information.

Role of project partners

The technical part of the task will be fully done by Tekniker, and the role of the project partners will be to provide data to feed the models.

FIB will provide Tekniker information of its available storage units. **DTU** might also provide Tekniker information of their available storage solutions to feed the models developed. When it comes to PPC, even if they do not have any storage solution installed, they will provide Tekniker techno-economic information (historical energy production, weather conditions, market data...) of their PV plant to perform the corresponding simulations of PV+storage hybridization.







1.16Task 5.1: Interconnection and integration into a comprehensive forecasting tool [UBI]

Background

Numerical weather prediction models (NWP) are currently the gold standard for weather forecasts and are used by major meteorological institutes such as ECMWF, DWD and GeoSphere. Due to their large-scale orientation, these models generally only have a very coarse resolution and are not specialized in energy forecasting. Other companies such as Windy and Tomorrow.io focus on specific aspects such as wind energy or the US market, but also do not have the fine resolution and specialized energy models required for accurate solar energy forecasting.

Some companies, like Meteomatics, take a similar approach to UBI by operating their own NWP models and providing renewable energy forecasts. UBI itself has developed and enhanced its NWP model through the Weather Research & Forecasting (WRF) system, specifically refined as Refined Atmospheric Condition Evolution (RACE). This tailored approach allows for adjustments in key parameters like topography, land use, and cloud cover. By intelligently integrating regional models, like RACE and global models, UBI delivers more precise forecasts for photovoltaic (PV) system performance.

Emerging AI/ML models in meteorology show potential to outperform traditional NWP models but remain in early research phases (TRL1-3) and face challenges with large-scale data integration. Seasonal forecasting tools like C3S are being explored for renewables but are still largely statistical and less useful for decision-making in energy applications.

The current key barriers to development are:

- Data quality and resolution limitations.
- Computational complexity for AI/ML models.
- Limited long-term forecast accuracy for PV systems.
- Lack of decision-support tools in seasonal forecasting.

Data and hardware requirements

All developments are software related, so no hardware is needed in this task.

As for the data requirements for this tool, both historical and real time data of the sites will be required. The historical and real data will be used to train and test the comprehensive forecasting tool developed in this task.

Required data inputs from demo partners are:







- Historical monitoring data: Historical data on the generated electrical power with a resolution of 15 minutes for a period of at least 2 years would be desirable
- Information about master data for PV demonstration site(s): type of PV plant, installed performance, orientation of the panels or information on whether they follow the position of the sun, coordinates of the location of the PV system
- live data or near live data on how much electrical energy is currently being produced (optional)
- Additional weather data from DTU generated by their own weather station (live data and optional also historical data)

Data inputs must align with the requirements defined for the demonstration sites in section 2, under "Comprehensive forecasting tool" and section 3.6.3 "Data and requirements from partners".

Technical specifications

The Comprehensive Forecasting Tool is designed to integrate accurate data with advanced forecasting models to enhance weather predictions and energy generation forecasts. The tool will feature an aggregation system that combines an enhanced AI-based nowcasting model and a Numerical Weather Prediction (NWP) model. It will also incorporate data on aerosols and pollution, improving the accuracy of weather forecasts, particularly during severe weather events. Additionally, the tool will leverage machine learning (ML) and artificial intelligence (AI) to provide reliable power generation forecasts and seasonal weather predictions.

To facilitate effective data utilization, a series of APIs will be developed. These APIs will standardize weather and energy production predictions, ensuring that data is presented consistently and can be easily integrated with existing applications, such as PV asset management software and energy trading tools. A master data API will also be created to enable seamless integration of vital PV characteristics, including installation details like location, orientation, elevation, and specific panel specifications such as power curves.

The project will further develop a web-based dashboard that offers plant operators advanced visualization, analytics, and reporting capabilities. This dashboard will provide clear graphical representations of weather and energy data, empowering operators to make informed decisions based on real-time information.

Method for testing and validation

The validation process relies on extensive long-term simulations conducted at the individual demonstrator sites, utilizing both historical and real-time data from the plants. This approach enables a thorough analysis of the accuracy of the developed models.







KPIs for assessing performance of the developed models, tools and hardware.

This task is covered by the following KPIs, detailed in section 5.2:

- KPI 2.2: Improvement of power generation forecasting accuracy (vs. Traditional physical forecast)
- KPI O1.1: Improvement of weather forecasting accuracy based on verification & skill scores (RMSE, CSI, Brier Score) (vs. Available forecast GFS, ECMWFS, ICON-D2)

Role of project partners

The technical part of the task will be fully done by UBIMET. No additional input from project partners is needed.

However, the tool will be developed in close cooperation with the demo partners and is also tailored to their specific needs.







1.17Task 5.2: Interconnection and integration into a PV asset management software [HELIO]

Background

Commercially available software for PV asset management is typically focused upon one particular operator role within an organization, to address specific tasks such as recording field interventions, coordinating maintenance schedules, assessing installation or fleet performance, and evaluating key financial performance indicators. Although these tasks are roles may be found within the same organization, information exchange between the various levels of these operations is neither automated nor capitalized to improve the effectiveness of each responsibility.

The tools developed in tasks T4.1, T4.3, and T4.4 will be combined into an integrated software for PV asset management:

- IoT platform for automated pseudo-real-time monitoring of PV systems with fault detection
- field app to control/instruct field operations in the context of reconfigurable topologies and corrective actions
- Fleet management tool integrating a predictive maintenance engine

The principle function of this software is thus to deliver effective application and human-machine interfaces to capitalize the functionalities of each tool. The key innovations of this integration objective are to maximise the utility of on-site, remote and analytic heuristics to improve the effectiveness of actors operating in each environment and ensure interoperability of multisource and multi-platform tools.

The bottleneck of achieving interoperability of energy analytics software has been explored through the EU research project Platoon that highlighted the importance of

- A common framework of ontology and taxonomy at the interface of individual software to enable accurate interchange of data
- Secure and traceable data exchange
- Generic connectors as a solution for interoperability of diverse software architectures

These issues shall be addressed for the integration of the tools to be developed within the Solaris project during the course of this task. Thanks to the diversity of tools to be integrated, it will be essential to overcome the barriers of data interchange between software that function at different spatial and temporal scales. For instance, the IoT and field application are strongly





reliant on a geospatial description of each solar facility whereas the fleet management tool will be constructed on a logical model of the systems. It is therefore necessary to introduce a suitable data model for all these tools.

Data and hardware requirements

A standalone software interface infrastructure will be constructed for the integration of the separate tools. This utility will be cloud based and deployed on a dedicated virtual machine on a commercial cloud service such as AWS.

The utility will comprise API endpoints for the required tools, an internal broker and task management service as part of a dedicated backend including a tool to manage data transactions. The requirements for data storage within this utility will be clarified once the developed of the individual software tools has advanced to a sufficient stage.

The integrated PV asset management tool will be developed on the model of a Software As A Service (SAAS), and thus will comprise a dedicated web application (frontend and backend) as a user interface with which to access and interacted with the individual tools.

A data ontology/taxonomy framework for the interchange of data between the tool will be elaborated by Heliocity in close collaboration with the key partners DTU, ELLC, AAU for this task. Furthermore, functional tests will be defined to demonstrate and evaluate the utility of data interchange.

Necessary data inputs (as per section 2)

Table 1.17-1. Necessary data input for integration in the HELIO PV Asset management software

PV Asset Managemer Software	nt GPS coordinates	Static data (description)
	Type of PV plant (ground, greenhouse, building, carport)	Static data (description)
	Integration type	Static data (description)
	Building type	Static data (description)
	PV plant commissioning date	Static data (description)
	Cable losses estimate	Static data (description)
	PV module model reference	Static data (description)
	PV inverter model reference	Static data (description)
	Layout description	Static data (description)
	Electricity Tariffs	Static data (description)
	Cleaning costs	Static data (description)





If available : digital geospatial description of the plant from Static data (description) partner If available: common "component labelling convention" Static data (description) Active power Meter Reactive power Meter Aparent power Meter Real position Tracker Target position Tracker Phase AC voltage Inverter Line AC voltage Inverter DC Link Voltage Inverter On-state voltage of IGBTs Inverter IGBT Junction temperature Inverter Phase AC current Inverter Active AC power Inverter Reactive AC power Inverter Inverter Power factor Inverter Frequency Inverter internal temperature Inverter DC MPPT Current Inverter DC MPPT Voltage Inverter Module temperature Weather station Horizontal Irradiance (GHI) Weather station Global Tilted Irradiance (GTI) Weather station Wind Speed Weather station Wind Direction Weather Station Ambient temperature Weather station Weather station **Relative Humidity** Flag for any limit in PV generation (curtailment, battery mode...)



Lab results

laboratory test





IV curves (Isc, Voc, Vn	npp, Impp, Rshunt, Rseries)	In situ measurements
measured VoC + Irraa	liance	In situ measurements
Disconnected string c	onfirmation	In situ measurements
Visual inspection (soil	ing, shading or local horizon)	In situ measurements
Module temperature		In situ measurements
Inverter alarm		Inverter
,	Drone inspection (faulty modules +fault types (activated diode, hotspot, visual damage))	

will be completed with other relevant variables from partners

This tool will be ready for demonstration at M30 (validating MS7).

Technical specifications

The integrated tool will utilize outputs from the individual software tools and provide specific inputs to these same applications in order to make data requests or issue commands. Regarding external interfaces, the technical specifications of the integrated tool will adhere to the input/output specifications of the individual tools. As specified in the previous section, a data interchange framework will be introduced to ensure accurate and secure interoperability between the platforms.

The interfaces will be deployed on the same dedicated cloud-based instance as the application. Regarding data throughput requirements, these are to be clarified once further details become available regarding the individual software. However, as the nature of the other services is already known it can be stated that the integrated application must be able to provide real time reactivity for the field app, and issue and receive the results of scheduled tasks for the other tools.

Method for testing and validation

The software is designed to equip operators with all necessary PV system management tools (failure detection and loss quantification, field control app, fleet management tool based on predictive maintenance) in a unique interface. The tests will therefore cover

- The correct operation of application interfaces ensuring timely and secure access to data
- The cross-referencing of data between the various tools to ensure a coherent and intelligible interface for the operator
- A demonstration of potential gains in production thanks to the interchange of data between the IoT platform, field application and fleet manager, and an accurate identification and quantitative evaluation of root causes of faults and failures







KPIs for assessing performance of the developed models, tools and hardware.

This task is covered by the following KPIs, detailed in section 5.2:

- KPI 1.2i: Average panel failure detection rate
- KPI 1.2ii: Average PV string failure detection rate
- KPIO3.1: Reduction of maintenance activities through improved scheduling
- KPIO3.4: Time the fault detection algorithm requires to analyse the data and detect the fault
- KPI1.3: PV system availability
- KPI2.6: Reduction of the LCOE

Role of project partners

The role of the project partners (HELIO, UBI, DTU, ELLC, TEK (Soiling tool)) will be further refined once the integrated "features" are decided. In any case, the data interchange framework, as well as the technical planning of the test and validation stage will be discussed and agreed in Q1 2025.







1.18Task 5.3: Development of an AI-based tool for the optimisation of the energy trading at plant level [TEK]

Background

Historically, PV power plants have mainly participated in energy markets, and they have always produced as much power as possible based on the resource availability in real time. In this sense, and considering pay-as-cleared market mechanisms, advanced trading strategies were not significantly critical for them, as they could expect an approval of their offer acceptances.

However, new market scenarios are making PV power plants require advanced strategic logics to ensure enhancing their market performance, and boost their profitability.

Among the reasons for this change, PV power plants now can and do participate in frequency regulation services, as they have proved the ability to react properly against frequency events. Therefore, the offers to the market refer now to more than one market type, and the amount of resource to offer in each is something to be decided by advanced control logics.

In addition, the high PV penetration is proved to cause a price cannibalisation at noon hours, which affects to the economic model of these plants. Moreover, forced curtailments are becoming a usual event in countries with high PV penetration, and therefore these plants cannot produce as much power as they could.

Under this scenario, hybrid projects combining PV with storage are starting to become popular, since this way they enhance their flexibility to shift the electricity production. In addition, PV plants have more margin to participate in additional markets, and provide further services to the grid.

All these aspects must be controlled and determined by advanced control systems, called energy management systems (EMSs), which based on production and price predictions, define the optimal operation of the plant for a rolling horizon.

Data and hardware requirements

All developments are software related, so no hardware is needed in this task.

As for the data requirements for this tool, both historical and real time data of the sites will be required. The historical and real data will be used to tune and test the energy management system (EMS) developed in this task.

All these specific data requirements are detailed in section 2 of this document.

Technical specifications

The energy trading tool is an algorithm that will be included inside an energy management system for the plant. This is a software that will be developed in either MATLAB/Simulink or Python







environment, and it will be based on a previous registered software of Tekniker, which will be improved during this task.

This EMS will include mathematical models of both the PV plant and the storage systems developed in Task 4.5. The trading algorithm inside this EMS will include, among others:

- Multi-objective optimization approach considering profit maximisation, storage system degradation minimisation, emissions reduction, etc.
- Multiple market participations, selecting the electricity markets to participate at and considering ancillary services such as the Automatic Frequency Restoration Reserve Market (aFRR).
- Optimality and robustness ensured, based on linearised formulation for ensuring in-time and feasible results, as well as heuristic algorithms for improving the linearised results.
- Real-time operation approach, whose feasibility is ensured by multi-scenario consideration (possibility to include stochastic approaches).

The inputs and outputs of this EMS are summarized in Figure 1.18-1.

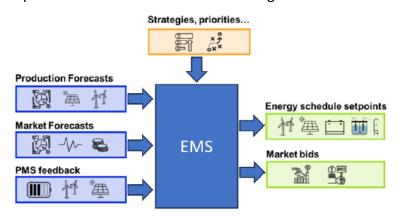


Figure 1.18-1. Diagram of the energy trading tool developed in Task 5.3.

The storage models themselves will provide several outputs such as state of charge of the system, input and output power and their state of health.

The EMS will be executed either in a specific hardware such a PC, or alternatively in a cloud-based system. In both cases, the inputs will be received in the usual format used in each site, and the EMS will be adapted to them. The outputs will also be adapted to specific requirements of the site.

Method for testing and validation

All the validation will be done based on long-term offline simulations using historical and real data of the plants, and both current and future market price scenarios will be analysed.







KPIs for assessing performance of the developed models, tools and hardware.

For the *PR2: AI-based energy trading tool*, the expected performance will be covered with the KPIs defined in section 5.2.

The site used to obtain these KPIs will be the one from PPC, since it is the only site in the project which participates in a liberalized market. This power plant currently does not have any storage system, and neither participates in the aFRR market, so the comparisons for obtaining the KPIs will be done based on future scenarios defined in the project, considering aspects such as expected market price variations during the day, expected curtailments at country level, etc. Similarly, BESS lifetime studies will be done based on comparing strategies of revenue maximization and multi-criteria operation, in which lifetime is also addressed.

Role of project partners

The technical part of the task will be fully done by Tekniker, and the role of the project partners will be to provide data to feed the models.

The operational historical data of PPC will be used as baseline to calculate the improvement of the techno-economic results obtained with the tool developed.





1.19Task 5.4: Manufacturing and preliminary testing of the impedance sensor device for retrofitting to existing power converters [EMA]

Background

The manufacturing of the impedance sensor is based on having circuit designs and layout files in place. The core document is thus the gerber file, that holds all the information about electronic components and their placement on the Printed Circuit Board Assembly (PCBA).

The procedure is to first make the PCB itself (without components). The PCB will be manufactured by "JLC PCB", and we aim at making 5 devices as prototypes. The prototype PCBs will be populated with components by hand and baked in our own oven to solder the components and create the actual PCBA. The mechanical enclosure needs to be watertight and robust enough for mounting connectors etc. The PELI protector case 1200 should be the ideal choice for the prototypes, and (EMA) we have years of experience fitting electronics inside these types of enclosures. The aim is indeed to do the preliminary testing using the prototype devices. Once the sensors including the data logger solution have been tested and found functional in our laboratory, we will install them at the DTU experimental solar park i.e. in close collaboration with DTU and AAU.

Data and hardware requirements

The mounting of the sensor (small box roughly 20x30x10 cm) is straight forward. It will be truly standalone hardware. We still need to coordinate with DTU where exactly to install the boxes and how we can power the devices. They can run on battery, but it will be easier if connected to grid power in the beginning.

Technical specifications

MC4 connectors are found between the modules, and at the terminals. In this way the EMA sensor is a stand-alone device that can be retrofitted to almost any PV system. The sensor will be inserted in parallel with the module string.

The main PCB for the sensor is planned to be 26x18 cm in the first revision.

The power supply for the field test instrument is the RRC2054, Standard lithium battery pack RRC2054 (4S1P). Experimental versions of the sensor will be equipped with a 5V power supply input for continues operation in the field. The enclosure will be IP67.

Method for testing and validation

The validation of the method (sensor) is ongoing data logging and accumulation of data. Over time the sensor will demonstrate that it can register string faults at an early stage and report these faults (data) before other monitoring equipment installed at the string level e.g. on-board inverter monitoring.







KPIs for assessing performance of the developed models, tools and hardware.

The KPI in question is Revised to be "KPI1.2ii: Average PV string failure detection rate", detailed in section 5.2, and the goal is to double the average number of strings faults detected over 1 year of operation, by adding the impedance sensor.

By using impedance testing, we can narrow down the number of possible root causes to in case of common string faults. The aim is to remove the ambiguity that appears when the energy monitoring is used, for diagnosing a specific fault. The KPI for the sensor is therefore defined as its ability to consistently register a fault before the energy monitoring does, as well as registering faults the inverter or energy monitoring does not catch. The sensor is installed as an add on device and it may be integrated in the inverter.

EMA will work with AAU on setting up the device at DTU, and we will work together on establishing the 2 monitoring solutions, to measure their effectiveness.

Role of project partners

By working with AAU and DTU we will set up extraction of energy monitoring directly from the string inverters and log the sensor data (impedance values) accordingly. To set up the best method validation it would be required to at least present SCADA data together with the sensor data (impedance as a function of time and environmental factors). At emazys we are also building a mobile reference cell, that we can use as an external data logger for irradiation (by using the SP-110-SS: Self-Powered Pyranometer), cell temperature and ambient temperature. The sensors for the reference cell come from Apogee (US) and Campbell Scientific (US) as do the dataloggers installed at the DTU site. Probably the best solution is to work with DTU / European Energy on getting access to the GANTNER cloud.







1.20Task 5.5: Manufacturing and preliminary testing of the novel inverter for reconfiguration to enhance the maintenance and inverter availability [AAU]

Background

PV inverters are the main part of the power process in PV power plants. There are various topologies for PV inverters including single- or three-phase, single- or multi-stage, 2-/3- level, with or without transformer However, they are not redundant or reconfigurable. Considering the fact that the PV power is not always at full rate, most of the time the inverters are operating in partial power mode. For this reason, in the project, we will develop reconfigurable structure for PV inverter to enhance its availability by decreasing the stress over different devices.

Data and hardware requirements

- We need Power prediction, solar irradiance and ambient temperature with the resolution of 1-15 minutes for at least one year, that will be provided by DTU and UBIMET, for long term mission profile analysis.
- For short term analysis, we will test the thermal behaviour of the PV inverter in AAU
 reliability lab and will measure the junction temperature to validate the impact of our
 solutions for lifetime prediction. Furthermore, in DTU's demo site we will measure the
 inverter voltage and current in ac and dc side as well as in state voltage of the power
 devices in the inverter.
- We will develop a reconfigurable inverter based on the mission profiles of DTU site and compatible with the PV array characteristics of DTU PV system. The inverter hardware design is the output of the SOLARIS project based on our optimization considering the mission profile impact and lifetime modeling.

Technical specifications

According to the developed inverter in WP3, the selected inverter will be developed. It would be either 2-level inverter or 3-level NPC inverter. The developed inverter will be up to 20 KW and compatible with the PV array specifications of DTU demonstration site.

Method for testing and validation

Reliability and availability require long term operation to be validated in real case application. Due to time limit, it is not feasible to run the inverter for long term and wait for a failure occurrence to demonstrate the performance of the proposed solutions. Instead, we will run the inverter for a short period of time and will manipulate fake failures in the inverter. We will use combination of test and simulation to calculate the downtime under proposed approach. It will be demonstrated how our approach will detect the failure before happening and how our







approach will run the inverter in partial power mode until full repair. Comparing this with the case that the failure happens and then it will be planned for the repair, demonstrates the reduction in the down time and increase in production-based availability. Once the viability of the developed approach is validated and demonstrated by the experimental tests, expected downtime will be simulated using the test data and optimizing the repair time and spare units over long-term operation for large scale PV power plants. In order to show the reduction in downtime, two cases will be analysed including the operation of the inverter with and without our solution. Furthermore, the inverter will run for a short period of time, and the Poduction based availability will be calculated under these two cases.

The following tasks will be performed to validate during demonstration at DTU site:

- AAU will develop novel inverter for reconfiguring and availability enhancement
- AAU will manufacturer the inverter at AAU's lab
- AAU will test and develop the algorithms at AAU's lab
- AAU with the help of DTU will install the inverter in DTU site
- AAU will perform online condition monitoring and lifetime prediction
- AAU will process the smart control for availability enhancement
- AAU will process the long-term date for maintenance scheduling

KPIs for assessing performance of the developed models, tools and hardware.

This task is covered by the following KPIs, detailed in section 5.2:

- KPI O2.3: Reduction in PV inverter inspection time/repair time
- KPI O3.3: Increasing PV inverter production-based availability

Role of project partners

AAU and DTU will demonstrate the developed PV inverter in the DTU demonstration site.







2. Data integration and interoperability specifications

2.1 Information required from demonstration sites

Pilot leaders were asked for information in order to understand the data available at the different pilot sites, which is summarized in Table 2.1-1.

Table 2.1-1. General information from pilot sites

Information needed	DTU	FIB	EILAT School	EILAT Agro	PPC
SCADA or software platform where the PV plant is monitored	GANTNER Instruments and Campbell Scientific Dataloggers	no commercial SCADA available - FIB internal database	fusion solar		SCADA
Connection methods offered by the SCADA	RS485 Modbus RTU, uploaded to Gantner cloud and DTU FTP server. Data can be retrieved from Gantner Cloud through API, access token is required, if European Energy gives access. The FTP data is imported into DTU Internal MSSQL database.	API (developed by FIB) or CSV-Exports	API, EXCEL	EXCEL	MBUS
Historical data stored in the SCADA	Since 2019 with some gaps	Depending on the asset, some have 15-minute values available, others (i.e. BESS) have data in 5 second values available for the last 2 years	Yes	Yes	From 2021- 2024
Historical failures stored in the SCADA	Yes, since spring 2024 we deployed controlled PV failed modules in 2 strings	No	Yes	Yes	Yes
Life data		Yes	Yes	Yes	No
Meteorological data, we can either use the park's own probe (which is the best) or use a meteorological API to extract this data.	Weather station data is uploaded to our SQL database, can be retrieved from there. Must be within DTU network.	No	Yes	Yes	Weather station
Weather station at the demonstration site		No, but we would like to have one	Yes	Yes	Yes
Cleaning procedure		Not on regular basis, just occasionally	4 times/year		Yes







Energy price source	No		0.45 NIS/kWh
Are batteries installed?	No	Yes	No
Master data of the PV plant			fusion solar
Endpoint	Might be possible for the PV plant Gantner cloud upon approval from European Energy who pay for the cloud service. Access to internal DTU databases only possible from within DTU network. Data can be provided upon request.	Endpoint at the FIB database to be established	

In the table below, pilot leaders were asked to select the measurements available in their pilot site from a list of typical measurements in solar plants, summarized in Table 2.1-2.

Table 2.1-2. Measurements available in the pilot sites

Category	Name	Unit	DTU	FIB	EILAT School	EILAT Agro	PPC
Meter	Phase voltage	V		yes	yes	yes	yes
Meter	Line voltage	V		Can be calculated	yes	yes	yes
Meter	Phase current	Α		yes	yes	yes	yes
Meter	Line current	Α		equal to phase current	yes		yes
Meter	Active power	kW		yes			yes
Meter	Reactive power	kW		yes			yes
Meter	Aparent power	kW		yes			yes
Meter	Active imported energy	kWh		yes			yes
Meter	Reactive imported energy	kWh		yes			yes
Meter	Aparent imported energy	kWh		yes			yes
Meter	Active exported energy	kWh		yes			yes
Meter	Reactive exported energy	kWh		yes			yes
Meter	Aparent exported energy	kWh		yes			yes
Meter	Power factor						yes
Inverter	Phase voltage	V	yes	Can be established if necessary	yes	yes	yes





Inverter	Line voltage	V	yes	Can be established if necessary	yes	yes	yes
Inverter	Phase current	Α	yes	Can be established if necessary	yes	yes	yes
Inverter	Active power	kW	yes	Can be established if necessary	yes	yes	yes
Inverter	Reactive power	kW	yes	Can be established if necessary	yes	yes	yes
Inverter	Aparent power	kW	yes	Can be established if necessary	yes	yes	yes
Inverter	Active energy	kWh	yes	Can be established if necessary	yes	yes	yes
Inverter	Reactive energy	kWh	yes	Can be established if necessary	yes	yes	yes
Inverter	Aparent energy	kWh	yes	Can be established if necessary	yes	yes	yes
Inverter	Power factor	-	yes	Can be established if necessary	yes	yes	yes
Inverter	Frequency	Hz	yes	Can be established if necessary	yes	yes	yes
Inverter	Inverter internal temperature	°C					yes
Tracker	Real position	-					
Tracker	Target position	-					
Inverter	DC MPPT Current	Α	yes				
Inverter	DC MPPT Voltage	V	yes				
Inverter	DC String Current	Α	yes				yes
Inverter	DC String Voltage	V	yes				yes
Weather station	PV module temperature	°C	yes				yes
Weather station	Global Horizontal Irradiance (GHI)	kWh/m²	yes		yes	yes	yes
Weather station	Global Tilted Irradiance (GTI)	kWh/m²	yes		yes	yes	yes
Weather station	Wind Speed	m/s	yes		yes	yes	yes
Weather station	Ambient temperature	°C	yes		yes	yes	yes







2.2 Information required from developers

Technical providers in the consortium in charge of developing novel sensors and tools were asked to complete the following tables below with the data outputs from the sensors to be installed at the pilot sites and data inputs/outputs from the tools they will develop in the project.

