Final Design of the agri-PV demonstrators

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 (EURAC)
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°	5.3
Task leader	EF SOLARE ITALIA
Document title	Final Design of the agri-PV demonstrators
Lead Beneficiary	EF SOLARE ITALIA
Dissemination level	PUBLIC
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Issue date	30/06/2024

History of versions

Version	Date	Author - Beneficiary	Comments
V1.0		Angelo Pignatelli – EF Solare Italia	Final Draft
V2.0	30.6.2024	David Moser - Eurac	Final review

Acknowledgements

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

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Executive Summary

The SYMBIOSYST project, supported by the EC Horizon Europe Programme, aims to bridge the gap between solar energy production and agriculture by developing tailored photovoltaic (PV) solutions for both greenhouse and open-field agriculture across diverse climatic conditions in three nations. The initiative includes the creation of several agri-PV demonstrators, encompassing scenarios from vegetable farming to fruit cultivation with traditional and other training systems under adjustable tracking systems or into greenhouses with roof partially covered by PV modules. An initial task was the development of technical specifications to serve as a comprehensive guide for these demonstrators, highlighting innovations in PV module integration, environmental considerations like anti-ice features and rainwater harvesting, and monitoring systems.

The effort of the previous project phases was to specify advanced modelling tools developed within the project, facilitating the seamless integration of photovoltaic systems into agricultural settings for mutual benefit. This involved the use of 3D simulation tools for detailed analysis of PV layout spatial arrangements, crop configurations, and support infrastructures. Techniques such as ray tracing and GPU-based 3D simulations were employed for a temporal analysis of light distribution over crops and PV modules, aiming to evaluate bifacial gains, shading impacts, and overall system efficiency comprehensively. The modelling covered both open agri-PV systems for crop and fruit production and closed systems for greenhouse agriculture, focusing on optimizing PV array placement and height on both fixed and tracker systems to encourage optimal crop growth alongside efficient energy production, and adapting PV module integration for both new and existing agricultural frameworks.

The aim of this phase of the project, described in this document, is to describe the final design of the agri-PV demonstrators that will be actually implemented in Italy, Netherlands, Spain to apply the modelling activity of the previous project steps, with the aim to demonstrate the validity of both the conceptual studies and the realization of models to synergically integrate agriculture and energy production through photovoltaic systems.

One of the very tangible added values of this stage of the Symbiosyst project is that the identified agrivoltaic demonstrators represent a very wide variety of crops that can be grown either in open environments or into greenhouses, and in particular:

- Bolzano (Italy) demonstrator is an open apple orchard combined with a PV tracking system that partially cover the apple trees.
- Barcelona (Spain) demonstrator is an open cultivation of short-stature and trellised seasonal vegetables such as tomatoes, onions, lettuce, and fava beans.
- Schipluiden (Netherlands) demonstrator is a greenhouse in which tomatoes are cultivated.
- Scalea (Italy) demonstrator is an open citrus fruit production, with existing PV systems (this is also a demo driver).

Besides the official demonstrators it’s worth mentioning the agrivoltaic plant built in Scalea (Italy) to cultivate citrus trees partially covered by PV trackers. The main features of this plant are also described in this document.

It's important to highlight that many of the findings that will emerge from demonstrators can be applied to different cultivations quite similar the one of the demonstrators.
Moreover, the demonstrators have been identified and designed to be far more than a small experiment but to prove that such advanced agrivoltaic plants can largely scale up to the fulfil the requirements of the agriculture industry.

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1. INTRODUCTION

1.1. DESCRIPTION OF THE DELIVERABLE CONTENTS

SYMBIOSYST covers both open and closed agri-PV. The focus of the project is on specific archetypes depending on the level of integration:

- For open agri-PV, solutions are developed to bring an increase in PV-crop synergies and optimise yield with a targeted electricity production. The selected demo sites are designed to demonstrate the difference between working on new (where the design of PV and crops can be fully integrated together with auxiliary systems such as irrigation, water catchment, crop protection, etc) or existing crops (where compromises and adaptation will be needed).
- For closed agri-PV, similarly, solutions are studied to be fully integrated in new greenhouses (the greenhouses structure can be modified to accommodate standard size PV modules) or adapted for existing greenhouses. The aim is to drive the development towards nearly zero energy greenhouses.

In SYMBIOSYST, the envisioned analysed scenarios for demonstration are:

Open agri-PV Scenario, for:

- Production of vegetables or horticultural crops characterized by a limited vertical development. The height of the tracker system in horizontal configuration needs to consider optimised crop yield, prevent human injury, and ensure free movement of semi-automatic agricultural devices. The ideal height is 3.5 m for tall herbaceous crops (e.g., trellised tomatoes) and tall equipment. A lower height of 2-2.5 m will allow for low herbaceous crops (e.g., lettuce, beans, etc.) and low height equipment. The minimum height of 2.1 m is required by both national and international standards for the agri-PV field to be in the class of "Innovative Photovoltaic" fields
- Production of fruit trees (apples, pears, citrons, lemons, ...) in a "Classic" configuration: tree growth in a 3D configuration, maximum height < 4 m, inter-row spacing of about 3.00 - 3.50 m.
- Apple production according to a different training system: tree growth in a 2D configuration, maximum height < 3.5 m, inter-row spacing < 2.5 m. This system is also of interest for grape production.

Closed agri-PV Scenario, for:

- Production of vegetables or horticultural crops in Venlo type greenhouses which are used for crops like tomatoes, cucumbers, peppers, but also for cut flowers like roses and many others and pot plants. These are characterized by glass spans of 3.2 m and gutter heights about 4-6 m to accommodate for high wire planting system, thermal screens, and supplementary lighting.

The scope of this deliverable is to report the status of the Technical Specification and the Conceptual Design of the agri-PV demonstrators after 1 year of project implementation.

The deliverable contains details on the process for the definition of the draft Technical Specifications for the demos yet to be built:

- Bolzano, Italy. Open agri-PV. Apple tree orchards.
- Barcelona, Spain. Open agri-PV. Tomatoes, onions, fava beans, lettuce.
- Netherlands. Closed agri-PV. Greenhouse. Tomatoes.

The deliverable also contains the Technical Specification of one existing Demo site, also used as demo driver:

- Scalea, Italy. Open agri-PV. Citrus fruits.

In this report the Technical Specification and the Conceptual Design of the agri-PV demonstrators are defined by reporting on the results of the modelling tools developed in SYMBIOSYST and applied on the demonstrators.

1.2. ABBREVIATION LIST

Table 1: Abbreviation list.

Abbreviation	Meaning
1P	PV layout with 1 row of PV modules installed in Portrait mode
AC	Alternating current
Agri-PV/ AV	Agrivoltaics
BEG	Bifacial energy gain
DC	Direct current
DHI	Diffused horizontal irradiance
DLI	Daily light integral
DNI	Direct normal irradiance
E-W	East-West
EOT	Electrical, optical and thermal
FS	Full sun
G_{AV}	Global irradiance for the agrivoltaic system
GCR	Ground cover ratio
GHI	Global horizontal irradiance
GPU	Graphics Processing Unit
G_{ref}	Global irradiance for the reference system
GTI	Global tilted irradiance
HSAT	Horizontal Single-Axis Tracker
HC	Half cell
kWh/m^2	Kilowatt-hour per square metre
MWh/m^2	Megawatt-hour per square metre
N-S	North-South
PAR	Photosynthetically active radiation
POA	Plane of array
PV	Photovoltaics
T_a	Air temperature
W/m^2	Watts per meter square
Wp	Watt peak
W_s	Wind speed

2. AGRIVOLTAIC DEMONSTRATOR 1 - BOLZANO

2.1. AGRIVOLTAIC PROJECT DESCRIPTION

The agri-PV solution that were considered for this open system were consisting of overhead PV modules that are either fixed or with tracking functionalities (location and taxonomy in Figure 1). A stilt-mounted and overhead PV array configuration was selected to ensure protection of the apple orchard consisting of this high-value crop. Two different training systems were considered; the 2D and a 3D slender spindle training system. The latter is depicted in Figure 2.

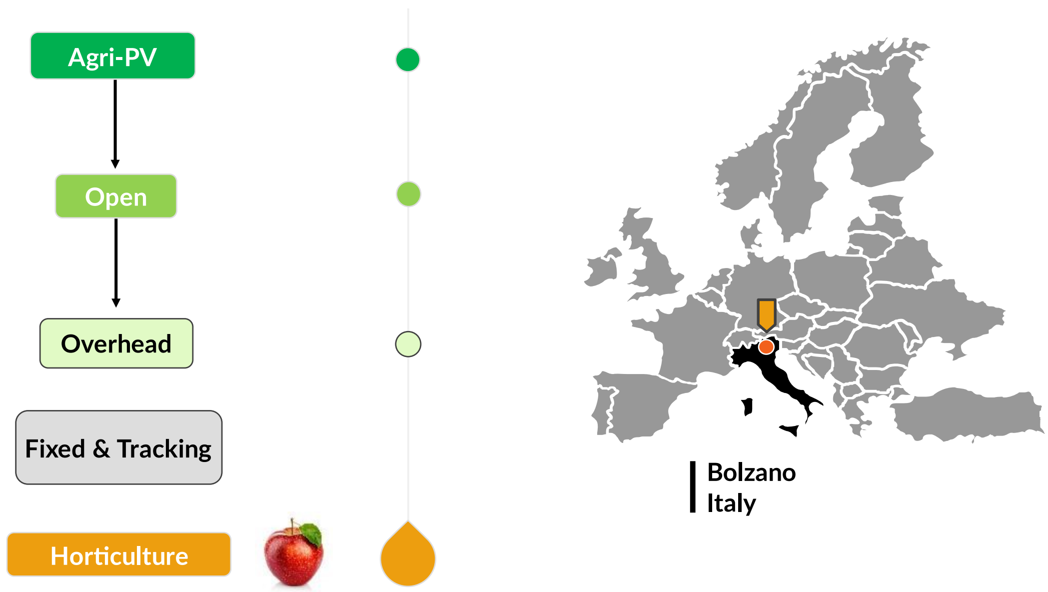


Figure 1: Agri-PV taxonomy and demonstrator location.

Figure 2: Apple orchard 3D spindle tree training configuration.

The activities of the modellers were focused on the new plant. The main parameters that specify orchard design are the pitch and height, which are based on the training system. With 2D training, the orchard can be modelled as a thin wall, or more specifically a translucent glass enabling a 2D analysis. On the other hand, this 2D simplification cannot be applied onto the 3D spindle setup, which required a more detailed orchard geometrical model.

Each orchard row consists of four groups of apple plants, with each group containing two apple trees. In other words, two apple trees under one group of 5 PV modules. Figure 3 provides a side view of an orchard row, showcasing the layout and height of the crops.

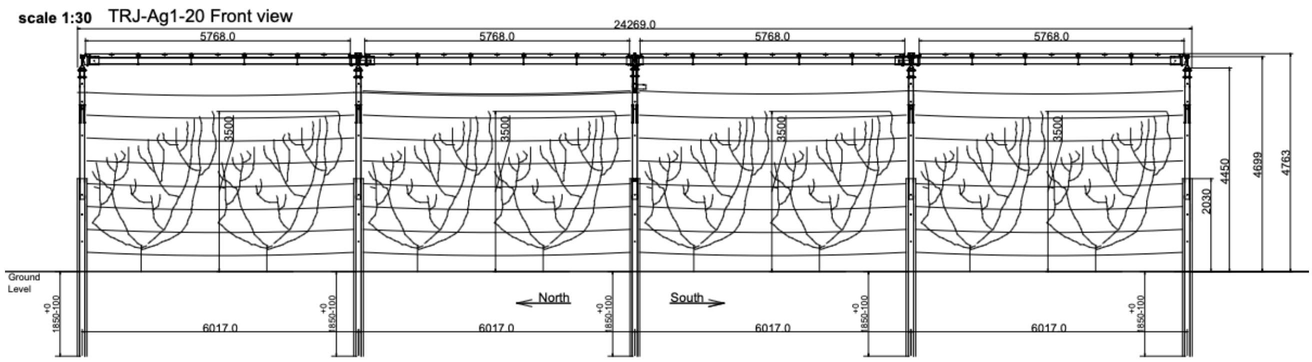


Figure 3: Front view of an apple orchard row for the 2D training system.

In the preliminary phase, 11 different scenarios were considered, each with a different installation solution. The various scenarios considered are summarized in Table 2.

Table 2: Envisioned Summary of the 11 different scenarios considered in the preliminary phase.

Name	Optimised Height	Tracker	On Existing Orchard	On New Orchard	Description	Every Row in the Orchard	Every Other Row in the Orchard
Traditional	N	Y	X		PV-System installed over a traditional orchard, without changing the pre-existing system		X
L1.E	N	Y	X		1 row of PV modules in landscape mode	X	
L1.N	Y	Y		X	1 row of PV modules in landscape mode	X	
L2.E	N	Y	X		2 rows of PV modules in landscape mode		X
L2.N	Y	Y		X	2 rows of PV modules in landscape mode		X
P1.E	N	Y	X		1 row of PV modules in portrait mode		X
P1.N	Y	Y		X	1 row of PV modules in portrait mode		X
P1.Fixed	Y	N		X	1 row of PV modules in portrait mode - FIXED		X
L1.Fixed	Y	N		X	1 row of PV modules in landscape mode - FIXED	X	
L2.Fixed	Y	N		X	2 rows of PV modules in landscape mode - FIXED		X
V2.Fixed	Y	N		X	PV modules mounted in a V shape - FIXED		X

After conducting a comparative analysis, the solution featuring an elevated single axis tracker with PV modules in a 1P configuration was selected as the optimal choice, striking a favourable balance among economic investment (CAPEX), anticipated producibility, and geometric regularity—offering the best integration with the orchard.

After all the techno-economic considerations and the results of the modelling, the Bolzano demo will consist of two distinct parts:

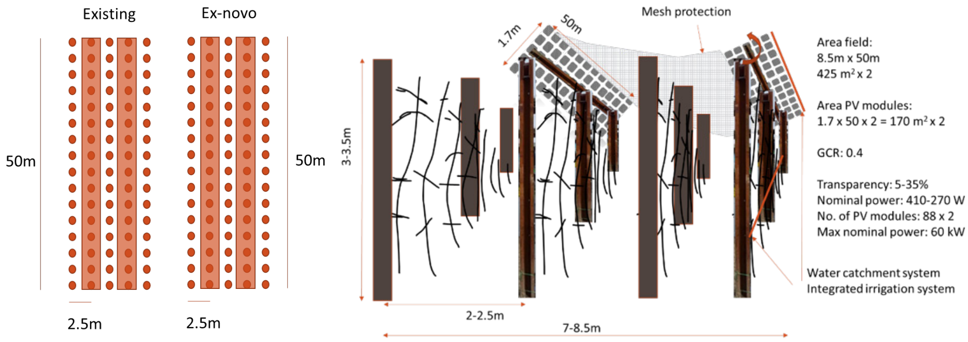
- The first portion, designated as "A," consists of four separate rows of trackers, each containing 20 modules. This portion will be installed on agricultural land where apple trees are already present.
- The second portion, designated as "B," consists of a 2 x 3 matrix of trackers, each with 20 modules. 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.

2.2. GENERAL TECHNICAL SPECIFICATIONS

Table 3 describes the envisioned features of the demo of Bolzano and the updates in terms of Technical Specifications at M12 and M18 of the project.

Table 3: Envisioned features of the demo of Bolzano and the updates in terms of Technical Specifications at M12 and M18 of the project.

