Design of demonstrators testing program

Symbiosyst

Horizon Europe EU project
Grant Agreement No. 101096352

Funded by
the European Union

public

Document control sheet

Project	**SYMBIOSYST – Create a Symbiosis where PV and agriculture can have a mutually beneficial relationship**
Topic identifier	HORIZON-CL5-2022-D3-01-06
Grant Agreement N°	101096352
Coordinator	ACCADEMIA EUROPEA DI BOLZANO
Duration	01/01/2023 – 31/12/2026
Work package N°	WP5
Work package title	Demonstration of novel agri-PV solutions
Work package leader	EF SOLARE ITALIA
Task n°	5.2
Task leader	LUCISUN
Document title	Design of demonstrators testing program
Lead Beneficiary	3E
Dissemination level	Public
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Issue date	28/03/2024

History of versions

Version	Date	Author - Beneficiary	Comments
v01	28/03/2024	Gofran Chowdury – 3E	Final version

Acknowledgements

The work described in this publication has received funding from the European Union Horizon Europe research and innovation program under grant agreement № 101096352.

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Executive Summary

SYMBIOSYST is an innovative project at the intersection of agriculture and renewable energy, aiming to address climate change and resource depletion. By integrating photovoltaic (PV) technology with agriculture, the project seeks to meet renewable energy demands, enhance agricultural productivity, and reduce environmental impact. Key Performance Indicators (KPIs) guide the project's sustainability efforts. Demonstrator projects in various locations provide practical insights into scalable and sustainable Agri-PV systems. A sophisticated monitoring infrastructure supports optimising and refining system design and management practices. Overall, SYMBIOSYST drives collaboration and innovation for sustainable agricultural energy solutions, promising transformative change in global agricultural energy production and resource management.

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1. INTRODUCTION

The SYMBIOSYST project is a flagship innovation and sustainability project at the intersection of agriculture and renewable energy. Against the backdrop of escalating global concerns surrounding climate change and the depletion of natural resources, SYMBIOSYST emerges as a pioneering initiative, offering a holistic solution to address these pressing challenges. By seamlessly integrating photovoltaic (PV) technology with agricultural practices, the project not only endeavours to meet the growing demand for renewable energy but also seeks to enhance agricultural productivity and mitigate environmental impact.

At its core, the SYMBIOSYST project embodies a vision of symbiotic coexistence between agriculture and energy generation. Through the strategic deployment of agri-PV systems, the project endeavors to harness sunlight's power to drive sustainable food production and renewable energy generation. This holistic approach underscores the project's commitment to fostering synergy between seemingly disparate sectors, thereby fostering a more harmonious relationship with the environment.

Key Performance Indicators (KPIs)
At the heart of the SYMBIOSYST project lies a robust framework of Key Performance Indicators (KPIs), meticulously designed to assess the sustainability and efficacy of Agri-PV systems. These KPIs serve as a compass, guiding the project's endeavours towards holistic and balanced outcomes that encompass social, environmental, and economic dimensions. Crafted through a collaborative and interdisciplinary process, the KPIs reflect a nuanced understanding of the complex interactions inherent in Agri-PV systems.
By encompassing a diverse array of parameters, including but not limited to energy efficiency, agricultural productivity, environmental impact, and social equity, the KPIs ensure that the project's goals are aligned with broader societal aspirations. Moreover, their adaptability to diverse contexts and their iterative refinement through real-world feedback underscores the project's commitment to inclusivity, scalability, and continuous improvement.

Demonstrators Overview
The SYMBIOSYST initiative unfolds through a network of demonstrator projects spanning various geographic locales, each serving as a crucible for practical experimentation and knowledge dissemination in Agri-PV integration. From the pioneering orchards of Bolzano, Italy, to the innovative agricultural regions of Barcelona, Spain, and greenhouse experiments in the Netherlands, these demonstrator projects embody a diversity of contexts and challenges encountered in real-world Agri-PV implementation. Through meticulous observation, data collection, and iterative refinement, these projects illuminate pathways towards scalable, resilient, and sustainable Agri-PV systems, heralding a paradigm shift in agricultural energy production and resource management.

Monitoring System
At the heart of the SYMBIOSYST project lies a sophisticated monitoring infrastructure meticulously designed to capture real-time data about both the PV infrastructure and agricultural components of Agri-PV systems. Fixed monitoring stations, strategically positioned across demonstration sites, serve as sentinel nodes, continuously measuring and recording key parameters such as solar irradiance, ambient temperature, soil moisture, and crop health indices. Augmenting these fixed stations are mobile monitoring systems equipped with cutting-edge sensors and robotics, facilitating dynamic data collection and enabling targeted analysis of system performance under varying conditions. This comprehensive data-driven approach empowers researchers to glean insights, optimize system design, and refine management practices, thereby steering Agri-PV systems towards enhanced sustainability, productivity, and resilience.

Digital monitoring:
Within the SYMBIOSYST project, the integration of 3E's SynaptiQ provides a cutting-edge digital platform designed to facilitate the development, operational management, and analytics of renewable energy projects, particularly in the context of Agri PV. SynaptiQ's role involves developing specialized analytics and recommendation engines tailored to address challenges unique to the PV operation of Agri PV, such as preventing crop overshadowing of PV modules and

optimizing operations synchronized with agricultural activities. Through the implementation of advanced simulation modelling, operational asset management, and solar analytics, SynaptiQ will implement comprehensive functionalities aimed at maximizing the benefits of agri-PV systems.

In summary, the SYMBIOSYST project emerges as a driver for innovation and collaboration in the pursuit of sustainable agricultural energy solutions. Through concerted interdisciplinary efforts, pioneering demonstrator projects, and state-of-the-art monitoring infrastructure, SYMBIOSYST addresses the complexities inherent in Agri-PV integration and charts a course towards transformative change in global agricultural energy production and resource management.

Relation with other activities in the project:
This report will be the input for work packages 2, 3, and 5. In essence, it will be used as a blueprint for later demonstration installation and monitoring phases.

2. KPIs

Under the SYMBIOSYST project, the Key Performance Indicators (KPIs) are used to provide a methodology to test the Agri-PV field and test if it has been designed sustainably. Sustainability can here be interpreted as respect for social responsibility, preservation, improvement of agricultural parameters and crop quality, and warranty of electrical performances. By evaluating the KPIs on an Agri-PV field, it is possible to highlight synergies between the PV modules and the crops (e.g., reduction in water required by the crops) or to spot eventual weaknesses of the Agri-PV field (e.g., excess of shading), and to find possible solutions for the specific issues that might arise from the measurement campaign.

In the project proposal phase we already identified the following generic KPIs as shown in Table 1.

Table 1: KPIs identified during the project proposal phase

Parameter	KPI	Means of verification
Combined yield		
Land Equivalent Ratio	Land Equivalent Ratio	sum of area related yields
Optimisation of electricity yield		
Highest possible efficiency with semitransparency	Power density [MWp/ha]	Direct measurement
Increase in electricity yield thanks to optimized tracking algorithm	Energy Yield [kWh/kWp or GWh/ha]	Direct measurement
Cost reduction in operation and maintenance	Cost per year [Euros/kWp]	Use of Cost Priority Number (CPN) methodology[1]
Optimisation of crop yield		
Use of semitransparent modules	PV module active area [m/m]	Direct measurement
Use of functional coating to shift solar spectra	PAR measurement [mmol/m^2 or W/m^2]	Direct measurement
Use of precision farming	Number of sensors connected to external devices for optimized crop yield	List of sensors
Adoption of water resource optimization measures	Amount of water collected compared to reference area	Directly measured / comparison with control area
Plant phenotyping and Postharvest Quality traits	Growth (height, diameter, etc.), chlorophylls, PAR, cycle tracking. total yield, commercial yield, Colour, Size, Texture, Sugar content, Acidity.	biomass, total n. of fruits or pods produced, n. of fruits per plant / n. of pods per plant / n. of seeds per pod, average fruit/pot weight
Improvement of site ecological value		
Improvement of biodiversity	Reduction in use of pesticide and fertilisers. Flowering. Presence of pollinators.	Comparison with control area
Soil improvement and preservation	Soil improvement	Qualitative
Landscape integration	Aesthetic impact	Qualitative / quantitative via the use of modelling tools

Parameter / Index	Description / Unit
Installed nominal power and power density	MW, MW/ha
LAOR: *Land area occupation ratio*	%
Power and area normalised Yield	(GWh/MW-year) (GWh/ha-year)
PV module efficiency	%

[1] Developed by EURAC https://doi.org/10.1002/pip.2857

Min. and max height of PV modules from ground	m
Azimuth / orientation / tilt angle	Fixed / Variable, …
Covered area	m^2
Agri-PV volume (area x structure height)	m^3
System type	Fixed/ tracked (single or double axis)
PV module type	Opaque / transparent / bifacial
Foundations type	Shallow, deep
Field consumption	Permanent / not permanent
Distance between mounting structure	m
Width of cultivated land	m
Ratio between cultivated land and the agri-PV system	%
Culture type	Vegetables, horticulture, fruits, etc
Possibility to rotate the culture type	%
Precision farming typology	Active linked / Passive not linked to productive cycle
Presence of total or partial water catchment	%

During the first year of the project a methodology has been developed with the goal to define some Eco-design requirements and guidelines for Agri-PV. This has been done by defining a list of KPIs that an Agri-PV field needs to measure to be defined as a "Sustainable Agri-PV plant" in terms of social, photovoltaic and agricultural parameters. The final list of Key Performance Indicators (KPIs) will be refined within the time of the project, and further details on the methodology will be available in the public SYMBIOSYST deliverable *D4.1 – "Eco-design requirements and guidelines for agri-PV"* due in December 2024.

The KPI list and the scoring method for each indicator have been defined by Eurac Research, in collaboration with EF Solare, UPC, and by collecting feedback from both agricultural and photovoltaic experts. Up to now, 18 social, 18 photovoltaic and 35 agricultural indicators have been selected; some of them are qualitative indicators, others more quantitative, and only photovoltaic and agricultural indicators are described in this report. The aim of this Chapter is to introduce the methodology and briefly explain each indicator (Table 2 and Table 3), while the specific measurement methods for the qualitative indicators will be further described in Section 5 of the present Report.

PHOTOVOLTAIC KPIS

The photovoltaic KPIs are listed in Table 2 and are related to the electricity production system. Their measurement is essential to ensure sustainable electricity production and an adequate synergy between electricity production and agricultural activity. The indicators are structured to reward the Agri-PV systems that install modules manufactured locally (Europe). This would avoid the greenhouse gas (GHG) emissions related to transportation from other exporting countries and simultaneously support local manufacturers. Furthermore, buying from local European manufacturers helps to guarantee a fair level playing field in terms of working conditions along the PV supply chain, since this might not often be the case. Aspects related to the labor framework and conditions will be considered in more detail in the Social KPI list, which will be available in the Deliverable D4.1 due in December 2024. With this methodology, PV systems are valued more if they are made with a higher share of recycled materials, with lower GHG embodied emissions, and if there is a structured plan for reuse or high-quality recycling at the end of their life.

Other indicators are dedicated to ensuring the PV system's adequate efficiency. Finally, to benefit the stabilization of the grid, the KPIs are meant to reward the Agri PV systems with a clear plan for the use of the electricity produced, favouring self-consumption or Power Purchase Agreements (PPAs) instead of pure grid injection.

Table 2 List of Photovoltaic KPIs

#	CATEGORY	KPI NAME	DESCRIPTION	UNIT
1	Material use	Material sourcing for PV	Are the PV modules manufactured locally (in Europe)?	n.a.
2	Material use	Material sourcing for Balance of System (BOS)	Are the Balance of System (BOS) - supporting components and auxiliary systems (e.g., mounting structures, trackers, inverter) - manufactured locally (Europe)?	n.a.
3	Circularity and Eco-design	Recycled input materials used - PV - weight indicator	Are recycled materials used to produce the PV modules used in the Agri-PV system?	n.a.
4	Circularity and Eco-design	Eco-design of PV plant	Do the PV system suppliers have written documents certifying that they are following eco-design principles in their manufacturing?	n.a.
5	End-of-life	End-of-life management plan of PV	Will the PV modules at their end-of-life follow a recycling process that is specific for PV systems, or will it follow a generic electronic waste route?	
6	End-of-life	Percentage of recycled waste	Percentage of PV waste (by weight) that is recycled at the PV system end-of-life	%
7	End-of-life	Reuse of PV-modules	At the end of its lifetime, are the PV module tested to be reused in the PV second-hand market in EU?	n.a.
8	Electricity	PV Energy yield	Annual AC photovoltaic electricity produced by 1 kWp of PV capacity installed	kWh/kWp
9	Electricity	PV energy coverage	Share of energy required by the farm (e.g., light, irrigation, charging of electric machines) that is covered by PV electricity	%
10	Electricity	PV energy usage	Is there a plan to use the electricity in most efficient way to optimize the grid stability?	n.a.
11	Electricity	Tracking system optimization	Are there optimized tracking algorithms in place, to maximize energy production?	n.a.
12	GHG emissions	GHG emissions for PV modules production	Kilograms of CO2-Equivalents emitted during the PV modules production step, for a defined functional unit (1 kWp of PV installed)	kg CO2-Eq/kWp
13	GHG emissions	GHG emissions for BOS production	Kilograms of CO2-Equivalents emitted during the Balance of System (BOS) production, for a defined functional unit (1 kWp of PV installed)	kg CO2-Eq/kWp
14	General	Environmental screening of new PV suppliers	Are the suppliers of PV systems checked in terms of environmental sustainability? (E.g., are they required to have an environmental certification/ label?)	n.a.
15	General	Communication on the environmental	Are the policies regarding environmental sustainability measurements	n.a.

		sustainability - inside the organization	transparently communicated and/or are there internal trainings on the topic, among the workers involved in the agri-PV system?	
16	General	Communication on environmental sustainability - outside the organization	Are the policies regarding environmental sustainability measurements transparently communicated and/or are there internal trainings on the topic, outside the organization?	n.a.
17	General	Landscape integration impact	Is there a plan to measure and collect information on the stakeholder perception of the visive impact of the Agri-PV system?	n.a.
18	General	Landscape integration measurements	Are there measurements in place to better integrate the Agri-PV system in its landscape (e.g., with colour modules)?	n.a.

AGRICULTURAL KPIS

The aim of the selected agricultural indicators listed in Table 3 is to prove and ensure that plants' health and crops' quality are equal – if not higher – in comparison with the same plants without an Agri PV system above.
In some cases, there might be synergies between agricultural parameters and the agri-PV system. For example, the PV modules above the plant could decrease the plant's water retention and soil underneath the modules, which could help to better cope with periods of drought. On the other hand, it is also essential to ensure that PV modules do not provide an extreme shadowing effect over the plant, do not block the photosynthetically active radiation (PAR) required, or negatively affect the plant's health for other reasons.

The KPI list also considers that, when installed on grasslands and pastures, agri-PV systems could influence the biodiversity of the field positively, for species that could take advantage of the shadow under the PV panels, but also in a negative way if not appropriately designed (e.g., not enough space for animal pasture).