Dust sensor

Table 2.2-1. Data outputs from the dust sensor

Sensor	Measurement	Format/Protocol	Unit	Frequency
Dust sensor	Evaluation of the detected "scattering"	32-bit float /MODBUS-RTU, registers 1002-1003	%	5min < x < 10 min
	Measurement of the "scattering" photosensors (D1)	32-bit float /MODBUS-RTU, registers 1004-1005	-	5min < x < 10 min
	Measurement of the reference photodetector (D2)	32-bit float /MODBUS-RTU, registers 1006-1007	-	5min < x < 10 min
	Temperature of the sensor	32-bit float /MODBUS-RTU, registers 1012-1013	°C	5min < x < 10 min
	Device status code	16-bit uint/MODBUS-RTU, register 1014	-	5min < x < 10 min

Wind load sensor

Table 2.2-2. Data outputs from the wind load sensor

Sensor	Measurement	Format/Protocol	Unit	Frequency	
Wind load sensor	Accelerometer	Float - Ethernet	m/s²	>100 Hz	
5011501	Force sensor	Float - Ethernet	N	>100 Hz	
	Strain gauge	Float - Ethernet	m/m	>100 Hz	

Novel inverter

Table 2.2-3. Data outputs from the novel inverter

Sensor	Measurement	Unit	Frequency
Novel inverter	DC voltage	V	40ms window, 2 kHz sampling frequency
	DC current	Α	40ms window, 2 kHz sampling frequency
	AC voltage	V	40ms window, 2 kHz sampling frequency
	AC current	С	40ms window, 2 kHz sampling frequency
	VCEon	V	10s window, 1 Hz sampling frequency







Junction temperature	°C	10s window, 1 Hz sampling frequency

Parsed drone image

The measurements from the parsed drone image are listed below:

- Multi-tiff 16 bit raw EL images 640x512 resolution + embedded metadata, 100-300 images frames per multitiff file, 1 multitiff file per 1-2 panels
- 16 bit Tiff and PNG images 640x512 resolution of processed multi-tiff EL images
- 24 bit Radiometric JPEG 640x512 Thermal IR images including GPS (lat, lon, alt) and pan&tilt metatada
- 24 bit JPEG 4000x3000 resolution VIS images including GPS (lat, lon, alt) and pan&tilt metatada
- MP4 video files 3840 x2160 resolution, 85090 kpbs, VIS recording + SRT file including GPS (lat, lon, alt) and pan&tilt metatada for frames
- MP4 video files 640x512resolution, 5998 kpbs, IR recording + SRT file including GPS (lat, lon, alt) and pan&tilt metatada for frames

Comprehensive forecasting tool

Table 2.2-4. Data inputs from the Comprehensive forecasting tool

Input	Category	Format/Protocol	Unit	Frequency
Energy production	Historical data of the last 2 years (minimum 1 year)	timestamp of the interval, UTC	MWh	x < 15 min
Energy production	live data/ nearly live data	timestamp of the interval, UTC	MWh	x < 15 min
Type of PV plant (ground, greenhouse, building, carport)	Static data (description)	N/A	N/A	static
GPS coordinates	Static data (description)	N/A	N/A	static
Datasheet of the PV modules - type of PV plant	Static data (description)	CSV	N/A	static
Datasheet of the PV modules - installed performance	Static data (description)	CSV	N/A	static
Orientation of the panels	Static data (description)	N/A	N/A	static
Ambient temperature	Weather station	timestamp of the interval, UTC	°C	5min < x < 15 min
Irradiance (all available, ideally global, diffuse and direct)	Weather station	timestamp of the interval, UTC	W/m²	5min < x < 15 min
Wind speed	Weather station	timestamp of the interval, UTC	m/s	5min < x < 15 min
Wind Direction	Weather Station	timestamp for end of interval, UTC	o	5min < x < 15 min
data from cloud camera	Weather station	timestamp of the interval, UTC	TBD	TBD





Energy trading tool

Table 2.2-5. Data inputs from the Energy trading tool

Input	Category	Format/Protocol	Unit	Frequency
Datasheet of the PV modules	Static data (description)	N/A	N/A	static
Datasheet of the inverters	Static data (description)	N/A	N/A	static
Datasheet of the transformer of the plant	Static data (description)	N/A	N/A	static
Datasheet of the storage system (if available): including technical and degradation data	Static data (description)	N/A	N/A	static
Cable losses estimate	Static data (description)	N/A	MWh or %Pmax	static
Layout description	Static data (description)	N/A	N/A	static
CAPEX and OPEX of the PV plant	Static data (description)	N/A	€	OPEX: monthly
CAPEX and OPEX of the storage system (if available)	Static data (description)	N/A	€	OPEX: monthly
Type of market participation model: SPOT market, PPA or combination	Static data (description)	N/A	N/A	N/A
Markets in which the plant participates: SPOT, aFRR, FCR	Static data (description)	N/A	N/A	N/A
Energy production	Historical data (minimum 1 year)	timestamp of the interval, UTC	MWh	x < 15 min
Energy production forecasts	Historical data (minimum 1 year)	timestamp of the interval, UTC	MWh - probability table	Existing frequency
Grid frequency	Historical data (minimum 1 year)	timestamp of the interval, UTC	Hz	x < 1 min
Ambient temperature	Historical data (minimum 1 year)	timestamp of the interval, UTC	°C	5min < x < 15 min
Irradiance (all available, ideally global, diffuse and direct)	Historical data (minimum 1 year)	timestamp of the interval, UTC	W/m²	5min < x < 15 min
Wind speed	Historical data (minimum 1 year)	timestamp of the interval, UTC	m/s	5min < x < 15 min
Storage state of charge	Historical data (minimum 1 year)	timestamp of the interval, UTC	MWh or %SOC	5min < x < 15 min
Storage state of health	Historical data (minimum 1 year)	timestamp of the interval, UTC	m/s	5min < x < 15 min







Economic revenues, disaggregated between the different types of markets	Historical data (minimum 1 year)	timestamp UTC	of	the	interval,	€	daily
Energy production	Meter	timestamp UTC	of	the	interval,	MWh	x < 15 min
Energy production forecasts	External provider	timestamp UTC	of	the	interval,	MWh - probability table	Existing frequency
Grid frequency	Meter	timestamp UTC	of	the	interval,	Hz	x < 1 min
Ambient temperature	Weather station	timestamp UTC	of	the	interval,	°C	5min < x < 15 min
Irradiance (all available, ideally global, diffuse and direct)	Weather station	timestamp UTC	of	the	interval,	W/m²	5min < x < 15 min
Wind speed	Weather station	timestamp UTC	of	the	interval,	m/s	5min < x < 15 min
Storage state of charge	Meter	timestamp UTC	of	the	interval,	MWh or %SOC	5min < x < 15 min
Storage state of health	Meter	timestamp UTC	of	the	interval,	m/s	5min < x < 15 min
Economic revenues, disaggregated between the different types of markets	Plant owner	timestamp UTC	of	the	interval,	€	daily

Table 2.2-6. Data outputs from the Energy trading tool

Output	Category	Format/Protocol	Unit	Frequency
PV energy setpoints	setpoint	JSON	MWh	15 min / 1 h, 24-48 h horizon
Storage energy setpoints	setpoint	JSON	MWh	15 min / 1 h, 24-48 h horizon
Market participation offers	offer	JSON	MWh	As requested by the market

Storage sizing tool

Table 2.2-7. Data inputs from the Storage sizing tool

Input	Category	Format/Protocol	Unit	Frequency
Datasheet of the storage system (if available): including technical and degradation data	Static data (description)	N/A	N/A	static
CAPEX and OPEX of the storage system (if available)	Static data (description)	N/A	€	OPEX: monthly







Storage state of charge	Historical data (minimum 1 year)	timestamp UTC	of	the	interval,	MWh or %SOC	5min < x < 15 min
Storage state of health	Historical data (minimum 1 year)	timestamp UTC	of	the	interval,	m/s	5min < x < 15 min
Storage state of charge	Meter	timestamp UTC	of	the	interval,	MWh or %SOC	5min < x < 15 min
Storage state of health	Meter	timestamp UTC	of	the	interval,	m/s	5min < x < 15 min

Table 2.2-8. Data outputs from the Storage sizing tool

Output	Format/Protocol	Unit	Frequency
Operational setpoints for PV and storage	JSON	MWh	15 min time-steps, full simulation horizon
Economic results of the plant	JSON	€	daily time-steps, full simulation horizon
Storage degradation	JSON	% state of health	daily time-steps, full simulation horizon

PV Asset Management Software

Table 2.2-9.Data inputs from the PV Asset Management Software

Input	Category	Format/Protocol	Unit	Frequency
GPS coordinates	Static data (description)			static
Type of PV plant (ground, greenhouse, building, carport)	Static data (description)			static
Integration type	Static data (description)			static
Building type	Static data (description)			static
PV plant commissioning date	Static data (description)			static
Cable losses estimate	Static data (description)			static
PV module model reference	Static data (description)			static
PV inverter model reference	Static data (description)			static
Layout description	Static data (description)	Nb of string, Nb of module/ string		static
Electricity Tariffs	Static data (description)	€/kWh		static
Cleaning costs	Static data (description)	€		static
If available : digital geospatial description of the plant from partner	Static data (description)			static







If available : common "component labelling convention"	Static data (description)			static
Active power	Meter	timestamp for end of interval,	kW	5min < x < 15 min
		UTC		
Reactive power	Meter	timestamp for end of interval, UTC	kVAr	5min < x < 15 min
Aparent power	Meter	timestamp for end of interval, UTC	kVA	5min < x < 15 min
Real position	Tracker	timestamp for end of interval, UTC	o	5min < x < 15 min
Target position	Tracker	timestamp for end of interval, UTC	o	5min < x < 15 min
Phase AC voltage	Inverter	timestamp for end of interval, UTC	V	5min < x < 15 min
Line AC voltage	Inverter	timestamp for end of interval, UTC	V	5min < x < 15 min
DC Link Voltage	Inverter	timestamp for end of interval, UTC	V	5min < x < 15 min
On-state voltage of IGBTs	Inverter	timestamp for end of interval, UTC	V	5min < x < 15 min
IGBT Junction temperature	Inverter	timestamp for end of interval, UTC	°C	5min < x < 15 min
Phase AC current	Inverter	timestamp for end of interval, UTC	А	5min < x < 15 min
Active AC power	Inverter	timestamp for end of interval, UTC	kW	5min < x < 15 min
Reactive AC power	Inverter	timestamp for end of interval, UTC	kVAr	5min < x < 15 min
Power factor	Inverter	timestamp for end of interval, UTC	N/A	5min < x < 15 min
Frequency	Inverter	timestamp for end of interval, UTC	Hz	5min < x < 15 min
Inverter internal temperature	Inverter	timestamp for end of interval, UTC	°C	5min < x < 15 min
DC MPPT Current	Inverter	timestamp for end of interval, UTC	A	5min < x < 15 min
DC MPPT Voltage	Inverter	timestamp for end of interval, UTC	V	5min < x < 15 min
Module temperature	Weather station	timestamp for end of interval, UTC	°C	5min < x < 15 min







Horizontal Irradiance (GHI)	Weather station	timestamp for end of interval, UTC	kWh/m²	5min < x < 15 min
Global Tilted Irradiance (GTI)	Weather station	timestamp for end of interval, UTC	kWh/m²	5min < x < 15 min
Wind Speed	Weather station	timestamp for end of interval, UTC	m/s	5min < x < 15 min
Wind Direction	Weather Station	timestamp for end of interval, UTC	0	5min < x < 15 min
Ambient temperature	Weather station	timestamp for end of interval, UTC	°C	5min < x < 15 min
Relative Humidity	Weather station	timestamp for end of interval, UTC	%	5min < x < 15 min
Flag for any limit in PV generation (curtailment, battery mode)			0 or 1	5min < x < 15 min
Lab results	laboratory test			
IV curves (Isc, Voc, Vmpp, Impp, Rshunt, Rseries)	Insitu measurements			
measured VoC + Irradiance	Insitu measurements			
Disconnected string confirmation	Insitu measurements			
Visual inspection (soiling, shading or local horizon)	Insitu measurements			
Module temperature	Insitu measurements			
Inverter alarm	Inverter			
Drone inspection (faulty modules +fault types (activated diode, hotspot, visual damage))				

Table 2.2-10. Data outputs from the PV Asset Management Software

Output	Category
local GTI refinement	Production simulation
Expected model Production	Production simulation
PR	Performance Indicator
Performance Index	Performance Indicator
Loss breakdown	Performance Indicator
Incidents	Performance Indicator
Performance Alarms	Performance Indicator
Failure probability prediction	Preventive







Actions recommendations	Actions

3. Demonstration sites

3.1 Main contacts

The main contact persons for the four SOLARIS demonstration sites are listed in Table 3.1-1.

Table 3.1-1 List of Demo Site responsible

Site	Responsible partner
DTU, Risø	"Sergiu Viorel Spataru" <sersp@dtu.dk></sersp@dtu.dk>
PPC	Matina Karakitsiou M.Karakitsiou@ppcgroup.com Konstantinos Chrysagis K.Chrysagis@ppcgroup.com
EILAT	Avi Naim avi-n@eilat.muni.il
FIB	Markus Resch; markus.resch@forschunginnovation-burgenland.at

3.2 DTU Demo Site

3.2.1. PV tracker Facility

Layout

The photovoltaic (PV) plant is located in Risø consists of 8 horizontal single-axis trackers (HSAT) oriented East-West and 8 south-facing trackers with an adjustable fixed tilt angle. Each tracker supports 4 strings arranged in 2 rows of 22 panels, except for few trackers. On the east side of the plant, there is an additional string mounted on a separate single-axis tracker, along with two dual-axis tracker systems (one broken). Therefore, different module manufacturers and capacities have been used. The same applies to the inverters, where various types of inverters have been used.

Figure 3.2-1. Layout of the DTU Risø PV plant Figure 3.2-1 provides an overview of the entire plant, showing the types of modules and inverters used, along with the configuration of all the arrays. The modules are installed in portrait orientation, with two rows of modules per table (2V).



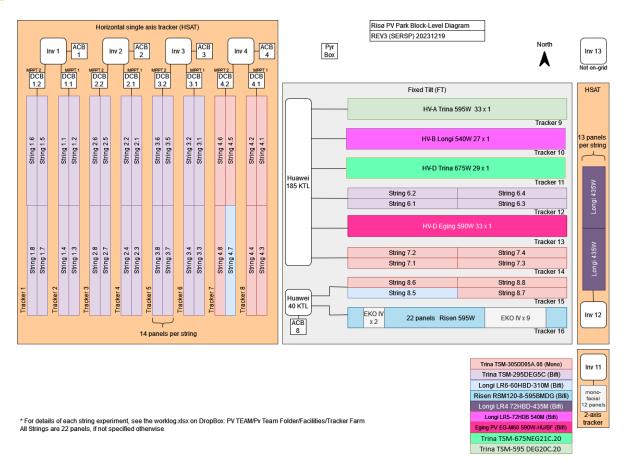


Figure 3.2-1. Layout of the DTU Risø PV plant

Table 3.2-1. DTU Risø PV plant array distribution. Table 3.2-1 presents a summary of the module distribution for the main trackers. For some trackers, the number of modules per string varies (sometimes higher or lower). The number of strings per inverter depends on the inverter's capacity, which can change based on the specific inverter used.

Table 3.2-1. DTU Risø PV plant array distribution.

Tracker	Module	Modules per string	Strings per tracker	PV panel configuration
T1-T3 & T6	Trina - TSM-295DEG5C	22	4	2V (Portrait)
T4	Trina - TSM-295DEG5C	14	4	2V (Portrait)
T7	Trina - TSM 305DD05A.08 (3) Longi - LR6-60HBD-310M (1)	22	4	2V (Portrait)
Т8	Trina - TSM 305DD05A.08	22	4	2V (Portrait)
Т9	Trina - TSM-595NEG21C.20	33	1	1V (Portrait)
T10	Longi - LR5-72HBD-540M	27	1	1V (Portrait)







T11	Trina – TSM-675DEG20C.20	29	1	1V (Portrait)
T12	Trina - TSM-295DEG5C	22	4	2V (Portrait)
T13	Eging PV - EG-590M60-HU/BF-DG	33		1V (Portrait)
T14	Trina - TSM 305DD05A.08	22	4	2V (Portrait)
T15	Trina - TSM 305DD05A.08 (3) Longi - LR6-60HBD-310M (1)	22	4	2V (Portrait)
T16*	Risen - RSM120-8-595BMDG Eging - 545W M72 Eging 590/600W M60	33	1	1V (Portrait)
Single Axis Tracker	Longi - LR4-72HBD-435M	13	1	1V (Portrait)

T16*: currently, the T16 features a string of 22 Risen panels (white in the image), a 2-channel EKO IV system with two Risen panels (Ref 2 bifacial, Ref 1 modified to be monofacial) connected to two loads and 9 Eging panels all individually connected to loads in a second (9-channel) EKO IV system. There is also a custom-made Irradiance Measurement Module featuring a number of irradiance sensors.

- Solar panels
- The different types of modules installed are:
 - o Trina TSM-305DD05A.08
 - o Trina TSM-295DEG5C
 - o Longi LR6-60HBD-310M
 - o Longi LR4-72HBD-435M
 - o Risen RSM120-8-595BMDG
 - o Longi LR5-72HBD-540M
 - o Eging PV EG-590M60-HU/BF-DG
 - o Trina TSM-675DEG20C.20

Trackers

Note that only one type of tracker has been used, but some are operated as fixed tilt with a specific angle. The fixed tilt trackers are south-facing, typically set to a 25-degree tilt, while the HSAT trackers face east (90°) before solar noon and west (270°) afterward.





On the HSAT, the rotation is varied from -60° in the morning (facing east) to $+60^{\circ}$ in the evening (facing west) by an algorithm that uses astronomical equations to track the sun in azimuth. The angular position is monitored by inclinometer sensors mounted on the back of the trackers. The HSAT rows have different row spacing at 15 and 12 m. The fixed tilt system has an adjustable tilt from 0 to 60 deg, but is usually set to 25 deg.

Table 3.2-2. DTU PV Plant Soltec tracker characteristics

Item	Single Axis Tracker	Fixed Tilt
Manufacturer	SolTec	SolTec
Model	SF7	SF7
Tracking limit angle / Tilt angle	± 60°	25°
Azimuth	90° or 270°	180°
Back tracking	Yes	NA
Length	45.1 m	45.1 m

Inverters

Currently there is a total number of inverters is 9, as a few old inverters have been replaced by new ones with higher capacity.

- The different inverters used are:
 - o Delta RPI M50A 12s
 - o Huawei SUN2000 -40KTL
 - o Huawei SUN2000 -185KTL

Sensors

The PV plant is equipped with sensors to monitor environmental conditions, electrical characteristics, and PV performance. Data is collected at 15-minute interval, and is collected since 2019 with some gaps. Figure 3.2-2 gives an overview of the placement of the sensors:

• Irradiance:

- Global Plane of Array (GPOA) Irradiance: Measured by pyranometers located on different trackers.
- Rear Plane of Array (RPOA) Irradiance: Measured by pyranometers at different heights.
- o **Albedo**: Measured using multiple albedometers to determine ground reflectance.
- Irradiance Spectra: Collected by various irradiance sensors.

• Temperature:

Ambient Temperature: Collected near the trackers.





- Module Temperature: Sensors are placed on several PV modules to measure the temperature.
- Soiling Ratio: Measured using DustIQ sensors to evaluate soiling on PV modules.
- Wind: Wind speed and direction.

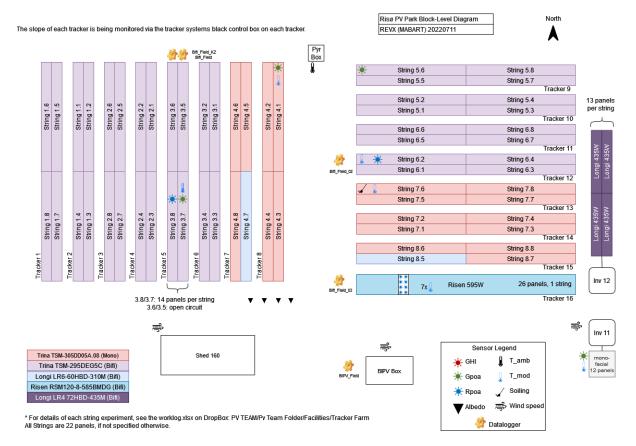


Figure 3.2-2. Location of sensors in DTU PV plant

• Electrical Data:

- Current (Impp), Voltage (Vmpp), Power Output: Collected by inverters and DC/AC boxes, and some specialized devices such as power optimizers.
- Power Factor: An electrical measurement indicating the efficiency of the power system.
- String Data: Collected by string bloxx monitors installed in DC boxes to monitor current and voltage at the string level.

3.2.2. Weather Station

In addition to the PV field, there is a solar resource meteorological station that is integrated with a data logging system. All the sensors installed are listed in Table 3.2-3.

The main irradiance components are sampled with 10s and data is available from 2018 onwards.









Sensor	Measurement	Comment	
All-in-one smart weather sensor	Temperature, humidity, wind speed, wind direction, pressure and precipitation.		
Pyrgeometer	Downwelling longwave irradiance.	From > 3um.	
Silicon photodiode	Global horizontal irradiance (GHI).	With a fast response time (< 1 Hz) from 300 nm - 1100 nm.	
Pyranometer	Global horizontal irradiance (GHI).	Response time of <0.5 seconds from 285 nm – 3000 nm.	
Shaded pyranometer	Diffuse horizontal irradiance (DHI).	With the 5° field of view (FOV) shadow ball that actively follows the sun and shadows.the sensor. Installed on a tracker.	
Pyrheliometer	Direct normal irradiance (DNI).	From 200 nm – 4000 nm. Has a 5° FOV collimating tube mounted on the senso body and actively tracks the sun.	
4-Quadrant photodiode		Allows the two-axis tracker to follow the sun with high accuracy during clear sky conditions.	
Direct normal spectroradiometer	DNI.	From 300 nm – 1100 nm. The sensor is covered by the same type of 5° collimating used on the pyrheliometer. Installed on a tracker.	
UV Radiometer	UV-B radiation.	Between 280 nm and 320 nm (MS-212W) and UV-A radiation between 315nm and 400nm (MS-212A)	
Global spectroradiometer	Diffraction grading based spectrometer for measuring spectrally resolved GHI.	From 300 nm – 1100 nm.	
Global spectroradiometer	Diffraction grading based spectrometer for measuring spectrally resolved GHI.	From 900 nm – 1700 nm.	
Diffuse spectroradiometer	Diffraction grading based spectrometer for measuring spectrally resolved GHI.	From 300 nm – 1100 nm. Installed on a tracker.	







3.3 PPC Demo Site

Plant Description

PPC's PV plant, named Bitakos, is in Thiva, or **Thebes, in central Greece**, approximately 90 kilometers northwest of Athens. Situated in the Boeotia plain, Thiva has a **Mediterranean climate** characterized by hot, dry summers and mild, wet winters. This climate provides favorable conditions for solar energy generation, with ample sunshine throughout the year. Summers often experience temperatures exceeding 30°C (86°F), ideal for consistent photovoltaic (PV) output.

Bitakos PV Plant was energized in February 2021 and has 20 years expected lifespan, till 2041.



Figure 3.3-1. Bitakos PV plant located in Thebes, Central Greece.

The installation has a total capacity of **2,641,410 Wp**. It operates as an independent power generation unit and is connected to the grid through a suitable substation, where the generated energy is directed. The photovoltaic panels are **arranged in series (strings)**, **in parallel** and are then connected to the inverters









Figure 3.3-2. Ground plan of Bitakos PV plant



Figure 3.3-3. Distribution Panel at the Bitakos PV Plant









Figure 3.3-4. Closer look at the PV panels of the Bitakos PV plant

Modules

This project includes the installation of **6,522 Jinko modules** with a **capacity of 405 Wp each** (**model JKM405-72H-V**). These modules are high efficiency, equipped with bypass diodes, and rated for 1500 Vdc. They are designed to resist PID (Potential Induced Degradation) and come with a warranty for linear power degradation. The Technical specifications of the modules are presented below:







Table 3.3-1. Technical specifications of PV modules

Module Type	JKM390 JKM390I			5M-72H M-72H-V	JKM400 JKM4001		JKM405 JKM405		JKM410	
	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax)	390Wp	294Wp	395Wp	298Wp	400Wp	302Wp	405Wp	306Wp	410Wp	310Wp
Maximum Power Voltage (Vmp)	41.1V	39.1V	41.4V	39.3V	41.7V	39.6V	42.0V	39.8V	42.3V	40.0V
Maximum Power Current (Imp)	9.49A	7.54A	9.55A	7.60A	9.60A	7.66A	9.65A	7.72A	9.69A	7.76A
Open-circuit Voltage (Voc)	49.3V	48.0V	49.5V	48.2V	49.8V	48.5V	50.1V	48.7V	50.4V	48.9V
Short-circuit Current (Isc)	10.12A	8.02A	10.23A	8.09A	10.36A	8.16A	10.48A	8.22A	10.60A	8.26A
Module Efficiency STC (%)	19.3	38%	19.	63%	19.	88%	20.	13%	20.3	38%
Operating Temperature (°C)					-40°C-	-+85°C				
Maximum System Voltage	1000/1500VDC (IEC)									
Maximum Series Fuse Rating	20A									
Power Tolerance	0~+3%									
Temperature Coefficients of Pmax	-0.35%/°C									
Temperature Coefficients of Voc	-0.29%°C									
Temperature Coefficients of Isc	0.048%℃									
Nominal Operating Cell Temperature	(NOCT)				45±	:2°C				

Electrical Performance & Temperature Dependence

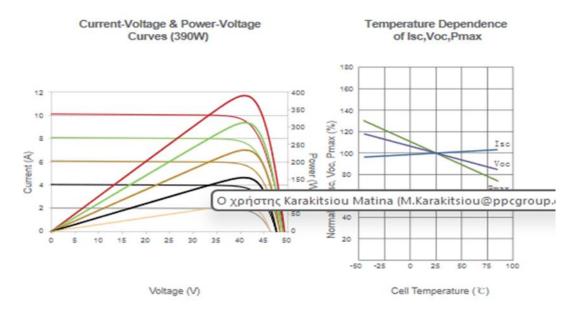


Figure 3.3-5. Electrical Performance and Temperature Dependance of PV modules

Key standards used for the design of the installation are:

• EN 62446-1: Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 1: Grid connected







- systems Documentation, commissioning tests and inspection.
- IEC 62548: Photovoltaic (PV) arrays Design requirements
- HD 60364: Low-voltage electrical installations
- EN 62305: Protection against lightning
- EN 61936-1: Power installations exceeding 1 kV a.c. Part 1: Common rules

Inverters

The PV plant has 24 inverters. The inverters are of the HUAWEI 100-KTL-M1 type, certified under EN 62109, suitable for 400V/50Hz with a TNS topology and IP66 rating. They operate within the local temperature range and offer a broad MPPT window. The technical specifications of the inverters are presented below.