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 2D plant growth. Trackers will be installed every other row.
Location	Province of South Tyrol Update M12: The coordinates where the prototype will be located are as follows (nearby the existing demo driver): • 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. Application extended to any type of guyot cultivation. Can be applied to vineyards and pears already in 2D configuration. 2500 ha per year worldwide [1].
Crop	The Bolzano demo will be focused on apple trees, N-S orientation, Guyot (< 3/3.5 m, 2D growth, <2.5 m interrow). Classical tall slender spindle will be studied but not considered for the field demo (4 m height with 3D growth, 3-3.5 m interrow). Update M12: In Bolzano the final height of the rotation axis will be at 4.7 m. The selected site is designated for the cultivation of fruit trees, more specifically, the Ipador (Giga) apple variety.
Solutions implemented in the demo and demo details	 Multifunctional trackers with height between 3 and 3.5 m (exact height to be determined depending on how the hail system is integrated) to ensure free movement of semi-automatic agricultural devices. Weathering steel will be used to manufacture the trackers, as 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. The site will be divided into (i) reference field with no PV system, (ii) trackers installed on existing fields (100 m of trackers), (iii) trackers installed together with new apple trees to allow for full integration and optimization. In total, the size of the PV system will be around 60 kWp (around 180 modules with various levels of semitransparency).

	UPDATE M12: The plan is for about 260m of trackers divided into 2 portions (4 + 6 trackers) with a total of 240 modules (to be discussed how many can be provided by ALEO using 2 levels of semitransparency). The nominal power will be around 90 kWp. UPDATE M18: The plan is for 260 m of trackers divided into 2 portions (4 + 6 trackers) with a total of 200 modules. The nominal power will be around 74,6 kWp.
Water catchment / irrigation	Water collected by the tracking system is comparable to a roof without gutter. Water will be conveyed to avoid issues to the plants below. Irrigation comes from sprinklers used also as antifreeze systems. UPDATE M12: Sprinklers are redesigned as actual sprinklers are at a height which is higher than the foreseen structures. UPDATE M18: CONVERT has designed a water catchment system specifically for the tracking solution.
Health &Safety	At the moment, there are no specific norms for agri-PV (grounding, etc). Rapid shutdown as from roof/facade systems will be studied. The use of pesticides which could reach the PV modules will also be considered.
System integration	70% of crops in South Tyrol covered by hail protection systems. Agri-PV needs to be integrated. Nets against insects are also becoming a new demand. UPDATE M12: Reuse of existing hail protection system for the existing section. New hail net will be fixed to the tracker structures for new Agri-PV section.
Use of electricity	LAIMBURG has identified several sites for the installation. The final choice will also depend on the existing availability of electricity connection, and we will create the conditions to electrify water pumps for irrigation to create an infrastructure for the charging of electrical tools. UPDATE M12: see above under "location".

2.3. LAYOUT

The PV plant layout is proposed in the figure below. Standard transparency PV modules are represented in blue, while those with increased transparency are represented in cyan.

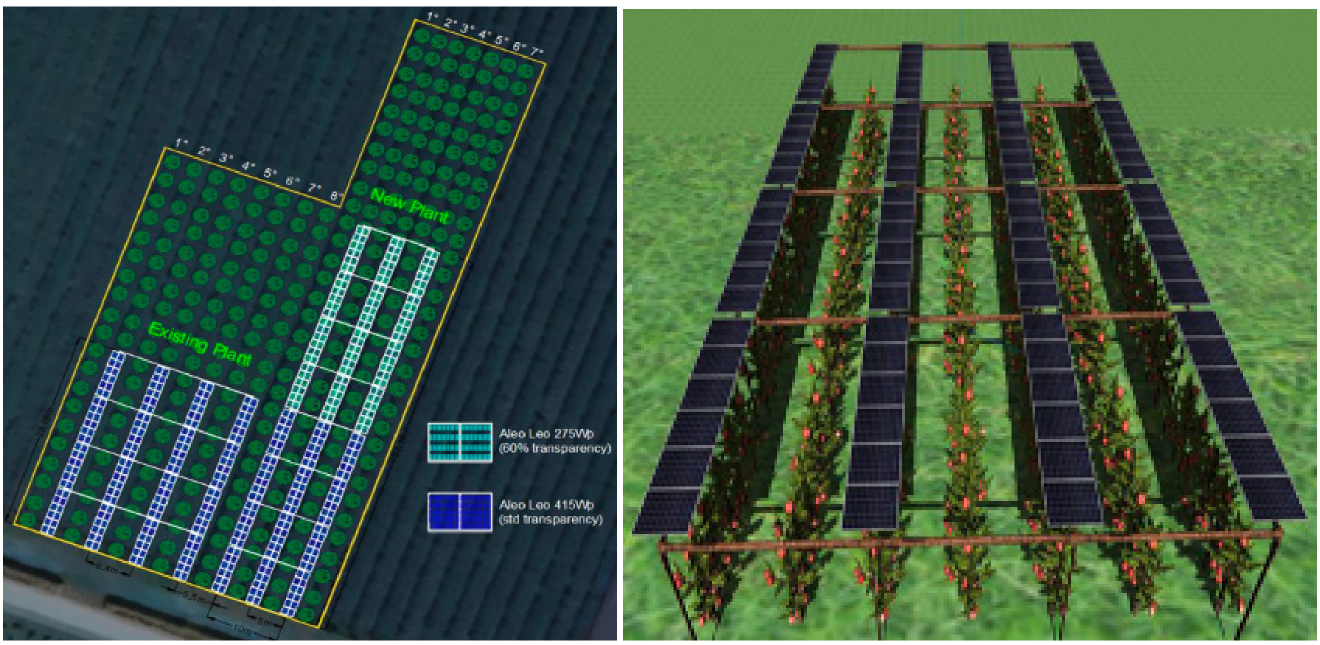


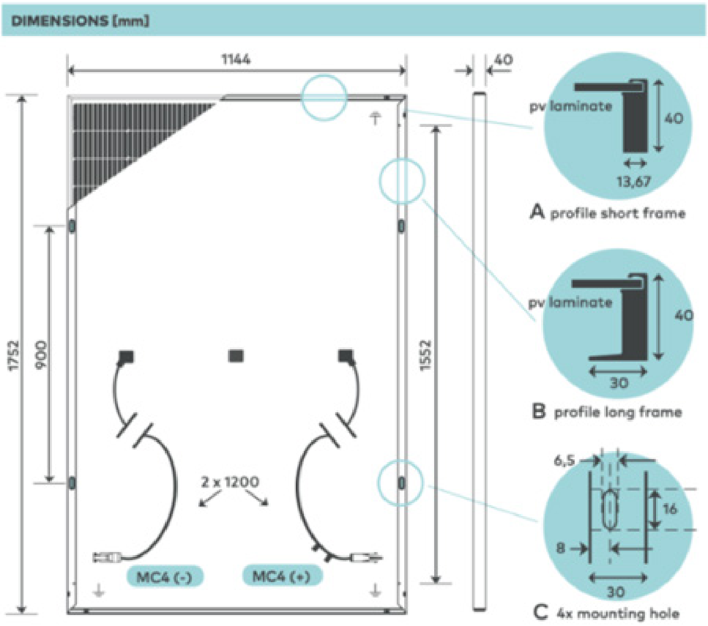
Figure 4: Layout of Bolzano's demo (complete top view, and 3D representation of existing plant section)

2.4. PV MODULES

The photovoltaic generator will consist of two different types of photovoltaic modules:

- bifacial 120 HC PV modules with an estimated transparency of less than 10% by aleo;
- bifacial 80 HC PV modules with an estimated transparency of about 40% by aleo.

Figure 5 provides the main technical information about the PV modules of aleo.



BASIC MODULE DATA		
Length x width x height	[mm]	1752 x 1144 x 40
Weight	[kg]	22
Number of cells		108
Cell size	[mm]	182 x 91
Cell material		Monocrystalline Si, PERC
Number of Busbars		10
Front sheet		3.2 mm Solar glass (TSG)
Back sheet		Polymere sheet, transparent
Frame material		Al alloy, black
BASIC DATA JUNCTION BOX		
3 parts junction box acc. to IEC 62790	[mm]	left & right: 62 x 58 x 14 middle: 49 x 55 x 14
Bypass diodes		3 (one per box)
IP class		IP68
Cable	[mm]	1200 (+), 1200 (-) acc. to EN 50618
Connectors		genuine MC4 acc. to EN 62852

Figure 5: Main technical information about the PV modules of aleo.

The four different solutions proposed by the PV module manufacturer are shown in Figure 6, corresponding to different semi-transparency levels.

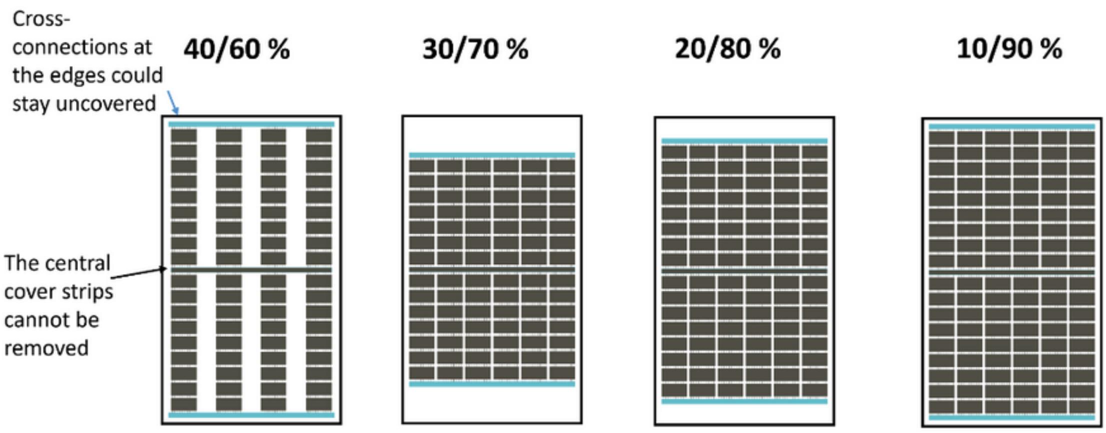


Figure 6: Overview of the four different solutions proposed by the PV module manufacturer, aleo

At present, the solution of most interest and therefore considered is the one with 40/60% transparency and the 10/90% solution (standard transparency).

Specifically:

- The A portion (Existing Plant) of the demo should consist of No. 80 standard modules (No. 4 trackers);
- The B portion (New Plant) of the demo should consist of No. 60 standard modules and No. 60 modules with increased transparency, for a total of No. 120 modules (No. 3 + 3 trackers).

2.5. INVERTER – STRING DESIGN

The current-to-alternating current conversion group (or inverter) performs the conditioning and control of the transferred power. The input voltage and current values of this equipment must be compatible with those of the connected photovoltaic field, while the output voltage and frequency values must be compatible with those of the distributor's grid to which it is connected. The converter is based on a forced-switching inverter (with PWM technique) and is capable of operating completely automatically, tracking the maximum power point (MPPT) of the PV power plant.

To better understand the electrical production parameters and distinguish them correctly based on various parameters (such as the pitch between structures and module transparency), the installation of three different inverters has been evaluated, specifically:

1. One inverter for the electrical strings of portion A (4 strings, total DC power output of 33.2 kWp).
2. One inverter for the electrical strings of portion B, composed of modules with standard transparency (3 electrical strings, total DC power output of 24.9 kWp).
3. One inverter for the electrical strings of portion B, composed of modules with higher transparency (3 electrical strings, total DC power output of 16.5 kWp (estimated)).

The three inverters identified are as follows:

1. HUAWEI string inverter, model SUN2000-30KTL-M3;
2. HUAWEI string inverter, model SUN2000-25KTL-M3;
3. HUAWEI string inverter, model SUN2000-15KTL-M3.

Their main technical specifications are provided below.

SUN2000-30/36/40KTL-M3

Technical Specification

Technical Specification	SUN2000-30KTL-M3	SUN2000-36KTL-M3	SUN2000-40KTL-M3
Efficiency			
Max. Efficiency	98.7%		
European Efficiency	98.4%		
Input			
Max. Input Voltage [1]	1,100 V		
Max. Current per MPPT	27 A (per MPPT) / 20 A (per Input)		
Max. Short Circuit Current per MPPT	40 A		
Start Voltage	200 V		
MPPT Operating Voltage Range [2]	200 V ~ 1000 V		
Rated Input Voltage	600 V		
Number of Inputs	8		
Number of MPP Trackers	4		
Output			
Rated AC Active Power	30,000 W	36,000 W	40,000 W
Max. AC Apparent Power	33,000 VA [3]	40,000 VA	44,000 VA
Rated Output Voltage	230 Vac / 400 Vac / 480 Vac, 3W/N+PE		
Rated AC Grid Frequency	50 Hz / 60 Hz		
Rated Output Current	43.3 A	52.0 A	57.8 A
Max. Output Current	47.9 A	58.0 A	63.8 A
Adjustable Power Factor Range	0.8 LG ... 0.8 LD		
Max. Total Harmonic Distortion	< 3%		
Protection			
Input-side Disconnection Device	Yes		
Anti-islanding Protection	Yes		
AC Overcurrent Protection	Yes		
DC Reverse-polarity Protection	Yes		
PV-array String Fault Monitoring	Yes		
DC Surge Arrester	Yes		
AC Surge Arrester	Yes		
DC Insulation Resistance Detection	Yes		
Residual Current Monitoring Unit	Yes		
Arc Fault Protection	Yes		
Ripple Receiver Control	Yes		
Integrated PID Recovery [3]	Yes		
Communication			
Display	LED Indicators, Integrated WLAN + FusionSolar APP		
RS485	Yes		
Smart Dongle	WLAN/Ethernet via Smart Dongle-WLAN-FE (Optional) 4G / 3G / 2G via Smart Dongle-4G (Optional)		
General Data			
Dimensions (W x H x D)	640 x 530 x 270 mm (25.2 x 20.9 x 10.6 inch)		
Weight (with mounting plate)	43 kg (94.8 lb)		
Operating Temperature Range	-25 ~ + 60 °C (-13 °F ~ 140 °F)		
Cooling Method	Natural Convection		
Max. Operating Altitude	4,000 m (13,123 ft.) (Derating above 2000 m)		
Relative Humidity	0% RH ~ 100% RH		
DC Connector	Amphenol Helios H4		
AC Connector	Waterproof Connector + OT/DT Terminal		
Protection Degree	IP 66		
Topology	Transformerless		
Nightime Power Consumption	≤ 5.5W		
Optimizer Compatibility			
DC MBUS Compatible Optimizer	SUN2000-450W-P2, SUN2000-600W-P,MERC-1100W/1300W-P		
Standard Compliance (more available upon request)			
Safety	EN 62109-1/-2, IEC 62109-1/-2, EN 50530, IEC 62116, IEC 60068, IEC 61683		
Grid Connection Standards	IEC 61727, VDE-AR-N4105, VDE 0126-1-1, BDEW, G59/3, UTE C 15-712-1, CEI 0-16, CEI 0-21, RD 661, RD 1699, P.O. 12.3,RD 413, EN-50438-Turkey, EN-50438-Ireland, C10/11, MEA, Resolution No.7, NRS 097-2-1, AS/NZS 4777.2, DEWA		

SUN2000-12/15/17/20/25KTL-M5

Specifiche tecniche

Specifiche tecniche	SUN2000 -12KTL-M5	SUN2000 -15KTL-M5	SUN2000 -17KTL-M5	SUN2000 -20KTL-M5	SUN2000 -25KTL-M5
Efficienza					
Efficienza max	98.4%	98.4%	98.4%	98.4%	98.4%
Efficienza ponderata europea	97.9%	98.0%	98.1%	98.1%	98.2%
Ingresso					
Potenza FV max suggerita[1]	18,000 Wp	22,500 Wp	25,500 Wp	30,000 Wp	37,500 Wp
Tensione di ingresso max [2]	1100 V				
Intervallo di tensione max del MPPT	370V~800V	410V~800V	440V~800V	480V~800V	530~800V
Intervallo di tensione nominale del MPPT 3	200 V ~ 1000 V				
Tensione di avvio	200 V				
Tensione di ingresso nominale	600 V				
Corrente di ingresso max per MPPT	30 A (due stringhe) / 20 A (unica stringa)				
Corrente di cortocircuito max	40 A				
Numero di tracker MPP	2				
Numero max di ingresso per MPPT	4				
Uscita					
Connessione rete elettrica	Trifase				
Potenza di uscita nominale	12,000 W	15,000 W	17,000 W	20,000 W	25,000 W
Potenza apparente max	13,200 W	16,500 VA	18,700 VA	22,000 VA	27,500 VA
Tensione di uscita nominale	220 Vac / 380 Vac, 230 Vac / 400 Vac, 239.6 Vac / 415Vac, 3W + N + PE				
Frequenza rete CA nomminale	50 Hz / 60 Hz				
Corrente d'uscita massima	18.2A/380Vac 17.3A/400Vac 16.7A/415Vac	25.2A/380Vac 23.9A/400Vac 23.1A/415Vac	28.6A/380Vac 27.1A/400Vac 26.1A/415Vac	33.6A/380Vac 31.9A/400Vac 30.8A/415Vac	42.0A/380Vac 39.9A/400Vac 38.5A/415Vac
Fattore di Potenza regolabile	0.8 capac ... 0.8 indut				
Max. Distorsione armonica totale	≤ 3 %				
Funzioni e protezioni					
Categoria di sovratensione	PV Ⅱ/AC Ⅲ				
Dispositivo di disconnessione lato ingress	Sì				
Protezione Anti-islanding	Sì				
Protezione da sovracorrente CA	Sì				
Protezione polarità inversa DC	Sì				
Rilevazione Guasti di stringa	Sì				
Scaricatore DC integrato	TIPO II				
Scaricatore AC integrato	CLASSE II				
Unità di monitoraggio di corrente residua	Sì				
Protezione da guasto arco	Sì				
Ripple control	Sì				
Modulo di ripristino PID integrato4	Sì				

Compatibility between PV field and inverters was evaluated using special compatibility tool, which shows the possibility of association between PV field and selected inverters.