Table 3 List of agricultural KPIs

#	CATEGORY	KPI NAME	DESCRIPTION	UNIT
1	End-of-life - Agriculture	End-of-life management plan for agricultural field	Is there a sustainable restoration plan in place for the Agri-PV field at the end of its lifetime?	N.A.
2	End-of-life - Agriculture	Valorization of agricultural waste	Is there an energetic valorization plan for agricultural waste (annual pruning)?	N.A.
3	Water	Water efficiency	The difference in water needs in the Agri-PV field, compared to the reference demand of the control area without Agri-PV, expressed as the difference in the humidity between the control area without PV and the area with Agri-PV	%
4	Water	Water resource optimization	Are there rainwater recovery systems in place?	N.A.
5	Land use	Land occupation	Agriculturally usable area/ Agri-PV overall area (%)	%
6	Land use	Land use efficiency	Comparison between amount of PV modules and number of plants in	%

			comparison with a control area, without Agri-PV	
7	Biodiversity	Presence of non-cultivated areas to improve biodiversity	Are there non-cultivated areas next to the cultivated ones (e.g., hedges, small ponds and rows of trees, to increase the presence of pollinators and maintain the landscape), that could improve biodiversity?	N.A.
8	Biodiversity	Flowering	Difference between the amount and diversity of flowering behind trees on a control area, and an Agri-PV area of the same size, in a certain time (only valid for grasslands and pastures)	N.A.
9	Biodiversity	Wild pollinators (bees)	Difference between the presence of wild pollinators on a control area, and an Agri-PV area of the same size, in a certain time? (only valid for grasslands and pastures)	N.A.
10	Biodiversity	Butterflies	Difference between the presence of butterflies on a control area, and an Agri-PV area of the same size, in a certain time? (only valid for grasslands and pastures)	N.A
11	Biodiversity	Birds	Difference between the presence of birds on a control area, and an Agri-PV area of the same size, in a certain time? (only valid for grasslands and pastures)	N.A.
12	Plant phenology	Plant vigor - Plant/ sprout height	Difference between average height of the plant (for horticulture)/ length of shoots (for trees) in a control area, and in an Agri-PV area of the same size, at certain point in time	m
13	Plant phenology	Plant vigor - Plant diameter	Difference between average diameter of the plant in a control area, and in an Agri-PV area of the same size, at collection time	m
14	Plant phenology	Number of fruits per plants (or total n. of fruits or pods produced/n. of pods per plant)	Difference between average number of the fruits/ vegetables/ pods per plant in a control area, and in an Agri-PV area of the same size, at collection time.	#/control area
15	Plant phenology	Photosynthetically active radiation (PAR)	Difference in PAR (Photosynthetically active radiation) between a control area, and an Agri-PV area of the same size, at the same point in time	W/m2
16	Postharvest Quality traits	Average fruit/ vegetable diameter	Difference between average diameter of the fruit/ vegetable in a control area, and in an Agri-PV area of the same size, at collection time	cm
17	Postharvest Quality traits	Average fruit/vegetable weight	Difference between average weight of the fruit/ vegetable in a control area, and in an Agri-PV area of the same size, at collection time	kg
18	Postharvest Quality traits	sugar content	Difference between average sugar content of the fruit/ vegetable in a control area,	brix

			and in an Agri-PV area of the same size, at collection time	
19	Postharvest Quality traits	acidity	Difference between average acidity level of the fruit/ vegetable in a control area, and in an Agri-PV area of the same size, at collection time	pH
20	Postharvest Quality traits	external appearance	Difference of color, sunburn, russetting etc. between fruit/vegetable in a control area, and in an Agri-PV area of the same size, at collection time	%
21	Postharvest Quality traits	market fit check	Does the harvest of the Agri-PV area fit in the same market standard of the harvest of the control area? Measure the % of harvest from the Agri-PV field, that fit the same market standard of the control area without Agri-PV	%
22	Postharvest Quality traits	Crop quality protection measurement	Are there measurements in place to protect crop quality (e.g., semitransparent modules, irrigation with sensors)?	
23	Soil improvement and preservation	soil ph	Difference between average acidity level of the soil in a control area, and in an Agri-PV area, at the same point in time	pH
24	Soil improvement and preservation	soil quality	Difference between average temperature of the soil in a control area, and in an Agri-PV area, at the same point in time	°C
25	GHG Saving in agricultural machinery activities	Agricultural machinery use	Difference between hours of machinery required in a control area, to harvest a certain quantity of biomass, and an Agri-PV area of the same size, in a certain time frame (year). Only for open fields	hours/year*control area size
26	GHG Saving in agricultural machinery activities	GHG of agricultural operations of machinery used in the field	Difference between GHG emissions of machinery used in a control area, to harvest a certain quantity of biomass, and an Agri-PV area of the same size, in a certain time frame (year). Only for open fields	kgCO2-eq/year* control area size
27	Plant phenology	Plant vigor - Plant/ sprout height	in the case of the newly planted apple orchard the new growth of annual shoots will be measured at the end of the vegetative season. On a selected number of trees all the shoots with length of >10 cm will be measured and recorded, yielding the total number of shoots, the sum of annual shoot growth and mean shoot length per tree	
28	Plant phenology	Plant vigor - Plant diameter	in the case of the newly planted apple orchard the increment of trunk diameter will be measured as the difference of trunk diameter at the beginning and at the end of	

			the vegetative season. Measurements will be taken with a measuring tape.	
29	Plant phenology	Number of fruits per plants (or total n. of fruits or pods produced/n. of pods per plant)	On a number of selected trees per treatment all the apples will be individually harvested into separate boxes. These boxes will be taken to an atuomatic grading machine, where for each apple the following parameters will be measured and recorded: fruit weight, percentage of green, yellow and red colour. These data will be used to calculate means/sums per tree	
30	Plant phenology	Photosynthetically active radiation (PAR)	PAR sensors connected to dataloggers will be installed in the different experimental plots according to a commonly defined protocol	
31	Postharvest Quality traits	Average fruit/ vegetable diameter	fruit weight will be recorded after harvest on a grading machine, fruit size will be derived from fruit weight	
32	Postharvest Quality traits	Average fruit/vegetable weight	fruit weight will be measuired and recorded after harvest on a grading machine	
33	Postharvest Quality traits	sugar content	Various samples will be taken from the different experimental plots for destructive analysis of sugar content, acidity and fruit firmness using a Pimprenelle automatic analyzer	
34	Postharvest Quality traits	acidity	Various samples will be taken from the different experimental plots for destructive analysis of sugar content, acidity and fruit firmness using a Pimprenelle automatic analyzer	
35	Postharvest Quality traits	external appearance	Fruit color will be assessed on all harvested apples with the automatic grading machine. External damage, such as sunburn will be recorded by visual assessment.	

3. DEMONSTRATORS

In this section, we aim to outline the progress made in the SYMBIOSYST project, focusing on the development of Agri-PV demonstrators. We share insights gained from designing these systems, introduce new findings, and recommend best practices.

Currently, the Agri-PV industry is in an early stage of development, emphasizing the learning process. Agri-PV systems need to be adaptable to specific local and regional needs. This implies that not all aspects need to be standardized immediately. In the SYMBIOSYST project, we are testing different hypotheses and types of demonstrators. Each one has its own unique features, strengths, and limitations.

This part of the report showcases our experiments and the rationale behind the design and testing of each demonstrator. Through this, we aim to contribute to the broader community's understanding of Agri-PV systems, highlighting the need for flexibility and adaptation to local contexts. This approach is intended to foster a more inclusive and comprehensible dialogue, inviting readers from varied backgrounds to engage with the findings and insights we have gathered so far.

Designing Agri-PV demonstrators implies several important considerations, which we list below. We then summarize the main findings we obtained when applying our modelling tools to the design of several demonstrators, which is related to a previous detailed work in Deliverable D5.1 “Conceptual Design of the agri-PV demonstrators”.

The system configuration can be driven by several key considerations, among which:

- Optimal panel orientation and spacing: Designing Agri-PV systems requires careful consideration of the solar panel layout to ensure adequate sunlight reaches the crops below. Studies suggest an east-west orientation maximizes light penetration, especially for row crops, while optimizing panel spacing minimizes shading and allows for machinery access.
- Height and tilting of panels: Adjustable panel heights and tilting mechanisms can accommodate different crop types and growth stages, improving light availability and reducing the risk of mechanical damage during agricultural operations.
- Selection of crop types: Prioritizing crops with lower light requirements or those that benefit from partial shading can enhance compatibility with Agri-PV. Research indicates that certain leafy greens and root vegetables exhibit improved quality and yield under Agri-PV conditions. However, in SYMBIOSYST, other parameters were also included in the decision-making process of choosing the crops to be tested, including their economic interest in Europe and suitability for the climates under study.
- Agricultural machinery adaptation: Customizing or selecting agricultural machinery that fits within the Agri-PV layout is crucial for maintaining operational efficiency and preventing damage to solar panels.

For the design of Agri-PV demonstrators, it is important to define the objectives and the project planning. Clear objectives should ideally include establishing clear, measurable objectives for Agri-PV demonstrators, such as yield improvement, water savings, or biodiversity enhancement, to guide the design process and evaluation criteria.

Stakeholder engagement is also a key factor for the success of Agri-PV demonstrators. It is, therefore, necessary to involve local farmers, communities, and researchers from the outset to ensure the project meets practical agricultural needs and facilitates knowledge exchange.

Scalability and replicability are also key elements to be considered because it is essential to allow for the assessment of system performance under various conditions and scales, enhancing the potential for broader adoption.

BOLZANO, ITALY

Use case 1	**Bolzano orchard of the future**
Unique Value Proposition	Solution for the Apple Orchard of the future that can integrate irrigation, antifreeze, hail and insect protection, resistant to chemical products keeping the height < 3.5 m for 3D and 2D plant growth. Trackers will be installed every other row.
Location	Province of South Tyrol The coordinates where the prototype will be located are as follows: • 46°20’38.94’’N; 11°16’40.82’’E; 
Replication potential	70 ha of Guyot apple tree, 600 ha/y of renewed apple fields in South Tyrol that could be converted to 2D plant growth. The application is extended to any Guyot cultivation. It can be applied to vineyards and pears that are already in 2D configuration. 2500 ha per year worldwide.
Crop	The Bolzano demo will be focused on apple trees, N-S orientation, on existing apple three (< 3/3.5 m, 3D growth, <3.2 m interrow) and on Guyot (< 3/3.5 m, 2D growth, <2.5 m interrow). The rotation axis will be 4.78 m high, which was decided according to the needs of the agricultural machinery passing through the rows. Given the length of the photovoltaic modules positioned in portrait mode, this tracker height allows a minimum module height of 3.8m. The selected site is designated for the cultivation of fruit trees, specifically the Ipador (Giga) apple variety.
Solutions implemented in the demo and demo details	Ten trackers with 24 modules each will be installed. The height of the trackers is such that all other components of the system will fit under them. In the case of the Laimburg Demo, the height will be 4.78 m to the beam. Weathering Steel for the structure will be considered (only if available at the time of tracker construction) as having a low environmental and

	visual impact in an agri-PV field. It is proposed to develop a crop + PV smart tracking algorithm for this project focused on the needs of Bolzano's side.
Water catchment/irrigation	Water collected by the tracking system is comparable to a roof without a gutter. Water will be conveyed to avoid issues with the plants below. Irrigation comes from sprinklers used also as antifreeze systems. An innovative prototype rainwater harvesting system (designed to be mounted on trackers) is under development.
Health &Safety	At the moment, there are no specific norms for agri-PV (grounding, etc). Rapid shutdown as from roof/facade systems is under consideration. The use of pesticides which could reach the PV modules will also be considered.
System Integration	Hail protection systems cover 70% of crops in South Tyrol. Agri-PV needs to be integrated. Symbosyst's plant design incorporates hail nets and frost protection into the structure.
Use of electricity	LAIMBURG has identified several sites for the installation. The final choice will also depend on the existing availability of electricity connections, and we will create the conditions to electrify water pumps for irrigation to create an infrastructure for charging electrical tools.

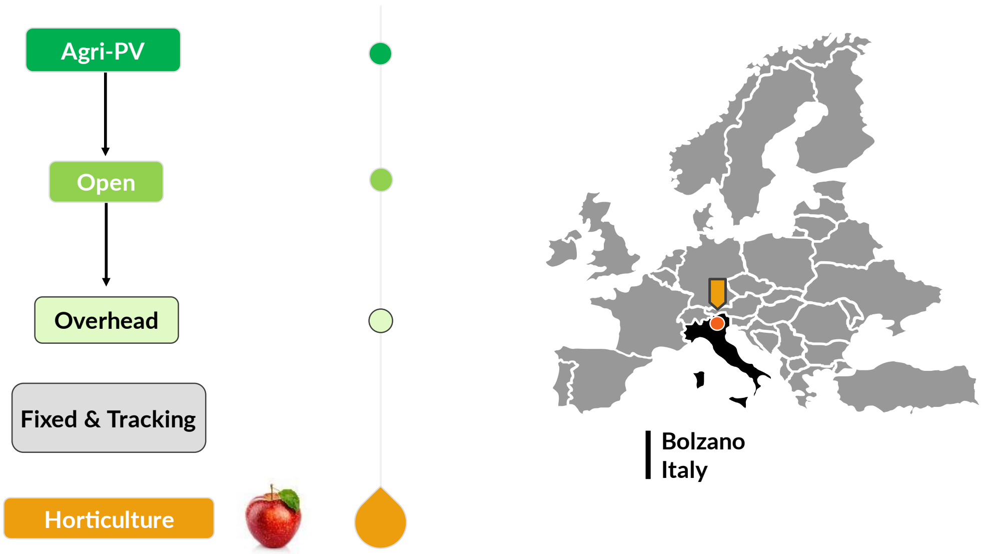


Figure 1: Agri-PV taxonomy and demonstrator location.

The location of the demonstrator, along with the agri-PV taxonomy, is displayed in Figure 1. Figure 2 shows the portion of land covered by the Bolzano Demo and the front view of an apple orchard row.

Figure 2: Front view of an apple orchard row on the left. On the right portion of land interested by the agri-PV demonstrator

The Bolzano demo will consist of three distinct parts:

- The first portion, designated as "Existing Plant," consists of four separate rows of trackers, each containing 24 modules. This portion will be installed on agricultural land where apple trees are already present. The distance between rows of plants in this area is 3m.
- The second portion, designated as "New Plant," consists of a 2 x 3 matrix of trackers, each with 24 modules. It will be installed on agricultural land where, concurrently, a new section of the existing apple orchard will be established. This new section will differ in terms of the spacing between the rows of trees. The distance between rows of plants in this area is 2.5m.
- Close to each portion, two reference areas, one with existing apple tree, another with new 2D orchard (without PV structures) are designed (and monitored) in order to provide measurements and yields for comparisons.

Another important difference between the two sectors, on an agronomic level, is the planting pattern. In the existing plant, the plants are of the 'spindle' type of training, whereas in the new plant, the plants are of the Guyot type, which allows for more 2D growth and, therefore, less width development.

As far as the tracker structure is concerned, an attempt was made to find a sufficient height for the axis of rotation of the panels so that it would be able to have spaces underneath it for plants, the frost protection system, irrigation systems and hail nets. Figure 3 shows the trackers used in the Bolzano demo laterally and in section.