Table 3.3-2. Technical specifications of the Inverters

	Efficiency		
Max. Efficiency	98.8%		
European Efficiency	98.6%		
	Input		
May Input Voltage	1,100 V		
Max. Input Voltage Max. Current per MPPT	26 A		
T	26 A 40 A		
Max. Short Circuit Current per MPPT			
Start Voltage	200 V		
MPPT Operating Voltage Range	200 V ~ 1,000 V		
Rated Input Voltage	600 V		
Number of Inputs	20		
Number of MPP Trackers	10		
	Output		
Rated AC Active Power	100,000 W		
Rated AC Apparent power	100,000 VA		
Max. AC Apparent Power	110,000 VA		
Max. AC Active Power (cosφ=1)	110,000 W		
Rated Output Voltage	400 V, 3W + PE		
Rated AC Grid Frequency	50 Hz / 60 Hz		
Rated Output Current	144.4 A		
Max. Output Current	160.4 A		
Adjustable Power Factor Range	0.8 LG 0.8 LD		
Max Total Harmonic Distortion	<3%		







	Protection	
nput-side Disconnection Device	Yes	
Anti-islanding Protection	Yes	
AC Overcurrent Protection	Yes	
DC Reverse-polarity Protection	Yes	
PV-array String Fault Monitoring	Yes	
DC Surge Arrester	Type II	
AC Surge Arrester	Type II	
DC Insulation Resistance Detection	Yes	
Residual Current Monitoring Unit	Yes	
	Communication	
Display	LED Indicators, Bluetooth/WLAN + APP	
RS485	Yes	
USB	Yes	
MBUS	Yes (isolation transformer required)	
	General Data	
Dimensions (W x H x D)	1,035 x 700 x 365mm (40.7 x 27.6x 14.4 inch)	
Weight (with mounting plate)	90 kg (187.4 lb.)	
Operating Temperature Range	-25°C ~ 60°C (-13°F ~ 140°F)	
Cooling Method	Smart Air Cooling	
Max. Operating Altitude	4,000 m (13,123 ft.)	
Relative Humidity	0 ~ 100%	
DC Connector	Staubli MC4	
AC Connector	Waterproof Connector + OT/DT Terminal	
Protection Degree	IP66	
Topology	Transformerless	
Nighttime Power Consumption	≤ 3.5W	
Country of Manufacture	China	
	Standard Compliance (more available upon request)	
Safety	EN/IEC 62109-1, EN/IEC 62109-2, IEC 62116	
Grid Connection Standards	AS/NZS 4777.2 2020	

Electrical Infrastructure Overview

The electrical infrastructure of the facility includes a robust and efficient setup designed to ensure reliable power distribution and monitoring. At the core of this system is a **1pc ABB 2500kVA transformer**, which operates at a primary voltage of 0.315kV and steps up to 20kV for medium voltage distribution. This transformer is essential for managing the facility's energy demands and providing a stable power supply.

To enhance operational safety and control, the system is equipped with **medium voltage (MV) switchgears**. These components facilitate the safe management and distribution of electrical power within the facility, allowing for quick isolation of electrical circuits during maintenance or emergencies.

In addition, the installation features a **Ground Level Voltage Panel (GLVP)**, which provides an interface for monitoring and controlling low voltage circuits. This panel is crucial for ensuring the safe and efficient operation of electrical equipment within the facility.

To maintain oversight and ensure security, a **SCADA** (Supervisory Control and Data Acquisition) monitoring system is implemented. This system allows for real-time monitoring of the electrical infrastructure, enabling operators to track performance, identify issues, and optimize energy use.





Finally, the infrastructure includes a **CCTV** and an alarm system, which enhances security by providing continuous surveillance of the facility and immediate alerts in the event of any unauthorized access or anomalies.

Historical Data sharing

For project SOLARIS, we will share historical SCADA data from a centralized location with a resolution of 10-15 minutes, starting from February 2021. The data will be provided in Excel format and shared in the project's shared folder or another designated repository within the next two months. At the Bitakos PV plant, we monitor various factors, including inclined irradiance, ambient temperature, dust levels, and wind speed. The following table lists the environmental sensors used at the PV plant, along with their manufacturers.

Table 3.3-3. Environmental sensors of Bitakos PV plant

#	Type of Sensors	Manufacturer
1	Inclined Irradiance (W/m^2)	Gantner
2	Ambient Temperature (°C)	Gantner
3	Soiling sensor (%)	Kipp & Zonen
4	Wind Speed (m/s)	Gantner

We will share data on the plant's energy production. In the following table, you can see the indicative factors that we will provide.

Table 3.3-4. Indicative Factors of Energy Production Data

Category	Name	Unit
Inverter	Phase voltage	V
Inverter	Line voltage	V
Inverter	Phase current	Α
Inverter	Active power	kW
Inverter	Reactive power	kW
Inverter	Apparent power	kW
Inverter	Active energy	kWh
Inverter	Reactive energy	kWh
Inverter	Apparent energy	kWh
Inverter	Power factor	







Inverter	Frequency	Hz
Inverter	Inverter internal temperature	ōС
Inverter	DC MPPT Current	Α
Inverter	DC MPPT Voltage	V
Inverter	DC String Current	А
Inverter	DC String Voltage	V

Cleaning Protocol for PV Panels

Our company follows the protocol below for the regular cleaning of PV panels to ensure safety, efficiency, and optimal energy output.

Cleaning Procedure

To maintain energy efficiency, PV modules are cleaned at least once a year or as required, based on site conditions.

Preparation:

- Cleaning is scheduled for early morning or late afternoon when solar radiation is lower, reducing thermal and electrical shock risks.
- Only soft, clean clothes are used for wiping, and we prefer dampened clothes with low-mineral content water to avoid mineral deposits on the glass.

Cleaning Process:

- Dry Cleaning: Light dust or dirt is removed gently using a soft, dry cloth.
- Damp Cleaning: For more stubborn dirt, a soft cloth dampened with low-mineral water is used, avoiding excessive water or pressure.
- No Chemicals or Abrasives: Chemicals, abrasive materials, or detergents are strictly avoided to protect the glass surface, ensure consistent energy output, and uphold the module warranty.

Safety Precautions:

 Modules with broken glass or exposed wiring are not cleaned due to shock hazards.







 High-pressure water jets, harsh chemicals, or abrasive tools are avoided to prevent damage to modules and efficiency loss.

By adhering to this protocol, our company ensures the reliable and efficient operation of PV panels, protecting their warranty and maximizing energy generation.

Dust origin in PPC plant

PPC plant is exposed to dust and occasional agricultural activity, which can contribute to dust accumulation on PV panels, reducing their efficiency. The dry season, combined with frequent winds, can exacerbate dust deposition, making regular maintenance and cleaning of PV installations essential for optimal performance.

Demonstration

At the Bitakos PV plant, PPC can demonstrate a wide range of physical and digital tools from the SOLARIS project. These include:

- Dust sensors and other environmental sensors
- Specialized cleaning fluid for PV panels
- Custom IR and EL drones
- Digital asset management software

Implementing these tools at PPC's Bitakos PV site will enhance the plant's operational reliability, improve performance by proactively addressing environmental and mechanical challenges, and reduce maintenance costs.

Potential Barriers for the Solaris Tools Demonstration

It is essential to establish certain prerequisites before the demonstration of the Solaris tools. We require detailed information regarding the sensors to be installed at the Bitakos PV plant, including the total number of sensors, their specific placement locations, and the expected duration of the installation process.

Similarly, for the drone inspection, we need to ascertain the schedule and duration of access to our premises.

Regarding the cleaning fluid, it is necessary to obtain the technical datasheet for the fluid, along with details on the number of panels it will be applied to. Additionally, we require assurances that the cleaning fluid will not cause any damage to our panels.







3.4 EILAT Demo Site

3.4.1. Rabin PV Plant

Plant Description

Eilat's PV plant, named Rabin, is in South Israel at Eilat Citys. has a extreme arid climate characterized by hot, dry summers and winters. Summers often experience temperatures exceeding +35°.

Rabin PV Plant was energized in April 2022 and has 25 years expected lifespan, till 2047.



Figure 3.4-1. Rabin PV plant located in Eilat, South Israel.

The installation has a total capacity of 250,560 Wp. It operates as a roof-top power generation unit and is connected to the grid through the high school connection. The photovoltaic panels are arranged in series (strings), in parallel and are then connected to the inverters.







Rabin- Layout Design

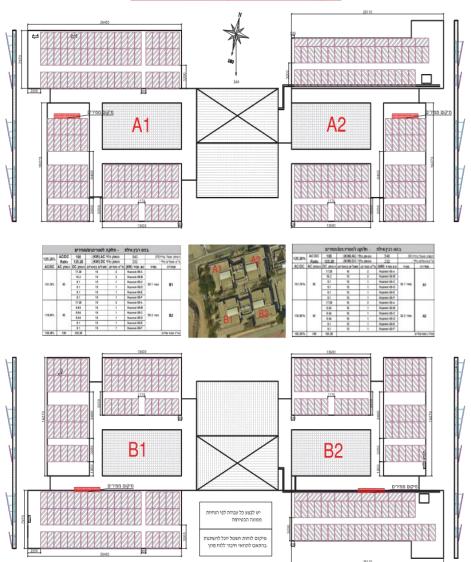


Figure 3.4-2. Ground plan of Rabin PV plant

Modules

This project includes the installation of 6,522 Jinko modules with a capacity of 405 Wp each (model JKM405-72H-V). These modules are high efficiency, equipped with bypass diodes, and rated for 1500 Vdc. They are designed to resist PID (Potential Induced Degradation) and come with a warranty for linear power degradation. The Technical specifications of the modules are presented below:

Key standards used for the design of the installation are:







- EN 62446-1: Photovoltaic (PV) systems Requirements for testing, documentation and maintenance - Part 1: Grid connected
- systems Documentation, commissioning tests and inspection.
- o IEC 62548: Photovoltaic (PV) arrays Design requirements
- o HD 60364: Low-voltage electrical installations
- EN 62305: Protection against lightning
- o EN 61936-1: Power installations exceeding 1 kV a.c. Part 1: Common rules

Inverters

The PV plant has 4 inverters. The inverters are of the HUAWEI 50-KTL-MO type, certified under EN 62109, suitable for 400V/50Hz with a TNS topology and IP66 rating. They operate within the local temperature range and offer a broad MPPT window. The technical specifications of the inverters are presented below.

Electrical Infrastructure Overview

The electrical infrastructure of the facility includes a robust and efficient setup designed to ensure reliable power distribution and monitoring. The plan of the facility is attached as a separate document.

Historical Data sharing

For project SOLARIS, we will share historical data through the "Fusion-Solar" monitoring system. The data will be provided in Excel format or through an API and shared in the project's shared folder or another designated repository within the next two months

Table 3.4-1. Environmental sensors of Rabin PV plant

#	Type of Sensors	Manufacturer
1	Inclined Irradiance (W/m^2)	
2	Ambient Temperature (°C)	
3	Soiling sensor (%)	
4	Wind Speed (m/s)	

Cleaning Protocol for PV Panels

Our company follows the protocol below for the regular cleaning of PV panels to ensure safety, efficiency, and optimal energy output.

Cleaning Procedure

To maintain energy efficiency, PV modules are cleaned at least once a year or as required, based on site conditions.

Preparation:







Cleaning is scheduled for early morning or late afternoon when solar radiation is lower, reducing thermal and electrical shock risks.

Only soft, clean clothes are used for wiping, and we prefer dampened clothes with low-mineral content water to avoid mineral deposits on the glass.

Cleaning Process:

Dry Cleaning: Light dust or dirt is removed gently using a soft, dry cloth.

Damp Cleaning: For more stubborn dirt, a soft cloth dampened with low-mineral water is used, avoiding excessive water or pressure.

No Chemicals or Abrasives: Chemicals, abrasive materials, or detergents are strictly avoided to protect the glass surface, ensure consistent energy output, and uphold the module warranty.

Safety Precautions:

Modules with broken glass or exposed wiring are not cleaned due to shock hazards.

High-pressure water jets, harsh chemicals, or abrasive tools are avoided to prevent damage to modules and efficiency loss.

By adhering to this protocol, our company ensures the reliable and efficient operation of PV panels, protecting their warranty and maximizing energy generation.

Dust origin in the city of Eilat plant

The PV plant is exposed to dust and occasional sand storms, which can contribute to dust accumulation on PV panels, reducing their efficiency. The dry season, combined with frequent winds, can exacerbate dust deposition, making regular maintenance and cleaning of PV installations essential for optimal performance.

Demonstration

At the Rabin PV plant can demonstrate a wide range of physical and digital tools from the SOLARIS project. These include:

Dust sensors and other environmental sensors

Specialized cleaning fluid for PV panels

Custom IR and EL drones

Digital asset management software

Cost analysis for the most efficient and financial analysis for cleaning times and frequency







Implementing these tools in Rabin PV site will enhance the plant's operational reliability, improve performance by proactively addressing environmental and mechanical challenges, and reduce maintenance costs.

Potential Barriers for the Solaris Tools Demonstration

It is essential to establish certain prerequisites before the demonstration of the Solaris tools. We require detailed information regarding the sensors to be installed at the Rabin PV plant, including the total number of sensors, their specific placement locations, and the expected duration of the installation process.

Similarly, for the drone inspection, we need to ascertain the schedule and duration of access to our premises.

Regarding the cleaning fluid, it is necessary to obtain the technical datasheet for the fluid, along with details on the number of panels it will be applied to. Additionally, we require assurances that the cleaning fluid will not cause any damage to our panels.

3.4.2. Agrivoltaics site

This project demonstrates a novel concept for off-grid Agrivoltaics (APV) as a food—energy—water system approach in drylands by monitoring multiple ecosystem dimensions. The dual use of land preserves and promotes sustainable agriculture methods, providing off-grid electrification solutions for developing and rural areas and enabling farmers from developed countries to become energy-independent by decentralizing energy resources and saving on electricity bills.

Two similar-sized APVs were built on the site in the past year and will be included in the experimental setup to provide additional blocks. Each frame's irrigation system is separate, providing a unique irrigation regime for each crop. All systems are designed as off-grid systems. Solar energy can play a significant role in providing electricity based on a stand-alone photovoltaic (SAPV) system to rural areas. The proposed SAPV system is independent and converts solar energy directly into electricity allowing clean electricity production, is easy maintain and operate, and a highly reliable system. One frame is already connected to an energy storage system, which operates a cooling warehouse and a water treatment unit







Figure 3.4-3. EILAT Agrivoltaics site photo #1



Figure 3.4-4. EILAT Agrivoltaics site photo #2









Figure 3.4-5. EILAT Agrivoltaics site photo #3





3.5 FIB Demo Site

3.5.1. General description

The focus of the project involves three key types of photovoltaic (PV) installations. First, small-scale domestic rooftop PV systems located in rural environments are being considered, where the challenge is often tied to the knowledge and capabilities of private owners. Secondly, there is a commercial-scale PV system at an agricultural college campus, which presents a larger infrastructure for both energy production and educational purposes. Finally, an Agri-PV system, still in the conceptual phase at the same agricultural college, offers an opportunity to explore the integration of photovoltaic technology with agricultural activities, providing a dual land-use solution that could be highly beneficial in rural settings.

Currently, the available sensors for these installations are limited, with only electrical generation and consumption being measured. This poses challenges in terms of optimizing the systems and ensuring long-term operational efficiency. For instance, private PV owners often lack the technical know-how to maintain and optimize their systems effectively. Moreover, the addition of sensors and diagnostic tools does not yield immediate economic benefits, making it difficult to justify their use, especially in small-scale setups. A major concern is that fault detection of PV modules is often neglected in these smaller installations, leading to potential inefficiencies or system failures. Another issue is the soiling of PV panels, which reduces their efficiency. Without an optimized cleaning schedule, the performance of the PV systems can degrade significantly over time.



Figure 3.5-1. Overview of the FIB test sites





The expected outcomes of the project aim to address these challenges directly. One key goal is to increase the energy yield of the PV systems by improving their overall efficiency. Another objective is to enhance maintenance procedures, likely through the implementation of novel diagnostic tools and optimized cleaning schedules. Furthermore, the project aims to demonstrate innovative solutions tailored for rural areas, which could significantly improve the viability and sustainability of photovoltaic systems in these regions.

3.5.2. Energy Storage Competence Center

The energy storage systems, which vary in both size and technology, are applied across different infrastructure levels, including substation and transformer station levels, as well as at building level. At the building level, these applications span industrial, commercial, and private settings, allowing for flexible use in diverse energy management environments.

A real-time monitoring system that utilizes high-resolution data transmission with intervals of 1/10th of a second is implemented. This system enables precise and continuous monitoring of energy flows and system performance. Additionally, an innovative battery control system is being developed as part of this initiative, aimed at enhancing the efficiency and responsiveness of battery storage operations. This control system will optimize energy storage and distribution, ensuring better integration with the overall energy management infrastructure.

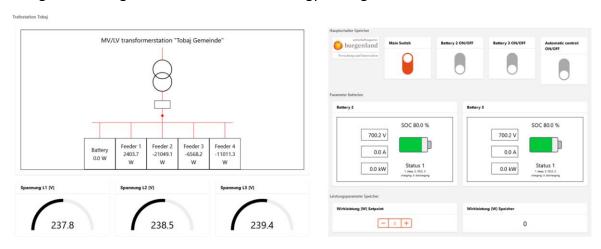


Figure 3.5-2. Representation of the FIB real-time monitoring system

Storage BESS1

The BESS1 has a capacity of 200 kW with 250 kWh of storage. During islanding mode, using a separate busbar, the system operates at 27 kW with a capacity of 50 kWh. In terms of energy management, the system supports several key functions. These include regional self-consumption optimization, which enhances the local use of generated energy, and peak shaving, which reduces the demand on the grid during peak usage times. Additionally, the system







contributes to energy efficiency improvement and offers grid support and stabilization through four-quadrant controllability (4Q), allowing for advanced power regulation and balance.





Figure 3.5-3.Picture of BESS1

Storage BESS2

BESS2 has a capacity of 50 kW, and 100 kWh is designed for building integration. Its energy management capabilities include optimizing self-consumption, allowing the building to make the most of the locally generated energy. Additionally, the system provides peak shaving to reduce demand on the grid during periods of high energy consumption. It also focuses on improving overall energy efficiency, ensuring better energy use and lower operational costs for the building.



Figure 3.5-4. Picture of BESS2

3.5.3. Agricultural College Güssing (LFS Güssing)

The baseline of the project is set within a biological farming operation that spans 42 hectares of arable land and 28 hectares of grassland. The farm also manages livestock, including cattle, pigs, and horses.

Current state at the Agricultural College (LFS)

In terms of energy infrastructure, the farm has a rooftop photovoltaic system with a capacity of 29 kWp for self-consumption, alongside an additional 100 kWp system that feeds energy entirely into the grid. A battery storage system (BESS 2) is also integrated into the energy setup, with a storage capacity of 100 kWh and a power output of 50 kW. While the BESS 2 is directly connected with the 29 kWp rooftop PV plant, the additional 100 kWp of PV are connected separately to the grid and thus do not utilize the BESS 2 directly.

This project focuses on monitoring both the college's electricity consumption and production. Additionally, there is a monitoring system in place for the medium- to low-voltage transformer, ensuring comprehensive energy management across the entire farm.







Future state at the Agricultural College with additional Agri-PV plant (LFS Agri-PV)

The initial estimate of the Agri-PV is based on an early stage of planning, meaning that many essential parameters have not yet been fully determined. Several site conditions are either unknown or only roughly estimated at this point. These include the foundation conditions and the required depth for the installation of pile profiles, the wind loads at the site, and the conditions for grid connection. The entire system is expected to deliver a total capacity of approximately 280 kWp.



Figure 3.5-5. Overview of the agricultural college campus in Güssing

The outlook of the school is centered on achieving self-sufficient energy solutions for agricultural operations. A key focus is the electrification of farming machinery, which plays a crucial role in securing food production through sustainable energy use.

To reach these goals, the project involves a detailed analysis of energy demand and potential flexibilities within the farm's operations. Innovative and sustainable technical solutions, alongside new business models, will be developed to support this transition. The electrification of farm machinery is a vital part of these efforts, as is the integration of battery storage systems into farmyards to optimize energy use.



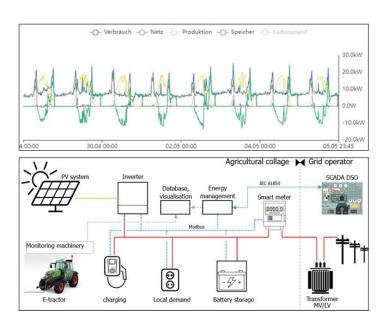


Figure 3.5-6. Layout of the research plan in the agricultural college in Güssing.

Additionally, the project seeks to connect local energy communities to both medium- and low-voltage networks, further promoting the decentralization and resilience of energy supply in rural agricultural areas by using energy storage systems.

3.5.4. Living Lab Tobaj

Th Living Lab covers a small town, Tobaj, in the district of Güssing, in the southern part of the Austrian province Burgenland. The town is supplied with electrical energy through three transformer stations connecting the 20 kV medium-voltage (MV) to the 0.4 kV low-voltage (LV) grid. Out of those three MV/LV transformer stations one is already equipped with additional energy measurement systems allowing the monitoring of the 4 LV feeders connecting the different prosumer buildings including their rooftop PV plants to the grid. An overview of the area and the individual connections of measurement devices is shown in Figure 3.5-7.



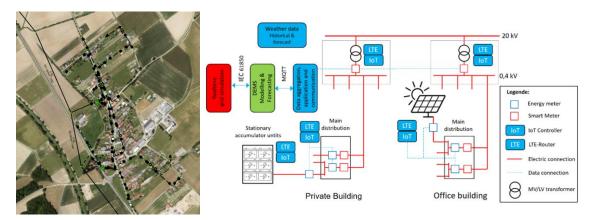


Figure 3.5-7. Scheme of the Living Lab Tobaj demonstration site.

The overview of the measurement and control panel has already been briefly described above as part of the Energy Storage Competence Center. In addition to the overview of energy consumption and generation on the transformer station level, some prosumers with rooftop PV have already been equipped with IoT infrastructure to monitor in more depth the specific generation of their PV plants together with their respective consumption.

In course of the SOLARIS project, it is foreseen to enlarge the amount of monitored private PV plants, in case this is finally selected as demonstration site.

3.5.5. Suggested Demonstration Activities for the FIB Demonstration

Based on the available site, different applications appear useful for the demonstration period. Those are summarized in Table 3.5-1 the below. A differentiation between 3 possible sites has been done based on the following. "LFS" refers to the agricultural college campus as it is, with no additional PV plants or BESS installed. "LFS Agri-PV" refers to the stage where the new Agri-PV is finally will be build and in operation. Since this will be a larger PV than the ones on the rooftops, more SOLARIS solutions are applicable. "LL Tobaj" as the third possibility refers to the Living Lab in the small town of Tobaj, where besides the grid size BESS 1 only private rooftop PV plants are available and thus forming a different type of application.

Table 3.5-1. Demonstrated SOLARIS solutions in the AT Demo-Site

	LFS	LFS Agri-PV	LL Tobaj
PR1Comprehensive Forecasting	Х	х	Х
PR2 Al-based energy trading tool			
PR3 Solutions Against Soiling	Х	х	(x)







PR4 Wind load sensing		х	
PR5 Novel impedance sensing			
PR6 Drone inspection (EL/PL/IR imaging)	х	х	(x)
PR7 Online IoT platform	Х	х	х
PR8 PV asset management software			







3.6 Data and requirements from partners

Table 3.6-1. List of task partners with data and demonstration activities

Responsible partner	DTU Demo Site	PPC Demo Site	EILAT Demo site	FIB Demo site
AAU, Saeed Peyghami (sap@energy.aau.dk)	Yes	No	NO	NO
EMA	Yes	No	No	No
UBI, "Verena Ruedl" <vruedl@ubimet.com></vruedl@ubimet.com>	Yes	Yes	Yes	Yes
UNIGE	Yes	Yes	No	No
HELIO (emeric.eyraud@heliocity.io)	Yes Field control app	Yes	Yes	Yes
ELLC (carmina.bocanegra@elliotcloud.com)	Yes	Yes	Yes	Yes
AIR6	Yes	Yes	Backup	Yes
DTU, "Sergiu Viorel Spataru" <sersp@dtu.dk></sersp@dtu.dk>	Yes	Yes Air6	Backup	Yes Air6
TEK, "Estibaliz Gomez" <egomez@tekniker.es> T3.2 Cleaning solution</egomez@tekniker.es>	Backup	Yes	Yes	Yes
TEK, "Oscar Gonzalo" <ogonzalo@tekniker.es>, T3.1 (wind)</ogonzalo@tekniker.es>	Yes	No	No	No
TEK, "Xabi Bazan" <xbazan@tekniker.es>, T3.1 (dust)</xbazan@tekniker.es>	Yes	Yes	Maybe (just for internal testing, no use case will be developed at this site)*	Maybe (just for internal testing, no use case will be developed at this site)*
TEK, "Jon Martinez" < jmartinez@tekniker.es>, T4.5 & T5.3	No	Yes	No	No

^{*} If the demo site partner is interested and there are enough sensors available after the chosen installations at DTU and PPC are fully arranged, sensors could be provided in a limited way for internal testing by other demo site partner without TEK's participation. That means that the "Multi-aspect smart sensing for PV systems monitoring - Smart soiling sensors" use case will not be developed in that case of internal testing.

3.6.1. AAU

General data and demonstration requirements

- Historical weather data including ambient temperature and solar irradiance with high resolution (agreed historical data with 10 sec resolution and long-term high-resolution data predicted by UBI)
- Predicted weather data for short term and seasonal forecast with high resolution







 Inverter failure data, weather the failure sources in DTU's site come from power devices (IGBT, capacitors) or from otehr parts of the converters.

DTU Demo site - specific data and demonstration requirements

- DC link voltage range and power level
- PV panels and arrays i-v characteristics
- Reconfiguration possibility in PV array and number of strings

3.6.2. EMA

We will in fact only need that MC4 connectors are used, and then we need WiFi. We will need a 5V outlet to power the sensor device. This could also be a 230V Ac outlet where we then add a small PSU instead. We strongly aim at not having dependencies and hence make a true standalone device for retrofitting.

3.6.3. UBI

General data and demonstration requirements

- Historical monitoring data needed: Historical data on the generated electrical power with a resolution of 15 minutes for a period of at least 2 years would be desirable
- live data on how much electrical energy is currently being produced
- Information about master data for PV demonstration site(s) is needed: type of PV plant, installed performance, orientation of the panels or information on whether they follow the position of the sun, coordinates of the location of the PV system
- Weather data available? Which specific weather parameters are measured and can be provided? Is historical weather data also available and if so, for what period?

All the data requirements from UBIMET are also summarized in section 2 of this document.

DTU Demo site - specific data and demonstration requirements

- Which specific weather parameters are measured at the weather station?
 - see description of weather station
- Is historical weather data from the station available?
 - Yes, see description of weather station
- What information do we get from the cloud camera? For example, percentage of cloud cover in the sky or type of cloud?