Impianto fotovoltaico				
Nome impianto	DC Power [kWp]	MT/AT	Coordinate	
			Latitudine [°]	Longitudine [°]
Bolzano Demo Driver	33,2	-	-	-

Condizioni									
STD Conditions		Temperatura dimensionamento		T_{max} modulo		T_{min} modulo		T_{op} modulo	
1000	W/m^2	25	°C	70	°C	-10	°C	50	°C
25	°C								
1,5	AM								

Modulo fotovoltaico							
Module brand	Aleo		Module model	LEO-4150W			
Potenza modulo	415	Wp	Bifacciale	No	Gain bifacciale	5	%
Lunghezza mod	1752	mm	Larghezza mod	1144	mm	Configurazione	1 P

	Valori a T_{std}		Valori a T_{max}		Valori a T_{min}		Valori a T_{op}	
Potenza max P_{mpp}	415	Wp	351,5	Wp	464,4	Wp	379,7	Wp
Tensione nom V_{mpp}	31,72	V	28,0	V	34,6	V	29,7	V
Corrente nom I_{mpp}	13,1	A	13,26	A	12,95	A	13,18	A
Tensione CA V_{oc}	37,44	V	33,1	V	40,8	V	35,0	V
Corrente di CC I_{sc}	13,7	A	13,90	A	13,57	A	13,81	A
Tensione operativa	1000	V						
Coeff. T in potenza	-0,34	%/°C						
Coeff. T in tensione	-0,26	%/°C						
Coeff. T in corrente	0,03	%/°C						

Stringa fotovoltaica						
Moduli per stringa	20	n°	V_{mpp} a T_{max}	V_{mpp} a T_{min}	V_{oc} a T_{min}	
P_{mpp} stringa a T_{std}	8,30	kWp	560,2 V	692,1 V	816,9 V	
Numero stringhe	4	n°	N. max stringhe per inverter		4	°n

Inverter								
Inverter brand	Huawei		Inverter model	Sun2000-30KTL-M3				
Numero inverter	1	n°	Tipologia	Stringa		PWR medio	1,11	pu
P_{AC} nominale	30	kWp	V_{max} ingresso	1100	V	PWR max	1,11	pu
V_{mppt} min	420	V	V_{mppt} max	850	V	I_{sc} MPPT	40	A
Max input per MPPT	2	n°	Ingressi totali	8	n°	MPPT	4	°n

Compatibilità stringhe - inverter		
La $V_{oc}(T_{min})$ della stringa è inferiore alla V_{max} ingresso inverter	Sì	
La $V_{mpp}(T_{min})$ della stringa è inferiore alla V_{mppt} max dell'inverter	Sì	
La $V_{mpp}(T_{max})$ della stringa è superiore alla V_{mppt} min dell'inverter	Sì	
La $V_{oc}(T_{min})$ è inferiore alla tensione operativa del modulo	Sì	
La $I_{sc}(T_{max})$ è inferiore alla I_{max} dell'inverter	Sì	
Se inverter di stringa		
Necessario ridurre n° ingressi per rispettare $I_{sc}(T_{max}) < I_{max}$ MPPT?	No	No
Numero stringhe pari o inferiore al numero di ingressi inverter	Sì	

Inverter-PV compatibility Portion A

Impianto fotovoltaico				
Nome impianto	DC Power [kWp]	MT/AT	Coordinate	
			Latitudine [°]	Longitudine [°]
Bolzano Demo Driver	24,9	-	-	-

Condizioni									
STD Conditions		Temperatura dimensionamento		T_{max} modulo		T_{min} modulo		T_{op} modulo	
1000	W/m^2	25	°C	70	°C	-10	°C	50	°C
25	°C								
1,5	AM								

Modulo fotovoltaico									
Module brand	Aleo		Module model	LEO-4150W					
Potenza modulo	415	Wp	Bifacciale	No	Gain bifacciale		5	%	
Lunghezza mod	1752	mm	Larghezza mod	1144	mm	Configurazione		1 P	
	Valori a T_{std}		Valori a T_{max}		Valori a T_{min}		Valori a T_{op}		
Potenza max P_{mpp}	415	Wp	351,5	Wp	464,4	Wp	379,7	Wp	
Tensione nom V_{mpp}	31,72	V	28,0	V	34,6	V	29,7	V	
Corrente nom I_{mpp}	13,1	A	13,26	A	12,95	A	13,18	A	
Tensione CA V_{oc}	37,44	V	33,1	V	40,8	V	35,0	V	
Corrente di CC I_{sc}	13,7	A	13,90	A	13,57	A	13,81	A	
Tensione operativa	1000	V							
Coeff. T in potenza	-0,34	%/°C							
Coeff. T in tensione	-0,26	%/°C							
Coeff. T in corrente	0,03	%/°C							

Stringa fotovoltaica						
Moduli per stringa	20	n°	V_{mpp} a T_{max}	V_{mpp} a T_{min}	V_{oc} a T_{min}	
P_{mpp} stringa a T_{std}	8,30	kWp	560,2 V	692,1 V	816,9 V	
Numero stringhe	3	n°	N. max stringhe per inverter		3	°n

Inverter								
Inverter brand	Huawei		Inverter model	Sun2000-25KTL-M3				
Numero inverter	1	n°	Tipologia	Stringa		PWR medi[illegible]	1,00	pu
P_{AC} nominale	25	kWp	V_{max} ingresso	1100	V	PWR max	1,00	pu
V_{mppt} min	530	V	V_{mppt} max	800	V	I_{sc} MPPT	40	A
Max input per MPPT	4	n°	Ingressi totali	8	n°	MPPT	2	°n

Compatibilità stringhe - inverter		
La $V_{oc}(T_{min})$ della stringa è inferiore alla V_{max} ingresso inverter	Sì	
La $V_{mpp}(T_{min})$ della stringa è inferiore alla V_{mppt} max dell'inverter	Sì	
La $V_{mpp}(T_{max})$ della stringa è superiore alla V_{mppt} min dell'inverter	Sì	
La $V_{oc}(T_{min})$ è inferiore alla tensione operativa del modulo	Sì	
La $I_{sc}(T_{max})$ è inferiore alla I_{max} dell'inverter	Sì	
Se inverter di stringa		
Necessario ridurre n° ingressi per rispettare $I_{sc}(T_{max}) < I_{max}$ MPPT?	No	No
Numero stringhe pari o inferiore al numero di ingressi inverter	Sì	

Inverter - PV Compatibility_Portion B.1

Impianto fotovoltaico									
Nome impianto	DC Power [kWp]	MT/AT	Coordinate						
			Latitudine [°]	Longitudine [°]					
Bolzano Demo Driver	16,5	-	-	-					
Condizioni									
STD Conditions		Temperatura dimensionamento		T_{max} modulo		T_{min} modulo		T_{op} modulo	
1000	W/m^2	25	°C	70	°C	-10	°C	50	°C
25	°C								
1,5	AM								
Modulo fotovoltaico									
Module brand	Aleo		Module model	LEO-275W					
Potenza modulo	275	Wp	Bifacciale	No	Gain bifacciale	5	%		
Lunghezza mod	1752	mm	Larghezza mod	1144	mm	Configurazione	1 P		
	Valori a T_{std}		Valori a T_{max}		Valori a T_{min}		Valori a T_{op}		
Potenza max P_{mpp}	275	Wp	232,9	Wp	307,7	Wp	251,6	Wp	
Tensione nom V_{mpp}	25,8	V	22,8	V	28,2	V	24,1	V	
Corrente nom I_{mpp}	10,7	A	10,79	A	10,54	A	10,73	A	
Tensione CA V_{oc}	30,5	V	26,9	V	33,2	V	28,5	V	
Corrente di CC I_{sc}	11,2	A	11,31	A	11,04	A	11,24	A	
Tensione operativa	1000	V							
Coeff. T in potenza	-0,34	%/°C							
Coeff. T in tensione	-0,26	%/°C							
Coeff. T in corrente	0,03	%/°C							
Stringa fotovoltaica									
Moduli per stringa	20	n°	V_{mpp} a T_{max}	V_{mpp} a T_{min}	V_{oc} a T_{min}				
P_{mpp} stringa a T_{std}	5,50	kWp	456,0 V	563,4 V	665,0 V				
Numero stringhe	3	n°	N. max stringhe per inverter	3	°n				
Inverter									
Inverter brand	Huawei		Inverter model	Sun2000-15KTL-M3					
Numero inverter	1	n°	Tipologia	Stringa		PWR medic	1,10	pu	
P_{AC} nominale	15	kWp	V_{max} ingresso	1100	V	PWR max	1,10	pu	
V_{mppt} min	410	V	V_{mppt} max	800	V	I_{sc} MPPT	40	A	
Max input per MPPT	4	n°	Ingressi totali	8	n°	MPPT	2	°n	
Compatibilità stringhe - inverter									
La $V_{oc}(T_{min})$ della stringa è inferiore alla V_{max} ingresso inverter	Sì								
La $V_{mpp}(T_{min})$ della stringa è inferiore alla V_{mppt} max dell'inverter	Sì								
La $V_{mpp}(T_{max})$ della stringa è superiore alla V_{mppt} min dell'inverter	Sì								
La $V_{oc}(T_{min})$ è inferiore alla tensione operativa del modulo	Sì								
La $I_{sc}(T_{max})$ è inferiore alla I_{max} dell'inverter	Sì								
Se inverter di stringa									
Necessario ridurre n° ingressi per rispettare $I_{sc}(T_{max}) < I_{max}$ MPPT?	No	No							
Numero stringhe pari o inferiore al numero di ingressi inverter	Sì								

Inverter - PV compatibility_Portion B.2

2.6. STRUCTURES

The photovoltaic modules will be mounted on horizontal single-axis trackers (HSAT) aligned along the NNE-SSW axis (roll trackers); orientation of modules will be 1P. In the northern Italian climate, this type of single-axis solar tracking structure enhances energy production by 15-20% compared to a fixed system with equivalent capacity. This improvement is achieved by optimizing the capture of direct solar irradiance on the PV module's surface throughout the day.

Moreover, the tracking system incorporates a backtracking algorithm, which effectively prevents mutual shading among modules on adjacent trackers during periods of low solar declination (early and late hours of the day). Consequently, a PV field equipped with trackers featuring this algorithm generates more energy than those lacking it. Additionally, the algorithm can be customized to meet specific crop-related requirements.

Each tracker is designed to accommodate 20 modules, organized into groups of 5 modules per span (across 4 spans), and allows for a maximum rotation of ±55° for the PV modules. These 20 modules are arranged in 4 groups of 5 modules each, with each group separated by 0.15 meters. In portion A, the trackers will be spaced with a pitch of 6.4 m to align with the current orchard spacing of 3.2 m. For portion B, the pitch is set at 5 m, corresponding to an orchard spacing of 2.5 m. In both cases, the rotation axis is positioned at an elevation of approximately 4.7 m, and the modules are configured in a 1P (Portrait 1) arrangement for optimal PV density and energy generated to cost ratio.

The front view of final design of a single tracker structure follows.

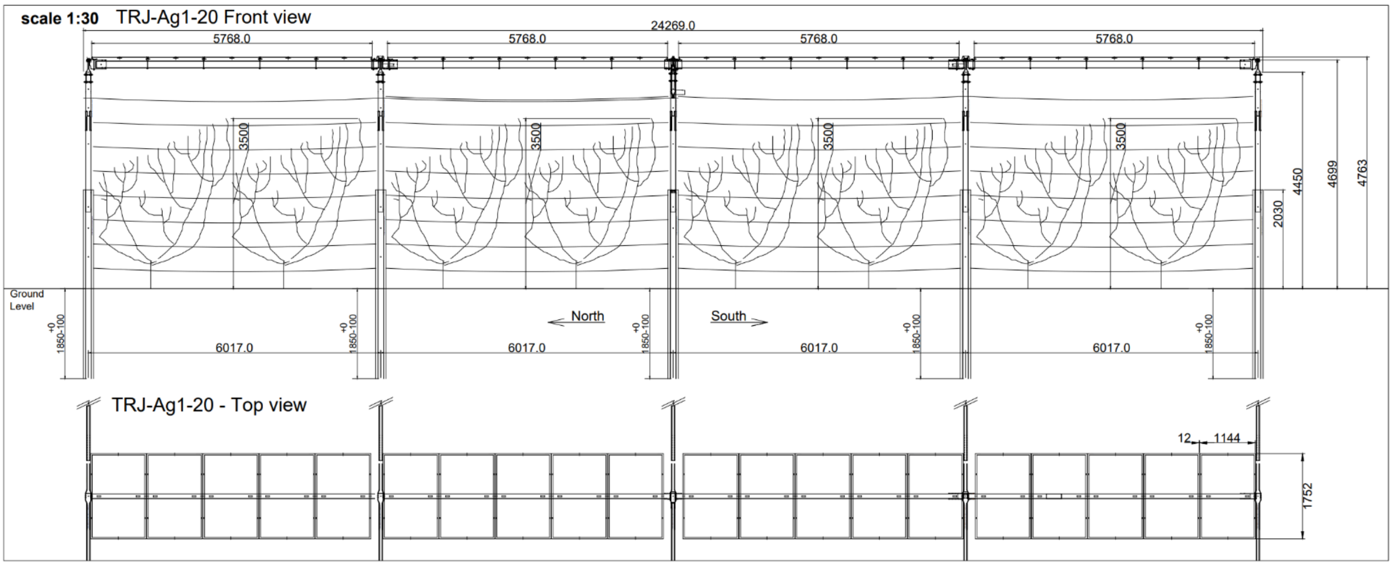


Figure 7: final design of tracker structure (front view)

The structure as a whole is statically indeterminate (hyperstatic) due to the presence of beams perpendicular to the tracker axis, resulting in a truss-type structure, as show in Figure 8 that provides the profile view of final design of tracker structure.