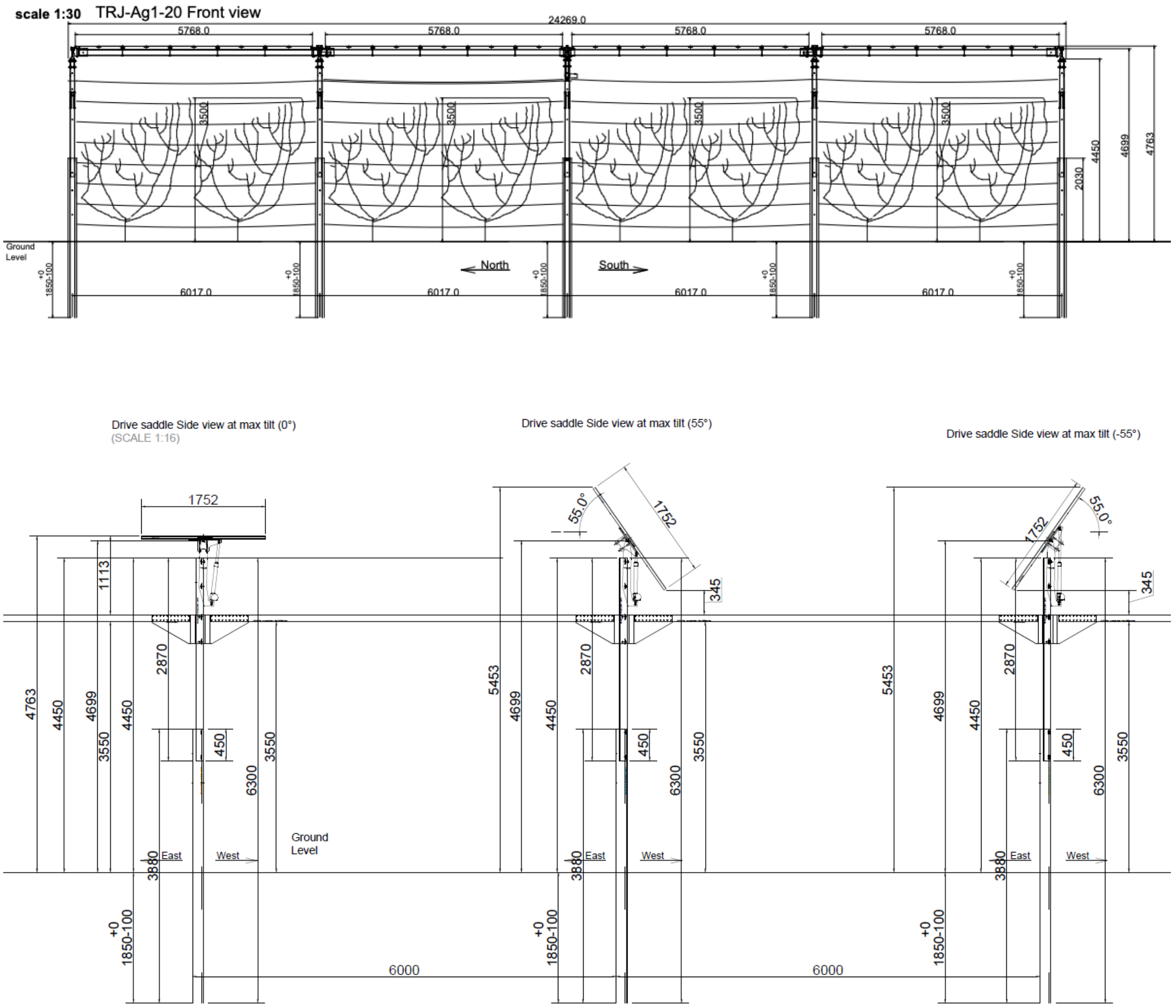


Figure 3: layout and details of the tracking system

With regard to the photovoltaic modules studied within the project and their impact on the agricultural crop planted underneath them, aleo solar presented some possible different levels of transparency (Figure).The four solutions proposed by the PV module manufacturer are shown in Figure 4.

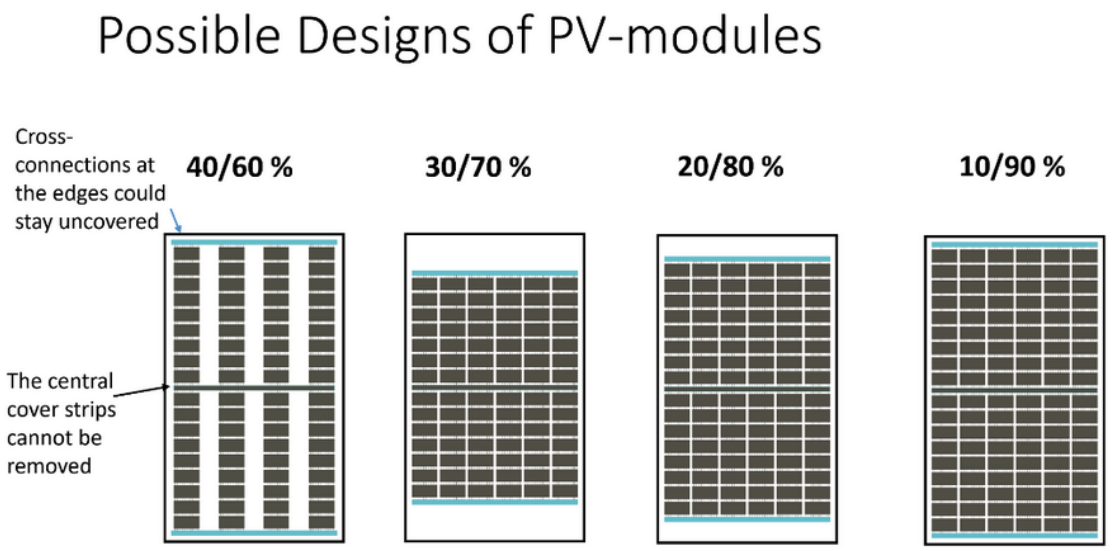


Figure 4: Overview of the four different solutions proposed by the PV module manufacturer, aleo

Within the SYMBIOSYST project for the Bolzano demo, the installation of two types of modules with two different levels of transparency was evaluated:

- aleo bifacial, standard transparency;
- aleo bifacial, with a higher transparency factor than the standard.

Figure 2 (right) shows the sections covered by the two types of photovoltaic modules. Currently, the solution considered to be of most interest and therefore considered is the one with 40/60% transparency and the 10/90% solution (standard transparency).

As part of the preliminary phase, we evaluated 11 distinct scenarios, each proposing a unique installation strategy for the PV modules. Through a thorough comparative analysis, we identified the implementation of an elevated tracker system with PV modules arranged in a 1P configuration as the superior solution. This method offers an optimal balance between capital expenditure (CAPEX), expected productivity, and geometric consistency, ensuring seamless integration with the existing orchard landscape.

Central to our design is the use of horizontal single-axis trackers (HSAT) aligned along the NNE-SSW axis, known as roll trackers. In Northern Italy's climate context, this solar tracking configuration is projected to enhance energy production by 15-20% compared to static installations. This increase in efficiency stems from the system's ability to adjust and optimize the angle of incidence for direct sunlight across the day.

An innovative feature of our tracking system is the integration of a backtracking algorithm, which significantly reduces the potential for shading between modules on adjacent trackers during times of low solar elevation. As a result, a PV installation utilizing this algorithm is expected to outperform systems without such technology in terms of energy yield. Furthermore, the algorithm is adaptable, allowing for adjustments to accommodate specific requirements associated with the underlying agricultural activities.

Each tracker in our agri-photovoltaic (PV) system is intricately designed to support 24 photovoltaic modules meticulously organized into four groups. Each group contains six modules distributed across four spans, allowing for comprehensive coverage that maximizes solar energy capture. This specific configuration enables the PV modules to rotate up to ±55°, a feature critical for optimizing the incidence angle of sunlight throughout the day. The spatial arrangement between the modules—0.15 meters apart within each group—ensures minimal shading while maintaining efficient use of space. In portion A, trackers are strategically placed 6.4 meters apart, a decision aligned with the pre-existing orchard spacing of 3.2 meters. For portion B, we have adapted the layout to a 5-meter pitch, corresponding to a denser orchard spacing of 2.5 meters, demonstrating the system is flexibility to various agricultural environments. The rotation axis of the trackers, positioned at an elevation of approximately 4.7 meters, and the modules' 1P (Portrait 1) configuration are critical design choices aimed at enhancing efficiency and integrating seamlessly with the agricultural landscape.

The engineering framework of our system introduces an element of complexity, rendering it statically indeterminate (hyperstatic). The incorporation of beams perpendicular to the tracker axis transforms the structure into a robust truss-type configuration. This design not only supports the mechanical stability of the system but also underscores the importance of engineering resilience in agri-PV setups.

Our photovoltaic generator leverages two types of bifacial PV modules: the aleo with standard transparency and the aleo with higher transparency. This diversity in module transparency is pivotal for agri-PV systems, allowing for tailored light penetration to meet the photosynthetic needs of the crops below. The decision to focus on configurations with 40/60% transparency and the standard 10/90% transparency solution emphasizes the project's commitment to optimizing the balance between solar energy production and agricultural yields.

Specifically, the first portion of the demo will incorporate 96 standard transparency modules across four trackers, while the second portion will blend 72 standard modules with 72 high transparency modules, totalling 144 modules across six trackers. This approach exemplifies good practice in agri-PV design, where the choice and arrangement of PV modules are carefully considered to support both energy and agricultural objectives.

Several additional considerations have been considered or are currently under discussion:

- **Anti-ice system**: The sprinklers, utilized both for irrigation and as an anti-ice system during the cold nights of spring's flowering season, are installed at a height incompatible with the mounting structures. A new system will be implemented, featuring dedicated sprinklers for each tree/plant. This system may also serve as a treatment against pests and fungi.
- **Hail-Net**: The existing hail protection system will be repurposed for portion A, while a new installation is planned for portion B. The discussion regarding the integration and compatibility with the tracker mounting structure is still in progress.
- **Rainwater collection systems**: The analysis of implementing a rainwater collection system on tracker structures, as opposed to fixed structures, has revealed challenges in finding a solution that does not significantly increase the iron content of the structure to collect water at the PV panels' edges. Efforts to identify a viable solution are ongoing.
- **Monitoring and sensors**: as described in the dedicated section.

A variety of parameters will be monitored to evaluate both the photovoltaic and agricultural aspects of the agri-voltaic system. On the agricultural side, monitoring will focus on assessing plant health, vigour, and crop yield, in addition to environmental and soil conditions. Photosynthetically Active Radiation (PAR) will also be tracked. For the photovoltaic component, a meteorological station will be established to measure standard parameters such as air temperature, humidity, wind speed, and direction.

Ongoing discussions aim to:

- Identify a solution for the rainwater collection system.
- Determine the precise placement of the sprinklers.
- Ascertain the exact locations for the fixed sensors.

This ambitious study benefits from the collaboration of several partners, each contributing distinct methodologies to investigate the feasibility and advantages of Agri-PV systems. A key goal of this project is to boost crop yields while concurrently generating renewable energy, thus fostering sustainable farming techniques.

The demonstration site in Bolzano has been carefully designed to support the cultivation of the Ipador (Giga) apple variety. This arrangement includes a dual-part setup that incorporates existing orchards and new planting areas. Optimized for a north-south orientation and utilizing the Guyot training system for apple trees, this setup aims for efficient space use and optimal sunlight exposure. The project showcases its dedication to environmental sustainability through the employment of Convert multifunctional trackers made of weathering steel, which blends seamlessly into the landscape and minimizes visual impact. These adjustable-height trackers are engineered to support semi-automatic farming equipment, reflecting the project's focus on technological innovation and integration.

A novel aspect of the project is its delineation of areas with and without PV installations, facilitating a detailed assessment of the Agri-PV system's effects on both crop development and energy yield. The system, designed to support approximately 90 kWp, will accommodate 240 modules with varying degrees of semi-transparency.

Innovative 3D modelling techniques utilized by partners such as LuciSun, Imec, and TU Delft simulate the Agri-PV system's performance. These simulations provide insights into shading patterns, energy efficiency, and potential impacts on crop yields, ranging from intricate representations of plant morphology to simplified models that streamline computational requirements while offering valuable perspectives on photosynthesis and crop development within Agri-PV settings. Preliminary results were described in Deliverable 5.1.

BARCELONA, SPAIN

Use case 3	AGRIVOLTOPOLIS
Unique Value Proposition	Solution for the vegetable crops of the future that can integrate bird and insect protection, resistant to chemical products keeping the height up to 3 m for 2D.
Location	Barcelona province (Baix Llobregat Area).
Replication potential	The Baix Llobregat area has 859 ha and Barcelona province has 4153 ha of vegetable crops. Application could be extended to other open field vegetable cultivation and seasonal field crops.
Crop	The demonstrator in Barcelona, Spain, will be aimed at the production of short-stature and trellised seasonal vegetables (tomatoes, melon, lettuce, and fava beans) cultivated in rows between & under the trackers. This choice is particularly useful for the project, as it is complementary to the demonstrator planned in the Bolzano area (apple tree) and Scalea (citrus).
Solutions implemented in the demo	To ensure free movement of semi-automatic agricultural devices, the module's low point should exceed 2 meters to avoid human injury, optimized for various crops like tomatoes. Without perennial cultures, steel pile driving is viable, similar to PV projects. Locally sourced wood will construct the tracker piles' visible parts, with steel for the rest. Convert will utilize weathering steel for tracker manufacturing to minimize environmental and visual impact. A smart tracking algorithm integrating crop and PV data will be developed. UPC will design an autonomous robot

	for real-time weather data collection and tracker communication, offering a more efficient alternative to numerous fixed sensors, especially with seasonal vegetables. Convert, EURAC, and 3E will oversee the algorithm's development. The Barcelona demonstration site will feature 10 trackers x 14 (or 15) modules for a nominal power of at least 44.24 kWp. The site will be divided into 5 trackers with opaque PV modules and 5 trackers with semitransparent PV modules. The pitch between the 2 solutions will vary with 5.8 (opaque modules) and 4.05 m (semitransparent modules), respectively. The final design will be described in the next deliverable.
Water catchment / irrigation	Water will be conveyed to avoid issues to the plants below. The water will be collected and redirected to the already available rainwater reservoir to later be used for drip irrigation.
Health &Safety	At the moment there are no specific norms for agri-PV (grounding, etc). Rapid/emergency shutdown will be studied. The use of pesticides and other chemical products will be done by following the safety rules and their possible harmful effect on the PV modules will also be considered.
System integration	In this Use Case, the biggest problem against vegetables are insects and birds. Therefore, the use of nets (that do not block excessively the sun) is suggested, to be tied to tracker posts.
Use of electricity	There is already an existing electrical installation. The PV modules could be directly connected to it, and the electricity could be later used in the irrigation system as well as to facilitate the charge of electrical tools and vehicles.

The Baix Llobregat area of Barcelona province, with its 859 hectares dedicated to vegetable crops out of the province's total 4153 hectares, is poised to become a pioneering region for the integration of agriculture and photovoltaic (PV) technology. The demonstrator project in Barcelona, Spain, focuses on the innovative production of short-stature and trellised seasonal vegetables such as tomatoes, melons, lettuces, and fava beans. These crops are strategically cultivated in rows between and underneath PV trackers, a method that not only optimizes land use but also complements other demonstrator projects focused on different crops and regions, such as apple trees in Bolzano and citrus in Scalea.

The PV system's output shall be connected to the main power distribution board of the Agròpolis site (the point where the electricity comes in from the street.). Feeding electricity into the grid is not allowed, so a mechanism to prevent this shall be installed. As all electricity from the system must thus be consumed onsite, the site host is encouraged to optimise their electricity use around peak generation times to take advantage of it. Finally, it is hoped that local legislation will change someday, allowing the sale of such renewable electricity to the local market via the existing grid connection.

A construction permit has been required from the local municipality, Viladecans. Furthermore, considering the proximity to the airport, an additional permit from the AESA (Spanish Aviation Safety and Security Agency) was required.