- Just images for now, it is a custom built camera
- o In the future we will do our own cloud detection

3.6.4. UNIGE

General data and demonstration requirements

UNIGE will test three main capabilities for each demo site:

- The ability to autonomously plan optimized flight routes above PV rows, starting from images acquired by drones and/or satellites. This will take into account constraints such as:
 - Take-off/landing/recharging areas, and
 - Battery capacity.
- The ability of aerial drones to follow PV rows in real-time, using machine learning techniques for panel segmentation. The drones will employ visual servoing to adjust their lateral position and height while moving along the PV rows. Additionally, GNSS-based navigation will guide the drones from one row to the next, according to the planned route.
- The ability to manage multiple aerial drones inspecting the plant simultaneously in real time. This will help avoid conflicts and collisions when drones are heading to takeoff/landing/recharging sites or are inspecting nearby PV rows.

It should be emphasized that UNIGE will bring their own aerial drones and technical staff to the sites and test the capability they developed by comparing autonomous and manual flight. Also, UNIGE demonstration will focus on enabling aerial drones to carry payloads (e.g., sensors suitable for defect recognition) along PV trackers, but it will not focus on defect recognition itself, as this is not part of their role in the project. Therefore, any partner proposing a defect recognition solution based on data collected by aerial drones will have the opportunity (provided that physical constraints are respected) to use their sensor as a payload that UNIGE's drones will carry during flights.

To this end, UNIGE can benefit from the following historical data for both sites. Data 1 and 2 should be ready by January 2025 to start development, followed by Data 3 in March 2025. Data 4 can be provided later in the project, as they are not critical for development.

- 1. Existing satellite and/or aerial images of the demo plant, to feed segmentation algorithms that will create a model of the PV plant for optimal route planning.
- 2. Higher-resolution aerial images of the plant taken at different times of the year and day, under varying sunlight and weather conditions. These will be used to:







- o Train machine learning algorithms for segmentation, and
- Provide texture for real-time simulation environments, based on the Robot Operating System and the virtual environment Coppelia. These will be used to model and simulate operations at each site before deployment.
- 3. GNSS data collected at the site at different times of the year and day, under various weather conditions. This will help estimate the dynamics of GNSS data and predict the errors that may occur when moving to the actual site.
- 4. Additionally, even though UNIGE will not focus on defect recognition but will instead provide capabilities for aerial drones to carry a partner-provided payload, UNIGE will benefit from thermographic images that can be used to train machine learning algorithms for defect recognition on PV panels. These images can be collected at the selected site or sourced from available datasets that partners may have access to, if they exist.

Other needs:

- UAV flight authorizations will be required for each site, considering that an operator will always be responsible for controlling the aerial drone as needed within line of sight.
 UNIGE will provide a technical expert to ensure the system operates correctly and to train local operators, supporting the initial stage of experiments at each site, starting with DTU and followed by PPC.
- A clear start/landing/recharging area is required for each site, along with the necessary electrical connections for PCs, monitors, battery charging stations, etc.

DTU Demo site - specific data and demonstration requirements

The DTU site is particularly interesting due to its smaller size, which simplifies initial experiments. There are no special requirements for this site beyond those already mentioned above.

PPC Demo site - specific data and demonstration requirements

The PPC site, on the other hand, is valuable due to its larger size and complexity, which will challenge algorithms to find and follow an optimal path during real-time operations. There are no special requirements for this site beyond those already mentioned above.

3.6.5. HELIOCITY

General data and demonstration requirements

Subject to data availability and demonstration requirements, Heliocity plans the following demonstrations:

 Remote failure detection and quantification of the PV Asset Management SW over the 4 testing sites







- Field Control App of the PV Asset Management SW at DTU testing site (at least)
- Fleet Management (mock-up) of the PV Asset Management SW: might be remote demonstration using data provided by Heliocity (no need for demo site)

The table below summarizes the data and demonstration requirements for each of these demonstrations.

Table 3.6-2. Summary of HELIO data and demonstration requirements

Features to be tested/ demonstrated	Historical monitoring data needed	 Description of the tests Activities Equipment needed Duration Manpower needed (onsite)
Remote Failure detection and quantification	Cf.SOLARIS_T1.2_Require d information 12 months historical data Static data Meter/ Tracker/ Inverter/Weather station/	 Activities: Perform a PV performance audit with results made available onto a SaaS platform Equipment needed: n/a (but data) Duration: ~1 month per demo site Manpower needed (onsite): 1 site responsible interlocutor to provide descriptive info and historical time series dataset. For at least at one site (DTU), a person can "trigger" a failure incident (string disconnection, faulty module)
Field Control App	ABOVE + in-situ measurements	 Activities: test the field app on site with data ingestion by local operator and visualization of proper treatment Equipment needed: Mobile phone (Android) + laptop Duration: ~1 or 2 days onsite Manpower needed (onsite): 1 operator to use the field app and authorised to access the PV power plant
Fleet Management (mock-up)	Historical (3 years minimum) + weather forecast prediction (real or test data set)	 Activities: online demonstration of the Fleet Management recommendations engine with test datasets to demonstrate the "ML" algorithm Equipment needed: n/a (but data) Duration: ~visio meeting/ demo (2 hours) Manpower needed (onsite): n/a







Demo site specific requirements

Remote failures detection and quantification

- PV Asset Management Software 'Static data (description)' as per section 2.2 (2 months before start of test (M30-2=M28)
- PV Asset Management Software 12 months 'Historical data' for Meter/ Tracker/ Inverter/Weather station to be provided by the demo site leader through ELLC as per section 2.2, (2 months before start of test (M30-2=M28)
- To be refined depending on final integration, possibly, collection of new data at the sites (e.g. additional sensing (soiling sensors), image datasets of aerial/satellite images of the site, with sampling time and duration)

Field Control App

- Data from above (Remote failures detection and quantification) but on a <u>near real-time</u>
 <u>basis</u>+ in-situ measurements as described in section 2.2 (2 months before start of test (M30-2=M28)
- Need for a local operator with Mobile phone (Android) + laptop during 1 or 2 days onsite

PPC/ EILAT/ FIB Demo Site

Remote failures detection and quantification

- PV Asset Management Software 'Static data (description)' as per in section 2.2 (2 months before start of test (M30-2=M28)
- PV Asset Management Software 12 months 'Historical data' for Meter/ Tracker/ Inverter/Weather station to be provided by the demo site leader through ELLC as per in section 2.2, (2 months before start of test (M30-2=M28)

ELLC

The platform will be designed to receive and process data arriving via MQTT or CSV for ingestion.

There are no other specific requirements for the platform.

If interoperability with the platform is necessary, it will be done via API.

a) Demo site-specific data and demonstration requirements

DTU

Must provide access to the database to collect all the necessary information by means of one or more scripts to read all the data.







Database queries may be predefined by DTU. Otherwise, a document must be provided to ELLC mapping each of the required variables and attributes including how to obtain them.

PPC

Must provide access to the database to collect all the necessary information by means of one or more scripts to read all the data.

Database queries may be predefined by PPC. Otherwise, a document must be provided to ELLC mapping each of the required variables and attributes including how to obtain them.

For the integration of historical data that are not present in the database, PPC will deliver an Excel document with all the measurements. Several Excel can be delivered if the same format is followed.

FIB

The data will be collected through an API Rest provided by FIB. Thus, a user manual must be sent to ELLC, and the corresponding access must also be provided.

EILAT

The data will be collected through an API Rest provided by EILAT. Thus, a user manual must be sent to ELLC, and the corresponding access must also be provided.

3.6.6. AIR6

General data and demonstration requirements

In close coordination with DTU, AIR6 will provide drone image acquisition flights at the preselected sites, in support of DTU.

UAV flight authorisations will be required for each site. Where the EU-wide UAV pilot license is not valid, a supervising UAV pilot (responsible pilot / RP) will be required. In such case, the AIR6 pilot will function as supporting pilot. The RP will oversee the flight operations and will be responsible for all flight authorisations. Coordination about valid insurance arrangements with the RP will need to be conducted.

Demo site - specific data and demonstration requirements

Availability of a clear start / landing area and one or multiple portable fire extinguisher would be required. Access to the overflown solar panels will be required at any time.

AIR6 will conduct flights in support of DTU. Please refer to all requirements as set out in below section DTU.







3.6.7. DTU

General data and demonstration requirements

DTU is developing PV fault detection methods based on visual, thermal infrared (IRT), and luminescence (EL/PL) imaging techniques acquired by aerial drones in commercial and utility-scale PV plants

DTU will collaborate closely with AIR6 who will be responsible for the image acquisition at the demo sites (except for DTU demo site)

DTU aims to demonstrate the ability of drone-based PV inspection and automated image analysis to detect more faults more accurately, compared with conventional fault detection and inspection performed by O&M staff, through manual inspection (visual and handheld IRT), electrical condition monitoring, and human-based analysis,

To achieve this, we will need primarily to carry out drone inspection flights at the demo sites, and we require technical information about the site, Access and Support, Existing O&M inspection reports and procedures, described in the Table below.

Table 3.6-3. Demo site requirements for DTU and AIR6 Drone inspection demonstration

Technical information	1. Location and age of the PV plant
	PV plant capacity, module types and datasheets, tilt, orientation, tracking or fixed
	3. Physical layout documentation, detailing, strings, inverters, module types, location of string combiner boxes
	4. Electrical layout of the strings and inverter
Access and support	Can we get access/permission for flying drones inside the park?
	o During daytime?
	o During nighttime?
	2. Can we disconnect some strings and inverters temporarily max 1h each string inspected to perform electroluminescence inspection which requires powering the PV strings from an external power supply?
	o During day?
	o During night?
	3. Can we get support from a local electrician for making the electrical connections to the PV strings?
	4. Is the 1/3 phase electrical grid accessible inside the parc, near the strings to power the supply for biasing the strings or we need to bring diesel generators?
O&M data	Has the PV plant been inspected before?







2.	When was the last inspection?
3.	What inspection methods were used?
4.	Can we get the O&M inspection reports for planning our own inspection?
5.	Have any faults been detected in the PV plant.

3.6.8. TEKNIKER

General data and demonstration requirements

All the data requirements from Tekniker are summarized in in section 2.2.

Demo sites - specific data and demonstration requirements

- T4.5: Tekniker will require data from the storage systems they have (if applicable) at DTU, FIB and PPC. The specific data is defined in section 2.2.
- T5.3: Tekniker will require historical and real data of DTU, FIB and PPC sites. The specific data is defined in section 2.2.
- T6.1: DTU, handle the installation of the dust sensors following the detailed installation protocol provided by TEK. DTU, provide the data defined in in section 2.2, DTU will follow the test procedures defined in section 1.5.
- T6.2: PPC, Handle the installation of the dust sensors following the detailed installation protocol provided by TEK in section 1.5.
- T6.3: PPC, Provide the data defined in sections 1.5 and 1.6., Section 2. PPC, Follow the test procedures defined in section 1.6.







4. Specific use-cases to be investigated in this project

4.1 Use case #1 – [Enhanced PV plant inspection using drones and automated image analysis]

Demo site(s) involved: DTU Demo site and/or PPC Demo site and/or FIB Demo site

Leading partner for demonstrating the use case: DTU

Other involved partners and their responsibilities related to the use case:

- AIR6 performs drone flights and image acquisition
- PPC provides access to a utility-scale PV plant for inspection, support for inspection, and previous O&M inspection reports for planning and benchmarking
- **FIB** provides access to its two rooftop PV systems for inspection, support for inspection, and previous O&M inspection reports for planning and benchmarking
- UNIGE will support the development of optimized flight plans for the inspection.
 Additionally, UNIGE will explore techniques (in parallel with and as an alternative to the
 capabilities provided by AIR6) to enable drones to autonomously navigate along PV rows
 using visual servoing techniques and GNSS-based navigation. NOTE: It's important to
 clarify that UNIGE is exploring a different strategy, by re-stating what was already in the
 original project.

Requirements to the demo site: refer to the sections of this document in sections 3.6.4, 3.6.6 and 3.6.7 where these are described.

Timeline of demonstrating the use case:

Spring/Summer 2025, 2026, 2027

Description of the use case:

• DTU is developing methods for detecting faults and degradation in PV plants through analysis of visual, thermal and luminesce images of the solar panels. Together with AIR6 Systems, who is a leader in drone who is a leader in drone inspection technology, they are developing faster and more accurate inspection techniques for PV plants, through combining multispectral imaging techniques, with airborne drone imaging systems and automated image analysis and fault detection. These methods are expected to greatly outperform current PV plant inspection practices that rely on manual inspection, failure evaluation and handheld cameras, or just on thermal imaging drones. UNIGE will explore a different solution, and test two main capabilities for each demo site. The first is the







autonomous planning of optimized flight routes above PV trackers using drone/satellite images, taking into account take-off/landing/recharging areas and battery capacity. The second is enabling aerial drones to follow PV trackers in real-time, using machine learning for panel segmentation, visual servoing for position adjustment, and GPT-based navigation between trackers. It should be emphasized that UNIGE will bring their own aerial drones and technical staff to the sites and test the capability they developed by comparing autonomous and manual flight. Also, UNIGE demonstration will focus on enabling aerial drones to carry payloads (e.g., sensors suitable for defect recognition) along PV trackers, but it will not focus on defect recognition itself, as this is not part of their role in the project.

Activities:

- DTU will prepare benchmark PV strings at its site, with known failures and faults of different types, for benchmarking conventional PV inspection methods with the developed drone methods
- DTU will carry out the conventional inspection at its plant (manual visual and handheld IR inspection, drone IRT inspection and performance monitoring), and have project partners evaluate the faults for the purpose of establishing a baseline
- PPC will provide technical information, access and support for carrying out the inspection, as well as pre-existing O&M reports from the site, for benchmarking the method.
- FIB will provide technical information, access and support for carrying out the inspection, as well as pre-existing O&M reports from the site, for benchmarking the method.
- AIR6 will perform at least 2 drone inspection campaigns at each of the demonstration sites and collect VIS, IRT and EL images of the site.
- DTU will perform drone inspection flights at the DTU site only
- DTU will process the raw VIS, IRT, and EL images through its image processing software and provide fault type and location information as an output
- UNIGE will perform at least 1 drone inspection campaign at each of the demonstration sites and collect data to validate the capabilities of aerial drones to perform autonomous navigation.

Expected outcomes and KPIs

 Improving KPI 1.2i: Average panel failure detection rate. DTU aims to increase the number of faults detection through inspection compared to conventional inspection methods







4.2 Use case #2- [Remote Failure detection and quantification (PV Asset Management SW)]

Demo site(s) involved: DTU Demo Site, PPC Demo Site, EILAT Demo site, FIB Demo Site

Leading partner for demonstrating the use case: HELIO

Other involved partners and their responsibilities related to the use case:

- ELLC : inputs data
- EMA: string failure detection based on impedance measurements
- DTU/ PPC/ EILAT/ FIB : site interlocutor

Requirements to the demo site: refer to section 3.6.5 of this document.

Timeline of demonstrating the use case: 2027

Description of the use case:

 a PV site owner or operator (USER) wants to understand the performance of a PV Power Plant, detect possible failure and estimate the quantitative effects of the failures onto the expected energy production.

System specifications (if relevant):

- Remote audit through data analysis,
- Daily refresh
- Results made available through a SaaS web-based platform

Activities

- Prerequisite:
 - Ensure all necessary historical data and data flows are available in ELLC cloud platform
- The USER is to request the service,
- Initial PV audit is performed and daily performance monitoring service is "live" during a 1 month period
- The USER can access the platform and is noticed when an incident happen







- Access to SaaS platform with performance dashboard
- Failure detection
- KPIs:
 - o KPI 1.2ii: Average PV string failure detection rate
 - KPIO3.4: Time the fault detection algorithm requires to analyse the data and detect the fault
 - o KPI1.3: PV system availability
 - o KPI2.6: Reduction of the LCOE







4.3 Use case #3– [Field Control App (PV Asset Management SW)]

Demo site(s) involved: DTU Demo Site

Leading partner for demonstrating the use case: HELIO

Other involved partners and their responsibilities related to the use case:

ELLC: inputs data

• DTU: site operator

Requirements to the demo site: refer to refer to section 3.6.5 of this document.

Timeline of demonstrating the use case: 2027

Description of the use case:

 a field operator uses his Mobile App to know what/ where to check onsite and to confirm information and enter field measurements.

System specifications (if relevant):

- Android Mobile App
- "Remote Failure detection and quantification" service running
- Laptop with web access to SaaS platform

Activities:

- Prerequisite:
 - o Ensure all necessary historical data and data flows are available in ELLC cloud platform
 - o Ensure "Remote Failure detection and quantification" service running
- Field operator to be on site with the mobile app and to follow instructions (detailed actions will be specified in the testing protocol for 5 features)
- Field operator will enter inputs into the mobile app and these inputs will be used to refine/ enrich the performance analysis of the PV site

Expected outcomes and KPIs

End-to-end integration check







- Detailed use cases tested
- KPIs: Minimum 5 on-site features will be tested at DTU to meet the KPIO 3.2.

4.4 Use case #4– [Fleet Management (mockup) (PV Asset Management SW)]

Demo site(s) involved: n/a (visio call)

Leading partner for demonstrating the use case: HELIO

Other involved partners and their responsibilities related to the use case: n/a

Requirements to the demo site: n/a (no physical demo site).

Timeline of demonstrating the use case: 2027

Description of the use case:

 An operator can, thanks to an online tool, optimize upcoming maintenance activities and enhance the bankability of solar installations by matching cost of intervention, expected financial gain and projected losses resulting from the maintenance schedule. The Fleet Management mockup will showcase how site interventions can be optimized thanks to optimization algoriths.

System specifications (if relevant):

 The use case will need a web application comprising frontend, dedicated backend with REST API to retrieve the results of offline computation undertaken by separate applications in a software stack

Activities:

- The web application is configured to manage a fleet of solar installations
- The operator will utilise the key features of the tool to improve his/her fleet management duties.
- module power loss risk assessment using inspection data
- Enhanced data labelling for continuous human reinforced machine learning
- Fleet management actions recommendations engine
- Maintenance intervention planner







- A simulated large fleet of PV installation will be used to demonstrate a quantified reduction in maintenance activities, equated to 15-20% in operational costs to meet KPIO 3.1
- Decreases in production losses will be demonstrated with the aid of the simulated fleet to meet KPIO 3.5.







4.5 Use case #5 – [Comprehensive forecasting tool]

Demo site(s) involved: DTU Demo Site

Leading partner for demonstrating the use case: UBIMET

Other involved partners and their responsibilities related to the use case: DTU/ PPC/ EILAT/ FIB

: site interlocutor

Requirements to the demo site: refer to refer to section 3.6.3 of this document.

Timeline of demonstrating the use case: TBD

Description of the use case:

An owner or operator of a PV system (USER) would like to receive an accurate estimate
of the expected PV output, recognize short-term weather events and receive warnings of
severe weather events in order to be able to protect the system accordingly

Activities:

- The development of the comprehensive forecasting tool will focus on integrating separate forecasting advancements from WP2 into a unified platform, ensuring seamless functionality and accessibility for PV asset management. Key activities include:
- Defining Tool Structure: Establishing a preliminary structure to support integrated workflows for real-time forecasting and analytics.
- o Developing Prediction APIs: Building APIs for real-time weather and energy forecasts, ensuring continuous data integration.
- Creating a Master Data API: Enabling seamless integration of PV system characteristics to tailor energy predictions.
- Enhancing the Dashboard: Expanding the web-based dashboard for visualization, analytics, and reporting, providing PV operators with real-time insights.

- KPI2.2: Improvement of power generation forecasting accuracy (vs. Traditional physical forecast)
- KPIO1.1: Improvement of weather forecasting accuracy based on verification & skill scores (RMSE, CSI, Brier Score) (vs. Available forecast - GFS, ECMWFS, ICON-D2)







4.6 Use case #6 – [Enhanced PV inverter availability using smart control for reconfigurable structure and online condition monitoring]

Demo site(s) involved: DTU Demo site

Leading partner for demonstrating the use case: AAU

Other involved partners and their responsibilities related to the use case:

EMA will integrate impedance sensing device in the developed inverter

Requirements to the demo site: refer to the sections 3.6.1 and 3.6.2 of this document.

Timeline of demonstrating the use case:

Spring/Summer 2026

Description of the use case:

- AAU is developing advanced solutions to enhance the operational availability and reliability of PV inverters using smart control for reconfiguration and maintenance scheduling according to the physics of failure lifetime prediction and online condition monitoring. These solutions are expected to enhance the inverter availability during operation by predicting the damaged devices and smartly handling thermal stresses as well as reducing the down time by predicting the maintenance periods and optimizing the slare units.
- This use case demonstrates the physics of failure based Digital Twin of PV inverter reliability for enhancing its availability.
- The input from the EMA impedance sensor will help to add data points, to better
 differentiate between failure modes. This is possible since impedance testing is often
 highly diagnostic when compared to e.g. IV curves which can be ambiguous when it comes
 to identifying the root cause of an issue.

Activities:

- AAU will develop novel inverter for reconfiguring and availability enhancement
- AAU will manufacturer the inverter at AAU's lab
- AAU will test and develop the algorithms at AAU's lab
- AAU with the help of DTU will install the inverter in DTU site
- AAU will perform online condition monitoring and lifetime prediction







- AAU will process the smart control for availability enhancement
- AAU will process the long-term date for maintenance scheduling
- EMA will develop and add the impedance sensor

- Improving KPI1.7ii: Prolonged lifetime of inverters
- KPI O2.3: Reduction in PV inverter inspection time/repair time
- KPI O4.3: Inverter operational reliability.







4.7 Use case #7– [Multi-aspect smart sensing for PV systems monitoring - Smart soiling sensors]

Demo site(s) involved: DTU, PPC

Leading partner for demonstrating the use case: TEK

Other involved partners and their responsibilities related to the use case:

• DTU, PPC: see next point

Requirements to the demo site:

- DTU, PPC: install the sensors, gather data required for KPIs and data specified in section
 1.5 "Data and hardware requirements, Dust sensors"
- Timeline of demonstrating the use case: timeframe will be limited by T6.1 (M31-M38), T6.2 (M33-M38) and T6.3 (M39-M48)

Description of the use case:

• In SOLARIS, functional soiling measurements will be collected under real scenario, as well as analysis of the correlation between the level of soiling and the output of the panels (previously the level of soiling was correlated with the reflectivity of the mirrors). DTU will act as a validation and support the finding of a suitable on-site distribution for the sensors. Sensors will then be sent to be installed at other demo sites (e.g. PPC), together with instructions for installation (screwed to the panels). TEK sensors will provide a realistic real time measurement of the dust deposited on PV panels of the plant. Information from the sensors will be gathered in the IoT platform and used by the fleet management tool for establishing a cost-effective cleaning schedule.

Activities:

- TEK: will prepare the dust sensors and material for installation and initial setup to be delivered to demo sites
- TEK: will support demo site partners in the installation and setup process and preliminary testing activities to check the correct operation of the dust sensors at demo sites
- DEMO SITE PARTNERS: will physically install and connect sensors and any required material provided by TEK
- DEMO SITE PARTNERS: will collect data required for KPIs and data specified in section 1.5
 "Data and hardware requirements, Dust sensors"







- TEK: will analyze the data provided by demo site partners
 - TEK: will further analyze the correlations between soiling data and other data collected by demo site partners to establish the soiling detections algorithm

- KPI 2.1i: Reduction of workforce for dust monitoring
- Calibration and continuous operation for soiling measurement
- Definition of soiling detection algorithms
- Develop easy non-invasive installation and management procedures







4.8 Use case #8— [Wind smart sensing for PV lifetime and limit the time in defence position]

Demo site(s) involved: DTU

Leading partner for demonstrating the use case: TEK

Other involved partners and their responsibilities related to the use case:

DTU: see next point

Requirements to the demo site:

 DTU, provide data about the plant (distribution, wind data, protection algorithms, hardware infrastructure, protection algorithms, define a way for evaluating the loss of efficiency or damage

Timeline of demonstrating the use case: The activities for the development of the hardware and the reduced models (Installation, characterization and monitoring) will be performed during the WP3-T3.1 (M7-M22), while the validation of the developments will be limited by T6.1 (M31-M38) and T6.2 (M33-M38)

Description of the use case:

• The wind smart sensor is a set of sensors that provide information about the vibrations and deformations of the PV and relate this information to the wind loads. Two set of sensors are planned in the project: (a) industrial sensors consisting on several precision sensors to obtain quality data in order to stablish the relationships between the wind load and the response of the PV; and (b) low cost sensors able to provide the suitable information in the required measuring ranges to perform the monitoring to protect the PV against wind loads.

This data will be used to define a Reduced Order Model able to identify the dangerous event taking the panel to a stow position that minimize the mechanical stress and vibration to the panels.

The sensors will be installed in selected panels and the control algorithms will be installed in the tracker controller or it will provide target to the control.

Activities:

 TEK: Selection of sensors and define the installation of these; modal characterization; setup of DAQ system and connect it to the current SCADA, collect and analyse data, define the reduced order models, implementation of the control algorithm.







 DTU: provide information about current hardware and software in the plant, provide information about wind events and defence position algorithms, support TEK with the sensors and DAQ installation, support TEK with the implementation of the control algorithms, provide a method to assess the loss of efficiency or damage to the panels due to wind events.

- o KPI1. 5: Reduction in time spent in defence position
- o KPI 1.7iii: PV system reliability and security
- o Definition of a set of low cost sensors to monitor wind damage to panels
- Definition and implementation of a stow algorithm to protect the panels against wind events.





4.9 Use case #9— [Antisoiling cleaning fluid]

Demo site(s) involved: DTU, PPC, EILAT, FIB

Leading partner for demonstrating the use case: TEK

Other involved partners and their responsibilities related to the use case:

DTU, PPC, EILAT, FIB see next point

Requirements to the demo site:

 Each demo site will provide data about the plant (distribution, cleaning procedure, frequency, type of soiling, weather monitoring)

Timeline of demonstrating the use case: The activities for the validation of the developments in the demo-case are limited by T6.1 (M31-M38) and T6.2 (M33-M38)

Description of the use case:

- The new water-based cleaning fluid will provide a long lasting semi-permanent selfcleaning and dust repelling effect on the PV glass. This fluid will optimize the cleaning processes by using additives in the cleaning water for delayed soiling.
- The antisoiling fluids will be tested on the demo sites. The procedure will consist of cleaning some of the PV panels of one string with water (conventional procedure) and other string with the antisoiling fluids developed in SOLARIS

Activities:

- TEK: TEK will prepare and send 1 to 5 litres of the concentrated formula to the demonstration sites with storage and dilution protocols and with application instructions
- DTU, EIALT, PPC, FIB: One of PV string will be cleaned following the standard frequency and procedures defined in the own site operation with water and conventional methods. Meanwhile, the other PV string will be cleaned with antisoiling fluids developed in the project Each partner will provide information about PV power, weather data, cleaning dates and still images of the tested PV lines before and after cleaning. It will be necessary to know the water consumption and composition.