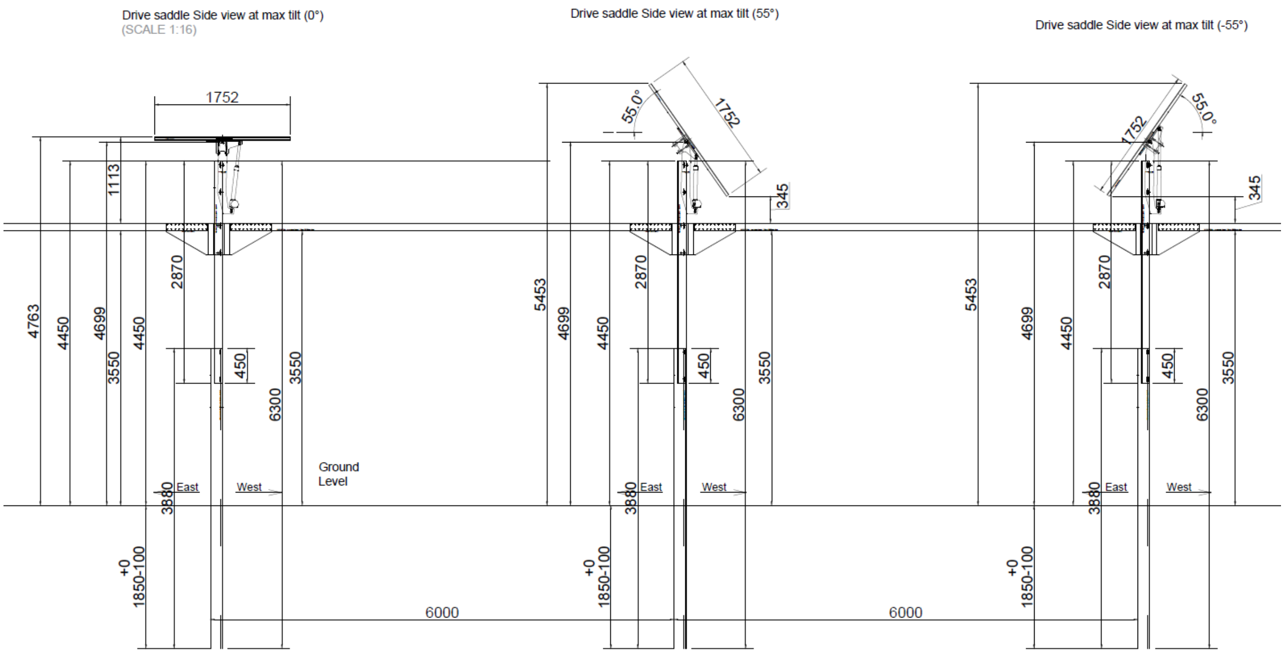
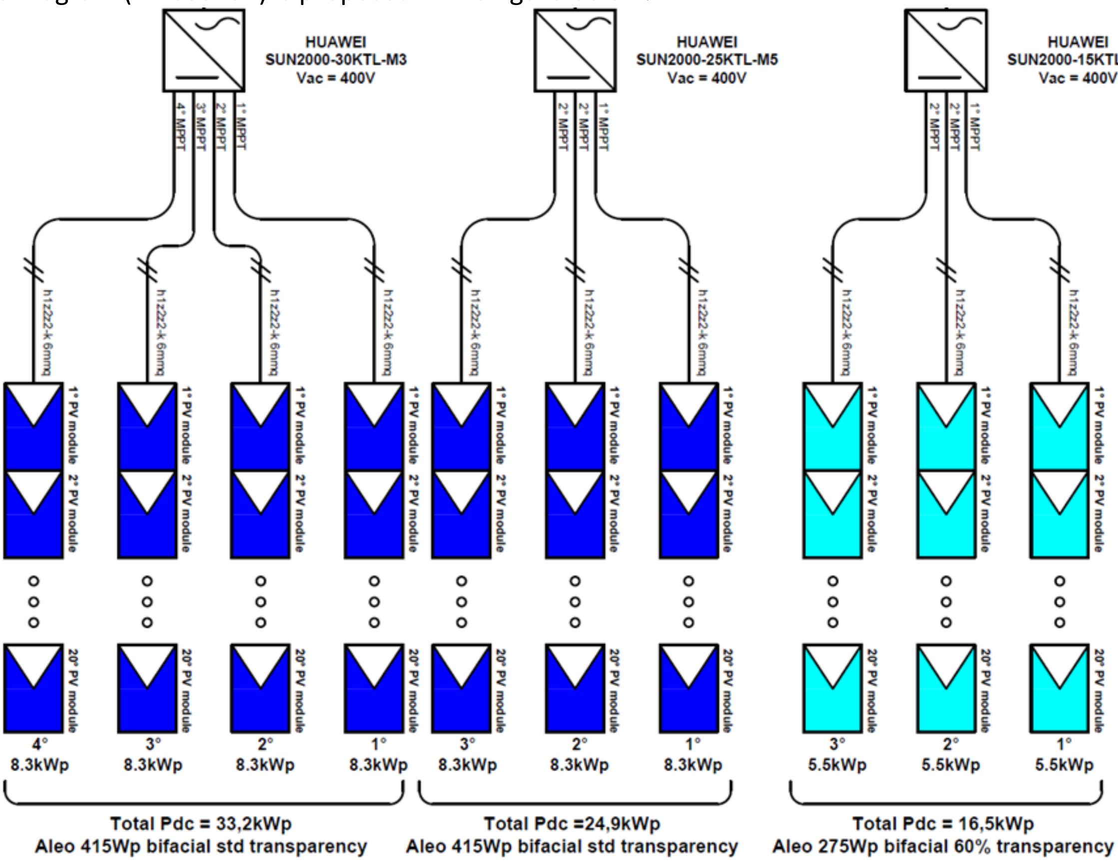


Figure 8 : final design of tracker structure (profile view)

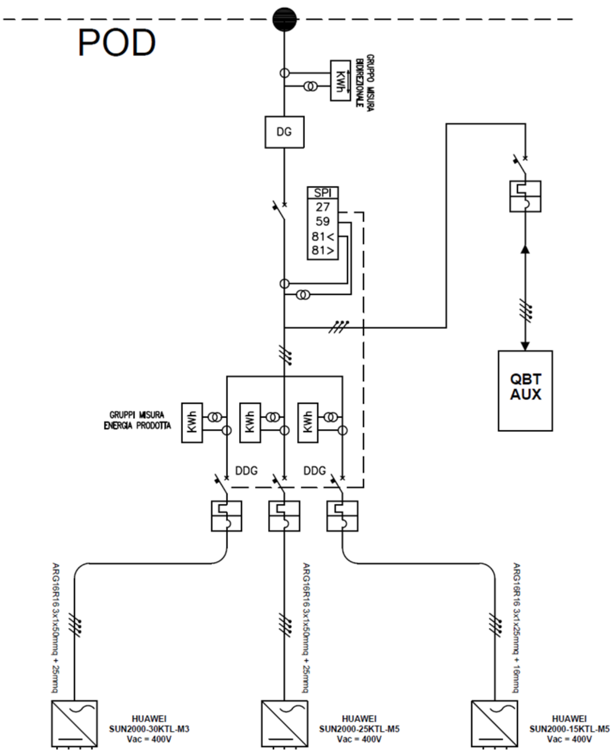
With regard to resistance to the external environment (corrosion), from an analysis of the Bolzano site it was agreed to classified it as C2/C3 light (as indicated in the ISO 9223). Therefore, it was considered a possibility to use Weathering Steel for all parts of the tracker that are not buried, and to limit hot-dip galvanising only in the buried parts. This choice, however, remains conditioned by the availability of Weathering Steel on the market in the thicknesses of interest, with a time frame compatible with the timing of WP5.

2.7. SLD – SINGLE LINE DIAGRAM

The Single Line Diagram (DC section) is proposed in the figure below.



The AC section is proposed in the figure below.



2.8. CROPS

The PV plant will be installed in an apple orchard, partly in an area which is already planted with apple trees (existing) and partly in an area where new trees will be planted in conjunction with the installation of the PV system (ex-novo). In the first case, the trees are trained as slender spindles with a planting distance of 3.2 x 1 metres and already in the stage of full production, whereas in the section of the newly planted orchard the trees will be planted at a spacing of 2.5 x 1.5 metres and trained as a multi-leader system leading to a narrow canopy allowing better light penetration. In both cases the trees are of the variety Ipador / Giga® grafted on dwarfing rootstocks (M9).

2.9. ANTI-FROST IRRIGATION, HAIL NET, RAINWATER COLLECTION SYSTEM

The site of the demonstrator orchard is located in a valley floor and therefore in an area prone to the risk of late spring frosts. Under such conditions the presence of an anti-frost irrigation system is a prerequisite for commercial apple production. Since the water delivered by the commonly used overhead sprinklers would be intercepted by the PV-modules, the demonstrator plots will be fitted with sprinklers characterized by a lower water trajectory, and which can be installed in such a way that the water will be emitted in the space between the treetops and the PV modules. A sprinkler model suitable for this purpose is the "Netafim Meganet 15D", installed at a spacing of about 12 x 6 metres.

Several additional considerations have been taken into account or are currently being discussed:

- Anti-frost system
  The sprinklers are used for anti-frost irrigation during cold nights in spring in the flowering season and are installed at a height which is not compatible with the mounting structures. A new system will be installed with dedicated sprinklers. This could potentially be used for treatments against pests / fungi, etc.
- Hail-Net
  The existing hail protection system will be reused for portion A while in portion B will be newly installed. For both cases discussion is ongoing on the integration and compatibility with the trackers' mounting structure.
- Rainwater collection systems
  The analysis of a rainwater collection system, for tracker structures instead of fixed ones, highlighted the difficulties to identify a solution without considerably increasing the amount of iron in structure to gather the water at the extremes of the PV panels. CONVERT has designed a solution that will be tested prior to future installation.

2.10. MONITORING SYSTEM AND SENSORS

The project will consider three distinct monitoring systems working together:

- a fixed system of sensors mounted directly on trackers.
- a system of sensors mounted on a robot guided by 3D-LIDAR sensors.
- a system of sensors mounted on a drone.

A series of parameters will be monitored, evaluating both the photovoltaic and agricultural parts of the agri-voltaic system.

On the agricultural side, parameters will be monitored to help assess the health of the plant, its vigour, and crop yield, as well as environmental and soil conditions. PAR radiation will also be monitored.

For the photovoltaic part, a meteo station will be set up to measure classic parameters such as air temperature and humidity, wind speed and direction. POA irradiance and Albedo will also be measured. The condition of the modules and their possible damages will also be monitored through Aerial Thermography and Electroluminescence. Moreover, a wind sensor and a snow sensor are planned to be dedicated exclusively to detecting dangerous wind or snow conditions and triggering procedures to bring trackers into a safe position. .

Discussion is ongoing to:

- identify a solution for rainwater collection system.
- identify the exact position of the sprinkler.
- identify the exact position of the fixed sensors.
- identify the exact level of transparency of portion B2.

The intent of the monitoring system being developed is to assess the impact of an elevated PV system, i.e. placed above the canopy of the underlying crop, on the health of the plants, their productivity, the microclimate in which they live, the soil and biodiversity. Remembering, however, that this is a symbiosis of two worlds, it is also interesting to assess the impact on the productivity and degradation of the PV modules due to the microclimate provided by the agricultural part, where irrigation systems, higher humidity, chemicals from plant protection products and pesticides are present, as well as a different albedo.

Table 4 Main measurand target of the static monitoring system installation.

PV part	**Unit**	**Agriculture part**	**Unit**
POA Irradiance	W/m^2	Horizontal Irradiance	W/m^2
PV **panel** temperature	°C	Soil Humidity	%vol or hPa
Wind Speed	m/s	Soil Temperature	°C
		PAR or ePAR	W/m^2
Relative Humidity	%rh	Rainfall sensor[1]	mm/h
Albedo	W/m^2		
DC/AC Current	A		
DC/AC Voltage	V		
DC/AC Power	W		

Several parameters were identified to arrive at a complete analysis of the demo. The static monitoring system is designed to collect continuously during the observation period the main parameters considered relevant to assess the impact and performance of the system analyzed in this project. Table 4 reports the main measured quantities. We divide the values into categories according to the main domains the measurand belongs to: 1) measurements more connected to the PV performance; 2) measurand that covers the agricultural component and 3) finally more general weather conditions (that holds for the entire plant, beyond the presence of PV and cultivation).
We design the monitoring system to monitor the main measurand of Table 4 in each combination of the changing factors (agricultural system and PV technology) replicating multiple time the same measurement.
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.

[1] The precipitation sensors will report beyond the precipitation quantity in mm/h further parameters connected type of precipitation and cloud coverage condition.

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.

The current chapter proceeds by providing a general description of the monitoring system design and concepts. Such part holds both for the demo in Bolzano (Section 2, current section) and in Barcelona (Section 3) has the same design concept and general structure. The system differs for the topology, adapted to each demo case, and for other customization provided to properly address the characteristics of each demo site.

Static monitoring system general design approach and technical specifications

The system is composed by a set of substations described in Figure 8. A main station is responsible for power supply and ensuring communication to the remote database. From this station, several digital buses (RS485) reach each substation or directly the digital sensors that embed such communication options. Supply (low voltage DC) is also distributed from the main substation. Secondary substations are located in the plant in proximity to each measurement point group. Here, they are called "Secondary substations" and are divided between fully equipped points (under the PV) and control substations located in the field, keeping the same plant cultivation system but without PV above. Figure 9 reports the different components. Sensors and transducer are connected to each afferent substation in order to reduce the distance from the acquisition modules. More details about the location of each substation will be provided in the following sections.

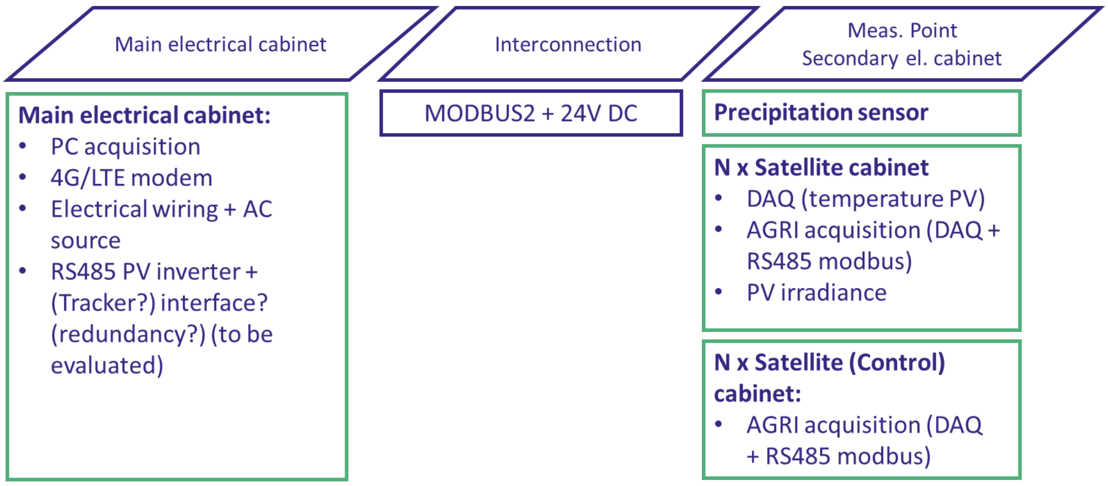


Figure 9 Component of the monitoring system. General Schema.