One of the key design considerations for this agri-PV system is ensuring the safety and efficiency of semi-automatic agricultural devices. The modules' lowest point will exceed 2 meters, minimizing the risk of human injury and facilitating the care of various crops, particularly tomatoes. The absence of perennial cultures in this system allows for the use of steel pile driving, a common practice in PV installations, with locally sourced wood and steel comprising the visible and structural components of the tracker piles, respectively. Convert's choice of weathering steel for tracker manufacturing reflects a commitment to minimizing environmental and visual impacts.

A sophisticated tracking algorithm is under development to harmonize the dual objectives of crop cultivation and PV energy generation. The Universitat Politècnica de Catalunya (UPC) is tasked with designing an autonomous robot capable of real-time weather data collection and communication with the trackers, representing an advanced alternative to traditional fixed sensor networks. This innovation is especially beneficial for managing the variable needs of seasonal vegetable crops. The algorithm's development is collaboratively overseen by Convert, EURAC, and 3E, ensuring a multidisciplinary approach to its creation.

Water management within the agri-PV system is meticulously planned to prevent any adverse effects on the plants below. Rainwater will be collected and redirected to existing reservoirs for subsequent use in drip irrigation systems, demonstrating an integrated approach to resource conservation.

The project also addresses the regulatory vacuum regarding agri-PV installations, with considerations for grounding requirements and emergency shutdown protocols underway. The application of pesticides and other chemical treatments will adhere to strict safety guidelines to prevent potential damage to the PV modules.

Insect and bird predation poses significant threats to vegetable crops, necessitating the implementation of protective netting that minimizes sunlight blockage. These nets will be affixed to the tracker posts, providing a practical solution to pest management without compromising solar energy capture.

The existing electrical infrastructure facilitates the direct connection of PV modules, enabling the generated electricity to be utilized for irrigation systems and the charging of electrical tools and vehicles, further enhancing the sustainability and self-sufficiency of agricultural operations.

The project's research component is rigorous, with a two-year study period focusing on four distinct crops across two growing seasons each year. The first fiscal year, 2025, will examine the cultivation of fava beans and lettuce during the autumn-winter season from November 2024 to March 2025. Detailed 3D modelling of the crops will aid in understanding the complex interactions between plant growth and PV system performance, with an initial emphasis on lettuce and tomato crops. This comprehensive approach to modelling and simulation is instrumental in optimizing the agri-PV system design for enhanced crop yield and energy production, setting a precedent for future agri-PV initiatives worldwide.

In the quest to optimize agricultural productivity under photovoltaic (PV) systems, the project employs a simplified approach to model the growth and spatial arrangement of lettuce and tomato crops, alongside detailing the layout for all four selected crops: lettuce, fava beans, tomatoes, and onions. This streamlined modelling technique is instrumental in assessing the impact of shading from PV installations on crop growth and optimizing light distribution for enhanced yield.

Lettuce Modeling

Lettuce crops are modelled as hemispheres with a radius of 10 cm, arranged in four rows divided into two groups, each containing two closely positioned rows. This configuration results in a compact grouping with a 20 cm gap between the two sets of rows. However, due to spatial constraints on the terrace, fitting four rows of lettuce within a 90 cm wide strip poses challenges, especially when maintaining the necessary spacing between rows. The arrangement necessitates 80 cm to accommodate the rows, leaving minimal space on the edges of the terrace.

Fava Beans Layout

The terrace will host two rows of fava beans, with a 0.6 cm pitch between rows and a 0.4 cm spacing within rows. This arrangement allows for the efficient organization of fava bean plants, ensuring optimal growth conditions.

Tomato Crop Representation

Tomatoes are represented by a rectangular cuboid to encapsulate a row of plants, with a designated height of 0.7 m—despite observations that most tomato plants do not exceed 0.5 m in height. This modelling choice is made to simplify the assessment of light distribution under the PV system. The unique growth pattern of tomatoes at this site, spreading across the ground without support structures, is noted for its distinctiveness compared to typical vertical growth patterns. Initially, the crop envelope is modelled with exaggerated dimensions to study the shading impact effectively, with plans to adopt a more realistic representation in later study phases.

Onion Planting Scheme

Onions are planted in four rows per terrace, divided into two groups with a 20 cm gap. The spacing within each row is also set at 20 cm, optimizing the use of space while accommodating the growth needs of the onion crops.

Summary of Crop Growth and Cultivation

This detailed approach to crop modelling under agri-PV systems underscores the project's commitment to advancing sustainable agriculture practices. By closely examining the spatial arrangements and growth patterns of specific crops, the project aims to derive insights that will inform the development of agri-PV systems capable of supporting diverse agricultural needs while maximizing renewable energy production.

The innovative agricultural photovoltaic (Agri-PV) system proposed for Barcelona represents a pivotal step in understanding the intricate balance between energy production and agricultural yield. This initiative focuses on the meticulous estimation of light penetration to the agricultural fields, specifically designated for the cultivation of crops, under the influence of the PV system. Such an analysis ensures that energy generation and crop growth are optimized within the Agri-PV system framework.

The core of this study revolves around the calculation of shading loss percentage. This critical metric quantifies the reduction in light levels due to the presence of the PV system compared to an unobstructed scenario. This quantification is crucial for adjusting the PV system design to enhance light availability for crops.

Further scrutiny reveals comparisons between Section 1 and two variants within Section 2: 2A and 2B, with Section 2A employing aleo PV modules known for their 40% semi-transparency and Section 2B differing in the height of its supporting frames. This distinction assesses how variations in the PV system's structure affect light penetration to the crops below.

The designated area for crop cultivation serves as the primary zone for evaluating the incident irradiance, crucial for understanding how the PV system's shading influences crop exposure to sunlight. The application of a mesh overlay in the analysis allows for precise measurement of irradiance at various points, facilitating a comprehensive understanding of light distribution patterns across different timescales.

This Barcelona Agri-PV project intends to cultivate a variety of short-stature and trellised seasonal vegetables, including tomatoes, onions, lettuces, and fava beans, beneath and between the PV trackers. This diversified approach not only aims to maximize land use efficiency but also complements other Agri-PV initiatives, thereby enriching the research landscape with varied agricultural experiments.

The project delineates the structural design of the PV module supports, integrating 3D modeling within the LuSim environment to detail every aspect of the supporting structures. This careful planning ensures that the PV arrays are optimally positioned to balance solar energy capture with minimal disruption to crop growth.

In assessing plant growth under the PV system, the study navigates through the complexities of modeling plant structures, from simple geometric shapes to more intricate representations. This phase aims to establish a baseline understanding of shading impacts on crop growth, paving the way for more detailed future analyses that may incorporate realistic plant growth patterns and behaviors.

The examination of different Agri-PV configurations, including their impact on shading and light exposure, provides invaluable insights into system design optimization. Such analysis is instrumental in developing Agri-PV systems that harmonize solar energy generation with agricultural productivity, ensuring sustainable practices that benefit both sectors.

The Barcelona Agri-PV system study thus embodies a comprehensive approach to integrating solar energy production with agricultural operations. By meticulously analyzing light distribution and plant growth under various PV system configurations, the project lays the groundwork for the development of Agri-PV systems that can efficiently coalesce renewable energy generation with the demands of agricultural production, marking a significant advancement towards sustainable agricultural practices.

NETHERLANDS

The generated electricity from the PV panels must be fed back into the grid. The electricity net in The Netherlands is currently overloaded. So, feeding the electricity into the grid is not always possible. https://www.vertalen.nu/woordenboek/nederlands-engels/. Greenhouse construction needs to be calculated and prepared for the extra mechanical load. PV panels cannot be installed in moving roof windows.

Local authorities are only involved in the building permit. If it is decided that it is allowed to build a greenhouse, the owner is free to install PV panels during the construction. The local community is generally not involved when it concerns PV installations.

The prototype located in Schipluiden, near Delft, in the Netherlands, embarks on an innovative journey to integrate Agri-PV systems within a greenhouse environment, specifically tailored for the cultivation of vegetables such as tomatoes, cucumbers, peppers, and lettuce. This initiative addresses the burgeoning demand for additional energy sources while navigating the greenhouse market's reservations about installing photovoltaic (PV) panels above vegetation areas. The prevailing concern hinges on the belief that sunlight availability should be maximized to ensure optimal crop yield. This demonstrator aims to quantify the extent of light blockage by PV panels and ascertain the feasible number of panels that can be installed without compromising crop yield, leveraging Daily Light Integral (DLI) data for this purpose.

The test area is methodically segmented into six zones, showcasing a strategic placement of southwest-facing PV panels in repetitive patterns above the vegetation. Zones 1 and 2 are equipped with 24 panels each, positioned 9 meters apart, while zones 3 and 4 will house 48 panels each, with a closer interval of 4.5 meters (Figure 5). Additionally, zones 1, 3, and 5 will feature Fotoniq's innovative diffusive PAR+ coating, while zones 2, 4, and 6 will utilize standard clear glass. PAR+, developed by FOTONIQ in Delft, the Netherlands, represents a semi-permanent, water-acrylic-based diffusive coating for glass greenhouses, designed to scatter light and enhance light distribution across the vegetation, promising an increase in light use efficiency and, consequently, crop growth (Figure 5).

This setup is poised to mitigate the complex shading effects often induced by the installation of multiple PV panels, especially under direct light conditions where an imbalance between light absorption and utilization can occur. The diffusive materials are expected to moderate the intensity peaks of light on the top leaves, thereby reducing photoinhibition and lowering leaf temperatures.

The application of the PAR+ coating, aiming for uniform coverage with specific transmittance and hortiscatter values, seeks to directly compare the effects of a light-diffusive material with that of clear glass in an Agri-PV context. This represents a unique field test designed to evaluate the potential benefits of integrating diffuse covering materials in greenhouse environments equipped with PV panels (Figure 6).

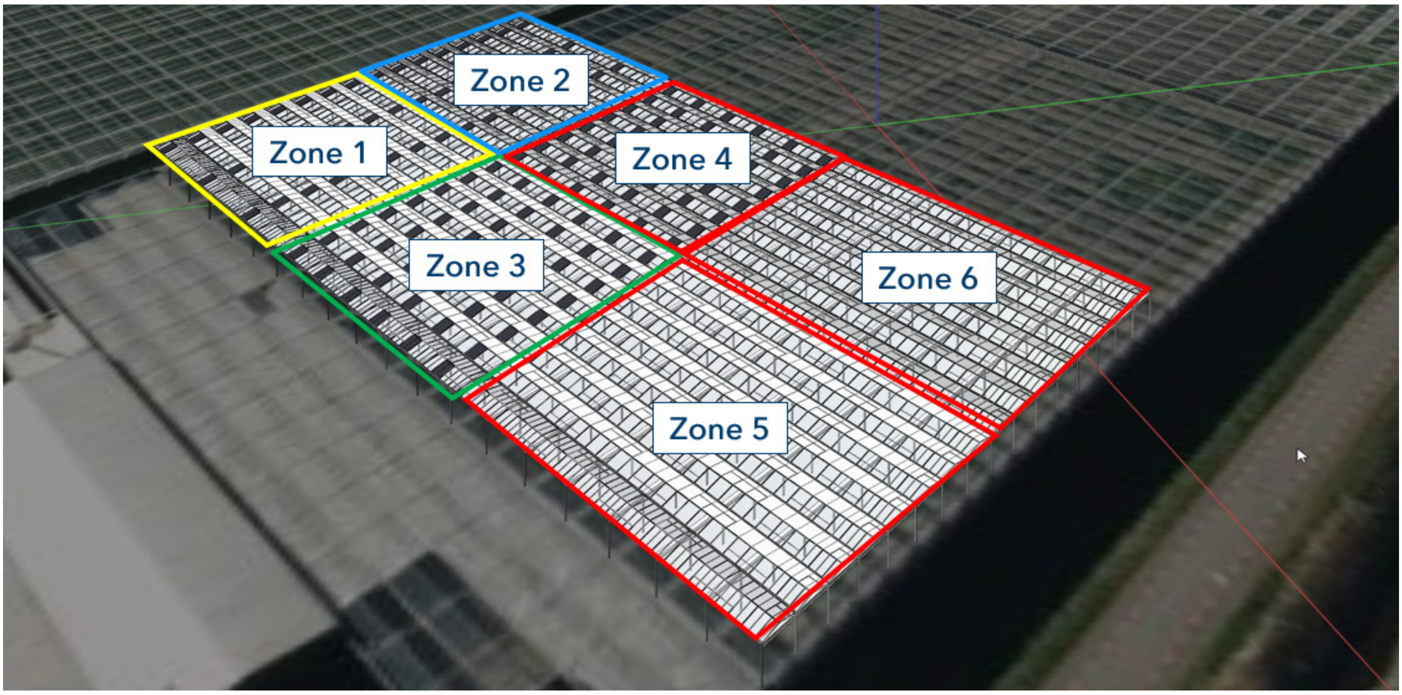
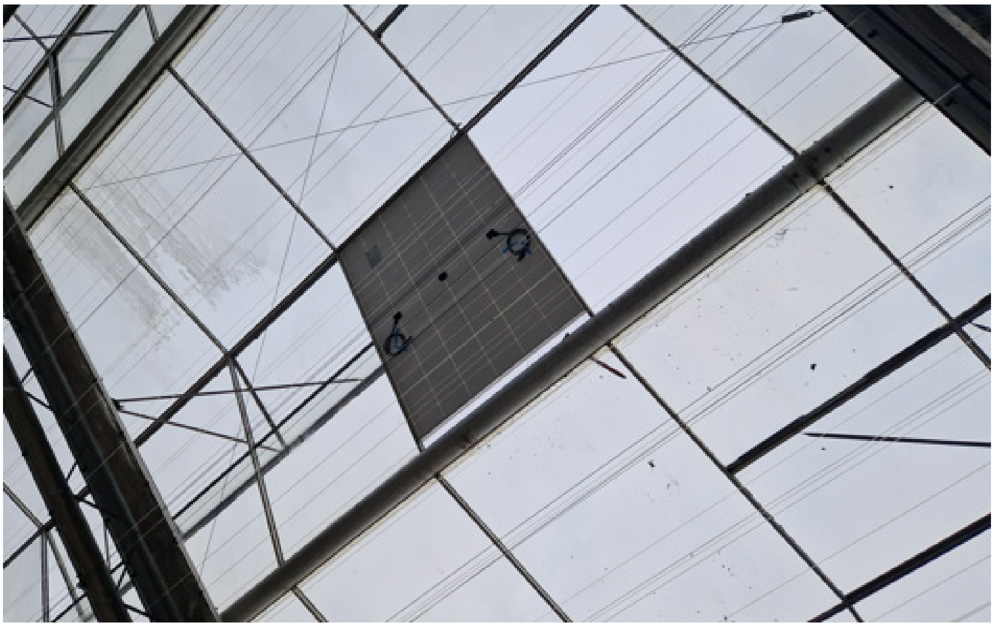


Figure 5: Top view of the demo site on the greenhouse with 6 distinct zones



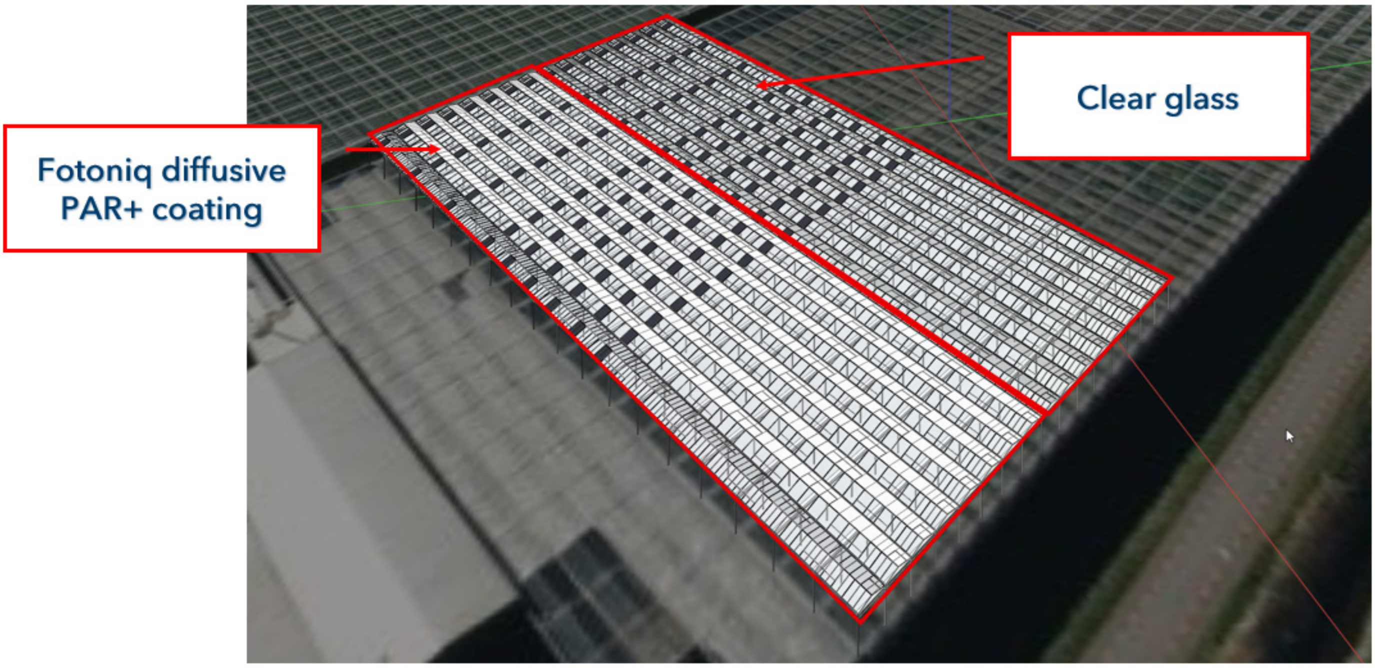


Figure 6: Picture of the greenhouse and layout**:** Layout of the zones containing coating and clear glass, respectively.