- KPI 1.6: Reduction in cleaning interventions
- New cleaning fluids with antisoiling semipermanent effect







5. Key Performance Indicators

5.1 Overview of Solaris KPIs

The original key performance indicators (KPIs) in the GA were reviewed by all the project partners and revised by the relevant partners, to expand on where applicable on the: method of calculation or measurement of the KPI, necessary data and tools for verification, relevant scientific literature, partners and sites involved in the verification of the KPI, timeline for verification. As a result, the KPIs that were redundant, duplicate, or insufficiently defined were revised in section 5.2. The mapping of the original KPI to the revised KPIs is summarized in Table 5.1-1.

Table 5.1-1. KPI revision map

Original KPI	Revised KPI	Comment
KPI 1.1: Number of use-cases	KPI 1.1: Number of use-cases	
KPI 1.2: Online early faults detection	KPI 1.2i: Average panel failure detection rate KPI 1.2ii: Average PV string failure detection rate	Revised the KPI to be more specific and measurable
KPI 1.3: PV system availability	KPI 1.3: PV system availability	Detailed the methodology of testing and evaluation of the KPI
KPI 1.4: Index of performance	KPI 1.4: Index of performance	Detailed the methodology of testing and evaluation of the KPI
KPI 1.5: Reduction in time spent in defense position	KPI 1.5: Reduction in time spent in defense position	Detailed the methodology of evaluation of the KPI
KPI 1.6: Reduction in cleaning costs KPI 1.7: PV performance improvement thanks to anti-soiling techniques	KPI 1.6: Reduction in cleaning interventions	The two original KPIs were very similar, therefore they were merged.
KPI 1.8i: Prolonged lifetime of BESS	KPI 1.7i: Prolonged lifetime of BESS	Detailed the methodology of testing and evaluation of the KPI
KPI 1.8ii: Prolonged lifetime of inverters	KPI 1.7ii: Prolonged lifetime of inverters	Detailed the methodology of testing and evaluation of the KPI
KPI 1.8.iii: Prolonged lifetime of panels	KPI 1.7iii: PV system reliability and security	Revised the KPI to be more specific and measurable
KPI 2.1i: Reduction of workforce for dust/wind sensors installation	KPI 2.1i: Reduction of workforce for dust monitoring	Revised the KPI to be more specific and measurable
KPI 2.1ii: Reduction of workforce for the impedance sensor operation	KPI 2.1ii: Reduction of workforce for the impedance sensor operation	Detailed the methodology of testing and evaluation of the KPI
KPI 2.2: Increase accuracy of PV production prediction	KPI 2.2: Improvement of power generation forecasting accuracy (vs. Traditional physical forecast)	Revised the KPI to be more specific and measurable
KPI 2.3: Reduction of the curtailment of variable renewable energy systems	KPI 2.3: Reduction of the curtailment of variable renewable energy systems	Detailed the methodology of testing and evaluation of the KPI
KPI 2.4i: Number of O&M providers reached		







	KPI 2.4: Number of PV plant and	
KPI 2.4ii: Number of technology providers reached	technology stakeholders reached through Solaris Result Dissemination	The two original KPIs were difficult to measure independently, therefore they were merged.
KPI 2.5i: Ratio of public datasets users - O&M providers KPI 2.5ii: Ratio of public datasets users - technology providers KPI 2.5iii: Ratio of public datasets users	KPI 2.5: Number of published open datasets	The two original KPIs were difficult to measure independently, therefore they were merged.
– policy makersKPI 2.6: Reduction of the LCOE	KPI 2.6: Reduction of the LCOE	Detailed the methodology of testing and evaluation of the KPI
KPI 2.7: Increase of PV systems revenues (thanks to SOLARIS)	KPI 2.7: Increase of PV systems revenues	Detailed the methodology of testing and evaluation of the KPI
KPI O1.1: Improvement of weather forecasting accuracy	KPI O1.1: Improvement of weather forecasting accuracy based on verification & skill scores (RMSE, CSI, Brier Score) (vs. Available forecast – GFS, ECMWFS, ICON-D2)	Detailed the methodology of testing and evaluation of the KPI
KPI O1.2: Improvement of power generation forecasting accuracy (vs. Traditional physical forecast)	KPI 2.2: Improvement of power generation forecasting accuracy (vs. Traditional physical forecast)	KPI O1.2 was merged into the revised KPI 2.2 due to duplication.
KPI O1.3: Revenue increase in the PV power plant related to market participation (vs. Historical revenues)	KPI 2.7: Increase of PV systems revenues	KPI O1.3 was merged into the revised KPI 2.7 due to duplication.
KPI O1.4: Revenue increase for adding a storage in the plant (vs. Without)	KPI 2.7: Increase of PV systems revenues	KPI 01.4 was merged into the revised KPI 2.7 due to duplication.
KPI O2.1: Reduction in the number of field investigations by automated monitoring	KPI O3.1: Reduction of maintenance activities through improved scheduling	KPI O2.1 was merged into the revised KPI O3.1 due to duplication.
KPI O2.2: Reduction of cleaning OPEX through reduction of interventions by extending cleaning periods	KPI 1.6: Reduction in cleaning interventions	KPI O2.2 was merged into the revised KPI 1.6 due to duplication.
KPI O2.3: Reduction in PV inverter	KPI O2.3: Reduction in PV inverter	Detailed the methodology of testing
KPI O2.4: Increase in the number of resolved root cause investigations	inspection time/repair time KPI 1.2i: Average panel failure detection rate KPI 1.2ii: Average PV string failure detection rate KPI 1.3: PV system availability	KPI O2.4 is covered by KPIs 1.2i, 1.2ii, 1.3, 1.4 and is replaced by them
KPI O2.5: Drones imagery data transmission time (below)	KPI 1.4: Index of performance	KPI O2.5 was removed as it was ill defined in the original GA. No new drone communication tech is being developed in this project.
KPI O2.6: Reduction in inspection time through group flight KPI O2.7: Latency in data acquisition	KPI O2.6: Reduction in inspection time through group flight KPI O2.7: Platform availability	Detailed the methodology of testing and evaluation of the KPI Detailed the methodology of testing
thanks to the IoT platform KPI O3.1: Reduction of maintenance activities through improved scheduling	KPI O3.1: Reduction of maintenance activities through improved scheduling	and evaluation of the KPI Detailed the methodology of testing and evaluation of the KPI







KDI O2 2. Etalal assetual asse	KDI O2 2. Field control con	
KPI O3.2: Field control app	KPI O3.2: Field control app	Detailed the methodology of testing
demonstrated on 4 sites with >5 on-	demonstrated on 4 sites with >5 on-	and evaluation of the KPI
site features	site features	
KPI O3.3: PV inverter time-based and	KPI O3.3: Increasing PV inverter	Detailed the methodology of testing
production-based availability (at least)	production-based availability	and evaluation of the KPI
KPI O3.4: Time the fault detection	KPI O3.4: Time the fault detection	Detailed the methodales, of testing
algorithm requires to analyse the data	algorithm requires to analyse the data	Detailed the methodology of testing
and detect the fault (below)	and detect the fault	and evaluation of the KPI
KPI O3.5: Decrease in PV systems'	KPI O3.5: Decrease in PV systems'	
production losses thanks to predictive	production losses thanks to predictive	Detailed the methodology of testing
maintenance	maintenance	and evaluation of the KPI
KPI 04.1: Months of demonstration of	KPIO4.1: Months of demonstration of	
the solutions	the solutions	-
KPI O4.2: PV plant index of	the solutions	
performance (of the theoretical	KPI 1.4: Index of performance	KPI O4.2 was merged into the revised
· ·	KPI 1.4. Illuex of performance	KPI 1.4 due to duplication.
performance ratio)	VDI 4 7" D. L. LUC V. C.	VDI 04.2
KPIO4.3: Inverter operational reliability	KPI 1.7ii: Prolonged lifetime of	KPI O4.3 was merged into the revised
(at least)	inverters	KPI 1.7ii due to duplication.
KPI O4.4: Reduced environmental	KPI O4.4: Reduced environmental	Detailed the methodology of testing
impact through increased lifetime and	impact through increased lifetime and	and evaluation of the KPI.
efficiency of installations	efficiency of installations	and evaluation of the RT.
KPI O4.5: Reduced LCOE through OPEX	KPI 2.6: Reduction of the LCOE	KPI O4.5 was merged into the revised
reduction and lifetime extension	KPI 2.6: Reduction of the LCOE	KPI 2.6 due to duplication.
KPI O5.1: Number of collaborations	KPI O5.1: Number of knowledge	KDI 05.4
with other PV systems' O&M projects	exchange and collaborations with	KPI O5.1 was revised and expanded to
(at least)	relevant research project and groups	be more realistic.
KPI O5.2: Number of members in the	KPI O5.2: Number of members in the	Detailed the methodology of testing
Stakeholder Forum (at least)	Stakeholder Forum	and evaluation of the KPI.
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5.2 Description of KPIs and methods of evaluation

KPI 1.1: Number of use-cases

Responsible project partner	AAU
Original KPI	
Description	SOLARIS will demonstrate its developments on the complete picture of use-cases encountered in Europe, ranging from ground mounted small- and utility-scale PV plants, rooftop PVs, AgriPVs, and floating PVs, i.e. 8 use-cases (KPI1.1)
KPI baseline value and assumptions	
KPI target and unit	8 cases
Revised KPI	
Description and significance	we expected 8 use cases in SOLARIS project, now all partners are planning to have 9 use cases to address comprehensively the achievements in the SOLARIS project.
Method of calculation or measurement	n/a







Data necessary, variables, formulas,	Please see all KPI requirements that will be used on various use cases.
tools	
Literature review and references of	n/a
baseline values	
Baseline value and unit	8 use cases
Target value and unit	9
Revised KPI Evaluation and Demonstra	tion within SOLARIS
How will you demonstrate that you ach	ieved it within the SOLARIS project?
At which demo sites will you	All demo sites
demonstrate it?	
What equipment, materials, and data	Please see all KPI requirements that will be used on various use cases.
	riedse see all Kri requirements that will be used on various use cases.
will you require?	
Timeframe for demonstration?	Over the project time line
What project partners are involved in	All partners
the successful demonstration and	74.2.2.6 (6)
what are their exact responsibilities?	Please see T1.3.3 Specific use-cases to be investigated in this project
What is the contingency if the KDI is	In this case we keep the existing number as 0 use cases
What is the contingency if the KPI is	In this case we keep the original number as 8 use cases.
not achieved?	
What is the contingency if	n/a
demonstration does not go as	
planned?	
•	

KPI 1.2i: Average panel failure detection rate

Responsible project partner	DTU
Revision authors	Sergiu Spataru (sersp@dtu.dk)
Original KPI	
Description	A focus will be made in SOLARIS on increasing <i>PV system performance</i> , notably thanks to online early faults detection (at least 20, KPI1.2) [GA pg 125]
KPI baseline value and assumptions	KPI1.2: (B) 4 demonstration sites with >5 on-site features
KPI target and unit	20 unitless
Revised KPI	
Description and significance	For clarity we need to make a distinction between Panel-Level and String-Level failures : we will distinguish failures detected at the panel level (through imaging inspection) from those identified at the system level (inverters and strings) via electrical performance monitoring.
	For context, failures are defined as follows:
	 Panel-Level Failures: Defects causing safety hazards (e.g., delamination, severe hotspots, glass breakage, frame loss), immediate power loss (e.g.,







	hunges diado failura, notantial indused degradation (DID), legalized esiliar
	bypass diode failure, potential-induced degradation (PID), localized soiling, severe cell cracks), or potential future power loss (e.g., microcracks, PID, light-induced degradation (LID), UV-induced degradation (UViD).
	 Strings-Level Failures: Issues affecting the broader PV inverter and connected strings assembly monitored, including shading, soiling, string disconnection, snow accumulation, data issues (frozen or missing data), and performance impacts (power clipping, current clipping, inverter failure, or derating).
	A more appropriate KPI would be the Average Failure Detection Rate , measured as the ratio of total failures detected over the number of PV panels or PV strings (inverter and connected strings) inspected, where the number of panels or PV strings is representative of the entire PV plant.
Method of calculation or measurement	KPI1.2i -> Average panel failure detection rate = # panel failures detected / # panels inspected
	KPI1.2ii -> Average PV string failure detection rate = # PV string failures detected / # PV strings inspected
Data necessary, variables, formulas,	Drone inspection of panels
tools	Access to PV string combiner box for string powering
	Access to AC electricity for powering DC string biasing supply or mobile AC generator
	Wind and irradiance measurements on site
	Electrical and physical layout of the PV plant
	Drone flight permission
	String fault detection using performance monitoring
	Irradiance, wind and temperature measurements on site
	String and inverter performance measurements
	Datasheets of components and electrical layout of the plant
Literature review and references of baseline values	There is no single, widely accepted definition of "failure" in the context of PV modules. Some studies use a decline in maximum power output as a definition of failure (e.g., a drop of more than 50% that cannot be fixed in the field). Others define module failure as an irreversible power degradation or safety problem.
	The long lifespan expected of PV modules makes it difficult to directly compare their failure rates with those of other consumer products [1].
	A field study of modules from 21 manufacturers installed for eight years predicts that approximately 2% of the modules will fail after 11–12 years (i.e., will not meet the manufacturer's warranty) [2].
	A study of returns from a fleet of over three million modules from around 20 manufacturers found that 0.44% of the modules were returned after an average of five years of deployment. About 66% of these were returned due to issues with





	interconnections in the laminate, such as breaks in ribbons and solder bonds, and about 20% were returned due to problems with the backsheet or encapsulant, such as delamination [2].
	[1] Jordan, Dirk C., Timothy J. Silverman, John H. Wohlgemuth, Sarah R. Kurtz, and Kaitlyn T. VanSant. "Photovoltaic Failure and Degradation Modes." <i>Progress in Photovoltaics: Research and Applications</i> 25, no. 4 (April 2017): 318–26. https://doi.org/10.1002/pip.2866 .
	[2] Köntges, M., S. Kurtz, C. Packard, U. Jahn, K. A. Berger, K. Kato, T. Friesen, H. Liu, and M. Van Iseghem. "Review of Failures of Photovoltaic Modules." IEA-Photovoltaic Power Systems Programme, 2014.
Baseline value and unit	The failure types and occurrence in a PV plant depend on age, location and type of components, and cand vary significantly.
	Therefore we will derive baseline values in three ways.
	For plants that have previous O&M inspection reports we will derive the panel and string failure rates from these reports
	2) For plants have not been previously inspected, we will compare the drone imaging panel failure detection rate with a conventional inspection method (visual inspection or handheld IR) that we will also perform onsite
	3) For the DTU plant we have several strings with known failures, that have been characterized in the lab which will be used for benchmarking the drone based panel failure detection.
Target value and unit	Double the average panel and string failure detection rate relative to previous O&M inspection reports
	Double the average panel and string failure detection rate relative to visual and handheld IR inspection
	3) Detect at least 90% of existing failures at the DTU-controlled failure test sites
Revised KPI Evaluation and Demonstr	ation within SOLARIS
How will you demonstrate that you ac	
At which demo sites will you demonstrate it?	(DTU) Drone based panel inspection at DTU, PPC and FIB
demonstrate it:	(EMA) Performance based inspection DTU, PPC FIB, and EILAT
What equipment, materials, and data will you require?	Drone based panel inspection will require permission to fly drones on the site, technical information about the site, Access and Support, Existing O&M inspection reports and procedures. The requirements are described in detail in <i>T1.3 Demonstration requirements & definition of use-cases</i>
Timeframe for demonstration?	Spring and Summer time, 2025, 2026, 2027
What project partners are involved	AIR6 – Drone flying and inspection at non-DTU sites
in the successful demonstration and what are their exact responsibilities?	HELIO – Performance based fault detection in PV strings







	Emazys – Impedance based fault detection in PV strings PPC, FIB, EILAT - for access to plants, technical info, O&M reports and performance data
What is the contingency if the KPI is not achieved?	Review and revise the measurement methodology and target of the KPIs based on more realistic assumptions.
What is the contingency if demonstration does not go as planned?	We have four sites available for testing, the demonstration should be successful for at least one.

KPI 1.2ii: Average PV string failure detection rate

Responsible project partner	EMA
Revision authors	Anders@emazys.com
Original KPI	
Description	Grant Agreement page 125: A focus will be made in SOLARIS on increasing PV system performance, notably thanks to online early faults detection (at least 20, KPI1.2)
KPI baseline value and assumptions	From Grant agreement page 125: KPI1.2: (B) 4
	demonstration sites with >5 on-site features.
KPI target and unit	The KPI target is that the sensor developed can detect 2x more string faults than what is reported by energy monitoring solutions on-site. The target does not have a physical unit.
Revised KPI	
Description and significance	Explanation of why it is a more suitable KPI than the original
	The objective is to double the average number of string faults detected within one year of operation by incorporating an impedance sensor into the monitoring solution.
	To our knowledge, the SOLARIS project is currently the only initiative utilizing on-site impedance testing as a monitoring solution for solar modules. A key innovation in our approach is the development and deployment of a mobile impedance testing instrument by EMA, which enables field-based diagnostics rather than relying solely on laboratory analysis.
	Electrical string faults detected by inverters and energy monitoring systems are often ambiguous, as these tools primarily highlight performance deviations without identifying root causes. At the utility scale, the most common causes of string faults are loss of electrical isolation or connectivity issues due to mismatched connectors—issues that are somewhat unrelated to photovoltaic absorbers or cells. Consequently, standard performance measurements often fail to pinpoint the underlying fault.
	By integrating impedance testing, we aim to reduce diagnostic ambiguity for common string faults. This approach enhances fault identification by narrowing potential root







	causes, surpassing the capabilities of energy monitoring alone. The KPI for the impedance sensor is defined as its ability to:
	Consistently detect faults earlier than energy monitoring systems.
	Identify faults that are not captured by conventional energy monitoring.
	The impedance sensor is designed as an add-on device but can also be integrated directly into the inverter.
	To validate this approach, EMA will collaborate with AAU to deploy the device at DTU, where the two monitoring solutions will be implemented and assessed for their relative effectiveness in detecting and diagnosing string faults.
Method of calculation or	PI1.2ii is the number of PV string faults detected in a year by the sensor divided by
measurement	the number of string faults detected by energy monitoring in a year.
Data necessary, variables, formulas,	For reference we will need the following "performance monitoring" information:
tools	Irradiance, wind and temperature measurements on site
	String and inverter performance measurements
Literature review and references of	Electrical issues in solar farms arise primarily due to data limitations, design
baseline values	challenges, and component failures. Key factors include:
	Data Accessibility: Historical performance data is scarce due to the limited operational history of PV systems, confidentiality, and high perceived monitoring costs for small-scale installations (<250 kWp). This is changing as the market grows, however!
	Failure Documentation: Inconsistent failure records and insufficient detail hinder statistical analysis and risk assessments.
	Common Failure Modes:
	 PV Modules: Failures often stem from laminate solder issues, backsheet degradation, or encapsulant discolouration, typically detectable through visual inspection. Subtle issues like hotspots or cracked cells are harder to identify.
	These module faults typically end up as loss of electrical isolation and/or series faults when connectors are involved.
	Mitigation and Advances:
	Standardized methods for categorizing failures and assessing economic impact are critical.
	 Addressing these root causes through consistent data collection and advanced diagnostics is essential to improve system reliability and investor confidence.
	Please refer to previous horizon project for validation of the above concepts: https://www.tuv.com/content-media-files/master-content/services/products/p06-







	solar/solar-downloadpage/solar-bankability d1.1 d2.1 technical-risks-in-pv-projects.pdf
Baseline value and unit	String faults in PV plants vary based on age, location, and component type, but perhaps the most important factor of allis installer craftsmanship!
	To establish baseline values, we will:
	Use Existing Data: Derive panel and string fault numbers from previous O&M inspection reports where available.
	 Benchmark with Known Failures: Utilize our vast library of string test results based on our mobile instruments, that are active logging standard parameters as well as impedance information. The data comes from solar farms in 40 countries and range from a few kW to hundreds of MW per site.
Target value and unit	Double the average string fault detection number relative to what is registered by the energy monitoring onsite.
Revised KPI Evaluation and Demonstr	ation within SOLARIS
How will you demonstrate that you ach	nieved it within the SOLARIS project?
At which demo sites will you	DTU
demonstrate it?	
What equipment, materials, and data will you require?	The optimal solution may involve collaborating with DTU and European Energy to gain access to the GANTNER cloud for centralized data integration. Installation (retrofit) of the sensor device is considered as a straightforward task.
Timeframe for demonstration?	We can start to work on demonstration as soon as the prototypes are manufactured. We build them by hand, so we have 100% control over delivery i.e. demonstrations can begin 4 weeks after finishing the design – primo 2026.
What project partners are involved in the successful demonstration and what are their exact responsibilities?	We will collaborate with AAU and DTU to enable energy monitoring data extraction directly from string inverters and log corresponding sensor data, including impedance values. For robust method validation, it is essential to integrate SCADA data with sensor data (impedance as a function of time and environmental factors).
	The optimal solution may involve collaborating with DTU and European Energy to gain access to the GANTNER cloud for centralized data integration.
What is the contingency if the KPI is not achieved?	The contingency plan is to increase the sensor frequency window i.e. add test frequencies to the impedance spectrum. We can both widen the spectrum or have more test frequencies in the same window to increase the accuracy.
What is the contingency if demonstration does not go as planned?	In this case we would reduce the Device under test (module string) to a much smaller and simpler system i.e. take out complexity and try from first principles. We did this with the instrument version of the sensor and learned much about what the relation between the impedance and various fault states.

KPI 1.3: PV system availability

Responsible project partner	HELIO







Revision authors	Emeric Eyraud emeric.eyraud@heliocity.io	
Original KPI		
Description	A focus will be made in SOLARIS on increasing PV system performance, notably thanks to online early faults detection (at least 20, KPI1.2) to reach 98% PV system	
	availability (KPI1.3) [GA pg 125]	
KPI baseline value and assumptions	(B) Average PV systems availability around 95%, i.e. 5% of	
	downtime of which ¾ linked to maintenance/failures.	
	(A) Relying on PR5&8, 3% of the 4% of downtime linked to maintenance/failures will be avoided	
KPI target and unit	98% PV system availability	
Revised KPI		
Description and significance	Explanation of why it is a more suitable KPI than the original	
	PV System availability has various definition: it can be technical availability (focused on equipment performance), operational availability (considering also external factors such as environmental conditions (snow,), grid constraints availability can be a time-based calculation or an energy-based calculation	
	To avoid entering into various absolute availability calculation methodologies, the revised KPIs is a relative increase 3% increase in Energy-weighted availability brought by the combination of SOLARIS innovation. The determination of the KPI will be model based simulation of two situation: with current HW and O&M practices vs. Solaris enhanced	
Method of calculation or measurement	Model based comparison with gain brought by Solaris innovations	
Data necessary, variables, formulas, tools		
Literature review and references of baseline values		
Baseline value and unit	Baseline: current practice with current inverters, monitoring platform (with inverter input data), local weather station for > 1 MWc power plant, maintenance routine (1 year, 3 years, 5 years)	
Target value and unit	3% increase in energy-weighted availability	
Revised KPI Evaluation and Demonstra	Revised KPI Evaluation and Demonstration within SOLARIS	
How will you demonstrate that you achieved it within the SOLARIS project?		
At which demo sites will you demonstrate it?	The KPI will be demonstrated through the application onto a general model of PV system availability of each of the benefits brough by SOLARIS innovation on the system availability.	
What equipment, materials, and data will you require?	n/a	







Timeframe for demonstration?	2027
What project partners are involved	All partners with an innovation impacting the availability.
in the successful demonstration and what are their exact responsibilities?	AAU, EMA, HELIO, DTU, TEK
What is the contingency if the KPI is not achieved?	Scope restriction or slightly decrease target: 2% instead of 3% gain
What is the contingency if demonstration does not go as planned?	n/a

KPI 1.4: Index of performance

Responsible project partner	HELIO
Revision authors	Emeric Eyraud emeric.eyraud@heliocity.io
Original KPI	
Description	Index of Performance > 90%
KPI baseline value and assumptions	The Index of Performance (IP) is stated as percent and describes the relationship between the actual and theoretical energy outputs of the PV plant. Baseline: average Index of Performance (measured production over expected production) of PV systems is ca. 80%,
KPI target and unit	Keep the PV system above 90% IP.
Revised KPI	
Description and significance	In order to properly illustrate the benefits of SOLARIS project on the overall performance of PV systems, this KPI aims at presenting the gain brought by each innovation to increase by 10% the IP of a PV system thanks to SOLARIS solutions. It is decided to use as a KPI the Energy "Index of Performance (IP)" rather than the Performance Ratio (PR) because the following factors can influence the PR value: age of the PV system, temperature of the PV module
Method of calculation or measurement	Energy IP = Actual reading of plant output(*) in kWh p.a. / Model based expected plant output(*) in kWh p.a. (*) plant output being AC energy produced at inverter output
Data necessary, variables, formulas, tools	A general model of average PV system losses breakdown based on literature will be used to compare and quantify the benefits brought by SOLARIS innovations.
Literature review and references of baseline values	A. Mathieu, G. Fraisse, M. Thebault, S. Thebault, S. Boddaert, and L. Gaillard, 'Failure Risk Analysis of Photovoltaic Systems Based on Literature Review', presented at the Eurosun 2022, Kassel, Germany, Sep. 2022.







	Chris Deline, Matt Muller, Robert White, Kirsten Perry, Martin Springer, Michael Deceglie, and Dirk Jordan, 'Availability and Performance Loss Factors for U.S. PV Fleet Systems', https://www.nrel.gov/docs/fy24osti/88769.pdf , Feb 2024 Dr Christoph Kost , 'Study: Levelized Cost of Electricity- Renewable Energy Technologies, Aug 2024' , Fraunhofer ISE
Baseline value and unit	Baseline 80% (for a PV system with average PR:80%)
Target value and unit	IP: 90%
Revised KPI Evaluation and Demonstrate How will you demonstrate that you act At which demo sites will you demonstrate it?	
What equipment, materials, and data will you require?	 PV system performance model, Measured/demonstrated benefits on each loss category
Timeframe for demonstration?	2027
What project partners are involved in the successful demonstration and what are their exact responsibilities?	All partners will need to provide with the measurable/ demonstrated gain in performance brought by their innovation.
What is the contingency if the KPI is not achieved?	If the objective is not met for all type of PV system, we might identify achievable performances for sub-segment (ie. Ground mounted, rooftops)
What is the contingency if demonstration does not go as planned?	If some site demonstration do not go as planned, we might refer to literature or similar projects.