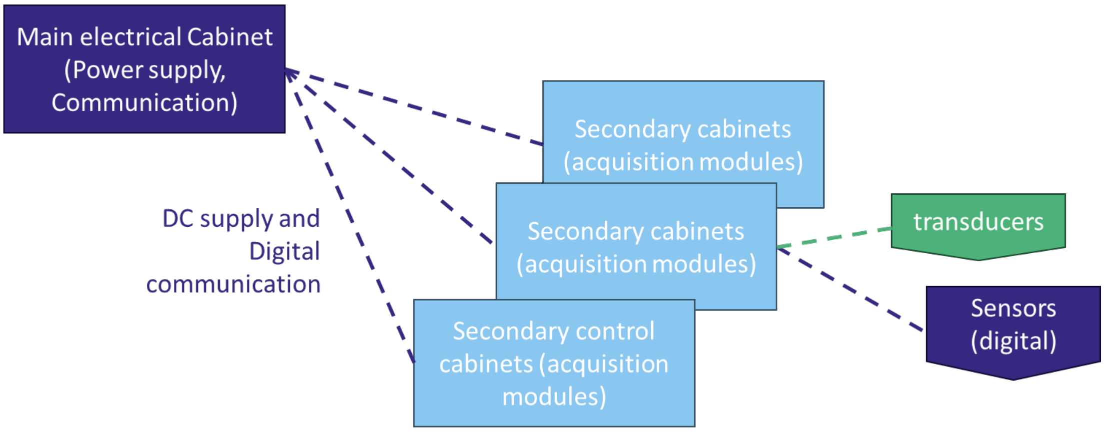


Figure 10 Topology of the system.

Figure 10 provides the design approach adopted for the integration of the hardware component of the system. Transducers with analog outputs are digitalized by industrial acquisition modules. Wherever possible, 4-20mA transducers (industrial standard) are adopted for better robustness to electrical noise from the proximity to PV system and power lines and other factors such as cable lengths (form transducer to actual acquisition module). Such a choice has as a drawback a typically higher power consumption compared to voltage outputs alternatives, that we are able to support as the entire system is powered from the grid and does not rely on batteries to operate. The communication from the acquisition modules and the sensors with embedded digital capabilities adopts RS485 with the Modbus-RTU standard. Such a mean can cover relatively long distances and supports multiple devices on the same bus with a proper addressing system and checksum to ensure communication error detection and consequent rejection of malformed values. The main cabinet contains a PC/ARM-based solution that interfaces with the RS485 busses actively collecting the data from each device on the bus. This computer performs a first basic sanity check on the acquired data and deals with possible issues in measurement, acquisition, or transmissions. LTE connectivity ensures connection to the remotely located ICT infrastructure that will store the data. Interconnection with other platform, data consumption and visualization will be therefore provided through the direct connection to the database hosted on such infrastructure (Figure 11).

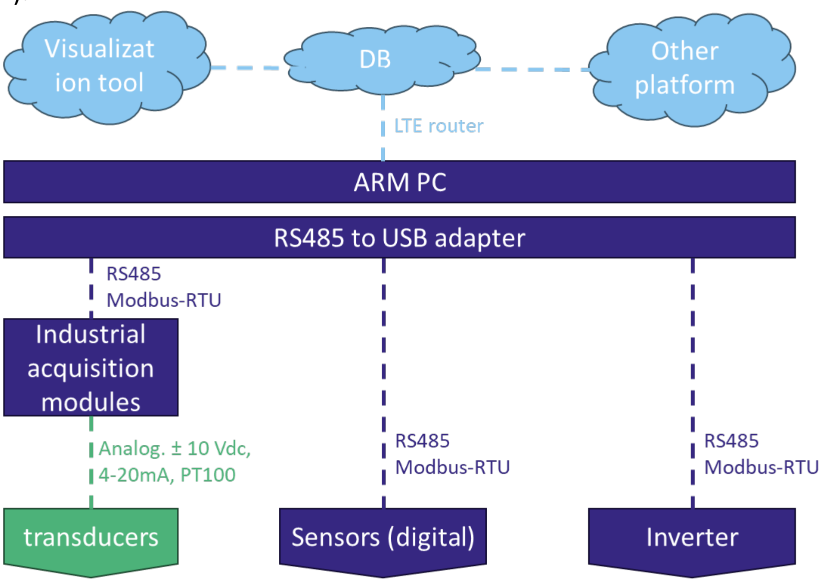


Figure 11 General layout of the system from a hardware perspective. Components and interconnection means and protocols**.**

The computer that acts as a gateway performs the actual acquisition, basic preprocessing, and delivery of collected data. This is ensured by a service that iteratively actively polls the values from the digital devices responsible for the

actual acquisition. This operation is repeated according to the requested acquisition interval (30-60s) in which a sample is collected and delivered with proper timestamp. The delivery to the remote database is performed with a lower frequency to reduce the amount of data transmitted through the LTE connection (with monthly limits).
The data are written directly to the database on the Eurac Research ICT infrastructure. Access to such resources will be provided to any interested partner that needs to consume data. Grafana will be provided for qualitative data visualization and data will be delivered with a lower sample rate to the Synaptiq platform of 3E. An additional repository will be provided to share pre-prepared standard CSV files on a regular basis.

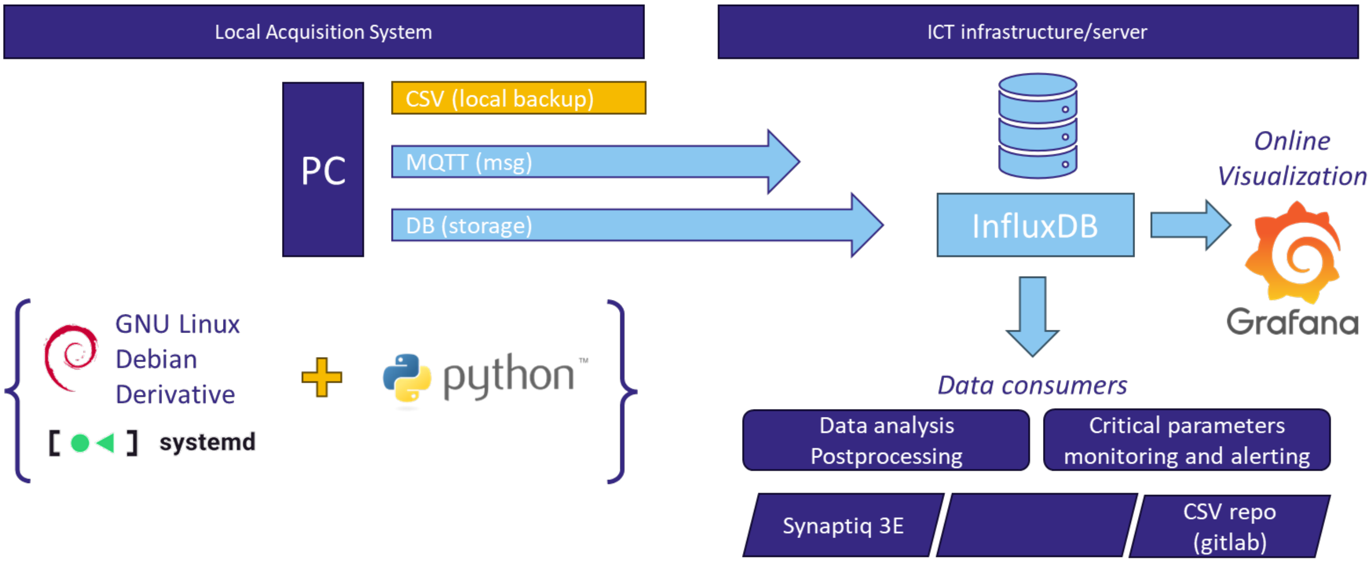


Figure 12 General layout of the monitoring system. A focus on the software part connected to the actual acquisition, transmission and storage of measurements performed in the Bolzano and Spain demo sites.

Transducer and acquisition modules
We opt for the installation of the transducers and acquisition modules described in the following section considering the design constraints and requests. A trade-off evaluation brings us to the selection of the device described in Table 5 and the industrial-grade acquisition systems described in Table 6 (where required).

Table 5 Table with transducer models.

Domain	sub-domain	measurand	Device / transducer	output	Acquisition module	product link
AGRI	air	Temperature	epluse HTP 201 4-20mA HTP201-M1-A6-E8-KL150	4-20mA	Seneca Z8AI	https://www.epluse.com/products/humidity-instruments/humidity-modules-and-probes/htp201
AGRI	air	Relative humidity		4-20mA	Seneca Z8AI	
AGRI	air	Dew point	*computed from T+RH information*			
AGRI	*air*	ePAR	Apogee SQ-618-SS modbus (ES only)[2]	digital		https://www.apogeeinstruments.com/sq-618-ss-modbus-digital-output-400-750-nm-epar-sensor/
AGRI	*air*	PAR	Apogee SQ-202X-SS modbus (IT only)[3]	0-2.5V	Seneca Z8AI	https://www.apogeeinstruments.com/sq-202x-ss-amplified-0-2-5-volt-original-quantum-sensor/
AGRI	soil	temperature		digital		

[2] Device adopted only for the demo in Barcelona.
[3] Device variant adopted only for the demo in Bolzano.

AGRI	soil	humidity	DeltaOhm HD3910.1.10 modbus			https://environmental.senseca.com/product/hd3910-1-hd3910-2-soil-volumetric-water-content/
PV	irradiance	G_POA	HuxeFlux SR05-D2A2 pyranometer	4-20mA	Seneca Z8AI	https://www.hukseflux.com/products/pyranometers-solar-radiation-sensors/pyranometers/sr05-d2a2-pyranometer
PV	irradiance	Albedo	HuxeFlux SR05-D2A2 pyranometer	4-20mA	Seneca Z8AI	https://www.hukseflux.com/products/pyranometers-solar-radiation-sensors/pyranometers/sr05-d2a2-pyranometer
PV	module	temperature	pt100 calss A 4 cavi (3?) silicone superficiali 15m (10)	PT100	Seneca Z4RTD	
PV	electrical	Inverter		expected digital		
WEATHER	air	temperature	epluse HTP 201 4-20mA	4-20mA	Seneca Z8AI	https://www.epluse.com/products/humidity-instruments/humidity-modules-and-probes/htp201
WEATHER	air	relative humidity		4-20mA	Seneca Z8AI	
WEATHER	precipitation		Luft ws100 UMB	digital		https://www.lufft.com/products/precipitation-sensors-287/ws100-radar-precipitation-sensor-smart-disdrometer-2361/
WEATHER	wind	speed	PCE-WS 4-20mA	4-20mA	Seneca Z8AI	https://www.pce-instruments.com/italiano/regolazione-e-controllo/sensore/sensore-di-vento-pce-instruments-sensore-di-velocit_-del-vento-con-uscita-4-20-ma-pce-ws-a-det_5935926.htm

Table 6 Industrial acquisition modules adopted for digitalization of transducer with analog output. Digital communication via Modbus-RTU RS485.

Acquisition module	**Target measurand**	**Product link**
Seneca Z-8AI	transducer with analog output (voltage, current)	https://www.seneca.it/linee-di-prodotto/acquisizione-dati-e-automazione/sistemi-io-modbus-rtu/moduli-io-analogici/z-8ai/
Seneca Z-4RTD	PT100	https://www.seneca.it/linee-di-prodotto/acquisizione-dati-e-automazione/sistemi-io-modbus-rtu/moduli-io-analogici/z-4rtd2/

Topology and customization for the Bolzano demo

Figure 12 reports a qualitative drawing of the Bolzano demo site. There we highlighted the so-called main substation located near the inverter location. Moreover, we reported each secondary substation located in the middle of each section of the PV plant. Two main factors change in the Bolzano demo, agricultural system (new and old plants) and PV technology (new plants only). For each combination of such factors, we locate a fully equipped measurement point (orange rhombus). Two reference (R) substations (green) are finally located to provide control measurements in the absence of the PV installation.

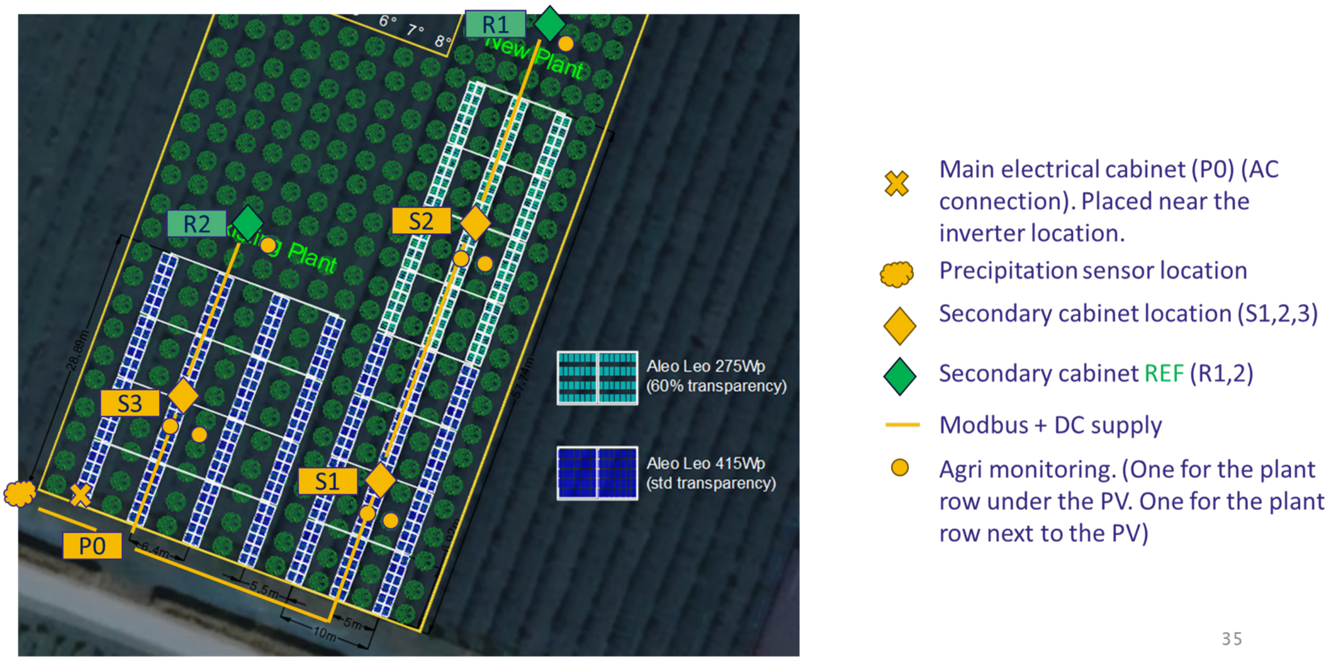


Figure 13: Bolzano demonstrator and layout of sensors. System topology in the plant field.

Figure 13 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 7 shows the sensors mounted on the weather station. This is mounted not to shadow the tracker structure (Figure 13). The device should be mounted in elevation at least 4.5m from the ground (1.5m above max height of plant structures) and it should have around a radius of 5m of free (no obstacles at the installation height). The device will be mounted either in tree rows without PV (West side of plant of Figure 12) or in the North of the PV installation plant marked as existent (the one of the left of Figure 12. Qualitative drawing of the final installation in Figure 13). The final positioning will be done during the field installation with the aim to avoid any kind of shadowing of the installed PV and to achieve a proper integration with the existent plant infrastructure.

Table 7 Measurement points in the Bolzano demo. Static monitoring system.