In the upcoming phase of this project, several objectives are outlined to enhance the demonstrator's efficacy and insights further:

- 3E is tasked with developing a user interface to visualize the data collected from light sensors and the electrical power generated by the PV panels, facilitating access and interaction for all project partners.
- LuciSun and TU Delft will focus on developing a 3D calculation tool for light measurement, which will undergo validation with the actual measurements collected in the greenhouse.
- The ultimate aim involves LuciSun and TU Delft creating a digital twin of the greenhouse that mirrors the real-time data, thereby providing a comprehensive tool for analyzing and optimizing the integration of PV systems in greenhouse agriculture.

SCALEA, ITALY

The Scalea project in Cosenza, Italy, presents an innovative solution for citrus orchards by integrating various systems such as irrigation, frost and snow protection, hail protection, agronomic sensors, and insect detection systems. This demonstration aims to address the challenge of maximizing energy production while maintaining crop yield, particularly in the context of citrus fruit trees. Below are the key components and observations of the Scalea demo:

- Location and Replication Potential: The prototype is located in Scalea, Italy, with a high potential for replication due to planned plantation renewals in Southern Italy and new plantations in the Mediterranean area.
- Crop and Configuration: The demo focuses on citrus fruit trees, specifically White Zagaria and 2KR Citrus Limon varieties, arranged in a "Classic" 3D configuration with trees not exceeding 2.5 meters in height. The orchard comprises four rows spaced 5.0 meters apart.
- Solutions Implemented: The demo features trackers designed by CONVERT, with a height of 3.20 meters, covering all four rows of the orchard. Weathering steel is used for tracker manufacturing to minimize environmental impact. Precision irrigation systems and hail protection nets are also integrated.
- Electricity Usage: The generated PV energy is fully utilized to power cultivation equipment, including tractors, pumps, and compressors, enhancing sustainability and efficiency.
- Observations and Data: Initial observations indicate no significant difference in growth between crops under the Agri-PV system and those in open fields. Agricultural sensors have monitored ground temperature, humidity, and photosynthetically active radiation (PAR) over a year, providing insights into climatic conditions and crop health.

Preliminary results:

- Average humidity remains below the critical threshold at 35%.
- Ground temperature ranges between 10°C and 25°C annually, optimal for lemon cultivation.
- Crops under the Agri-PV system exhibit fewer stress symptoms, suggesting a beneficial microclimate provided by overhead PV modules.

Future outlook:

- Comprehensive results and analyses are expected in the third and fourth years of the project, aligning with the planned research timeline.
- Overall, the Scalea demo serves as a significant endeavour to explore the feasibility and benefits of integrating PV systems with citrus orchards, contributing to sustainable agricultural practices and energy generation.

4. MONITORING SYSTEM AND PLATFORM

MONITORING SYSTEM

The objective of the monitoring system is to analyse and study the behaviour of the two parts of an agri-voltaic system: a tracker-equipped PV system and the underlying agricultural part. It also allows a digital twin of the monitored system to be generated. This is to study the impact of a high PV plant on the biology of the plants, the soil, and the microclimate in which they are to grow.
Several parameters were identified to arrive at a complete analysis of the demo. They will then be divided into parameters related to the PV part and the agricultural part, summarised in Table 4.

Table 4: Parameters and Sensors

PV part	Unit	Agriculture part	Unit
POA Irradiance	W/m^2	Horizontal Irradiance	W/m^2
Temperature	°C	Soil Humidity	%vol or hPa
Wind Speed	m/s	Soil Temperature	°C
Wind Direction		PAR or ePAR	W/m^2
Relative Humidity	%rh	NDVI	$W/m^2/nm\ sr$
Albedo	W/m^2	RGBD	
DC/AC Current	A	Thermal Camera	
DC/AC Voltage	V	Rainfall	mm/s
DC/AC Power	W	LIDAR	

The monitoring part dedicated to the photovoltaic system allows performance verification and the evaluation of the system in the presence of agricultural crops beneath it.

The innovative and more interesting aspect is the analysis of the behaviour of the agricultural part coupled with a photovoltaic system. First, temperature and humidity sensors will be installed in the soil: this is to understand how the shading given by the PV structure can help to lower temperature and evaporation, helping to maintain humidity and, consequently, reduce the need for water for irrigation. In addition to these, ePAR (Extended Photosynthetically Active Radiation) sensors will be used. These sensors evaluate the part of electromagnetic radiation that can be used for photosynthesis by the crops. Finally, NDVI sensors will be mounted and thermal, and RGBD cameras will be used. NDVI (Normalized Difference Vegetation Index) sensors can be used to evaluate leaf density and the active canopy. Thermal cameras can help study any hydric stress of plants. RGBD camera helps to analyse the height and volume of crops. These last three measurements help to study the health of plants and their growth in the presence of photovoltaic modules on them.

In addition to monitoring these parameters, an aerial analysis of the photovoltaic modules using drones is also planned. This will be divided into a thermography and an electroluminescence analysis. This will make it possible to evaluate the health of the modules and any damage.

DEMONSTRATORS

BOLZANO, ITALY

The fixed monitoring system of the Bolzano demo includes three types of stations:

- Weather Station
- Monitoring Station
- Reference Station

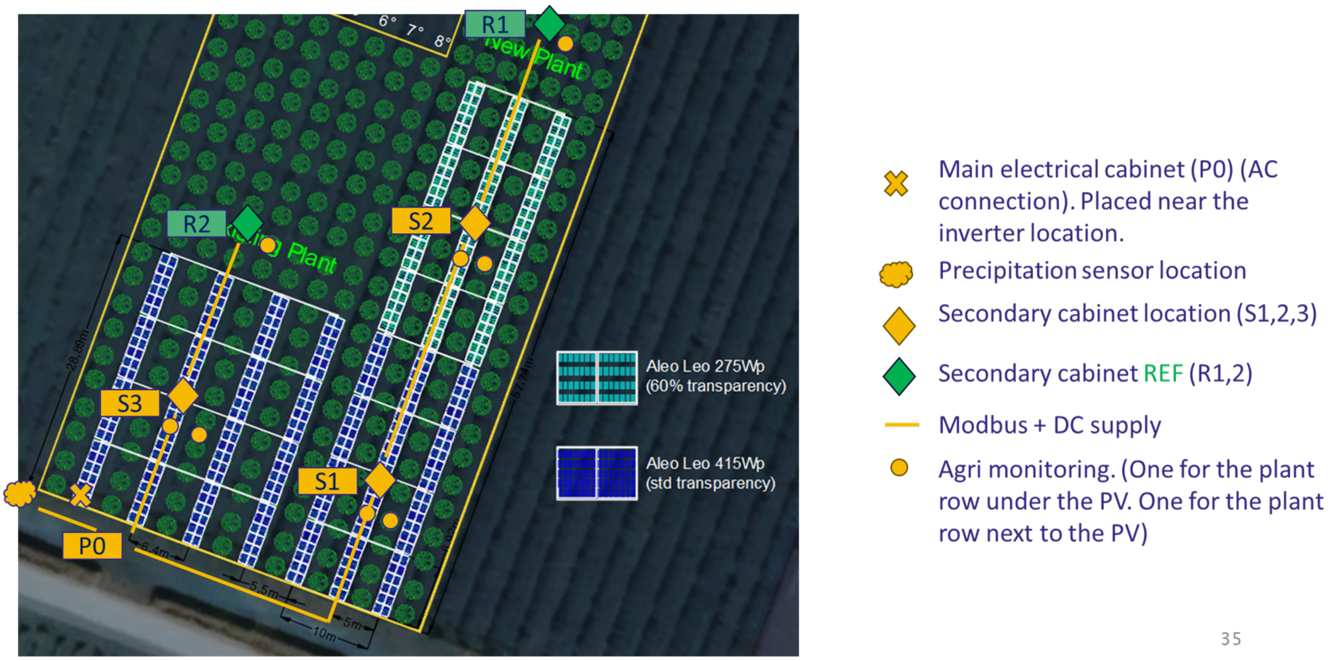


Figure 7: Bolzano demonstrator and layout of sensors

Figure 7 shows the positioning of the various stations within the Bolzano demo. The demo is characterized by 3 different sectors with different combination plants (an existing plant and a new plant) and PV technology. The system includes the monitoring of the main quantities for each combination of plants and PV technology.

Follows the analysis of each component of the monitoring system. Table 5 shows the sensors mounted on the weather station. This is mounted not to shadow the tracker structure (Figure 8).

Table 5: Sensors included in the weather station component.

Domain	Measured Parameter	Type	Accuracy
AIR	Temperature		± 0.3 °C at 23°C
	Relative Humidity		± 2.5 % RH at 23°C
	Precipitations type and quantity	Sensor with radar technology	
	Wind Speed	Anemometer	> 4 m / s: ± 3%

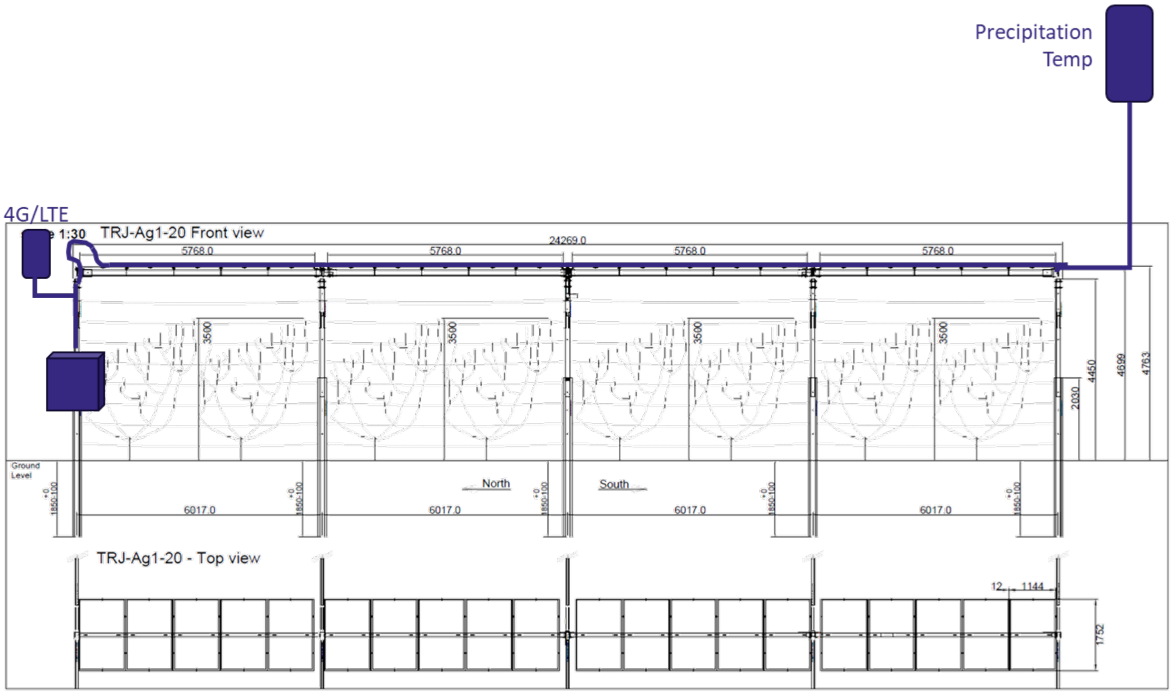


Figure 8: Mounting of the weather station.

In addition to the weather station, there are three monitoring stations named S1, S2 and S3, located within the tracker sections, each with one set of sensors monitoring the photovoltaic part and one set monitoring the agricultural part of the system. Table 6 and Table 7 summarize the sensors located on S1-3 stations with a focus on the agricultural part of the system (Table 6) and the photovoltaic system (Table 7).

Table 6: Sensors in S1-S2-S3 Stations – Agri Part

Domain	Measured Parameter	Type	Accuracy
AIR	Temperature	Polycarbonate Probe with Cable	± 0.3 °C at 23°C
	Relative Humidity		± 2.5 % RH at 23°C
IRRADIANCE	ePAR	Pyranometer	<5 %
SOIL	Temperature	NTC 10 kΩ @ 25°C	± 0.5°C
	Measures the soil volumetric water content (VWC)	Capacitive	± 3 %

Table 7: Sensors in S1-S2-S3 Stations – PV Part

S1-S2-S3 Stations – PV Part				
Domain	**Measured Parameter**	**Type**	**Accuracy**	**Description**
PV MODULES	G_POA	Pyranometer (IEC 61724-1:2021 compliance Class B)		
	Albedo	Pyranometer (IEC 61724-1:2021 compliance Class B)		
	Module Temperature	PT100 class A		

Two additional stations, R1 and R2, are located outside the area of the crops covered by the PV modules. They provide data from the crops not covered from the PV system and are adopted as reference to assess the impact of the presence of PV on the plants. Table 8 shows the list of sensors mounted on the Reference station that mostly focus on the agricultural domain.

Table 8: Sensors mounted on the Reference station

Domain	Measured Parameter	Type	Accuracy
AIR	Temperature	Polycarbonate Probe with Cable	± 0.3 °C at 23°C
	Relative Humidity		± 2.5 % RH at 23°C
IRRADIANCE	ePAR	pyranometer	<5 %
SOIL	Temperature	NTC 10 kΩ @ 25°C	± 0.5°C
	Measures the soil volumetric water content (VWC)	Capacitive	± 3 %

Figure 9 provides a sketch with the qualitative position of the sensors in relation to the rows of apple plants for the two different topologies of stations.