KPI 1.5: Reduction in time spent in defence position

Responsible project partner	TEKNIKER
Revision authors	Oscar Gonzalo <oscar.gonzalo@tekniker.es></oscar.gonzalo@tekniker.es>
Original KPI	
Description	Innovations on PR3 & 4 will allow to reach a 50% reduction in time spent in defence position instead of solar tracking mode in windy Areas (KPI1.5), as well as a 30% reduction in cleaning costs (KPI1.6) And 40% PV performance improvement (KPI1.7) thanks to adapted solutions against soiling and scheduling in dusty areas. [GA pg 125]
KPI baseline value and assumptio	ns KPI1.5: (B) For a flexible traditional tracker adapting stow position at a wind speed threshold of 14 m/s, the plant is in stow at 30° ca. 600h over the year for a plant with







	a wind speed distribution similar to worldwide wind speed distribution ⁴⁷ . (A)
	Assuming the wind
	load accurate sensing will have the same effect as to push the wind speed threshold to 16m/s (at lower cost), the plant is in stow at 30° for 250h over the year ⁴⁷ , meaning a reduction of ca. 50% . [GA pg $125\text{-}126$]
KPI target and unit	50%
Revised KPI	
Description and significance	Innovations on PR 4 will allow to reach a 50% reduction in time spent in defence position instead of solar tracking mode in windy Areas
Method of calculation or measurement	KPI1.5: (B) For a flexible traditional tracker adapting stow position at a wind speed threshold of 14 m/s, the plant is in stow at 30° ca. 600h over the year for a plant with a wind speed distribution similar to worldwide wind speed distribution ⁴⁷ . (A) Assuming the wind load accurate sensing will have the same effect as to push the wind speed threshold to 16m/s (at lower cost), the plant is in stow at 30° for 250h over the year ⁴⁷ , meaning a reduction of ca. 50%. [GA pg 125-126] How this could be measured? Can it be registered from the PLC or Scada?
Data wasaanii wasiahlaa famuulaa	Astrophysics of defence monthing times in the DTH plant
Data necessary, variables, formulas,	Actual data of defence position time in the DTU plant.
tools	Measurement of the time spent in defence mode once implemented the wind sensor.
Literature review and references of	
baseline values	
Baseline value and unit	Wind speed 14 m/s, 600 h/year at defence position (Tilt angle 30 degrees)
Target value and unit	250h/year at wind speed of 16 m/s.
Revised KPI Evaluation and Demonstr	ation within SOLARIS
How will you demonstrate that you ac	hieved it within the SOLARIS project?
At which demo sites will you demonstrate it?	DTU
What equipment, materials, and	Wind data from the current sensors installed in the plant.
data will you require?	Information about the time spent in defence position linked to wind data.
	Access to the plant to install the sensors (accelerometers, strain gauges and force sensors.
Timeframe for demonstration?	15 months
What project partners are involved	TEK: Sensors installation and data analysis
in the successful demonstration and	DTU: Provide information about current wind measurements and time spent in the
what are their exact responsibilities?	defense position.
	DTU: Implementation of the control algorithms in the PLC or tracker.
What is the contingency if the KPI is	Assess the causes and establish what was the error in setting the expected KPI value.
not achieved?	Assess the causes and establish what was the error in Setting the expected KPI value.







What is the contingency if	Check for demonstration in other plant.
demonstration does not go as	
planned?	

KPI 1.6: Reduction in cleaning interventions

Responsible project partner	TEKNIKER
Revision authors	Estibaliz Gomez <estibaliz.gomez@tekniker.es></estibaliz.gomez@tekniker.es>
Original KPI	
Description	Innovations on PR3 & 4 will allow to reach a 50% reduction in time spent in defence position instead of solar tracking mode in windy Areas (KPI1.5), as well as a 30% reduction in cleaning costs (KPI1.6) And 40% PV performance improvement (KPI1.7) thanks to adapted solutions against soiling and scheduling in dusty areas [GA pg 125]
KPI baseline value and assumptions	KPI1.6: B) Cleaning cost by nanocoating is 19% cheaper than cleaning cost by conventional methods ⁴⁸ ; (A) Semi-permanent effect (PR3) and optimised cleaning scheduling (PR8) will reduce cleaning costs by ca. 10% more. KPI1.7: (B) Electrical power output reduced by up to 50% in arid, dusty regions due to the soiling effect ⁴⁹ . (A) Optimised anti-soiling strategies (PR3) allow a 4/5 increase. K [GA pg 125-126] Reduction of cleaning OPEX through reduction of interventions by extending cleaning periods: 30 %; [GA pg 105]
KPI target and unit	30 % reduction cleaning costs
Revised KPI	
Description and significance	In dusty areas, cleaning operations require a lot of means and personnel. Semipermanent coatings could allow the panels to get soiled more slowly and therefore cleaning operations could be delayed. For dusty areas, if we can increase the period between cleaning operations by up to 30%, cleaning costs could be reduced accordingly.
Method of calculation or measurement	One selected string will be cleaned with antisoiling water based additives, while other string will be cleaned by conventional methods. The power efficiency of both strings will be measured and compared. This will be the main parameter to compare the behaviour of the PV panels cleaned with the antisoiling fluids and the PV panels cleaned with conventional procedures
Data necessary, variables, formulas, tools	Power efficiency monitoring
Literature review and references of baseline values	Article about PV cleaning mechanisms. (PDF) A Review on Solar Panel Cleaning Through Chemical Self-cleaning Method (researchgate.net)
Baseline value and unit	Depends on the demo site. Described in Deliverable T1.1
Target value and unit	30% extending cleaning periods
Revised KPI Evaluation and Demonstration within SOLARIS How will you demonstrate that you achieved it within the SOLARIS project?	





At which demo sites will you	Austria, Greece and Israel
demonstrate it?	Denmark, lab tests
What equipment, materials, and	String power efficiency. Human efforts are also needed for the application of the fluids
data will you require?	
Timeframe for demonstration?	During Task T6.1 and T6.3
What project partners are involved	TEK, FIB, , DTU, EILAT PPC
in the successful demonstration and	
what are their exact	
responsibilities?	
What is the contingency if the KPI is	Evaluate other cleaning processes for applying the semipermanent coatings (i.e.
not achieved?	wipping, brushing before the application of the antisoiling additives, etc.)
What is the contingency if	It is assumed that the KPI will not be achieved in all the demo sites, because the dusty
demonstration does not go as	environment and climatology will be different in each demo site.
planned?	

KPI 1.7i: Prolonged lifetime of BESS

Responsible project partner	TEKNIKER
Revision authors	Jon Martinez <jon.martinez@tekniker.es></jon.martinez@tekniker.es>
Original KPI	
Description	PV system reliability and security will be increased relying on strategies and control for prolonged lifetime of strategic PV equipment (KPI1.8), increasing by 10% the lifetime of PV inverters (PR5), 25% for BESS (PR2), 20% for PV panels using adequate self-protection strategies (PR4) [GA pg 125]
KPI baseline value and assumptions	KPI1.8: i) BESS: (B) Proper management of charging profile will increase the battery lifetime ⁵⁰ up to 25%; ii) Inverters: (B) The lifetime of fault-tolerant inverters can be up to doubled vs. 'classic' inverters in simulation ⁵¹ . (A) Reconfiguration of the inverter in SOLARIS optimises working conditions, which can increase the inverter lifetime by 10% ⁵² ; iii) Panels: (B) Degradation rate 2 times faster due to wind load ⁵³ . (A) Accurate wind load sensing and tracking strategies will reduce it by 20%. [GA pg 126]
KPI target and unit	25% longer lifetime BESS
Revised KPI	
Description and significance	PV power plants integrating battery energy storage systems (BESSs) can enhance their profitability due to a higher flexibility when it comes to bidding in electricity and reserve markets. However, an excessive use of the BESS can reduce significantly their lifetime, leading to non-cost-effective investments in these systems.







	In SOLARIS project, it will proved that using advanced operation strategies, BESS degradation can be reduced up to 25 % comparing to using them just focusing on revenues maximization.
Method of calculation or measurement	None of the sites of the project have currently PV and BESS combined for market-oriented operation. Therefore, the KPIs will be obtained based on realistic scenario-based simulations, performed with the BESS models developed in task T4.5 and fed with data from the partners.
Data necessary, variables, formulas, tools	PV production data from the sites participating in electricity markets will be required to take it as baseline to compare the optimal operation. In addition, historical real meteorological data and forecasting data will be required to simulate the plant's operation in real conditions.
	The software tools used to perform the simulations will be provided by Tekniker, which will develop the BESS models, as well as the PV plant operation model.
Baseline value and unit	Baseline degradation values will be calculated considering a plant operation strategy focused on revenue maximization. Degradation will be measured in loss % of nominal capacity from the one at the beginning of life (%CNom BoL)
Target value and unit	Target values will be obtained comparing the results of a plant operation addressing an optimal BESS use + revenue maximization with the baseline scenario, and once again will be obtained based on the nominal capacity loss.
Revised KPI Evaluation and Demo	nstration within SOLARIS
How will you demonstrate that you	a achieved it within the SOLARIS project?
At which demo sites will you	PPC, as it is the only utility-scale PV plant. This will be done with simulations,
demonstrate it?	considering that currently there are no BESS installed in the plant.
What equipment, materials, and	Historical data related to energy production, meteorological data, forecasting
data will you require?	data and additional datasheet information. Moreover, market participation
	and conditions data will be required.
Timeframe for demonstration?	Simulation based, last stage of the project once the AI based trading tool and
	storage models are ready.
What project partners are	PPC
involved in the successful	
demonstration and what are	
their exact responsibilities?	
What is the contingency if the	If BESS-based operation alone does not improve the expected lifetime,
KPI is not achieved?	additional storage hybridizations will be proposed and studied in detail,
	considering economic aspects (CAPEX, paybacks)







KPI 1.7ii: Prolonged lifetime of inverters

Responsible project partner	AAU
Revision authors	Saeed Peyghami (sap@energy.aau.dk)
Original KPI	
Description	PV system reliability and security will be increased relying on strategies and control for prolonged lifetime of strategic PV equipment (KPI1.8), increasing by 10% the lifetime of PV inverters (PR5), 25% for BESS (PR2), 20% for PV panels using adequate self-protection strategies (PR4) [GA pg 125]
KPI baseline value and assumptions	KPI1.8: i) BESS: (B) Proper management of charging profile will increase the battery lifetime50 up to 25%; ii) Inverters: (B) The lifetime of fault-tolerant inverters can be up to doubled vs. 'classic' inverters in simulation ⁵¹ . (A) Reconfiguration of the inverter in SOLARIS optimises working conditions, which can increase the inverter lifetime by 10% ⁵² ; iii) Panels: (B) Degradation rate 2 times faster due to wind load ⁵³ . (A) Accurate wind load sensing and tracking strategies will reduce it by 20%. [GA pg 126]
KPI target and unit	10% longer lifetime of PV inverter
Revised KPI	
Description and significance	Kept as original KPI. PV inverters are one of the key parts of energy conversion in PV systems. Failure of PV inverters will cause full shut down of PV system and thus loss of energy for the corresponding downtime. One of the key failure sources in PV inverters is the semiconductor devices. Thermal stress over these devices causes wear out over operation time and thus increasing the risk of loss of energy. In SOLARIS, we will develop advanced solution to prolong its lifetime by active thermal management and reconfiguration. By these approaches, we
	active thermal management and reconfiguration. By these approaches, we will enhance the inverter lifetime by at least 10 %. This will help 10% more operation of inverters without extra investment on inverter replacement that makes high reduction in replacement costs in large scale PV power plants.
Method of calculation or measurement	In practice measurement of the lifetime of the Power Electronics converters (or any devices) require long term operation, that is not practical due to the time limitation. For this reason, in SOLARIS, we will have two methods to measure the lifetime enhancement of the PV inverter lifetime. First, we will use laboratory tests to demonstrate that our advanced control and reconfiguration solution will decrease the thermal stress on the inverter semiconductor devices in short term operation. We will use these test data to validate our lifetime model, and then we will use long term mission profile simulations to demonstrate the lifetime enhancement for long term operation [a].







	[a] S. Peyghami, Z. Wang and F. Blaabjerg, "A Guideline for Reliability Prediction in Power Electronic Converters," in IEEE Transactions on Power Electronics, vol. 35, no. 10, pp. 10958-10968, Oct. 2020, doi: 10.1109/TPEL.2020.2981933.
Data necessary, variables, formulas, tools	We need solar irradiance and ambient temperature with the resolution of 1-15 minutes for at least one year, that will be provided by DTU and UBIMET, for long term mission profile analysis. For short term analysis, we will test the thermal behaviour of the PV inverter in AAU reliability lab and will measure the junction temperature to validate the impact of our solutions for lifetime prediction.
	The short term test will be used to measure the thermal stress and number of cycles to failure according to the following equation:
	$N_f = A \cdot \Delta T_j^{\alpha} \cdot \exp\left(\frac{\beta}{T_{jm} + 273}\right) \cdot \left(\frac{t_{on}}{1.5}\right)^{-0.3}$
Literature review and references of baseline values	The PV inverter lifetime depends on the operating and climate conditions, so it can be varies between 15-20 years [b]
	[b] Best Practices for Operation and Maintenance of Photovoltaic and Energy Storage Systems; 3rd Edition, National Renewable Energy Laboratory, Sandia National Laboratory, SunSpec Alliance,
	and the SunShot National Laboratory Multiyear Partnership (SuNLaMP) PV O&M Best Practices Working Group
Baseline value and unit	PV inverter lifetime with silicon technology is usually between 15-20 years. However, the operation conditions will impact this lifetime. Therefore, the base line for our demonstration will be the lifetime of the developed inverter that will be operated under conventional operation strategies, and will be compared to the case that we will apply our lifetime enhancement solutions.
Target value and unit	We expect to achieve 10% lifetime enhancement with our proposed solutions compared to the case that the inverter is operated under conventional operating conditions.
Revised KPI Evaluation and Demonstration within SOLARIS	
How will you demonstrate that you ac	
At which demo sites will you demonstrate it?	We will test it at AAU reliability lab with the data provided by DTU based on their demonstration site.
What equipment, materials, and data will you require?	We will develop novel PV inverter in SOLARIS based on the PV system specification at DTU demonstration site, the details of the PV system







	including PV panel characteristic, their connections have been provided by DTU. Also, DTU and UBIMET will provide high resolution annual mission profile for solar irradiance and ambient temperature at DTU site. We will use AAU reliability test facilities to measure the junction temperature of devices using thermal measurements, and the junction temperature will be used for our further simulations and analysis.
Timeframe for demonstration?	This will be evaluated during the development of the tasks 2.4 and 3.5 of the project.
What project partners are involved in the successful demonstration and what are their exact responsibilities?	DTU and UBIMET, they will provide solar irradiance and ambient temperature profile.
What is the contingency if the KPI is not achieved?	If the proposed advanced control approach and reconfiguration cannot enhance the lifetime of the PV inverter, we will focus on using SiC/GaN devices to enhance its lifetime as their thermal performance if better than silicon devices.

KPI 1.7iii: PV system reliability and security

Responsible project partner	TEKNIKER and all partners
Revision authors	Oscar Gonzalo <oscar.gonzalo@tekniker.es></oscar.gonzalo@tekniker.es>
Original KPI	
Description	PV system reliability and security will be increased relying on strategies and control for prolonged lifetime of strategic PV equipment (KPI1.8), increasing by 10% the lifetime of PV inverters (PR5), 25% for BESS (PR2), 20% for PV panels using adequate self-protection strategies (PR4) [GA pg 125]
KPI baseline value and assumptions	KPI1.8: i) BESS: (B) Proper management of charging profile will increase the battery lifetime50 up to 25%; ii) Inverters: (B) The lifetime of fault-tolerant inverters can be up to doubled vs. 'classic' inverters in simulation51. (A) Reconfiguration of the inverter in SOLARIS optimises working conditions, which can increase the inverter lifetime by 10%52; iii) Panels: (B) Degradation rate 2 times faster due to wind load53. (A) Accurate wind load sensing and tracking strategies will reduce it by 20%. [GA pg 126]
KPI target and unit	
Revised KPI	
Description and significance	PV system reliability and security will be increased relying on strategies and control for reduced damage due to wind loads. iii) Panels: (B) Degradation rate 2 times faster due to wind load. (A) Accurate wind load sensing and tracking strategies will reduce it by 20%.







	There is not an easy way for measurement of the efficiency loss or the damage to the panel due to wind loads. Furthermore, the damage could come from more sources, so the contribution of wind loads to damage could be unclear, especially in the short time scope of the project as the lifetime of a PV is significantly longer than the project duration. The proposed method is related to the limitation of the stress suffered by the panels, that finally result in microcracks, reducing the efficiency of the panel. This will be measured based on the deformation of the different zones of the panel that are directly linked to the stress in the panel. The deformation will be assessed using the information provided by the vibration and displacement monitoring, considering the relative displacement or the displacements associated to the excitation of vibration modes.
	So, the proposed KPI is the evaluation of the deformation resulting from wind events, evaluating this as a cumulative variable when the defence position is adopted.
Method of calculation or measurement	Initially a characterization of the stress of the panel under different deflections and vibration modes will be done, using the information provided by the laboratory set of sensors (accelerometers, force sensors and strain gauges) and the FEM analysis of the panels, establishing a scaled indicator of the pseudo-stress suffered by the panel. This indicator will be used to compare the current situation and that using the new wind sensors and defence algorithms.
	The method will provide a cumulative indicator consisting of:
	Damage Indicator = Σ ("Exposition Time" * "Pseudo-stress Indicator")
	This leads to a comparison between the Damage Indicator in two situations:
	 Using the current defence position algorithm.
	 Using the SOLARIS defence position algorithm.
Data necessary, variables, formulas, tools	Current measurement of the wind direction and speed, data of the time spend in defence position current.
	For the scaled indicator of the pseudo-stress, the signal of the accelerometers, force sensors and strain gauges will be used, evaluating the maximum values that could lead to damaging stress to the panel. This will be scaled in a 0 to 1 range.
	The cumulative damage Indicator will be evaluated during a fixed period of time (Minimum of 3 weeks) to compare the current and SOLARIS defence algorithms.
Literature review and references	No references have been found.
of baseline values	







Describes and only	The breeding on bree will be exactly below a discrete above and the
Baseline value and unit	The baseline values will be established during the project
Target value and unit	Damage Indicator (SoLARIS defence position algorithm) < = 0.8*Damage
	Indicator (Current defence position algorithm)
Revised KPI Evaluation and Demo	potrotion within COLADIC
Revised KPI Evaluation and Demo	nstration within SOLARIS
How will you demonstrate that you	achieved it within the SOLARIS project?
At which demo sites will you	DTU
demonstrate it?	
What equipment, materials, and	See D1.1 in the chapter related to task 3.1 and 4.2.
data will you require?	
Timeframe for demonstration?	This will be evaluated during the development of the task 3.1 and 4.2 of the
	project.
What project partners are	TEK: Development of the sets of sensors to evaluate the behaviour of the
involved in the successful	panels. Definition of the defence algorithm and the positions based on the
demonstration and what are	information provided by the sensors. Characterization of the mechanical
their exact responsibilities?	behaviour of the panels and link to damage.
	DTU: Provide access to the testing facilities and the current monitoring data
	of the plant. Collaboration with the installation of the sensors and the
	implementation of the defence position algorithm in the controller of the PV.
	and the second of the second o
What is the contingency if the	Assess the causes and check if a better evaluation of the damage to the panel
KPI is not achieved?	can be found.
What is the contingency if	Check for evaluation in another site or in test panels in Tekniker.
demonstration does not go as	
planned?	

KPI 2.1i: Reduction of workforce for dust monitoring

Responsible project partner	TEKNIKER
Revision authors	Xabier Bazan <xabier.bazan@tekniker.es></xabier.bazan@tekniker.es>
	Oscar Gonzalo <oscar.gonzalo@tekniker.es></oscar.gonzalo@tekniker.es>
Original KPI	
Description	The novel dust (PR3) and wind load (PR4) sensors will be developed to be easily retrofitted to existing installations and reduce by 2 the workforce needed for installation vs commercially available ones (KPI2.1) [GA pg 126]
KPI baseline value and assumptions	Lighter and smaller sensors dust sensors that can be screwed to the panel vs integrated in it; ii) Wind load sensing through accelerometers instead of 3m-above-ground anemometers. [GA pg 126]
KPI target and unit	Half number of hours







Revised KPI

Description and significance

This KPI will not be applied to the novel wind load sensors considered in the project since it makes no sense to compare them with the wind sensors currently used in PV installations. They are not similar and serve a different function, they do not compete. Thus, in a PV installation they will work together and complement each other.

In the case of the novel dust sensors, the KPI has been revised and reformulated since just sensor installation time on its own was not a suitable indicator. Instead, the workforce required for dust monitoring will be targeted which will comprise a global time per year. This global time will include not only the time required for installation but also the operation time. In this regard, innovations on PR 3 will allow to reach at least 20%* reduction in global time per year.

*Percentage of time reduction is still tentative (still under evaluation)

In order to have a clearer idea of how this comparison will be applied, it is necessary to consider how the determination or estimation of soiling levels in PV panels is currently carried out. One of the possible approaches involves the use of an external sensor design based on two reference PV panels or strings. In the operation to be followed, one of the reference panels or strings is kept clean while the other one is left to get dusted along with the rest of the panels of the installation. In this way, it is possible to compare the production of the clean reference panel/string against the panel/string that becomes dusted and to decide whether the panels of the installation need to be cleaned. This operation requires a workforce to install the sensor and an operation time: someone must clean the reference panel, gather data and make the comparison.

Alternatively, the dust levels could be determined by (subjective) assessment of the level of soiling of PV panels in the installation. This option would be less time/effort consuming since it does not involve additional periodic cleaning of the reference panel or installation any kind of sensor, but it would still require some operation time and would be less reliable than the previous approach. It is precisely this operating time, present in both approaches, that would be eliminated by using the novel dust sensor.

Thus, what will be considered in this KPI is the reduction of the workforce required for the dust level monitoring and control operation due to the use of the novel dust sensor. This workforce will be evaluated by means of a global time resulting from the sum of the installation time and the operation time. In the case of the novel dust sensor, there will be no operation time to consider. Thus, global time will only include the time required to setup n dust sensors in a particular installation (so that the data obtained is representative of different areas).





Backbad of calculation on	For our months that death as a sharing a page of the	
Method of calculation or	For any particular dust monitoring approach:	
measurement	Global time (per year) = Installation/maintenance time + Operation time (per year)	
	For approaches that use no sensor:	
	Installation/maintenance time = 0 (minimal)	
	Global time (per year) = Operation time (per year)	
	For the approach based on the novel dust sensor:	
	Operation time (per year) = 0 (minimal)	
	Global time (per year) = Installation time (per year)	
	% of reduction of workforce for dust monitoring related to the use of the novel dust sensor:	
	% Reduction of workforce (per year) = (Novel sensor global time (per year) * 100)/Other approach global time (per year)	
	% Reduction of workforce (per year) = (Novel sensor installation/maintenance time * 100)/Other approach global time (per year)	
Data necessary, variables, formulas, tools	Data of the workforce (global time) requited at demo sites for current dust monitoring procedures	
	Data of the workforce (installation\maintenance time) requited at demo sites for installation of the novel dust sensors	
Literature review and references of baseline values		
Baseline value and unit	% of time [hours]	
Target value and unit	20%* reduction in global time per year.	
	*Percentage of time reduction is still tentative (still under evaluation)	
Revised KPI Evaluation and Demo	nstration within SOLARIS	
How will you demonstrate that you achieved it within the SOLARIS project?		
At which demo sites will you demonstrate it?	Denmark (DTU)	
What equipment, materials, and data will you require?	Data of the workforce (global time) requited at selected demo sites for dust monitoring	
	Data of the workforce (installation\maintenance time) requited at selected demo sites for the novel dust sensors	







Timeframe for demonstration?	For installation time data gathering, timeframe will be limited by T6.1 (M31-M38) and T6.2 (M33-M38), selected demo sites and available sensor distribution among selected demo sites
What project partners are involved in the successful demonstration and what are their exact responsibilities?	TEK: provide a detailed guide to dust sensor installation and operation, analyse the generated data Demo site partners: install the sensors, gather data about used workforce
What is the contingency if the KPI is not achieved?	Assess the causes and review the sensor installation guide
What is the contingency if demonstration does not go as planned?	Check for demonstration in other demo site: Greece (PPC)

KPI 2.1ii: Reduction of workforce for the impedance sensor operation

Responsible project partner	EMA
Revision authors	Anders Rand Andersen
Original KPI	
Description	No field measurement needed anymore with the impedance sensing device.
KPI baseline value and assumptions	Number of unplanned field trips involving string testing to diagnose electrical issues related to connectors and deviations in string Voc, Isc.
KPI target and unit	0 (zero) unplanned field trips involving string testing.
Revised KPI	
Description and significance	50 % reduction in unplanned site visits (truck rolls) for string faults related to DC side of assets.
Method of calculation or measurement	Service team logbooks / field trip invoicing. Data input from field workflow apps i.e. emazys Z300 PVT controller app.
Data necessary, variables, formulas, tools	Field trips can be monitored via the emazys test equipment controller app, which also functions as a task manager, that helps plan work in the field (planned or unplanned).
Literature review and references of baseline values	Reference: MORTENSON US solar farm sites ranging from 300-600MW in Florida. To be tested in 2025 with 3 units of Z300 (test instrument) as part of commissioning. MORTENSON to share data to build reference data scenario.
Baseline value and unit	Baseline depends on the O&M contract for each test instrument user/company.







Target value and unit	50 % reduction in unplanned site visits	
Revised KPI Evaluation and Demonstration within SOLARIS		
How will you demonstrate that you achieved it within the SOLARIS project?		
At which demo sites will you	DTU	
demonstrate it?		
What equipment, materials, and	Impedance sensor, firebase cloud solution.	
data will you require?		
Timeframe for demonstration?	2026 1/1 and rest of project.	
What project partners are	DTU and AAU	
involved in the successful		
demonstration and what are		
their exact responsibilities?		

KPI 2.2: Improvement of power generation forecasting accuracy (vs. Traditional physical forecast)

Responsible project partner	UBIMET
partite	
Revision authors	Verena Ruedl (vruedl@ubimet.com)
Original KPI	
Description	Increase accuracy of PV production prediction
KPI baseline value and	
assumptions	
KPI target and unit	10%
Revised KPI	
Description and	Better description: Improvement of power generation forecasting accuracy: 10% vs.
significance	Traditional physical forecast
	Definition of physical forecast: The physical prediction method refers to a technology
	that excavates the factors related to PV power generation from the principle and then
	creates a physical model. Specifically, a simple physical method modeling is based on
	numerical weather prediction (NWP) by utilizing atmospheric physical data including
	parameters like radiation and temperature.
Method of calculation	RMSE: The root mean square error (RMSE) measures the average difference between
or measurement	a statistical model's predicted values and the actual values. Mathematically, it is the
	standard deviation of the residuals. Residuals represent the distance between the regression line and the data points.