				Location					
				Main Cabinet	New plant			Existing	
					PV	PV transp	CTRL	PV	CTRL
Domain	**sub-domain**	**measurand**	**transducer**	**P0**	**S1**	**S2**	**R1**	**S3**	**R2**
AGRI	air	temperature	epluse HTP 201 4-20mA HTP201-M1-A6-E8-KL150	-	2	2	1	2	1
AGRI	air	relative humidity		-	2	2	1	2	1
AGRI	air	dew point	*Computed*	-	1	1	1	1	1
AGRI	*air*	ePAR PAR	Apogee SQ-202X-SS 0-2.5V	-	4	4	2	4	2
AGRI	soil	temperature	DeltaOhm HD3910.1.10 modbus	-	4	4	2	4	2
AGRI	soil	humidity		-	4	4	2	4	2
WEATHER	air	temperature	epluse HTP 201 4-20mA	1	-	-	-	-	-
WEATHER	air	relative humidity		1	-	-	-	-	-

WEATHE R		precipitation/rai n	Luft ws100 UMB	1				-	-
WEATHE R	wind	direction		0				-	-
WEATHE R	wind	speed	PCE-WS 4-20mA	1				-	-
PV	irradianc e	G_POA	HuxeFlux SR05-D2A2 pyranometer (4-20mA)		*1*	***0***		**<u>1</u>**	-
PV	irradianc e	Albedo	HuxeFlux SR05-D2A2 pyranometer (4-20mA)		*1*	***1***		**<u>1</u>**	-
PV	module	temperature	pt100 class b 3/4 wire cilican flat 15m (10m)		*4*	***4***		**<u>4</u>**	-
PV	electrical	***	modbus interface inv	4				-	-

Table 8 provides the full list of sensors installed for each substation described in Figure 12. More details follow for each substation. We notice that for each installation under the PV we are going to monitor both the row of trees directly below the PV as the one next to the PV. A set of sensors for the agricultural domain is present for each row according to the yellow circles of Figure 12.

Table 8: 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%

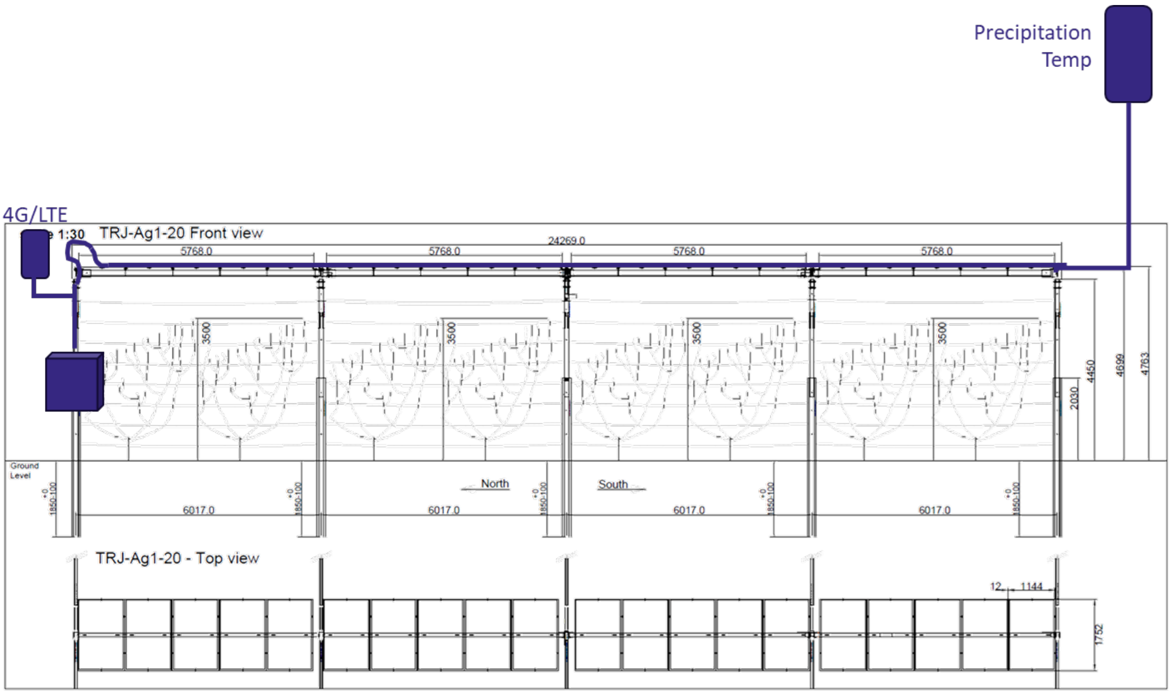


Figure 14: Mounting of the weather station.

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 9: 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 10: 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 11: 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.

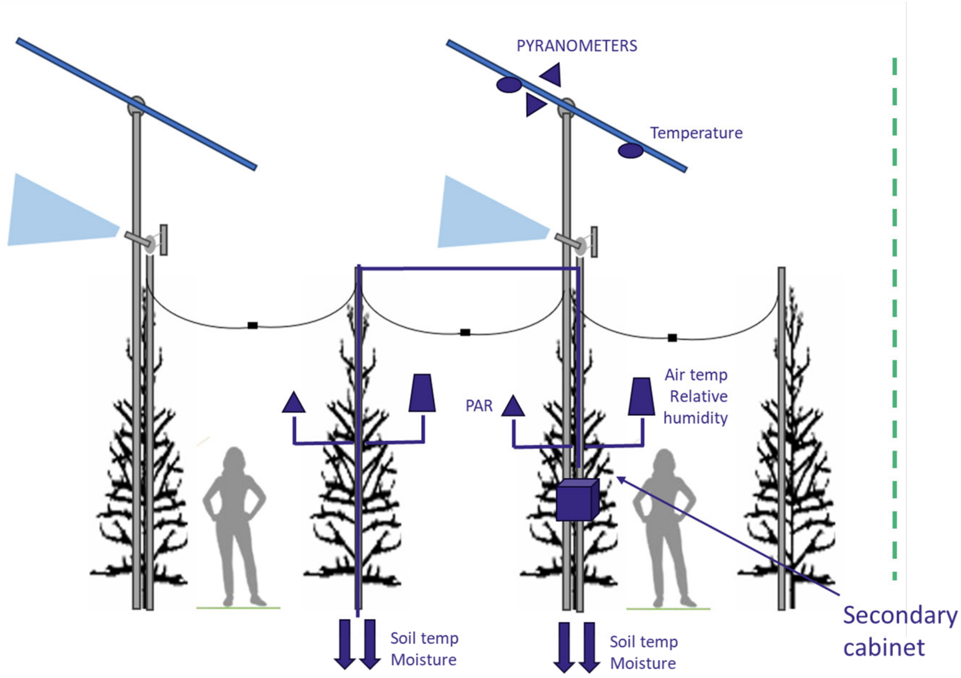


Figure 15: Positioning of the sensors.

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).

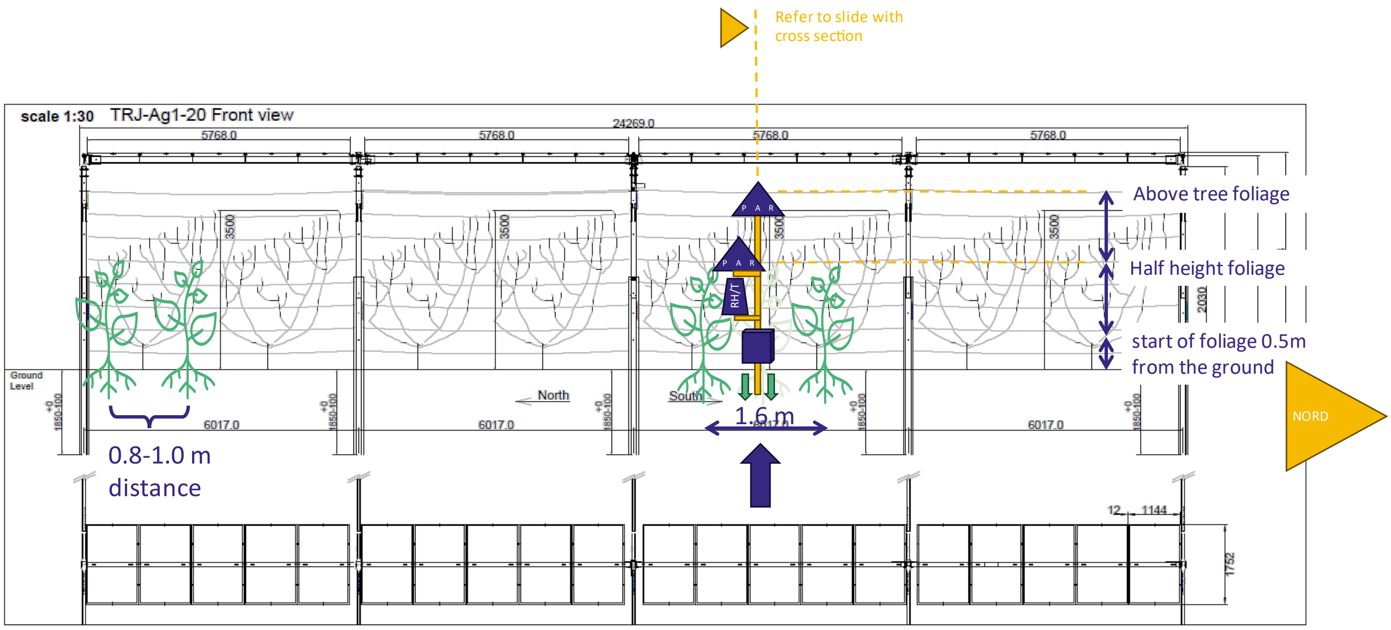


Figure 16 Positioning of agricultural related sensors. One plant is missing, and the sensors are located in place of the plant itself. One PAR sensors is located above the tree crown.

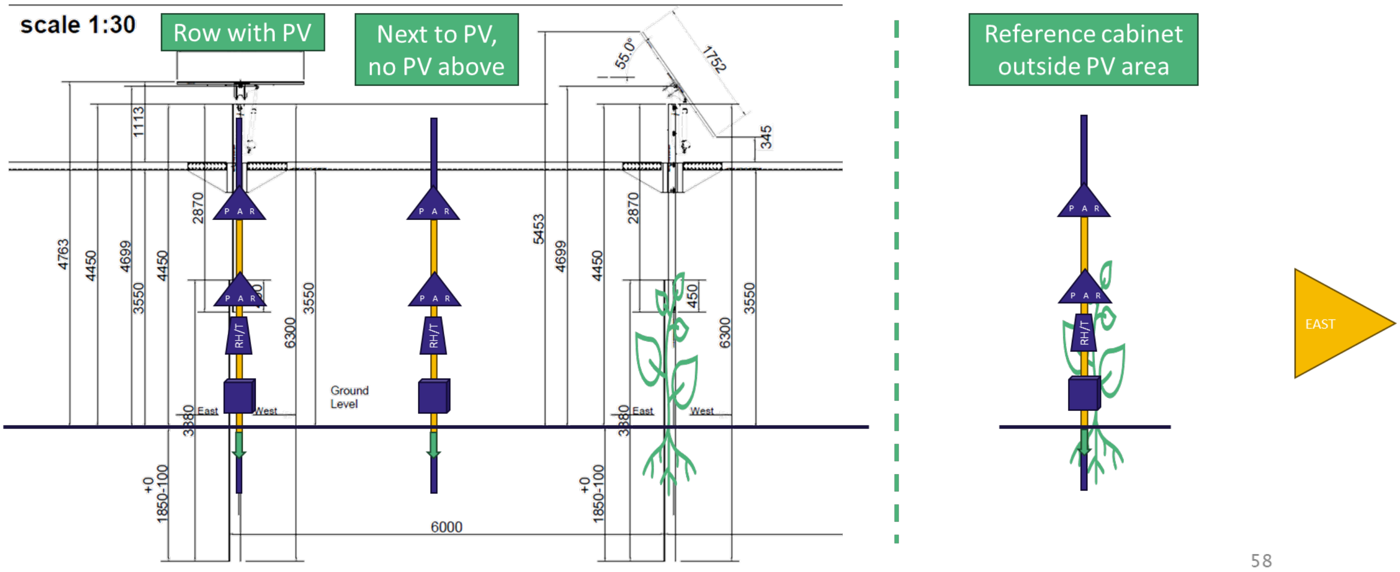


Figure 17 Positioning of agricultural related sensors. Cross section view. Measurement points are repeated below PV and in the row directly next to the PV installation. Finally, we represent the installation in the reference substation outside the PV.

Figure 16 and Figure 17 provide final details on the installation of the sensors related to the agricultural domains. For each secondary substation (therefore under PV), a measurement point will be placed in the row under the PV and one in the row next to it. A tree is removed to allow to install the pole that holds all the sensors. The PAR sensors are installed one above the tree crown (3.5m from ground) and the other at half height (in the range 1.5-2.0m from ground). The RHT transducer shares the same height of the previous device (1.5-2.0 m from ground). Both PAR and RHT sensors probe will be mounted on the pole toward south (pole located at North). A radiation shield protects the RHT probes from direct irradiation of the sun and from the direct impact of external agent on the sensing element. The assembly of probe and shield should not be completed suffocated from the vegetation as a certain amount of air (>0.2m/s) should go through the assembly to allow a proper measurement.
The soil moisture sensors present in Figure 15 and Figure 16 will be installed vertically underground according to the indication of the manufacturer. The probe should be completely covered by the ground (expected depth of the sensor handle > 10cm) and the hole should be filled with soil made powder in order not to damage the device. The temperature sensor is located in the handle part of the sensors that should therefore be also properly buried in the ground. The hole should be completely filled with soil in order to remove any residual empty space. The probe should be located sufficiently far from poles and large objects (Stones, poles, metal parts) compared to the dimension of the probe. Final installation will be realized according to the constraint of the field where the probe will be located.

3. AGRIVOLTAIC DEMONSTRATOR 2 – BARCELONA

3.1. AGRIVOLTAIC PROJECT DESCRIPTION

The proposed Agri-PV plant has two sections, Section 1 corresponding to West side and Section 2 to the East side, respectively. Figure 18 shows the overall 2D top-view representation of the plant as initially conceived; this has then been subject to modifications based on the output of the modelling results.