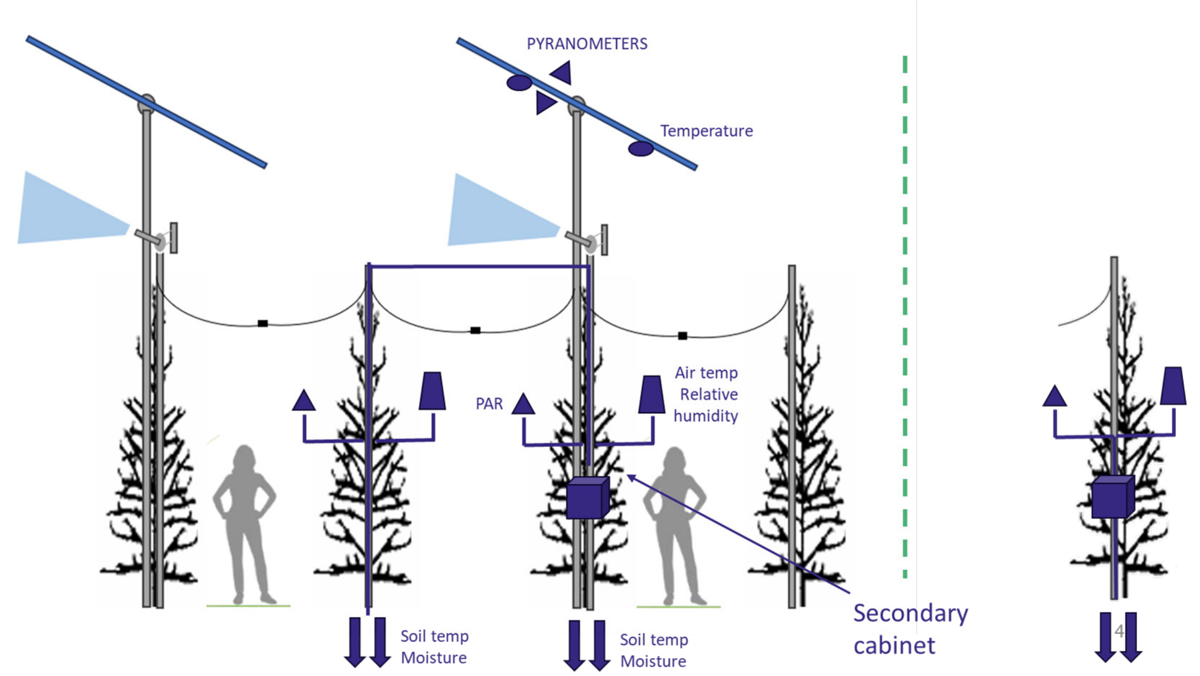


Figure 9: Positioning of the sensors.

As far as the actual height of the ePAR sensors is concerned, this will be decided following the final results of the simulations (see Deliverable 5.1 [https://www.SYMBIOSYST.eu/wp-content/uploads/2024/03/Conceptual-Design-of-the-agri-PV-demonstrators.pdf]).
The SCADA system of Convert's trackers is also used and monitored, and one of the goals is to integrate the monitoring of the entire Agri-PV system within the SCADA itself (prototype).

BARCELONA, SPAIN

Outlined in the following table are diverse physiological and agronomical parameters pertaining to horticultural plants, to be assessed in relation to the presence/absence and impact of photovoltaic sections.

Table 9: Crop measurements proposed for Barcelona

			When measured?		Crops[1]			
Indicator	**Parameter**	**Unit**	**Crop cycle**	**Harvest**	**Let**	**Fava b.**	**Tom**	**On**
Plant Phenolgy and physiology	Height	cm	x		x	x	x	x
	Diameter[2]	cm	x	x	x	-	-	x
	Crop cycle (phenology)	BBCH	x	x	x	x	x	x
	Leaves number	Number	x	x	x	-	x	x
	Crop health status	---	x	x	x	x	x	x
	Vigor indices	Spad, NDVI	x	x	x	x	x	x
Yield And yield components	Harvest yield, fresh	kg/ha or t/ha	-	x	x	x	x	x
	Harvest yield, dry	kg/ha or t/ha	-	x	x	x	x	x
	Fruits per plant	Fruit num./plant	-	x	-	x	x	-
	Plant density at harvest	Plants/m^2	-	x	x	x	x	x
	Fruit weight[3]	g/fruit	-	x	x	x	x	x
Quality traits	Nitrate content	mg NO3-N/kg	-	x	x	-	-	-
	Sugar content	ºBrix					x	
	Acidity / trit. acidity	pH / %	-	x	x	-	x	-
	chlorophyll content	Spad	-	x	x	-	-	-
	Pod length	cm	-	x	-	-	x	-
	Fruit diameter	cm	-	x	x		x	x
	Fruit color	color					x	
	Fruit texture	kg	-	x	-	x	x	x

[1] Let = Lettuce. Fava b. = Fav bean. Tom = tomato. On = onions
[2] Plant diameter for lettuce. Bulb diameter for onions
[3] Fruit (tomato, fava beans), bulb (onion) or plant (letucce)

In Barcelona, monitoring of environmental (soil and atmosphere), plant and PV parameters is divided into two different systems: 1) monitoring with fixed systems and 2) monitoring with mobile systems:

The fixed monitoring system designed for the Spanish demonstrator is schematised in Figure 10. There are three measuring stations located within the three monitored sectors: sector S1, which the trackers with the standard modules characterise; sector S2, which is characterised by the semi-transparent modules; and sector R1, which is the reference. In addition to these, a weather station P0 is also installed.

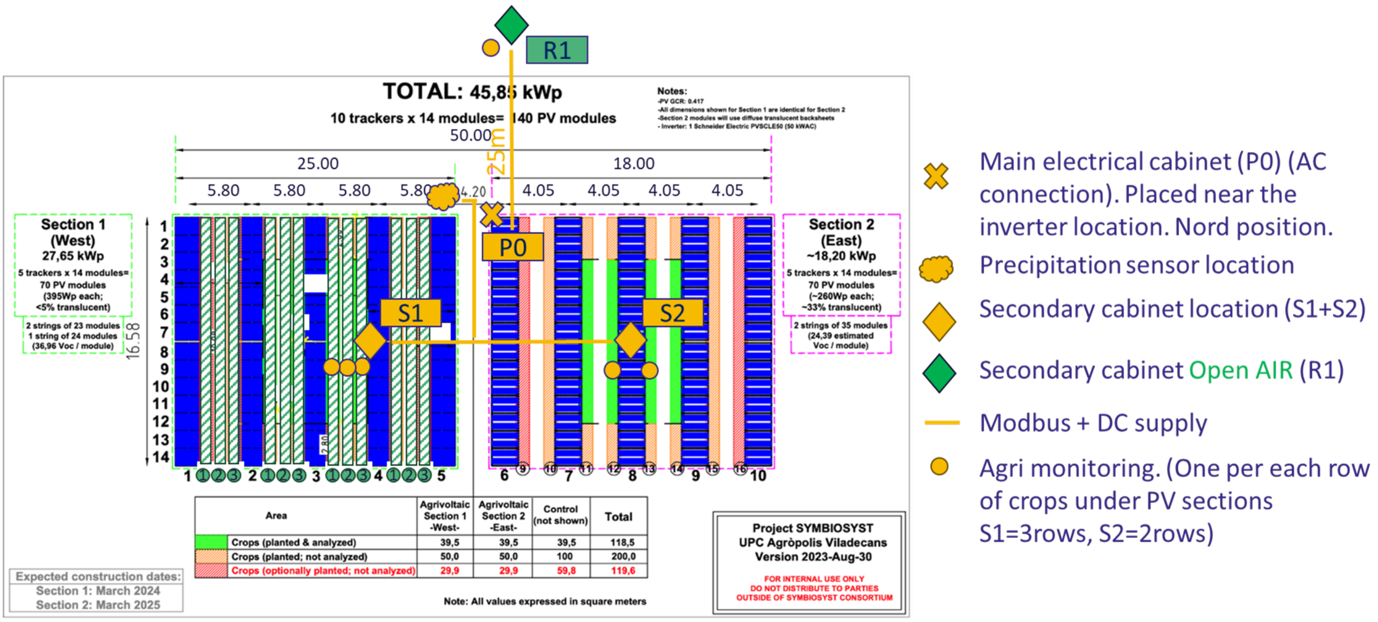


Figure 10: Position of Sensors in Barcelona Demo (Final design/layout of agri-PV system still pending)

Going into more detail: firstly, a weather station (P0) was implemented on which the sensors summarised in Table 10: Weather station are located. The latter is installed in the northern part of the monitored system and in a position at least 1m above the trackers so as not to shadow the structure. It is also about 5 m away so as not to be influenced by it.

Table 10: Weather station

Weather Station				
Domain	**Measured Parameter**	**Type**	**Accuracy**	**Description**
AIR	Temperature	Polycarbonate Probe with Cable	± 0.3 °C at 23°C	
	Relative Humidity		± 2.5 % RH at 23°C	
	Precipitations type and quantity	sensor with radar technology	± 0.16 mm	
	Wind Speed	Anemometer	> 4 m / s: ± 3%	

In addition to the weather station, there are two monitoring stations, S1 and S2, located within the tracker sections, each of which has one set of sensors monitoring the photovoltaic part and one set monitoring the agricultural part of the system. Table 11 and Table 12 summarize the sensors present on S1 and S2 stations.

Table 11: S1 and S2 Stations – Agri Part

Domain	**Measured Parameter**	**Type**	**Accuracy**
AIR	Temperature	Polycarbonate Probe with Cable	± 0.3 °C
	Relative Humidity		± 2.5 % RH
IRRADIANCE	ePAR	Pyranometer	<5 %
SOIL	Temperature	NTC 10 kΩ @ 25°C	± 0.5°C
	Measures the soil volumetric water content (VWC)	Capacitive	± 3 %

Table 12: S1 and S2 Stations – PV Part

Domain	Measured Parameter	Type	Accuracy
PV MODULES	G_POA	Pyranometer	< 2.4 %
	Albedo	Pyranometer	< 2.4 %
	Module Temperature		

Finally, a reference station, R1, is installed outside the tracker sectors. This serves to have a dataset to help analyse the terrain without the presence of trackers to assess the impact of an Agri-PV plant on the plants themselves. Table 13 shows the list of sensors mounted on the Reference station.

Table 13: R1 Station

R1 Station				
Domain	**Measured Parameter**	**Type**	**Accuracy**	**Description**
AIR	Temperature	Polycarbonate Probe with Cable	± 0.3 °C	
	Relative Humidity		± 2.5 % RH	
IRRADIANCE	ePAR	pyranometer	<5 %	
SOIL	Temperature	NTC 10 kΩ @ 25°C	± 0.5°C	
	Relative Humidity	Capacitive	± 3 %	Measures the soil volumetric water content (VWC) by using a capacitive measurement principle

Figure 11 shows the position of the sensors in relation to the support post.

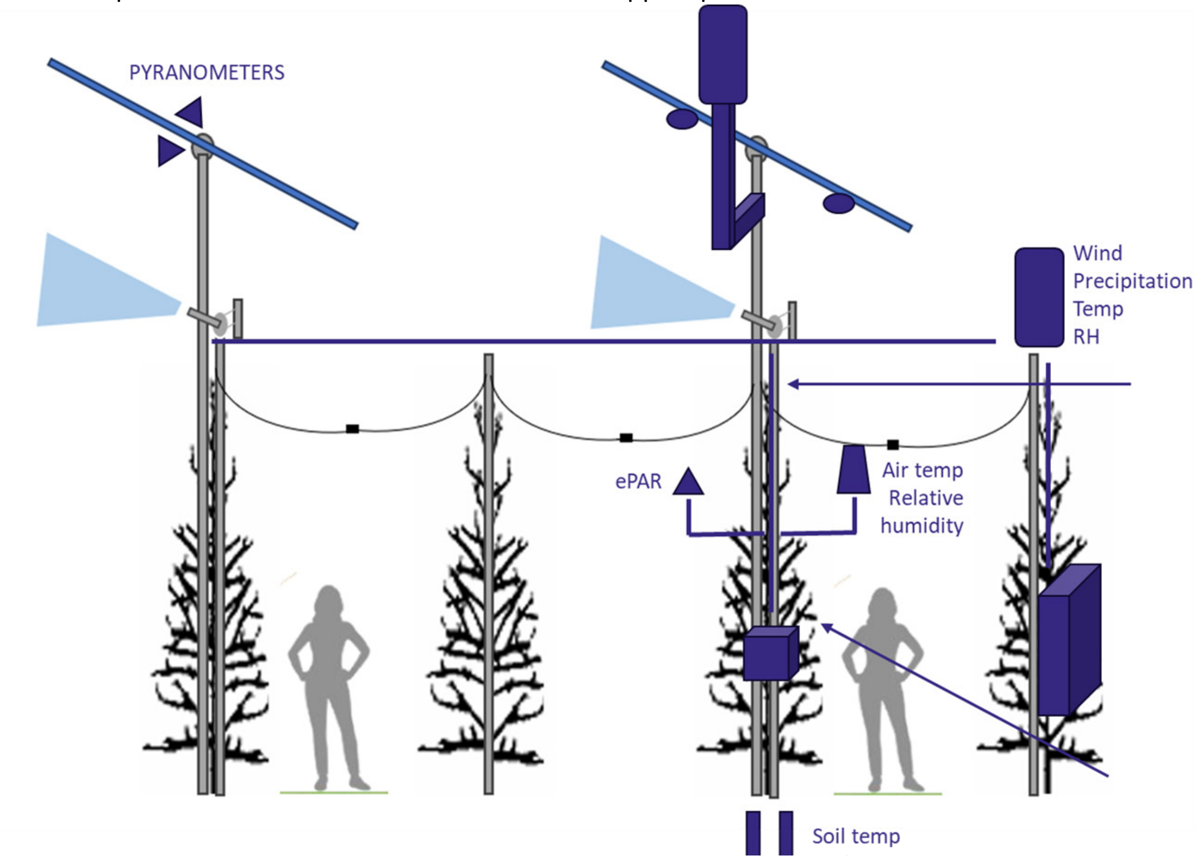


Figure 11: Position of the sensors.

As far as the actual height of the ePAR sensors is concerned, this will be decided following the final results of the simulations (see Deliverable 5.1 [https://www.SYMBIOSYST.eu/wp-content/uploads/2024/03/Conceptual-Design-of-the-agri-PV-demonstrators.pdf]).
The SCADA system of Convert's trackers is also used and monitored, and one of the goals is to integrate the monitoring of the entire AgriVoltaic system within the SCADA itself (prototype).

Monitoring with mobile systems is based on an autonomous, all-terrain mobile robot (called MEDIR) that currently integrates the following sensors (with the possibility of integrating new sensors throughout the project Figure 13): thermal cameras and RGB-D cameras that allow for the collection of crop temperature data (its leaves) and, therefore, among other parameters, infer the value of its water stress. The combination of these cameras also allows for monitoring the temperature of critical elements of solar panels, especially the back part (junction box), and determining if there is overheating or failure in any of them. The robot also equips an NDVI sensor that allows for monitoring crop health parameters such as NDVI, 3DNDVI, NIR, and SAVI, and, along with the RGB-D camera, can provide biomass parameters. All these data are georeferenced in space with centimeter precision, thanks to GNSS and LIDAR sensors, in order to send the necessary data to the server and build a Digital Twin with accurate information and very high resolution.