	$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (f cst_i - obs_i)^2}$
Data necessary, variables, formulas, tools	 Observation data for actual power output – from demo partners Improved forecasted power generation – developed by UBIMET Traditional physical forecast – provided by UBIMET
Literature review and references of baseline values	Ye, H., Yang, B., Han, Y., & Chen, N. (2022). State-Of-The-Art Solar Energy Forecasting Approaches: Critical Potentials and Challenges. frontiers in Energy Research. https://www.frontiersin.org/journals/energy-research/articles/10.3389/fenrg.2022.875790/full Hyndman, Rob J.; Koehler, Anne B. (2006). "Another look at measures of forecast accuracy". International Journal of Forecasting. 22 (4): 679–688. 10.1016/j.ijforecast.2006.03.001
Baseline value and unit	% RMSE of installed capacity
Target value and unit	Baseline value * 0,9
	nd Demonstration within SOLARIS e that you achieved it within the SOLARIS project?
At which demo sites	DTU
will you demonstrate it?	
=	 Historical observation data for power output – provided by demo partners Master data – provided by demo partners Near-Live data (optional) – provided by demo partners Meteorological forecast – provided by UBIMET
it? What equipment, materials, and data will	 Master data – provided by demo partners Near-Live data (optional) – provided by demo partners
it? What equipment, materials, and data will you require? Timeframe for	 Master data – provided by demo partners Near-Live data (optional) – provided by demo partners Meteorological forecast – provided by UBIMET Timeframe will be limited by T2.1 and T2.2 (M7-M18), selected demo sites and





OLARIS

What	is	the	Check for demonstration on another demo site: Greece (PPC)
continge	ency	if	
demons	tration	does	
not go a	s planne	d?	
_			

KPI 2.3: Reduction of the curtailment of variable renewable energy systems

Responsible project partner	TEKNIKER
Revision authors	Jon Martinez <jon.martinez@tekniker.es></jon.martinez@tekniker.es>
Original KPI	
Description	Through more accurate predictions (PR1), systems' flexibility enabled by storage (PR2), SOLARIS will enable accurate control and potential prediction of PV systems (accuracy increase by 10%, KPI2.2), towards increased integration of PV generation into the European energy system and reduced curtailment of variable renewable energy systems by 5% thanks to SOLARIS (KPI2.3) [GA pg 126]
KPI baseline value and assumptions	Digitalisation could reduce the curtailment of variable renewable energy systems by more than 25% by 2030 ⁵⁴ . (A) SOLARIS contributes to 1/5, through PR1,2,4 [GA pg 126]
KPI target and unit	5%
Revised KPI	
Description and significance	Through more accurate predictions (PR1), systems' flexibility enabled by storage (PR2), SOLARIS will enable reducing the curtailment of the PV power plant by 5%. This will be done by advanced and optimized operation strategy, based on the trading tool developed in the project.
Method of calculation or measurement	Curtailment rates will be measured by comparing the available energy production of the PV plant and the real energy production registered. All these measurements will be done based on realistic simulations performed based on historical data from the plant, and by adding different storage systems, whose models and sizing methods will be developed during the project. $PV\ curtailment\ [\%] = \left(1 - \frac{PV\ energy\ production}{PV\ energy\ available}\right) \cdot 100$
	The comparisons will be done with and without using the storage systems hybridized with the PV power plant.
Data necessary, variables, formulas, tools	 Historical energy production, forecasts, grid conditions and market prices







	- Datasheet information to model the PV plant properly
	- Future market price and grid congestion scenarios, obtained based on reference estimation sources
	The tools used to perform the calculation will all be software based, and will be developed by project partners
Literature review and references of baseline values	Baseline values for curtailment rates are highly dependent on the country conditions, renewable penetration, distribution and transmission lines dimensioning and additional factors. Therefore, the specific case of PPC will need to be deeply studied during the project. However, note that the methodology will be applicable to any other site in which the plant participates in electricity markets.
Baseline value and unit	The baseline value of the PV curtailment will be based on the simulations performed based on the historical data of the plant, combined with the realistic scenarios considered for future market prices and grid congestion ratios. The baseline value will be obtained by operating the PV plant without any storage system.
Target value and unit	5%
Target value and unit Revised KPI Evaluation and Demo	
Revised KPI Evaluation and Demo	nstration within SOLARIS
Revised KPI Evaluation and Demo	nstration within SOLARIS u achieved it within the SOLARIS project?
Revised KPI Evaluation and Demo	nstration within SOLARIS
Revised KPI Evaluation and Demo How will you demonstrate that you At which demo sites will you	nstration within SOLARIS a achieved it within the SOLARIS project? PPC. This will be done with simulations of future market and grid scenarios
Revised KPI Evaluation and Demo How will you demonstrate that you At which demo sites will you demonstrate it? What equipment, materials, and	nstration within SOLARIS a achieved it within the SOLARIS project? PPC. This will be done with simulations of future market and grid scenarios (related to grid congestion and solar capture price effects). Historical data related to energy production, meteorological data, forecasting data and additional datasheet information. Moreover, market participation and conditions data will be required. Grid data will also be required related

KPI 2.4: Number of PV plant and technology stakeholders reached through Solaris Result Dissemination

Responsible project partner	DTU
Revision authors	Sergiu Spataru







Original KPI	
Description	This will be supported by strong business cases and exploitation plan, towards <i>high penetration</i> of SOLARIS' innovations into the European -and worldwide- market, reaching >25 O&M providers & >65 technology providers (KPI2.4).
KPI baseline value and assumptions	
KPI target and unit	25 O&M providers and 65 technology providers
Revised KPI	
New name	Number of PV plant and technology stakeholders reached through Solaris Result Dissemination
Description and significance	We will disseminate the most significant and relevant results relating to PV plant operation and performance to PV plant stakeholders.
	Who are the PV plant and technology stakeholders:
	PV plant developers, EPCs, O&M companies, owners
	PV plant development and operation engineers
	PV inverter and module manufacturers
	Solar and PV sensors and equipment manufacturers
	PV financing institutions
	PV communities and interest groups
	Inspection drone and payload developers
	Sister project
	How do we determine who these stakeholders are:
	 Each project partner will propose minimum 10 PV plant and technology stakeholders with contact info (email and contact person)
	What will we disseminate?
	An executive summary of the project's main outcomes and results, including:
	Technology brief from each of the tech partners
	List of publications







 Link to the Solaris website where more details are published Contact info of relevant partners that want to commercialize their solution will we reach the stakeholders: Emailing the project result executive summary Webinar with dissemination of these results and register who participates
 their solution will we reach the stakeholders: Emailing the project result executive summary Webinar with dissemination of these results and register who participates
 Emailing the project result executive summary Webinar with dissemination of these results and register who participates
Webinar with dissemination of these results and register who participates
participates
en will we disseminate/reach them?: M46
o will disseminate ?: DTU with help from partners that have direct act to the stakeholders
nber of stakeholders reached by email with executive summary of ris Results
25+65) individuals and minimum 50 companies
tion within SOLARIS ieved it within the SOLARIS project?
5
 at is the role of the Solaris partners: All: propose 10 stakeholders each DTU: contact and disseminate TEK, HELIO, UBI, EMA, AAU, DTU, UNIGE to prepare a short product/technology brief for their own results. EQY help with typesetting & branding of the executive summary







What is the contingency if	n/a
demonstration does not go as	
planned?	

KPI 2.5: Number of published open datasets

Responsible project partner	DTU, TEK, UNIGE, EMA
Revision authors	Sergiu Spataru
Original KPI	
Description	Further encouraging developments and to empower AI for digital, demonstration datasets (incl. labeled ones) will be made publicly available (PR9) and are foreseen to be used at 50% rate by O&M providers, 40% by technology providers, 10% by policy makers (KPI2.5)
KPI baseline value and assumptions	This KPI is based on the PR9: Demonstration data, labelled data and long-term PV potentials for regions of demonstrations made available online without user access (c.f. methodology)
KPI target and unit	50% rate by O&M providers, 40% by technology providers, 10% by policy makers
Revised KPI	
Description and significance	The SOLARIs partners will publish a number of labeled open datasets from the measurements and data acquired during the project for use by the wider PV research community for developing and validating PV models and inspection methods.
	What are the expected datasets that will be published?
	 A dataset of images of PV modules (visual, thermal and EL) with labelled faults, module datasheet and measurement conditions, taken indoor and in the field for use in training and validating Al failure detection models (DTU & AIR6), acquired from DTU and partner demo sites
	A dataset of timeseries electrical measurements with labelled faults of PV strings, including weather data and string layout and module datasheet information, acquired from DTU and partner demo sites (DTU & HELIO)
	Soiling dataset TEK
	Impedance measurements dataset EMA







	60.1
	Drone flight test UNIGE
	Where will the datasets be published?
	data.dtu.dk for datasets where DTU has copyright to
	• https://zenodo.org/
	• https://osf.io/
	• ELLC?
	TEK, UNIGE do you have own data repositories
	• Others?
	What will the copyright license?
	The data owners must make sure they own the data, and get permission from the plant owners
	To be decided by the data owner, options
	o <u>CC BY</u>
	o This license enables reusers to distribute, remix, adapt, and build upon the material in any medium or format, so long as attribution is given to the creator. The license allows for commercial use. CC BY includes the following elements:
	o BY: credit must be given to the creator.
	o CC BY-ND
	 This license enables reusers to copy and distribute the material in any medium or format in unadapted form only, and only so long as attribution is given to the creator. The license allows for commercial use. CC BY- ND includes the following elements:
	o BY: credit must be given to the creator.
	 ND: No derivatives or adaptations of the work are permitted.
Mothod of colouistics	Number of datacets published
Method of calculation or measurement	Number of datasets published







Data necessary, variables, formulas, tools	 Data from the partners acquired at the demo site Metadata describing the dataset 	
Literature review and references of baseline values	• License n/a	
Baseline value and unit Target value and unit	n/a 5	
Revised KPI Evaluation and Demonstration within SOLARIS How will you demonstrate that you achieved it within the SOLARIS project?		
At which demo sites will you demonstrate it?	Any demo site that authorises data publication	
What equipment, materials, and data will you require? Timeframe for demonstration?	Data from demonstration M46	
What project partners are	Each partner that plans to produce and publish a dataset (DTU,)	
involved in the successful demonstration and what are their exact responsibilities?	Prepare the dataset	
and caucitopolisis	 Get all permissions for publishing (from demo site owners) Decide on the license 	
	Decide where to publish it	
	Publish it EQY will keep track of the KPI	

KPI 2.6: Reduction of the LCOE

Responsible project partner	HELIO and CIEMAT and ALL partners
Revision authors	Emeric Eyraud emeric.eyraud@heliocity.io
Original KPI	
Description	As a consequence of EO1(Increase utility-friendly integration of PV generation into the European energy system at high-penetration levels and the profitability of PV systems), the increase in performance, reliability and prolonged lifetime, and flexibility thanks to SOLARIS' solutions will directly contribute to the increased profitability of all type of PV systems, with a reduction of LCOE by 10% (KPI2.6) [GA pg 126]







KPI baseline value and assumptions	Improved maintenance, profitability & lifetime of strategic components reduces LCOE by 10% at project end.
KPI target and unit	10% LCOE reduction
Revised KPI	
Description and significance	In order to properly illustrate the benefits of SOLARIS project on the LCOE of PV systems, this KPI aims at presenting the gain brought by each innovation to decrease by 10% the LCOE of a PV system thanks to SOLARIS solutions.
Method of calculation or measurement	The use of PV LCOE model to estimate the gain brought by Solaris
Data necessary, variables, formulas, tools	A general model of LCOE for PV system losses based on literature will be used to compare and quantify the benefits brought by SOLARIS innovations.
Literature review and references of baseline values	Dr Christoph Kost , 'Study: Levelized Cost of Electricity- Renewable Energy Technologies, Aug 2024' , Fraunhofer ISE
Baseline value and unit	Baseline : LCOE before SOLARIS
Target value and unit	10% LCOE reduction
Revised KPI Evaluation and Demor	achieved it within the SOLARIS project?
At which demo sites will you demonstrate it?	This KPI is rather an aggregation of others KPI, a projection of the benefits onto LCOE
What equipment, materials, and data will you require?	A model of LCOE with the impact of the SOLARIS action demonstrated onto other demo sites/ KPIs
Timeframe for demonstration?	2027
What project partners are involved in the successful demonstration and what are their exact responsibilities?	All partners shall assess the impact of their contribution onto LCOE.
What is the contingency if the KPI is not achieved?	This metric might be restricted to a lower scope, for e.g. to rooftops only if the KPIs is not met for all type of PV plant
What is the contingency if demonstration does not go as planned?	n/a







KPI 2.7: Increase of PV systems revenues

Responsible project partner	TEKNIKER
Revision authors	Jon Martinez jon.martinez@tekniker.es
Original KPI	
Description	The energy trading tool (PR2) will optimize energy distribution, also considering new market opportunities (aFRR) and storage, allowing a 20% increase in revenues (KPI2.7) [GA pg 126]
KPI baseline value and assumptions	(B) New trading markets & 211 optimization incl. energy arbitrage and storage allows up to 50% revenue increase ⁵⁹ , and (A) ca. half reachable by SOLARIS [GA pg 126]
KPI target and unit	20%
Revised KPI	
Description and significance	The energy trading tool (PR2) developed in the project will improve the revenue streams of the PV plant by optimally dispatching the use of the storage systems added to the plant and selecting the optimal participation in the aFRR markets.
Method of calculation or measurement	The plant revenues will be calculated by comparing the economic influx obtained by the PV plant operating in the following conditions:
	 Current case (SC-A): operating without any storage system and just participating in the day-ahead energy market (which is the current operating scenario of the studied PV plant)
	 Future case (SC-B): operating with different storage systems and by adding the participation in the aFRR markets
	These two scenarios will be compared based on different sensitivity studies related to future market prices and conditions. These future scenarios will be generated based on the historical data registered in the site's country and based on the estimations and future perspectives adding aspects such as price cannibalization or grid congestion.
	At the end, the revenues will be compared with the following formulation: $extra\ rev\ [\%] = \frac{rev^{SC-B} - rev^{SC-A}}{rev^{SC-A}} \cdot 100$





	$SC-A$ $\sum_{c,DAM}^{T}$ DAM
	$rev^{SC-A} = \sum_{t=1}^{N} \delta_t^{DAM} \cdot e_t^{DAM}$
	$rev^{SC-B} = \sum_{t=1}^{T} \delta_t^{DAM} \cdot e_t^{DAM} + p_t^{aFRR+} \left(\delta_t^{p aFRR+} + \alpha \Delta t \delta_t^{e aFRR+} \right) + p_t^{aFRR-} \left(\delta_t^{p aFRR-} - \beta \Delta t \delta_t^{e aFRR-} \right)$
	$+p_t^{aFRR-}ig(\delta_t^{p aFRR-}-eta\Delta t\delta_t^{e aFRR-}ig)$
	rev^{SC-X} : revenue in scenario X
	δ^X_t : price at period t in market X
	p_t^X : power band offered at period t in market X
	lpha: energy production rate at period t in the aFRR+ market
	$oldsymbol{eta}$: energy production rate at period t in the aFRR- market
	DAM: day-ahead energy market
	p aFRR +: power band aFRR + market (upward)
	p aFRR —: power band aFRR - market (downward)
	e aFRR +: energy aFRR + market (upward)
	e aFRR —: energy aFRR - market (downward)
	The studies will be performed considering the PICASSO project application ¹ . Therefore, upward and downward aFRR market offers will be done independently.
	¹ https://www.entsoe.eu/network_codes/eb/picasso/
Data necessary, variables, formulas, tools	- Historical energy production, forecasts, grid conditions and market prices
	- Datasheet information to model the PV plant properly
	- Future market price and grid congestion scenarios, obtained based on reference estimation sources
	The tools used to perform the calculation will all be software based, and will be developed by project partners
Literature review and references	Revenues from electricity market participation are directly conditioned by
of baseline values	the prices registered in each country, and specially affected by aspects such as the price spread during the day ² . However, a proper sensitivity study
	provide robust conclusions. As an example, currently in countries such as







	Spain, it is observed that up to 14% extra revenues can be obtained from
	adding a BESS into the system ³ .
	² https://doi.org/10.1049/icp.2023.1442
	³ <u>Development of a Plant Controller for Grid-Connected Hybrid Renewable</u>
	Power Plants with Enhanced Market Participation Strategies
Baseline value and unit	Reference revenues obtained by the plant without adding a storage system and just participating in the day-ahead energy market. The revenues will be measured in the local currency (€), and will refer to the economic influx achieved from providing market services. This will be studied based on simulating the operation in the future market scenarios proposed in the project and agreed with the site.
Target value and unit	20%
Revised KPI Evaluation and Demo	nstration within SOLARIS
How will you demonstrate that you	achieved it within the SOLARIS project?
At which demo sites will you	PPC, as it is the only utility-scale PV plant participating in electricity markets.
demonstrate it?	This will be done with simulations, considering that currently the plant only participates in energy markets, and does not have a storage system.
What equipment, materials, and	Historical data related to energy production, meteorological data, forecasting
data will you require?	data and additional datasheet information. Moreover, market participation
	and conditions data will be required. Grid data will also be required related to PV production integration at country level.
Timeframe for demonstration?	Simulation based, last stage of the project once the trading tool and storage models developed in the project are ready.
What project partners are	PPC. They will be responsible for sending the required data for performing
involved in the successful	the simulations.
demonstration and what are their exact responsibilities?	
What is the contingency if the	Additional revenue streams will be investigated initially not considered to
KPI is not achieved?	obtain the KPI, such as capacity markets.
What is the contingency if	
demonstration does not go as	
planned?	

KPI O1.1: Improvement of weather forecasting accuracy based on verification & skill scores (RMSE, CSI, Brier Score) (vs. Available forecast – GFS, ECMWFS, ICON-D2)

Responsible	project	UBIMET
partner		







Revision authors	Verena Ruedl (vruedl@ubimet.com)
Original KPI	
Description	Improvement of weather forecasting accuracy: 10% vs. Available forecast – GFS, ECMWFS, ICON-D2
KPI baseline value and assumptions	
KPI target and unit	10%
Revised KPI	
Description and significance	
Method of calculation or measurement	- RMSE: The root mean square error (RMSE) measures the average difference between a statistical model's predicted values and the actual values. Mathematically, it is the standard deviation of the residuals. Residuals represent the distance between the regression line and the data points. $RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(fcst_i - obs_i)^2}$
	 CSI: If detected events are considered as success, the Critical Success Index (CSI) is the proportion between number of successes and number of successes and failures together. It indicates how well the system predicts true events from the total number of events that should have been detected. CSI = 0 means no observed events were correctly forecasted or there were no forecast at all CSI = 1 means observed events were correctly forecasted and there were no false alarms or misses CSI = number of events were correctly forecasted and there were no false alarms or misses
	 Brier Score: Mean Squared Difference between forecasted probability and event occurrence indicator (0 = non-event, 1 = event). o 0 (best outcome) would indicate that we always predict events with a 100% chance, and non-events with a 0% chance.





	o Outcomes higher than 0.5 would indicate that the forecasts are		
	worse than if they would be created randomly		
	BS _{fcst}		
	$BSS = 1 - \frac{BS_{fcst}}{BS_{ref}}$		
Data necessary,	- Observations from weather stations (provided by UBIMET and also from		
variables, formulas,	demo sites, that operate their own weather station)		
tools	- GFS, ECMWFS, ICON-D2 data (provided by UBIMET)		
	GIS, ECHANTS, ICON DZ data (provided by Oblivier)		
	- In house developed weather forecasts (developed by UBIMET)		
Literature review and	Ebert, E., Wilson, L., Weigel, A., Mittermaier, M., Nurmi, P., Gill, P., Watkins, A.		
references of baseline	(2023). Progress and challenges in forecast verification. RMetS - Royal Meteorological		
values	Society. https://rmets.onlinelibrary.wiley.com/doi/epdf/10.1002/met.1392		
	Brier, G. W. (1950). VERIFICATION OF FORECASTS EXPRESSED IN TERMS OF		
	PROBABILITY. MONTHLY WEATHER REVIEW. https://viterbi-		
	web.usc.edu/~shaddin/teaching/cs699fa17/docs/Brier50.pdf		
Baseline value and unit	- RMSE: unit of parameter (e.g. temp, wind)		
	- CSI: dimensionless value between 0 and 1		
	- Brier Score: dimensionless value between 0 and 1		
Target value and unit	- Reduction of RMSE value by 10%		
	- Increase of CSI value by 10%		
	- Reduction of Brier Score by 10%		
Revised KPI Evaluation a	nd Demonstration within SOLARIS		
How will you demonstrate	e that you achieved it within the SOLARIS project?		
At which demo sites	DTU		
will you demonstrate			
it?			
What equipment,	- Observations from weather stations – provided by UBIMET		
materials, and data will	- GFS, ECMWFS, ICON-D2 data – provided by UBIMET		
you require?			
Timeframe for	Timeframe will be limited by T2.1 (M7-M18)		
demonstration?			
What project partners	- DTU for weather data delivery		
are involved in the			
successful			
demonstration and			
what are their exact			
responsibilities?			







What	is	the	Assess the causes and cross-correlate with surrounding WMO weather stations
contingency if the KPI is		e KPI is	
not achie	ved?		
What	is	the	Check for demonstration on another demo site: Burgenland (FIB)
continger	ncy	if	
demonst	ration	does	
not go as planned?		d?	

KPI 02.3: Reduction in PV inverter inspection time/repair time

Responsible project partner	AAU			
Revision authors	Saeed Peyghami (sap@energy.aau.dk)			
Original KPI				
Description	Reduction in the number of field investigations by automated monitoring: 40%; Reduction of cleaning OPEX through reduction of interventions by extending cleaning periods: 30%; Reduction in PV inverter inspection time/repair time: 40%; Increase in the number of resolved root cause investigations: 50%; Drones imagery data transmission time: <15min; Reduction in inspection time through group flight: 100%/N+5% (N number of drones, 5% possible interferences between drones); No latency in data acquisition thanks to the IoT platform. [GA pg 105]			
KPI baseline value and assumptions				
KPI target and unit	30% Reduction in PV inverter inspection time/downtime			
Revised KPI				
Description and significance	Kept as original KPI. PV inverters are one of the key parts of energy conversion in PV systems. Failure of PV inverters will cause full shut down of PV system and thus loss of energy for the corresponding downtime. One way to prevent downtime is to reduce to failure rate that will be addressed in prolonging the lifetime be reducing the failure rate as discussed in KPI 1.8ii. Another approach is to reduce the inspection time and downtime. This will be facilitated by developing the accurate lifetime model and making reliability digital twin to predict the failure occurrence as well as active thermal management and reconfiguration to operate in derated mode instead of full downtime until repair. By this, we will be able to predict the lifetime and wear out failure probability according to the operating conditions and thus optimizing the maintenance or repair time and optimizing the spare units. With developing reliability digital twin, the wear out can be predicted and inspection time will be reduced. By optimizing the repair time we can have O&M			







	personnel and spare units to perform on-time maintenance as well as having optimized number of spare inverters will reduce the active repair time. These will reduce the inverter down time and hence increase its availability.
Method of calculation or measurement	This factor requires long term operation to be validated in real case application. Due to the time limit, we will use combination of test and simulation to calculate the downtime under proposed approach. Since the failure occurrence will take longer time, fake failure in inverter will be manipulated and it will be demonstrated how our approach will detect the failure before happening and how our approach will run the inverter in partial power mode until full repair. Comparing this with the case that the failure happens and then it will be planned for the repair, demonstrates the reduction in the down time. Once the viability of the developed approach is validated and demonstrated by the experimental tests, expected downtime will be simulated using the test data and optimizing the repair time and spare units over long-term operation for large scale PV power plants. In order to show the reduction in downtime, two cases will be analysed including the operation of the inverter with and without our solution.
Data necessary, variables, formulas, tools	We need solar irradiance and ambient temperature with the resolution of 1-15 minutes for at least one year, that will be provided by DTU and UBIMET, for long term mission profile analysis.
	For short term analysis, we will test the thermal behaviour of the PV inverter in AAU reliability lab and will measure the junction temperature to validate the impact of our solutions for lifetime prediction.
	The down time is a function of various factors according to the following equation [a]:
	Downtime = access time+diagnosis time+ active repair time+ checkout time
	Optimal repair time is calculated by minimizing the unavailability of the inverter using following equation [b]:
	$U(t_0) = \frac{T_D(t_0)}{T_R(t_0) + T_D(t_0)}$ $= \frac{T_P \cdot (1 + (k - 1) F(t_0))}{T_R(t_0) + T_P \cdot (1 + (k - 1) F(t_0))}$







	 [a] Rausand, Marvin, and Arnljot Hoyland. System reliability theory: models, statistical methods, and applications. Vol. 396. John Wiley & Sons, 2003., APA, [b] Peyghami, Saeed, et al. "System-level design for reliability and maintenance scheduling in modern power electronic-based power systems." IEEE Open Access Journal of Power and Energy 7 (2020): 414-429., APA,
Literature review and references of baseline values	PV inverter inspection time and down time depends on various factors including control strategies, power plant site, spare unit availability, O&M personnel availability, inverter type and topology, etc. For instance, SUNGROW as one of the PV inverter manufacturer reported 6 hours down time for their central inverters, which can be reduced to 2 hours by modular design [a]. [a] 2024 Photovoltaic Inverter Reliability Workshop Summary Report & Proceedings, Daniel J. Friedman, Peter L. Hacke, Mowafak Al-Jassim, Silvana Ovaitt, and Susannah Shoemaker, National Renewable Energy Laboratory
Baseline value and unit	As mentioned downtime depends on various factors. Therefore, the base line for our demonstration will be the downtime of the developed inverter that will be operated under conventional operation strategies, and will be compared to the case that we will apply our lifetime prediction approach solutions.
Target value and unit	We expect to achieve 30% reduction in PV inverter inspection time/downtime.
Revised KPI Evaluation and Demonstration within SOLARIS How will you demonstrate that you achieved it within the SOLARIS project?	
At which demo sites will you	DTU demonstration site
demonstrate it?	
What equipment, materials, and data will you require?	We will develop novel PV inverter in SOLARIS based on the PV system specification at DTU demonstration site, the details of the PV system including PV panel characteristic, their connections have been provided by DTU. The required data during the test will be inverter voltage and current in ac and dc side, as well as on state voltage of power semiconductor devices.







Timeframe for demonstration?	This will be evaluated during the development of the task 3.5 and 5.5 of the project.
What project partners are involved in the successful demonstration and what are their exact responsibilities?	DTU will support in installing and testing the inverter in their site over the demonstration period.
What is the contingency if the KPI is not achieved?	Might be a slightly lower target (e.g 20% decrease instead of 30%)
What is the contingency if demonstration does not go as planned?	If the demonstration at DTU site does not go as planned we will test it in our reliability lab using developed PV inverter with PV emulator modelling PV panel characteristics and climate conditions.

KPI O2.6: Reduction in inspection time through group flight

Responsible project partner	UNIGE
Revision authors	Antonio Sgorbissa
Original KPI	
Description	UNIGE will perform tests with 1, 2 and possibly 3 drones, by measuring the corresponding time for covering the whole PV plant
KPI baseline value and assumptions	There are no baselines in the literature. We are not measuring the absolute time required to cover the plant, but rather how the time decreases as the number of drones increases.
KPI target and unit	100/N+5
Revised KPI	
Description and significance	The KPI will provide an estimate of the advantages of using autonomous aerial drones to cover the PV plant. Since the drones autonomously fly along the PV plant rows, the time required to cover the entire plant is expected to decrease with an increasing number of drones, while the need for human operators is expected to remain almost constant, highlighting the benefit of the proposed solution.
Method of calculation or measurement	The time required to cover the whole plant is measured with an increasing number of drones (and possibly with different control policies, if more
Data necessary, variables, formulas, tools	
Literature review and references of baseline values	There are no baselines in the literature. We are not measuring the absolute time required to cover the plant, but rather how the time decreases as the number of drones increases.