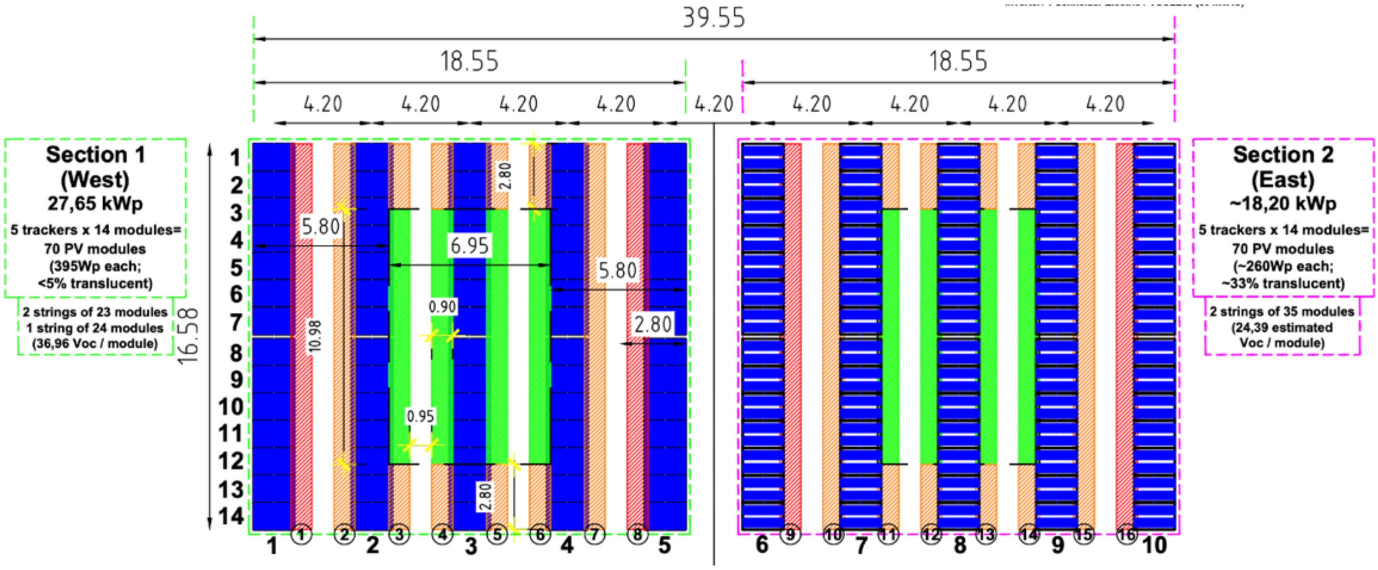


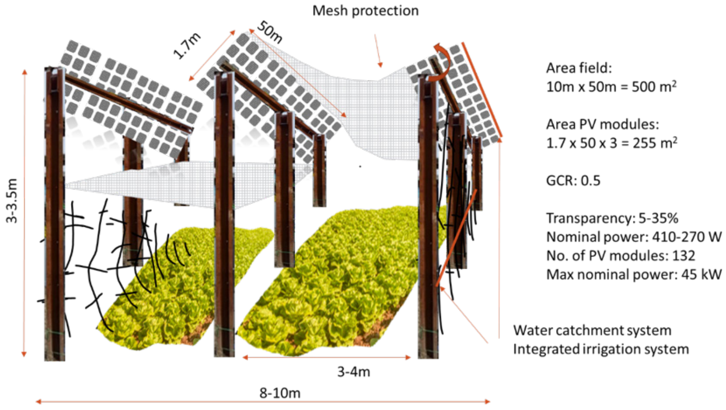
Figure 18: Initial layout for the Agri-PV system in Barcelona as proposed at M12.

3.2. GENERAL TECHNICAL SPECIFICATIONS

Table 12 describes the envisioned features of the demo of Barcelona and the updates in terms of Technical Specifications at M12 and M18 of the project.

Table 12: Envisioned features of the demo of Barcelona and the updates in terms of Technical Specifications at M12 of the project**.**

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.
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, onion, 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 people and semi-automatic agricultural devices, the module's low point should exceed 2 meters to avoid human injury. Without perennial cultures, steel pile driving is viable, similar to standard ground-mounted PV projects. Locally sourced wood had been envisioned for use as a substitute for certain structural components of the tracker. Our studies have shown that this is indeed a promising solution, but one that requires more rigorous structural testing, and thus it was chosen not to include on this project. Convert furthermore had proposed to use weathering steel for tracker manufacturing to minimize environmental and visual impact, but due the highly corrosive marine environment, this option will not be built on the Barcelona project. 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.
Water catchment / irrigation	Rainwater will be captured with gutters to avoid issues to the plants below. The water will be distributed away from the crop areas to allow for soil moisture homogenity, and possibly connected to a storage / water reuse tank at a later date.
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 to power the offices and other agricultural loads onsite. 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.

3.3. LAYOUT

From a modelling perspective in the modelling tool LuSim, the Agri-PV plant is segmented into three components:

a) The PV modules support structure
b) The PV system layout
c) The crop layout

Four distinct kinds of crops are to be used, namely Lettuce, Fava beans, Onions and Tomato.

The crops will be studied for two years' time, and more precisely for two seasons in each year, where two crops will be studied for each season in each year. Thus, it is required to model four scenarios for each season in each year using two crops at a time. Specifically, for the first fiscal year 2025, the first season, i.e. Autumn-winter, in the period November 2024 - March 2025 will contain Fava beans and lettuce.

When assessing plant growth, the incident irradiance must be integrated separately for specific plant zones. In the realm of 3D modelling, several key questions arise regarding how to best represent plants and define these zones of interest. For plant shapes, it is possible to select either simple shapes, which approximate the outer boundaries of the crops, or more intricate shapes, which attempt to faithfully replicate the geometry of plant organs and leaves in detail. Basic geometric shapes, such as parallelepipeds, cylinders, spheres, or cones, can be employed to represent the outer envelopes, whereas shapes of varying complexity between the simplest and most detailed forms are also viable options. Each approach comes with its own set of advantages and disadvantages. Complex geometries attempt to realistically represent the shape of crops. They facilitate the utilization of more intricate models used to evaluate crop photosynthesis and good estimates of the 3D optical porosity.

However, this approach demands significantly higher computational resources because of the concomitant substantial increase in required spatial resolution and of the number of points where irradiance must be assessed. It also restricts the use of simpler agronomic models that have been developed based on a preliminary evaluation of the irradiance incident on the external canopy envelope. In contrast, the use of basic shapes that depict the external envelope of crops reduces the computational complexity significantly by reducing the number of points where irradiance calculations are necessary. This approach also facilitates the direct utilization of parametric models that assess photosynthesis in the canopy based on the solar radiation reaching its outer envelope. When employing these straightforward models, optical properties including optical porosity cannot be directly modelled, but must be incorporated through a parametric model attached to the object's texture. In most agrivoltaic applications modelled using LuSim, experience has favoured the use of basic geometric shapes alongside parameterized optical properties. If necessary, the optical porosity can be initially modelled using a high-resolution 3D representation of the plant under scrutiny, and the results can then be applied to all simple shapes employed in modelling the entire agrivoltaic system.

Figure 19 and Figure 20 provide the crop layout specific to the sections and the seasons.

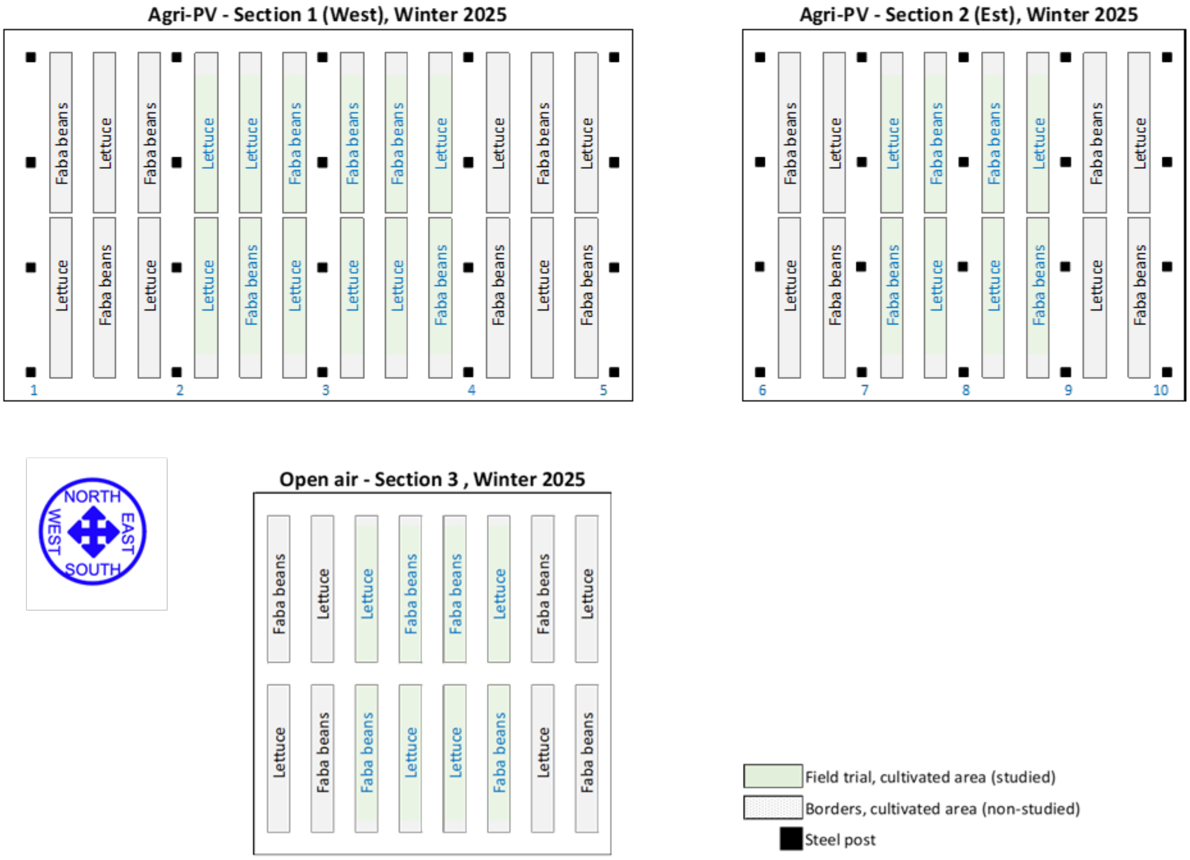


Figure 19: Crop layout for the first year of the Barcelona site (November 2024 – March 2025)

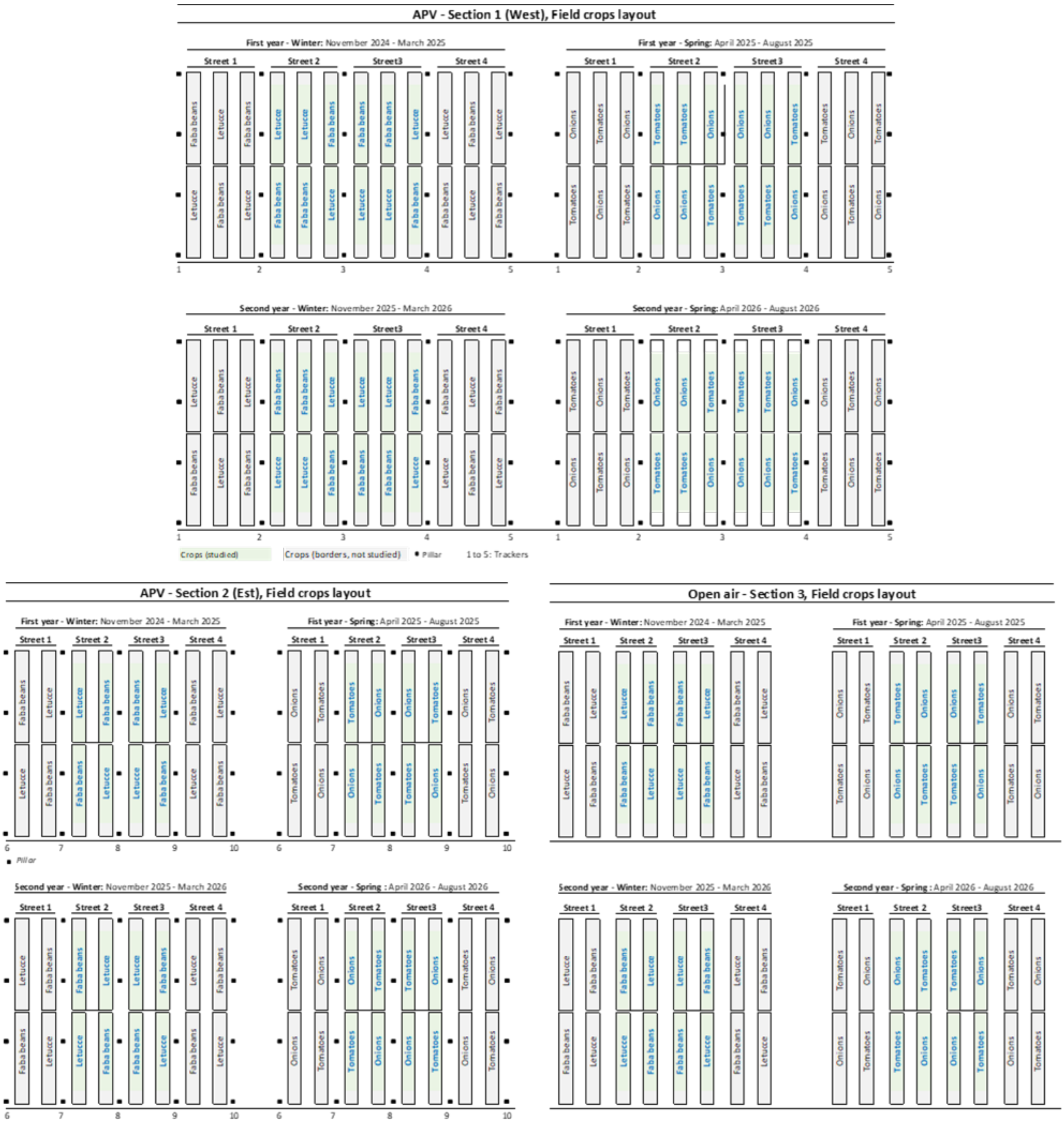


Figure 20: Crop arrangement specific to the seasons and the sections.

As mentioned above, it is possible to model the crops encompassing the intricate details and making it representative of the real crop as much as possible. As the focus will be primarily on the lettuce and tomato crop in this modelling phase of the demonstrator, Figure 21 shows a detailed modelling of complex structures of lettuce (right) and tomato (left).

Figure 21: Complex models of lettuce (left) and tomatoes (right).

3.4. CROPS

The following section discusses the details on the simplified approach for crop modelling for lettuce and tomato while detailing the layout information of all the four crops.

1. **Lettuce**

The shape of the external envelope, representing each lettuce, is assumed to be a hemisphere with a radius of 10 cm. The spacing between rows, or pitch, is set at 20 cm. Figure 22 illustrates that there are four rows of lettuce, organized into two groups with each group containing two rows. This arrangement means that two rows are positioned in close proximity to each other, followed by a larger gap, and then another two rows are positioned at the same distance as the first two rows. The gap between the two groups of rows is specified as 20 cm. However, given the shape and dimensions of the envelope, accommodating four rows of lettuce on a single terrace is not feasible if this gap is to be maintained. Specifically, the total width available on the strip for crop planting is 90 cm, and with the lettuce radius assumed to be 10 cm, a total of 80 cm is required to fit four rows of lettuce. This arrangement leaves no space within the rows and only a 5 cm width from the edge on either side of the crop cultivation land strip, as depicted in Figure 22, which presents a section of the terrace containing lettuce, where the arrangement of lettuce rows is shown to accommodate four rows within a terrace.

Figure 22: Lettuce arrangement in the agricultural land.

2. Fava beans

A total of 2 rows of fava beans will be planted in a terrace with 0.6 cm pitch between two rows of fava beans and the pitch among fava beans within the row is 0.4 cm.

3. Tomato

As shown in Table 10, the height of the tomato plant is listed as 0.7 m, although agronomists at this demonstration site note that the majority of tomato crops do not exceed 0.5 m in height. For the purpose of this study, the size of the tomato crop is represented by a rectangular cuboid, encapsulating a complete row of tomato plants within that section. The dimensions of this cuboid are a height of 0.7 m, a width of 0.7 m, and a length of either 8.4 m or 5.6 m, depending on the specific terrace section. Unlike other demonstration sites or the typical dimensions observed for tomato crops, the plants at this site in Barcelona exhibit unique characteristics in terms of vertical growth. Here, the crops grow without the use of tutoring or support structures, causing them to spread across the ground similar to melon crops, with a maximum height ranging from 0.5 m to 0.7 m.

Despite the actual growth form of the crops, for the initial phase of this study, the crop's envelope is considered to be a rectangular cuboid with a height of 2m and a width of 0.7m. This approach is adopted to facilitate the assessment of light distribution under the photovoltaic (PV) system and to analyse the evolution of shading loss at various heights above the ground. Furthermore, this study investigates the impact of shading by the PV system on the light reaching the ground or crop plantation area. Given that all crops, with the exception of fava beans, maintain a height within the 0.5m to 0.7m range as per Table 10, the findings from the ground level analysis are applicable to these crops due to their low stature.