The design of the robot is such that it is divided into two distinct sections Figure 12: The lower part houses all the drive elements for powering the transmission and wheels. This drive section is equipped with two powered wheels and, consequently, two degrees of freedom. On the other hand, the upper part is independent of the lower section and can rotate over it. It has one degree of freedom. The upper part is responsible for accommodating all the sensors.

Thanks to the robot's unique configuration and integrated navigation algorithms, it can have omnidirectional navigation over rough terrain, facilitating control and data collection, reducing cycle time, and enhancing the robot's agility.

As for the sensor distribution on the robot, it is as depicted in the following image Figure 14. Mounted on the upper part of the robot, at the ends, there are steel blocks rigidly attached to the robot's sturdy structure, which allow for the attachment of custom-made gadgets. An aluminium structure that holds all the sensors is anchored in this case. The central part of the structure mainly houses the sensors necessary for navigation, such as the LIDAR and the RGB-D cameras (the exact number of cameras to be determined). The robot is equipped to carry up to 4 cameras to cover all angles. It also includes various IMUs and a GPS sensor.

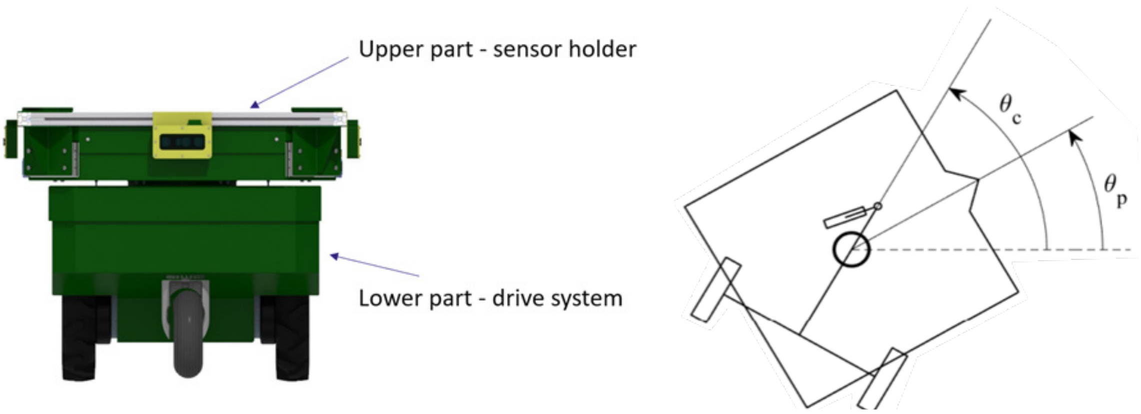


Figure 12: MEDIR configuration and omnidirectional capabilities.

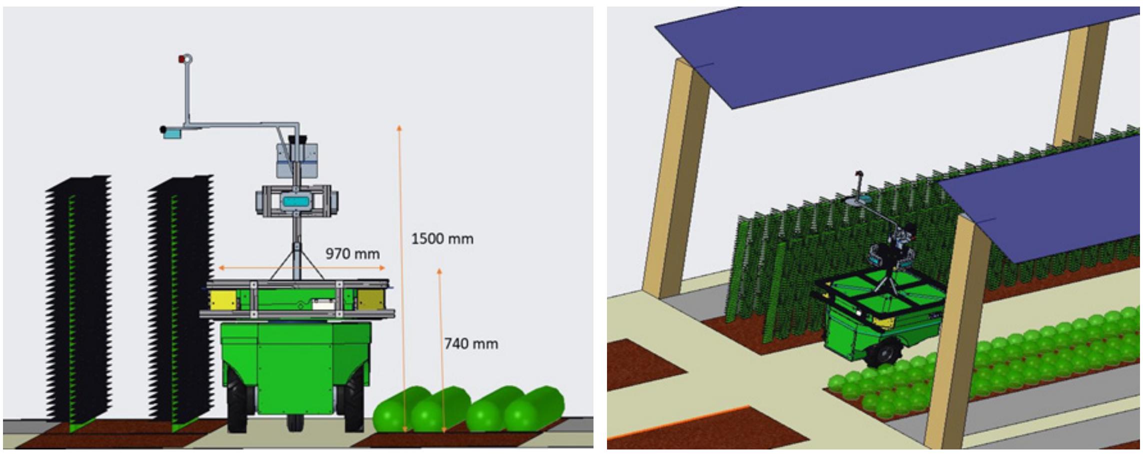


Figure 13: 3D layout of MEDIR taking data in the agri-PV facilities cultivated with lettuce and broad beans

The distribution of the crop and solar panel sensors is primarily focused on an adjustable height arm, which can rotate together with the robot's upper part, independent of the wheel orientation. This setup allows for the sensors (thermal cameras, RGB-D camera, and NDVI sensor) to target the crops from a bird's-eye view, which provides the most reliable data collection from the specified sensors. The arm's height is adjustable, so the robot can automatically modify its height to optimize the distance to the crops at any given time. There is a clear difference between crops like lettuce and broad beans hence this degree of freedom is necessary.

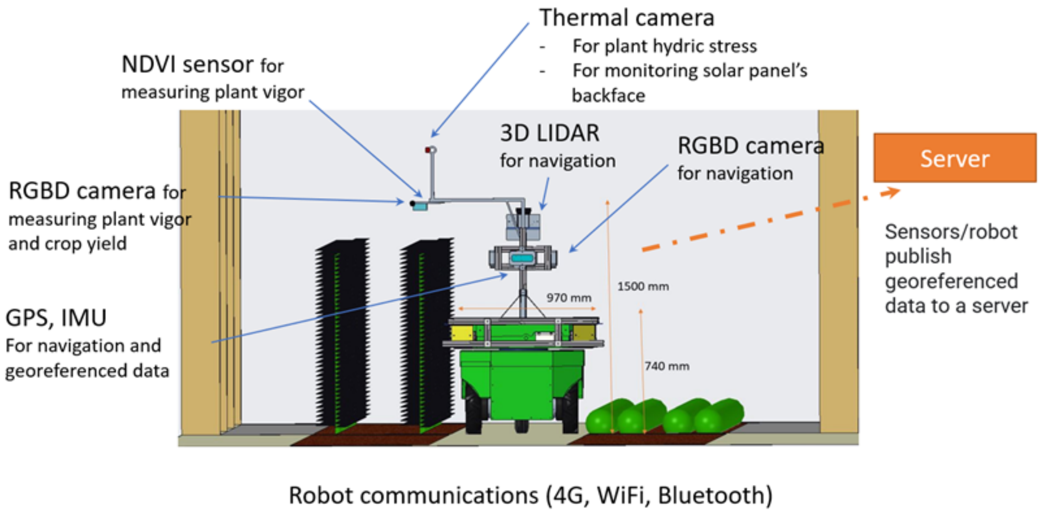


Figure 14: MEDIR's sensor layout.

The following describes the sensors equipped on the robot, the information they provide, and how this data is processed and used, whether for robot navigation or environmental monitoring.

The Ouster OS-1-32 is a LIDAR Figure 15 (Light Detection and Ranging) sensor, a technology that measures the distance to an object or surface using laser pulses. This high-resolution sensor is used for various applications, including mapping, robotics, and autonomous navigation. The "32" in the OS-1-32 model indicates the number of laser channels the device has, meaning it can emit 32 laser beams at different angles to capture distance data within an environment and create precise 3D images of it. This feature enhances the robot's detailed perception of the environment or mapping. The OS-1-32 is known for its compact design, durability, and capability to operate under various environmental conditions, making it suitable for agri-PV settings.

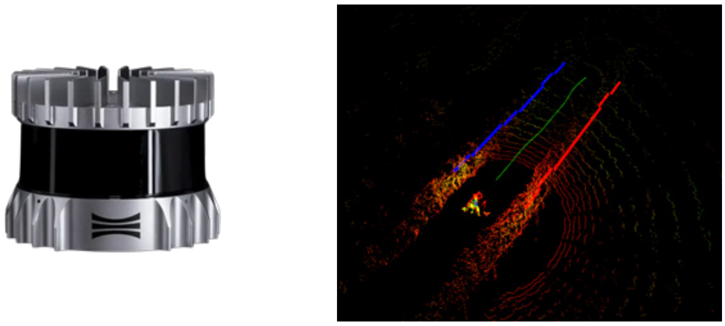


Figure 15: Ouster OS-1-32 is a LIDAR (left); point cloud and path planning created in vineyard (right).

This sensor enables local perception for the detection of obstacles and other environmental elements that inform path planning, avoiding obstacles and choosing the most efficient route. The system is designed so that the robot must perform an initial mapping trip, typical of SLAM (Simultaneous Localization and Mapping) navigation algorithms. With the input from the LIDAR point cloud (10 Hz), the robot can create a map and generate a path through the crop in real time. This is enhanced by IMU measurements (100 Hz) and GNSS data (1 Hz), which improve its localization precision.

The RGB-D camera sensors (Intel RealSense D457 RGB Camera Figure) use an RGB camera to capture detailed, human-like visual perception in colour. They incorporate depth-sensing technology to generate a 3D map of the environment, providing spatial awareness for navigation and scene analysis. The high-resolution images facilitate detailed scene analysis. Resolution: 1280 × 800 pixels. RGB Frame Rate: 30 fps. RGB Sensor Technology: Global Shutter.

Figure 16: Intel RealSense D457 RGB Camera (left); Optris Xi 400 Thermal Camera (right).

Figure 17: Crop Circle ACS-211 sensor.

The thermal camera (Optris Xi 400 Thermal Camera) captures infrared imaging for thermal perception, offering high-resolution thermal images for real-time temperature monitoring. It has rapid capture capabilities and heat detection technology. Resolution: 382 x 288 pixels. RGB Frame Rate: 80 fps. Distance-to-spot-size ratio up to 390:1.

Together, these two cameras enable the identification of the temperature of specific objects. The RGB-D camera provides images to YOLOv8, trained with a curated dataset of images for real-time segmentation to accurately outline plant structures. Merging this information with data from the thermal camera—which has been correlated through exhaustive prior calibration—allows for the extraction of information from thermal images. This harnesses the fusion of RGB-D and thermal data to unlock invaluable insights into plant health and hydration levels.

Figure 18: Results of the fusion of images from RGB-D camera and thermal camera in an experimental lettuce plantation.

The Crop Circle ACS-211 sensor (Figure 17) is an agricultural instrument that uses light in the visible and near-infrared spectrum to measure plant reflectance, aiding in the assessment of their health and vigour. This data enables farmers to make precise adjustments in the use of fertilizers, water, and other inputs, thus optimizing crop yield and improving resource management. It measures plant/soil reflectance at 670 and 780 nm, calculating the Normalized Difference Vegetation Index (NDVI) independently from ambient lighting conditions, offering a reliable indicator of plant health regardless of the lighting environment.

All this information will be processed by the robot, which uses ROS2 as its operating system. The processed data is georeferenced and stored in an InfluxDB database, making it accessible remotely Figure 18.

Aerial Imaging and Monitoring System

In addition to the fixed and mobile monitoring system, for both of the open Agri-PV demos, technology will be researched and developed for the aerial analysis of the entire system using drones equipped with the necessary sensors.
For the agricultural part, a multispectral camera will be implemented that can assess various types of plant stress and diseases.
For the Photovoltaic part, solutions will be implemented for module analysis using Thermography and Electroluminescence. Image processing is updating to segment frameless bifacial modules. Also, the automation is being updated to recognize anomalies over bifacial modules.

NETHERLANDS

In the Netherlands, we monitor the light intensities and levels in the greenhouse. Next to the conditions in the greenhouse, we also monitor conditions outside the greenhouse (light, temperature, humidity, shading, etc.) Together with the energy generation from the PV panels, we hope to find PV configurations that are suitable for different crops. This demonstrator explores the feasibility of Agri-PV systems within greenhouse environments and contributes to the broader dialogue on sustainable agricultural practices that harmonize energy generation with food production. Through meticulous research and innovative technology, this project seeks to dispel concerns regarding PV panel installations above vegetation and pave the way for energy-efficient greenhouse operations that do not sacrifice crop yield.

For on-field Daily Light Integral (DLI) measurements, a total of 90 Quantified PAR light sensors will be employed. Figure 19 depicts a Quantified sensor attached to a tomato plant for illustration purposes. Each zone comprises 9 to 16 sensors positioned in a grid-like formation, as demonstrated in **Figure 20**.

Figure 19: Quantified sensor attached to a tomato plant

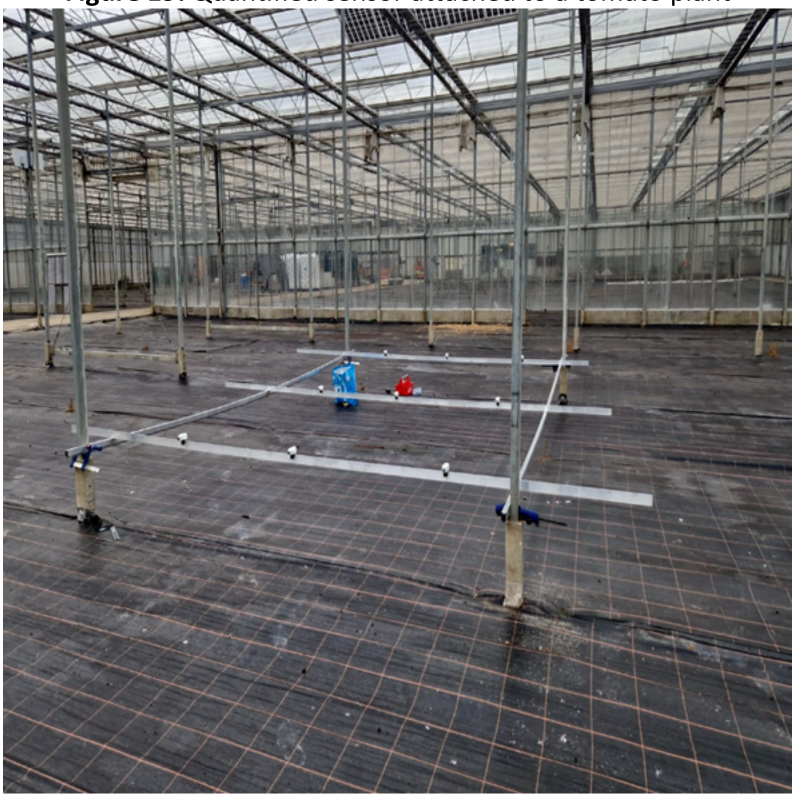


Figure 20: each zone containing 9 to 16 sensors placed in a grid-like formation

DIGITAL PLATFORM

SynaptiQ is an advanced digital platform designed to facilitate the development, operational management, and analytics of renewable energy projects worldwide. Leveraging a physics-based digital twin and profound domain expertise, SynaptiQ supports the comprehensive management of renewable assets, encompassing planning, development, construction, and operation. Key attributes of SynaptiQ include streamlined asset deployment, sophisticated simulation modelling, targeted operational asset management, and advanced solar analytics. The SYMBIOSYST project integrates agriculture and photovoltaic systems to boost agricultural output and electricity generation. SynaptiQ's role involves developing specialized analytics and recommendation engines for Agri PV, addressing challenges like preventing crop overshadowing of PV modules. The project focuses on detecting degradation, assessing soiling losses, and optimizing operations through axis tracking and cleaning schedules synchronized with agricultural activities. Ultimately, the aim is to maximize the benefits of agri-PV systems by harmonizing crop growth and energy production.

Easy Asset Deployment (SynaptiQ Configurator): The SynaptiQ Configurator streamlines the deployment of assets in SynaptiQ most efficiently using a uniform object model. The Configurator lets users define a business plan and the plant configuration data. After deployment, the configuration data is used to map the incoming data flow on the asset model, which allows for advanced Key Performance Indicator (KPI) integration, smart alarm generation, and data enhancement within the digital twin.