Baseline value and unit	-
Target value and unit	-
Revised KPI Evaluation and Demon	stration within SOLARIS
How will you demonstrate that you	achieved it within the SOLARIS project?
At which demo sites will you	DTU
demonstrate it?	
What equipment, materials, and	UNIGE will need two or three aerial drones with identical capabilities, along
data will you require?	with a supporting PC to run the software for path optimization and real-time
	coverage of the PV plant through visual servoing.
Timeframe for demonstration?	The demonstration will require one week for setup and configuration, as
	well as a few days for data collection. UNIGE will send their technical staff
	to carry out these tasks.
What project partners are	DTU should provide on-site support for conducting experiments.
involved in the successful	
demonstration and what are their	
exact responsibilities?	
What is the contingency if the KPI	If the KPI is not achieved, UNIGE will evaluate the performance of a single
is not achieved?	drone and provide a comprehensive analysis of its behavior under various
	conditions, including speed, time of day, weather conditions, and more.
What is the contingency if	If the demonstration does not proceed as planned, UNIGE will present all
demonstration does not go as	their results and evaluate performance in the CoppeliaSim real-time
planned?	simulator, controlling drones in a simulated yet physically realistic
	environment.

KPI O2.7: Platform availability

Responsible project partner	ELLC	
Revision authors	Carmina Bocanegra (carmina.bocanegra@elliotcloud.com)	
Original KPI	Original KPI	
Description	No latency in data acquisition thanks to the IoT platform	
KPI baseline value and assumptions		
KPI target and unit	No latency	
Revised KPI		
Description and significance	Platform availability	







	The platform must be robust and guarantee a high availability. This means that it must not withstand long-term interruptions with the loss of data or management alerts. It is very important that the point of failure is not the central management platform, since it impacts the overall project.
	The ability of a company's information technology (IT) systems to be operational and accessible at all times implies that systems must be able to withstand threats and recover quickly in the event of failures.
	As a baseline, we can estimate that current availabilities can be around 90%.
Method of calculation or measurement	Availability = (Hours per year – Hours downtime) / Hours per year
Data necessary, variables,	Hours per year = 8760
formulas, tools	Hours downtime
Literature review and references of baseline values	Baseline based on experience.
	000/
Baseline value and unit	90%
Baseline value and unit Target value and unit	97%
	97%
Target value and unit Revised KPI Evaluation and Demo	97% nstration within SOLARIS
Target value and unit Revised KPI Evaluation and Demo	97%
Target value and unit Revised KPI Evaluation and Demo How will you demonstrate that you	97% Instration within SOLARIS In achieved it within the SOLARIS project?
Target value and unit Revised KPI Evaluation and Demo How will you demonstrate that you At which demo sites will you	97% Instration within SOLARIS In achieved it within the SOLARIS project?
Target value and unit Revised KPI Evaluation and Demo How will you demonstrate that you At which demo sites will you demonstrate it? What equipment, materials, and	97% Instration within SOLARIS If achieved it within the SOLARIS project? All
Target value and unit Revised KPI Evaluation and Demo How will you demonstrate that you demonstrate it? What equipment, materials, and data will you require? Timeframe for demonstration? What project partners are involved in the successful	97% Instration within SOLARIS If achieved it within the SOLARIS project? All ELLC can measure this KPI using tests.
Target value and unit Revised KPI Evaluation and Demo How will you demonstrate that you demonstrate it? What equipment, materials, and data will you require? Timeframe for demonstration? What project partners are	97% Instration within SOLARIS If achieved it within the SOLARIS project? All ELLC can measure this KPI using tests. - We will need contribution from pilot leaders in order to gather their data in
Target value and unit Revised KPI Evaluation and Demo How will you demonstrate that you At which demo sites will you demonstrate it? What equipment, materials, and data will you require? Timeframe for demonstration? What project partners are involved in the successful demonstration and what are	97% Instration within SOLARIS If achieved it within the SOLARIS project? All ELLC can measure this KPI using tests. - We will need contribution from pilot leaders in order to gather their data in our platform. ELLC will be responsible for the correct data processing in order to meet this
Target value and unit Revised KPI Evaluation and Demo How will you demonstrate that you demonstrate it? What equipment, materials, and data will you require? Timeframe for demonstration? What project partners are involved in the successful demonstration and what are their exact responsibilities?	97% Instration within SOLARIS If achieved it within the SOLARIS project? All ELLC can measure this KPI using tests. - We will need contribution from pilot leaders in order to gather their data in our platform. ELLC will be responsible for the correct data processing in order to meet this KPI
Target value and unit Revised KPI Evaluation and Demonstrate that you demonstrate that you demonstrate it? What equipment, materials, and data will you require? Timeframe for demonstration? What project partners are involved in the successful demonstration and what are their exact responsibilities? What is the contingency if the KPI is not achieved?	nstration within SOLARIS a achieved it within the SOLARIS project? All ELLC can measure this KPI using tests. - We will need contribution from pilot leaders in order to gather their data in our platform. ELLC will be responsible for the correct data processing in order to meet this KPI We are sure we can meet this KPI using Elliot Cloud's IoT platform

KPI O3.1: Reduction of maintenance activities through improved scheduling

Responsible project partner	HELIO (support from others)
Revision authors	Emeric Eyraud emeric.eyraud@heliocity.io







Original KPI	Original KPI	
Description	Reduction of maintenance activities through improved scheduling: 20% [GA pg 105]	
KPI baseline value and assumptions	a simulation on a large PV fleet showing how early detection and tasks optimization, thanks to SOLARIS, can help reducing maintenance activities costs	
KPI target and unit	20% - in euros	
Revised KPI		
Description and significance		
Method of calculation or measurement		
Data necessary, variables, formulas, tools		
Literature review and references of baseline values		
Baseline value and unit		
Target value and unit		
	Revised KPI Evaluation and Demonstration within SOLARIS How will you demonstrate that you achieved it within the SOLARIS project?	
At which demo sites will you demonstrate it?	No need for dedicated site demo. It will be a simulation on a large PV fleet showing how early detection and tasks optimization can help reducing maintenance activities costs	
What equipment, materials, and data will you require?	n/a (but reports/feedback from Solaris demos)	
Timeframe for demonstration?	2027	
What project partners are involved in the successful demonstration and what are their exact responsibilities?	HELIO	
What is the contingency if the KPI is not achieved?	Might be a slightly lower target (e.g 15% decrease instead of 20%)	
What is the contingency if demonstration does not go as planned?	n/a	







KPI O3.2: Field control app demonstrated with >5 on-site features

Responsible project partner	HELIO (support from others)
Revision authors	Emoris Euraud amaris auraud@haliasity ia
Revision authors	Emeric Eyraud emeric.eyraud@heliocity.io
Original KPI	
Description	Field control app demonstrated on 4 sites with >5 on-site features [GA pg 105]
	Revised KPI: Field control app demonstrated with >5 on-site features
KPI baseline value and assumptions	Field control app demonstrated on 4 sites with >5 on-site features
KPI target and unit	>5 on-site features
Revised KPI	
Description and significance	It is decided to limit this KPI to one site demonstration for the sake of the complexity of having onsite operator in several sites.
Method of calculation or measurement	On-site feature demo & report count (>=5)
Data necessary, variables, formulas, tools	n/a
Literature review and references of baseline values	n/a
Baseline value and unit	n/a
Target value and unit	>5 on-site features
Revised KPI Evaluation and Demor	stration within SOLARIS
How will you demonstrate that you	achieved it within the SOLARIS project?
At which demo sites will you	DTU
demonstrate it?	Cf WD4/T4 2 Daniel Arthur and Art
What equipment, materials, and data will you require?	Cf. WP1/T1.3 Demonstration requirements & definition of use-cases
Timeframe for demonstration?	2027
What project partners are involved in the successful demonstration and what are their exact responsibilities?	HELIO+DTU







What is the contingency if the KPI is not achieved?	Less features
What is the contingency if demonstration does not go as planned?	n/a

KPI 03.3: Increasing PV inverter production-based availability

Responsible project partner	AAU
Revision authors	Saeed Peyghami (sap@energy.aau.dk)
Original KPI	
Description	Field control app demonstrated on 4 sites with >5 on-site features; Reduction of maintenance activities through improved scheduling: 20%; PV inverter time-based and production-based availability: >99%; Time the fault detection algorithm requires to analyse the data and detect the fault: <48h; Decrease in PV systems' production losses thanks to predictive maintenance: 25%. [GA pg 105]
KPI baseline value and assumptions	
KPI target and unit	0.5% increase in PV inverter production-based availability
Revised KPI	
Description and significance	Production-based availability or energy availability is one of the main performance measures of PV inverters. It is kind of energy efficiency of the inverter. Having low values of this measure shows higher loss of energy and thus decreasing profitability of a power plant. In the original KPI we defined time-based and production-based availability of at least 99% for the developed PV inverter. Time-based availability is kind of linked to the downtime and it is addressed in KPI O2.3. On the other hand, production-based availability of the inverter depends on different factors such as operating conditions, inverter type and topology, and its value varies between 98 and 99.8% [a]. Therefore, instead of approaching at least 99% production-based availability in our developed inverter, we will focus on increasing it at least 0.5%. That means, we will develop reconfigurable inverter with advanced control approach to enhance its production-based availability 0.5% compared to the same inverter operating under same conditions but using conventional control approach and without reconfigurability. This increase in the production-based availability will remarkably increase the energy production over long-term operation in large scale PV power plants.





	[a] 2024 Photovoltaic Inverter Reliability Workshop Summary Report & Proceedings, Daniel J. Friedman, Peter L. Hacke, Mowafak Al-Jassim,	
	Silvana Ovaitt, and Susannah Shoemaker, National Renewable Energy Laboratory	
Method of calculation or measurement	Due to time limit, it is not feasible to run the inverter for long term and wait for a failure occurrence to demonstrate the performance of the proposed solutions. Instead, we will run the inverter for a short period of time and will manipulate fake failures in the inverter. Then, we will calculate the production-based availability of the inverter under the proposed approaches and the conventional approaches.	
Data necessary, variables, formulas, tools	We need solar irradiance and ambient temperature with the resolution of 1-15 minutes for at least one year, that will be provided by DTU and UBIMET, for long term mission profile analysis.	
	Production-based availability can be calculated over a period of time using following equation [a]:	
	Production-based availability = (1-loss of energy/total expected energy production)	
	[a] Li, Wenyuan. Risk assessment of power systems: models, methods, and applications. John Wiley & Sons, 2014., APA,	
Literature review and references of	Production-based availability of the inverter depends on different factors	
baseline values	such as operating conditions, inverter type and topology, and its value varies between 98 and 99.8% [a].	
	[a] 2024 Photovoltaic Inverter Reliability Workshop Summary Report & Proceedings, Daniel J. Friedman, Peter L. Hacke, Mowafak Al-Jassim, Silvana Ovaitt, and Susannah Shoemaker, National Renewable Energy Laboratory	
Baseline value and unit	In SOLARIS project, instead of approaching at least 99% production-based availability in our developed inverter, we will focus on increasing it at least 0.5%. That means, we will develop reconfigurable inverter with advanced control approach to enhance its production-based availability 0.5% compared to the same inverter operating under same conditions but using conventional control approach and without reconfigurability.	
Target value and unit	We expect to increase 0.5% production-based availabiltiy of PV inverter .	
Revised KPI Evaluation and Demonstr	Revised KPI Evaluation and Demonstration within SOLARIS	
How will you demonstrate that you ac	hieved it within the SOLARIS project?	
At which demo sites will you	DTU demonstration site	
demonstrate it?		
What equipment, materials, and	We will develop novel PV inverter in SOLARIS based on the PV system	
data will you require?	specification at DTU demonstration site, the details of the PV system	







	including PV panel characteristic, their connections have been provided by DTU. The required data during the test will be inverter voltage and current in ac and dc side, as well as on state voltage of power semiconductor devices.
Timeframe for demonstration?	This will be evaluated during the development of the task 3.5 4.4, and 5.5 of the project.
What project partners are involved	DTU will support in installing and testing the inverter in their site over the
in the successful demonstration and	demonstration period.
what are their exact	
responsibilities?	
responsibilities:	
What is the contingency if the KPI is	n/a
not achieved?	
What is the contingency if	n/a
demonstration does not go as	
planned?	
piaca.	

KPI O3.4: Time the fault detection algorithm requires to analyse the data and detect the fault

Responsible project partner	HELIO (support from others)
Revision authors	Emeric Eyraud emeric.eyraud@heliocity.io
Original KPI	
Description	Time the fault detection algorithm requires to analyse the data and detect the fault [GA pg 105]
KPI baseline value and assumptions	
KPI target and unit	48 hours.
Revised KPI	
Description and significance	
Method of calculation or measurement	
Data necessary, variables, formulas, tools	
Literature review and references of baseline values	
Baseline value and unit	
Target value and unit	







Revised KPI Evaluation and Demor	nstration within SOLARIS	
How will you demonstrate that you	How will you demonstrate that you achieved it within the SOLARIS project?	
At which demo sites will you	DTU for continuous monitoring and 3 other sites for one short PV	
demonstrate it?	performance diagnosis	
What equipment, materials, and	Cf. WP1/T1.3 Demonstration requirements & definition of use-cases	
data will you require?		
Timeframe for demonstration?	2027	
What project partners are	HELIO+DTU +other sites	
involved in the successful		
demonstration and what are		
their exact responsibilities?		
What is the contingency if the KPI	n/a	
is not achieved?		
What is the contingency if	n/a	
demonstration does not go as		
planned?		







KPI O3.5: Decrease in PV systems' production losses thanks to predictive maintenance

Responsible project partner	HELIO (support from others)
Revision authors	, , , ,
	Emeric Eyraud <u>emeric.eyraud@heliocity</u> .io
Original KPI	
Description	Decrease in PV systems' production losses thanks to predictive maintenance [GA pg 105]
KPI baseline value and assumptions	Based on PV performance audits and recommendations
KPI target and unit	tbd
Revised KPI	
Description and significance	
Method of calculation or measurement	
Data necessary, variables, formulas, tools	
Literature review and references of baseline values	
Baseline value and unit	
Target value and unit	
Revised KPI Evaluation and Demor	nstration within SOLARIS
How will you demonstrate that you	achieved it within the SOLARIS project?
At which demo sites will you	No need for dedicated site demo. It will be a simulation on an emulated large
demonstrate it?	PV fleet showing how predictive maintenance can decrease production
	losses.
What equipment, materials, and	
data will you require?	
Timeframe for demonstration?	2027
What project partners are involved in the successful demonstration and what are their exact responsibilities?	HELIO
What is the contingency if the KPI is not achieved?	n/a





planned?



KPI O4.1: Months of demonstration of the solutions

Responsible project partner	CIEMAT (support from others)
Revision authors	Ana Rosa Gamarra
Original KPI	
Description	Duration of the period in which the solutions are working in the demonstration sites (in months).
KPI baseline value and assumptions	16
KPI target and unit	Months
Revised KPI	
Description and significance	
Method of calculation or measurement	
Data necessary, variables, formulas, tools	
Literature review and references of baseline values	
Baseline value and unit	
Target value and unit	
Revised KPI Evaluation and Demonstration within SOLARIS How will you demonstrate that you achieved it within the SOLARIS project? At which demo sites will you demonstrate it?	
What equipment, materials, and data will you require?	Data on solutions installation and implementation
Timeframe for demonstration?	Tbd
What project partners are involved in the successful demonstration and what are their exact responsibilities?	Demonstration sites, All







What is the contingency if the KPI is not achieved?	n/a
What is the contingency if demonstration does not go as planned?	n/a

KPI O4.4: Reduced environmental impact through increased lifetime and efficiency of installations

Responsible project partner	CIEMAT (support from others)
Revision authors	Ana Rosa Gamarra
Original KPI	
Description	Quantify the reduction of the environmental impacts along the life cycle of the PV plants in the demonstration sites comparing with and without solutions. Benefits of energy efficiency, better management of the resources and increasing of the lifetime are expected to reduce the environmental impact. The methodology Life Cycle Assessment will be used to quantify the impacts. Data on materials and energy consumption of the plants in the demonstration sites and of the solutions. LCA data will be provide by partners (Template).
KPI baseline value and assumptions	Tbd - Baseline scenario (PV plants without solutions)
KPI target and unit	10%
Revised KPI	
Description and significance	Quantify the reduction in environmental impact over the life cycle of the PV systems in the demonstration sites, compared with and without solutions. It is expected that the benefits of energy efficiency, better management of resources and increased lifetime thanks to the SOLARIS solutions will reduce the environmental impact. The relevance of the environmental impact assessment and the monitoring of the result by following this KPI is crucial as an indicator of the success of the project solutions and the alignment with the objectives (O4).
Method of calculation or measurement	The method of calculation is comparative Life Cycle Assessment (LCA). The Life Cycle Assessment (LCA) methodology will be used to quantify the impacts of the solutions (manufacturing, installation, use and end of life (eol)) as well as the impacts of the electricity produced at each demonstration site with and without the implementation of the solutions, taking into account the entire life cycle of the PV installation (manufacturing, installation, operation and maintenance and eol). Life Cycle Assessment (LCA), standardised by ISO 14040/44, is a tool that assesses the environmental impacts of a product or service over





its entire life cycle, from raw material extraction to end of life. LCA provides a holistic approach and a framework for decision making. LCA has four iterative phases: Goal and Scope Definition, Inventory Analysis, Impact Assessment and Interpretation.

The goal and the scope will be properly defined. The functional unit will be electricity produced (kWh or MWh). A functional unit describes a quantity of a product or product system based on the performance it delivers in its end-use application. The results are then expressed in terms of the functional unit that allows comparability (e.g. kg CO2 eq./kWh).

The Life Cycle Inventory (LCI) is based on the data provided by 1) the partners on the processes for the deployment of the solutions and 2) the data from the demonstration sites detailing the energy, material and transport processes involved in the subsequent stages of the life cycle. The LCI consists of detailed data on reference flows, inputs and outputs (emissions, wastes, effluents) and allows the identification and quantification of the substances and elements potentially harmful to the environment. These substances and elements are then linked to the different environmental impacts using characterisation factors for each environmental impact category. Each impact category has its reference unit: e.g. kg CO2-eq for climate change. A substance can contribute to more than one impact (NOx contributes to acidification and tropospheric ozone formation) and impacts are caused by more than one substance (e.g. carbon footprint is caused by CO2, CH4, N2O, etc.) with different intensities (the global warming potential of CH4 is four times higher than that of CO2). Characterisation allows potential impacts to be aggregated into a number of environmental impact categories. There are several impact assessment methods. For instance, The Product Environmental Footprint (PEF) method recommended by the European Commission covers 16 impact categories. Depending on the product or process under study, different categories can be result in a negligible impact and other can be deeply studied.

Finally, the interpretation phase examines the results together with the inventory and evaluates key decisions and results.

Data necessary, variables, formulas, tools

Data on materials, energy and transport processes along the life cycle of 1) solutions and 2) demonstration sites will be required.

A template will be shared with partners to guide data collection. A dedicated workshop will be held to help partners fill in the template, discuss how to overcome potential difficulties and suggest alternatives where primary data is lacking.

Literature review and references of baseline values

There is a large body of LCA of PV along the whole life cycle, focusing on the manufacturing stage. However, there are few works that focus







	on the use/O%M stage. Among the more relevant data and state of the art literature on the sustainability and in particular the environmental impacts of PV, the dedicated reports of the IEA Task 12 (https://iea-pvps.org/research-tasks/pv-sustainability/) are consulted. NREL has also published recent data on the life cycle assessment of PV (https://www.nrel.gov/docs/fy24osti/87372.pdf). Some literature (Bouman et al. 2020, in the Eionet report - ETC/CME 4/2020) found that the main impacts of PV could be carbon footprint, water consumption and freshwater ecotoxicity, as well as mineral and metal resource depletion and land use.
	For the O&M phase of PV and strategies to improve this phase, few ongoing studies were found due to the novelty of this research. Therefore, there is a limited literature on LCA focusing on the O&M of PV installations.
Baseline value and unit	Tbd (baseline, impact of the PV system under study before implementation of solution(s))
Target value and unit	10% of the reduction of the main impacts of the PV life cycle related to the functional unit (kWh) due to the combined effect of the implementation of the SOLARIS solutions. The key environmental impact categories are carbon footprint, water depletion and freshwater ecotoxicity, mineral and metal resource depletion and land use).
Revised KPI Evaluation and Demonstr	ation within SOLARIS
How will you demonstrate that you acl	hieved it within the SOLARIS project?
At which demo sites will you demonstrate it?	All
What equipment, materials, and data will you require?	Data on LCA to be filled (dedicated templates) by partners in charge of solutions development and demonstration sites (PV installations)
Timeframe for demonstration?	n/a
What project partners are involved in the successful demonstration and what are their exact responsibilities?	All, partners should provide input data on energy, materials and transportation processes according to the template
What is the contingency if the KPI is not achieved?	The novel strategies and solutions developed could be not achieve the desired target of improvement of the PV installation performance resulting in a lower reduction of some of the environmental impact categories. In this case, after a review of the potential of improvement, the KPIs will be revised.
What is the contingency if	Literature could help to complete data on PV plants/installations of the







KPI O5.1: Number of knowledge exchange and collaborations with relevant research project and groups

groups	
Responsible project partner	DTU
Revision authors	Sergiu Spataru
Original KPI	
Description	Number of collaborations with other PV systems' O&M projects (at least)
KPI baseline value and assumptions	
KPI target and unit	10
Revised KPI	
Description and significance	Number of knowledge exchange and collaborations with relevant research project and groups
	 What are relevant research project and groups? Any ongoing research project PV plant performance, operation, O&M, reliability, inspection Any active research groups working on PV plant performance, operation, O&M, reliability, inspection What are knowledge exchange and collaborations? Organization of common meetings and seminars where results or topics from Solaris and the collaborator are presented/discussed and discussed Hosting a student or guest from a collaborator to a Solaris Partner or vice-versa, working on a SOLARIs relevant research topic Collaborating on a research paper or research application between a SOLARIS partner and an external collaborator on a SOLARIS relevant research topic
Method of calculation or measurement	Each partner will keep track of their external collaborations as defined above, describing: • the nature of the collaboration • external collaborator involved







	time and place	
	Topic involved	
	Outcomes of the collaborations	
	DTU will compile these at the end of the project	
Data necessary, variables, formulas, tools	n/a	
Literature review and references of baseline values	n/a	
Baseline value and unit	n/a	
Target value and unit	20	
Revised KPI Evaluation and Demonstration within SOLARIS How will you demonstrate that you achieved it within the SOLARIS project?		
At which demo sites will you demonstrate it?	n/a	
What equipment, materials, and data will you require?	n/a	
Timeframe for demonstration?	M46	
What project partners are involved in the successful demonstration and what are their exact responsibilities?	Each partner will keep track of their external collaborations as defined above. DTU will compile these at the end of the project	
What is the contingency if the KPI is not achieved?	?	
What is the contingency if demonstration does not go as planned?	n/a	

KPI O5.2: Number of members in the Stakeholder Forum

Responsible project partner	DTU
Revision authors	Sergiu Spataru
Original KPI	
Description	Number of members in the Stakeholder Forum (at least)
	Partners will create a Stakeholder Forum (StF), gathering both PV systems' operators/end-users and technology providers, and particularly helpful during the design of strong business models for







	each solution developed and of the overall project exploitation plan to reach market integration of SOLARIS' solutions.
	Contribute to the sharing of research outputs as early and as widely as possible, mainly through the StF
	Engage key stakeholders from the beginning of the project (through Consortium members, as well as the StF) to promote responsible R&I, increase trust in science, as well as the chances to deliver the project objectives.
	Personal data will not be collected, to the exception of the Consortium & StF contacts. They will be available in the project SharePoint and accessible following the GDPR rules.
	Furthermore, the participation of relevant actors in the StF will clear the framework and align it with current regulations to ensure proper progress of the project until commercialisation of its solutions.
	Moreover, a StF will be created, gathering industrial members and endusers of SOLARIS' innovations, which will follow actively the project progress.
	Creation of a StF gathering >50 members at project end. A first list of members will be available at M12 (MS12). Such members will be gathered on a yearly basis (e.g. side event of consortium meetings) and will actively participate in networking activities and provide guideline to the Consortium ensuring to raise interest to relevant external stakeholders;
KPI baseline value and assumptions	
KPI target and unit	50
Revised KPI	
Description and significance	Who are the possible members of the Stakeholder Forum?
	PV plant developers, EPCs, O&M companies, owners
	PV plant development and operation engineers
	PV inverter and module manufacturers
	Solar and PV sensors and equipment manufacturers
	PV financing institutions
	PV communities and interest groups
	Inspection drone and payload developers







	PV policy makers
	 Members of international PV interest organizations and standardization bodies
	 Researchers from external research groups and projects that work on SOLARIS relevant topics
	What are the minimum responsibilities of the Stakeholder Forum members?
	They agree to be named in the StF
	They agree to receive yearly email updates on the SOLARIS project most important developments and results
	They agree to receive email invites to SOLARIS events
	 They agree to receive and respond based on availability on at least three SOLARIS questionnaires requesting feedback on the project methods and results.
	Is an NDA required for the StF members?
	Normally no, as the results disseminated in the newsletter should not contain sensitive information
	 However if some stakeholders will be involved more closely with some of the WPs and partners, where an NDA is necessary, this needs to be put in place for the specific stakeholder
	How will the StF members be recruited?
	Each SOLARIS partner will propose and invite at least 5 stakeholders
Method of calculation or measurement	Number of individual stakeholder members
Data necessary, variables, formulas,	Stakeholder info:
tools	Name, function/expertise, country, related partner, accepted terms, NDA signed where necessary
Literature review and references of baseline values	n/a
Baseline value and unit	n/a
Target value and unit	50
Revised KPI Evaluation and Demonstration within SOLARIS	







How will you demonstrate that you achieved it within the SOLARIS project?		
At which demo sites will you	n/a	
demonstrate it?		
What equipment, materials, and	n/a	
data will you require?		
Timeframe for demonstration?	M12	
What project partners are involved	Each SOLARIS partner will propose and invite at least 5	
in the successful demonstration and	stakeholders	
what are their exact responsibilities?	DTU and FOY will keep track of the STF members in the	
	 DTU and EQY will keep track of the STF members in the SOLARIS general file 	
	301 1110_benefat file	
What is the contingency if the KPI is	?	
not achieved?		
What is the contingency if	n/a	
demonstration does not go as		
planned?		