The object model underpinning the configurator ensures the creation of a consistent digital twin, encapsulating pertinent configuration details of physical assets such as device datasheet information of the devices (PV modules, inverters…), hierarchical assembly of the devices into the system (Single Line Diagram) and relevant design information (location, shading, module placement…). This standardized approach is uniformly applied across projects and solutions, ensuring coherence and user-friendliness.

Advanced Simulation Model: SynaptiQ employs the advanced simulation model to provide insights into the performance of assets. It leverages real-time data alongside high-granularity satellite irradiation data and meteorological data. This methodology ensures a robust asset performance assessment, enabling early detection of recoverable losses and prompt intervention.

The simulation model was developed to estimate the expected energy yield under specified environmental conditions, as experienced by the installation, based on our photovoltaic power plant modelling experience. Similar to PVSYST, it uses the datasheet information of the PV modules and inverters in combination with the design information brought forward. The simulation model considers the module technology (such as poly-or mono-crystalline), azimuth and the tilt angle of the modules, string configuration (number of modules in series), efficiency curve of the inverters, thermal properties of the installation type, electrical losses in the cabling and other parameters such as shadowing and tracking technology.

Focused Operational Asset Management (SynaptiQ Asset Operations): Solar energy assets can be very different, having variable components, designs, and installations. These differences affect the functioning of the plants and, thus, the monitored data. In addition, external parameters also influence plant monitoring, such as varying weather conditions or power and grid constraints. Altogether, these factors complicate assessing individual performance and comparing asset performance.

SynaptiQ Asset Operations solves this issue by using an advanced simulation model to compute near-real-time KPIs for different stakeholders. These KPIs can be defined by stakeholders like O&M managers, asset managers, data analysts, asset owners, or field engineers. The application allows users to access monitored and calculated data, indicating how well the assets perform using Dashboards (see Figure 21). Visualizing this data helps users interpret the observed information and detect recoverable losses early.

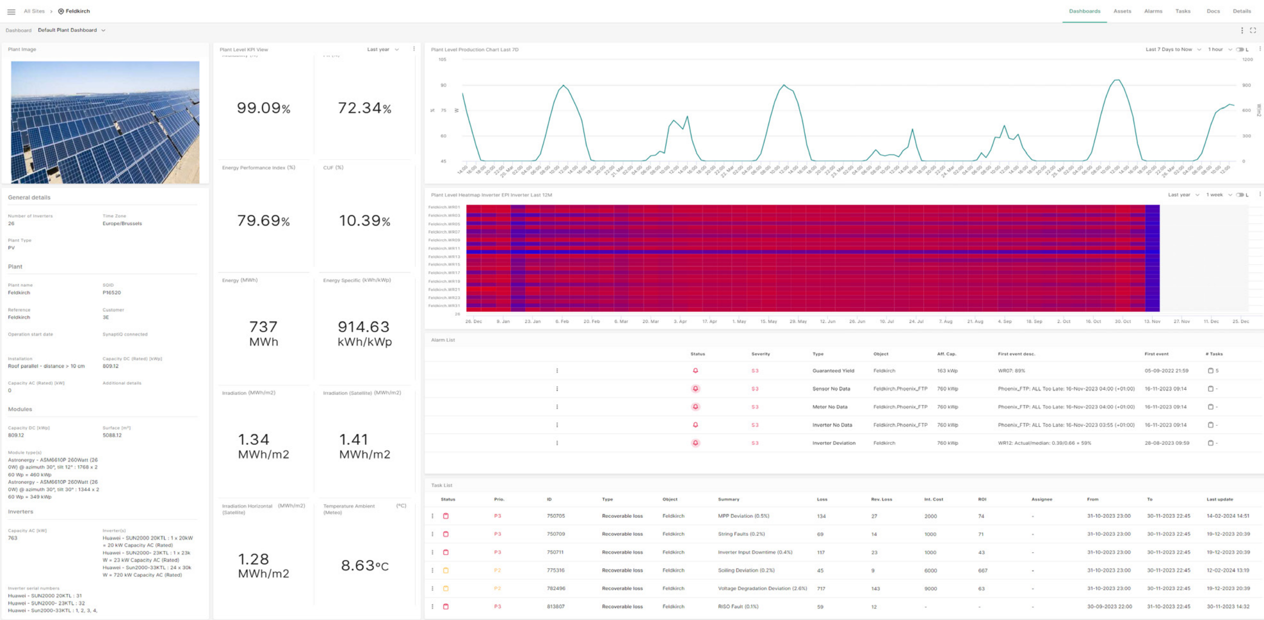


Figure 21: Default dashboard for SynatiQ Asset Operations

A smart alarm system also promptly alerts users to critical issues, facilitating proactive maintenance strategies. The alarms can be received directly from assets or triggered by the real-time monitoring of indicators, which will bring unexpected events to the user's attention. A task can then be created to resolve the cause of an alarm (corrective maintenance) or prevent alarms from appearing (preventive maintenance). A task defines which actions are needed to solve the alarm.

Thus, SynaptiQ provides comprehensive functionalities for internal and external stakeholders, including a smart alarm engine, customizable task management, dashboards configured by domain experts, and flexible reporting. The simple and intuitive design of Asset Operations helps users access these functionalities quickly, thus focusing on improving the efficiency of their renewable energy assets.

SynaptiQ Solar Analytics: A typical solar plant produces a constant stream of thousands of different time series. When performance goes down, it takes a lot of work to dig through this data to find out the root cause of underperformance. Even for known issues, quantifying the exact energy loss is a tedious and error-prone task. With budgets under pressure, avoidable losses are detected late or never at all.

The Solar Analytics application automates identifying and quantifying performance and availability losses, offering granular insights with exceptional accuracy. The results of this advanced analytics can be analyzed using dashboards like loss waterfall (see Figure 22). The key features of Solar Analytics are:

- Production loss breakdown: SynaptiQ's unique modelling approach automatically identifies and quantifies losses from expected to measured energy production. The losses are split into 21 loss components, each having a single root cause, e.g., shading, soiling, etc. It is also possible to break down the loss from the energy business plan when measuring energy production. SynaptiQ's unique physics-based modelling approach leads to a loss split-up with industry-leading granularity and accuracy.
- Recommendation engine: Solar Analytics' recommendation engine proposes automated actions based on (partially) recoverable losses and provides cost-benefit estimations for corrective actions. The engine applies different thresholds to the recoverable losses to determine loss severity.

- Configuration check: The application automatically identifies data quality issues and recommends actions for improvement. It checks the data integrity and completeness of the plant, using its digital twin in SQC. These checks will help users understand whether the results of Solar Analytics are reliable and, if not, recommend actions to improve the data.
- Sensor check: Like the configuration check, if a plant has irradiance sensors, an extensive sensor check is executed to evaluate their calibration. Solar Analytics uses SynaptiQ satellite data to perform diagnostic checks on the on-site irradiation sensors. This way, potential measurement issues, failures, and ageing effects can be identified as separate from performance losses.

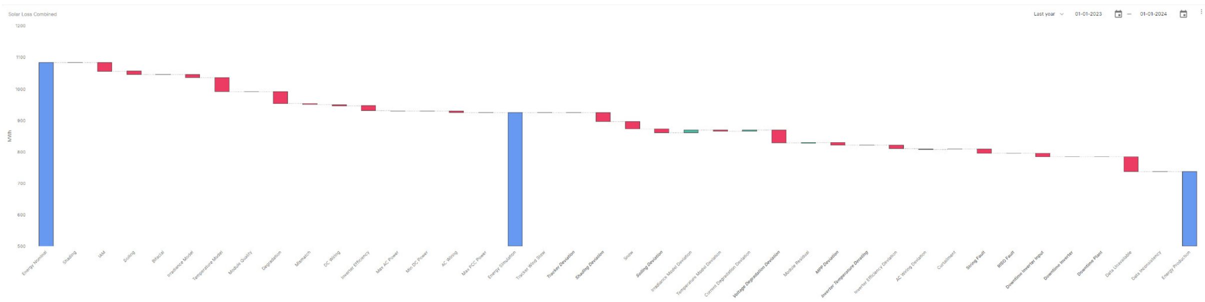


Figure 22: Example of loss waterfall with expected and unexpected losses.

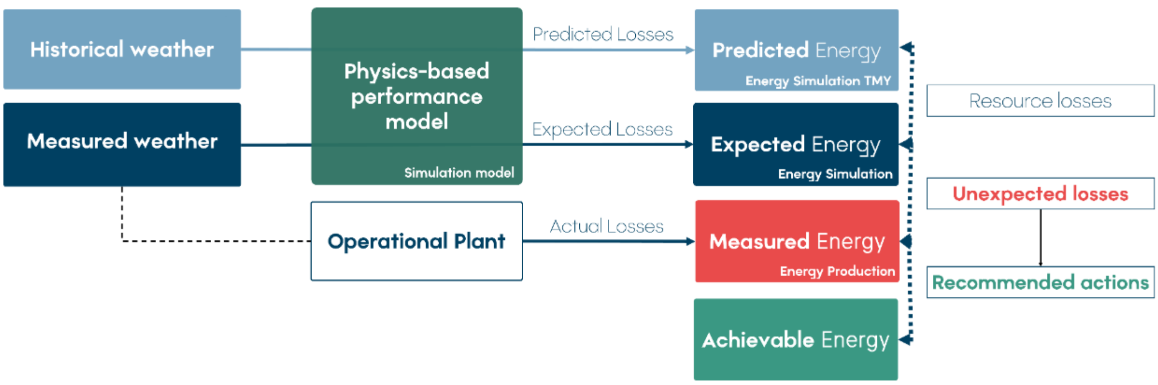


Figure 23: Performance analysis flow in SynaptiQ Solar Analytics

The performance analysis flow in SynaptiQ is modelled as seen in Figure 23 .

- Calculate expected system losses, which are losses from the simulation model (also see left side of loss waterfall in Figure : Example of loss waterfall with expected and unexpected losses.).
- Calculate unexpected system losses, namely, Simulation Loss Deviations: deviations between actual and simulated losses and Additional Losses: loss components that come on top of the expected losses, like due to downtime or snow (also see right side of loss waterfall in).
- Recommend actions to avoid future losses. These recommendations are issued whenever a recoverable loss exceeds a preset threshold. A recoverable loss is a potentially avoidable loss.

The SYMBIOSYST project endeavours to lead innovation by bridging this gap, aiming to maintain or increase agricultural output while maximizing electricity generation from PV. However, the project faces challenges unique to Agri PV, such as distinct boundary constraints and industrial requirements compared to standard PV installations (See Figure 24)

For instance, in an agri-PV setting, it is imperative to prevent crops from overshadowing PV modules, which could substantially hinder energy production. Thus, reliable detection mechanisms for such occurrences are essential but have yet to be fully developed and validated.

In its inaugural year, the SYMBIOSYST project has laid the groundwork by designing testing platforms to address these boundary constraints. The project will expand existing solar asset management platforms with advanced analytics and recommendation engines tailored specifically for Agri PV, focusing on failure detection and predictive maintenance.

Key areas of focus include:

- Detection of degradation mechanisms in Agri PV
- Assessment of soiling losses
- Detection of shading from vegetation growth
- Operational optimization of crop growth, energy production, and maintenance actions, including axis tracking and cleaning optimization aligned with agricultural operations.

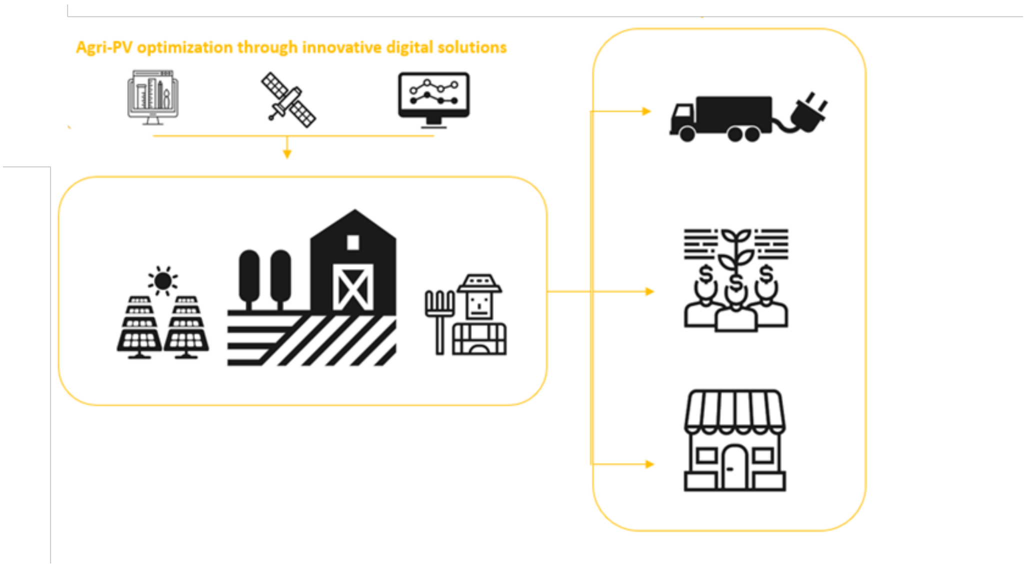


Figure 24: Conceptual framework of stakeholder interaction with Agri PV digitial monitoring platform

The SYMBIOSYST project aims to develop monitoring and analytics that are finely tuned to the agri-PV context, considering degradation and environmental factors specific to this setting. Leveraging expertise from consortium partners experienced in the field, the project will integrate these factors into the monitoring platform to quantify Agri PV's susceptibility to specific degradation mechanisms.

Additionally, the project will address soiling losses resulting from agricultural activities and devise an optimized cleaning schedule synchronized with agricultural operations. This holistic approach aims to ensure smoother operation and facilitate cost-benefit analysis for Agri-PV systems. Ultimately, the project's recommendation engine will consider factors such as axis tracking and panel tilt/orientation to achieve a harmonized optimization of crop growth and energy production, maximizing the benefits of agri-PV systems.

5. CONCLUSION

In conclusion, the SYMBIOSYST project represents an innovative initiative at the convergence of agriculture and renewable energy, addressing critical global challenges like climate change and resource scarcity. By seamlessly integrating photovoltaic (PV) technology with agricultural practices, SYMBIOSYST aims to foster a harmonious relationship between these sectors while promoting sustainable food production and renewable energy generation. This report serves as a blueprint for future project demonstrations and inspiration for future Agri-PV business cases.

The development of Key Performance Indicators (KPIs) provides a robust framework for evaluating the sustainability and effectiveness of Agri-PV systems. These KPIs reflect a comprehensive understanding of social, environmental, and economic dimensions, ensuring alignment with broader societal goals and facilitating ongoing improvement of Agri-PV.

Demonstrator projects, dispersed across various geographic regions, serve as platforms for practical experimentation and knowledge dissemination, offering insights into scalable, resilient, and sustainable Agri-PV systems. The monitoring infrastructure, meticulously designed to capture performance data on both PV infrastructure and agricultural components, empowers researchers to optimise system design and management practices. Digital monitoring plays a crucial role in facilitating Agri-PV projects' development, operational management, and analytics. Tailored to address Agri-PV challenges, such as digital monitoring, it enhances performance monitoring, enables predictive maintenance, and maximises the benefits of Agri-PV systems.

As the SYMBIOSYST project progresses, it underscores the importance of flexibility, stakeholder engagement, scalability, and replicability in the design and implementation of Agri-PV systems.