4. Onions

In a terrace, a total of four rows of onions are planned for planting, organized into two groups with each group consisting of two rows. The gap between the two groups of rows is specified as 20 cm. Additionally, the spacing between individual onions within each row, also known as the pitch, is set at 20 cm. This arrangement allows for efficient use of space while ensuring adequate room for the growth and maintenance of the onion crops.

Table 13 shows the crop growth cycle and the cultivation system for the above-mentioned crops.

Table 13: Crop growth cycle and cultivation system.

Season	Crop	Growth cycle - Dates		Cultivation system			Estimated maximum plant height (cm)	Drip irrigation lines*
		Plant or seeding	Harvest	Rows of crop/terrace	Between Rows (cm)	Between plants (cm)		
Autumn -	Lettuce	15-30/1	30/3–5/4	4, quincunx	20	30	50	2
winter	Fava beans	1-15/11	1-10/4	2	60	40	150	2
Spring –	Tomatoes	1-15/4	15/7 – 15/8	2, quincunx.	40	60	70	2
summer	Onions	1-15/4	1-15/7	4, quincunx.	20	20	60	2

** Installed under plastic film mulch*

3.5. PV MODULES

Figure 23 and Figure 24 detail dimensions and different possible transparencies of the PV modules considered.

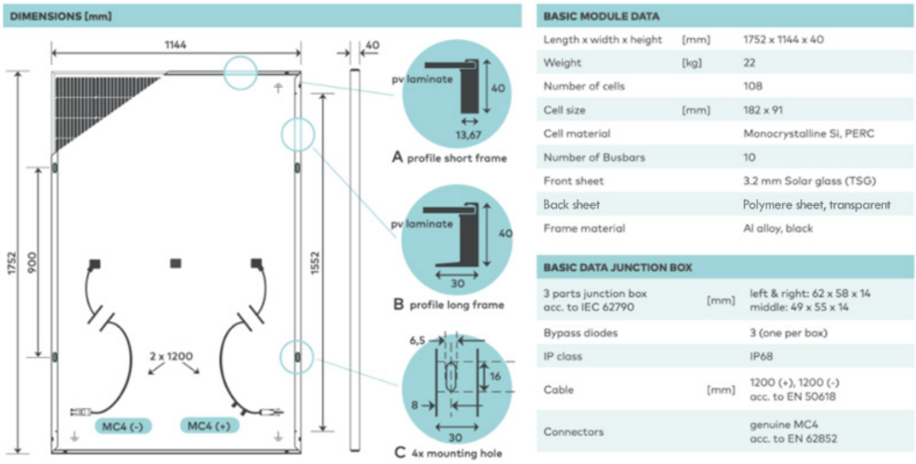


Figure 23: PV module dimensions.

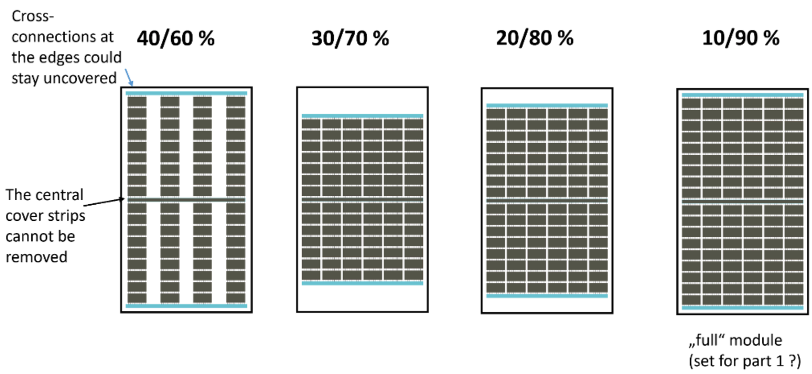


Figure 24: Possible designs for PV module transparency.

3.6. INVERTER – STRING DESIGN

The PV installation consists in two sections, called Sectoin 1 (West) and Section 2 (East).

Section 1 (West) is composed by 5 trackers with 15 PV modules (395 Wp) each installed, so 29.6 kW overall.

Section 2 (East) is composed by 5 trackers with 15 PV modules (237 Wp) each mounted, so 17.775 kWp.

These sections will be equipped with distributed multi-MPPT inverters and the strings will be composed by considering the different voltages of the strings composed by different types of PV modules, evaluating both the MPPT range of the inverter and the easiness of the cabling over the trackers.

3.7. STRUCTURES

Each section consists of 5 rows of tracking PV modules, with each row containing 15 bifacial PV modules arranged in portrait fashion with a gap of 0.01 meter among them. In Section 1, the pitch between trackers is 5,9 meters on-center, and for Section 2, 4,1 meters.

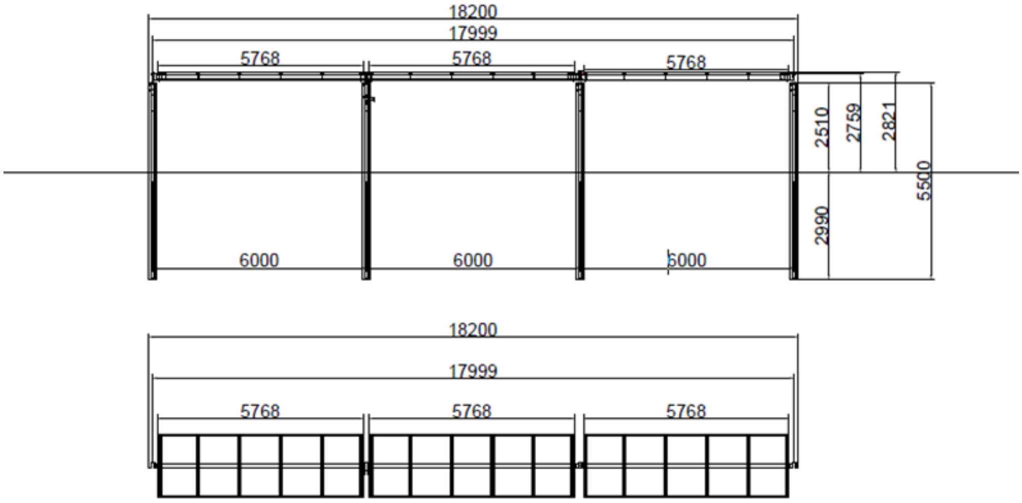


Figure 25: Frame dimensions for section 1.

With regard to resistance to the external environment (corrosion), from an analysis of the Barcelona site (which is close to the sea and a source of pollution such as the airport) it was agreed to use steel with a zinc coating. Assuming for the dimensioning of the latter (thickness) a useful life > 20 years and a class of corrosion of site: C3 (as indicated in the ISO 9223).

3.8. MONITORING SYSTEM AND SENSORS

The fixed monitoring system designed for the Spanish demonstrator is schematized in Figure 26. There are three measuring stations located within the three monitored sectors: sector S1 (tracker with standard PV modules characterize); sector S2 that is characterized by the semi-transparent modules; and sector R1, which is the reference, located outside the area with PV panels. In addition to these, a weather station is also installed in correspondence of the main electrical cabinet marked as P0 in Figure 26.

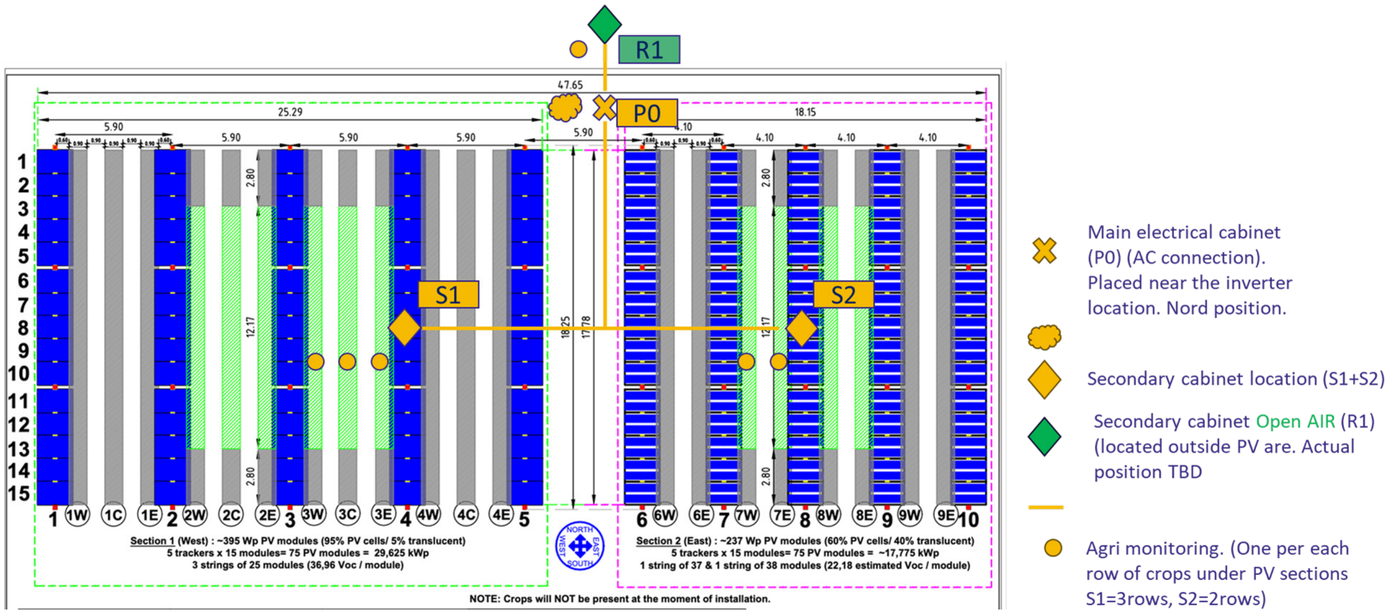


Figure 26: Position of Sensors in Barcelona Demo

The complete table of measurement point of the Barcelona demo case is presented in Table 13. The two demos in Bolzano and Barcelona present the same sensor models. This is true except for the (e)PAR sensor selected separately depending on the requirements of the relevant research centers (Laimburg and UPC) and the possibility of using the purchased instruments potentially in the future also in other research center systems. The Barcelona case study presents the ePAR Apogee SQ-618-SS sensor as indicated in the Table 14. The complete list of sensors and their relative transducer is already introduced discussing the Italian demo and holds also for the Spanish case study.

Table 14 Measurement points in the Barcelona demo case. Static monitoring system.

				Location								
			Electrical Cabinet / substation	Main Cabinet (P0)	PV section 1 (S1)			PV section 2 (S2)			Open air CTRL (R1)	
					East row	Center	West row	East row	Center	West row	Center	
Domain	**sub-domain**	**measurand**										
AGRI	air	temperature	epluse HTP 201 4-20mA HTP201-M1-A6-E8-KL150		1	1	1	1	_	1		
AGRI	air	relative humidity			1	1	1	1	_	1		
AGRI	air	*dew point (computed)*			1	1	1	1		1	1	
AGRI	*air*	ePAR	Apogee SQ-618-SS modbus		1	1	1	1	_	1	1	
AGRI	soil	temperature	DeltaOhm HD3910.1.10 modbus		2	2	2	2	_	2	2	2
AGRI	soil	humidity			2	2	2	2	_	2	2	2
WEATHER	air	temperature	epluse HTP 201 4-20mA								1	
WEATHER	air	relative humidity									1	

WEATHER		precipitation/rain	Luft ws100 UMB	1								
WEATHER	wind	speed	PCE-WS 4-20mA								1	
PV	irradiance	G_POA	HuxeFlux SR05-D2A2 pyranometer (4-20mA)		1			1				
PV	irradiance	Albedo	HuxeFlux SR05-D2A2 pyranometer (4-20mA)		1			1				
PV	module	temperature	pt100 calss b 4 cavi (3?) silicone superficiali 15m (10)		4			4				
PV	electrical	*** Inverter Modbus		2								

The assembly indications provided at the end of section holds also for the current demo case. In this case, the weather station will be positioned in the North of the plant in proximity of the PV inverter. Same prescriptions related to the installation height and to avoid shadowing holds also for this installation. To reduce acquisition hardware, the wind speed sensors and humidity and temperature probes related to the general plant are located on the reference cabinet positioned outside the PV area in open field. The different cultivation with respect to the Bolzano demo imposes a customization also of the installation approach.

Going into more detail: firstly, a weather station (P0) was implemented on which the sensors summarized 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 1 meter above the trackers so as not to shadow the structure. It is also about 5 meters away so as not to be influenced by it.

Table 15: 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. A set of probes is located near each row of vegetables. Considering the different design of section 1 and 2 (refer to Figure 26), three measurement points are located in section 1 and two in section 2. In both cases the probes related to the PV domain (temperature and irradiance) are present one per row in correspondence of the row of PV monitored.

The figures below propose a qualitative diagram of the final position of the selected probes for each section of the plant. The probe will be mounted on vertical poles (on the side of the pole facing South to avoid the shadow of the pole itself) with a height in the range 0.5-2.0 meter according to the best position identified for each cultivation culture.

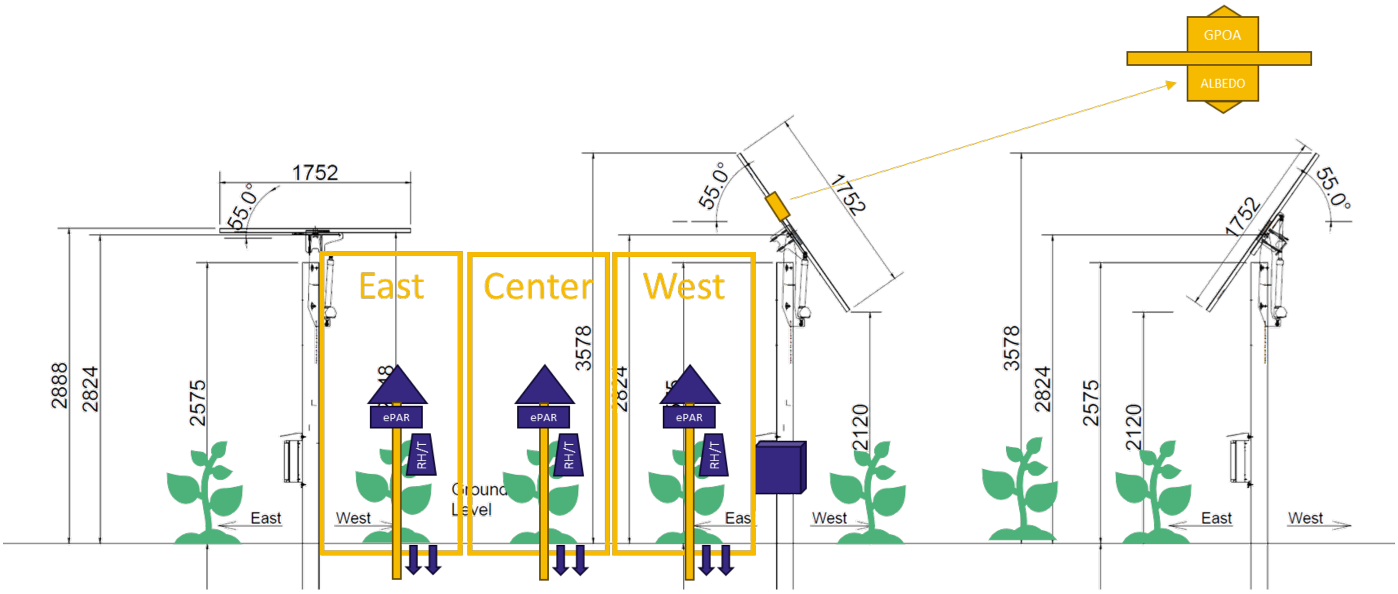


Figure 27 Qualitative mounting diagram of the probes in the Barcelona demo case (detail of plant section 1 with 3 row of vegetables between each rows of PV).

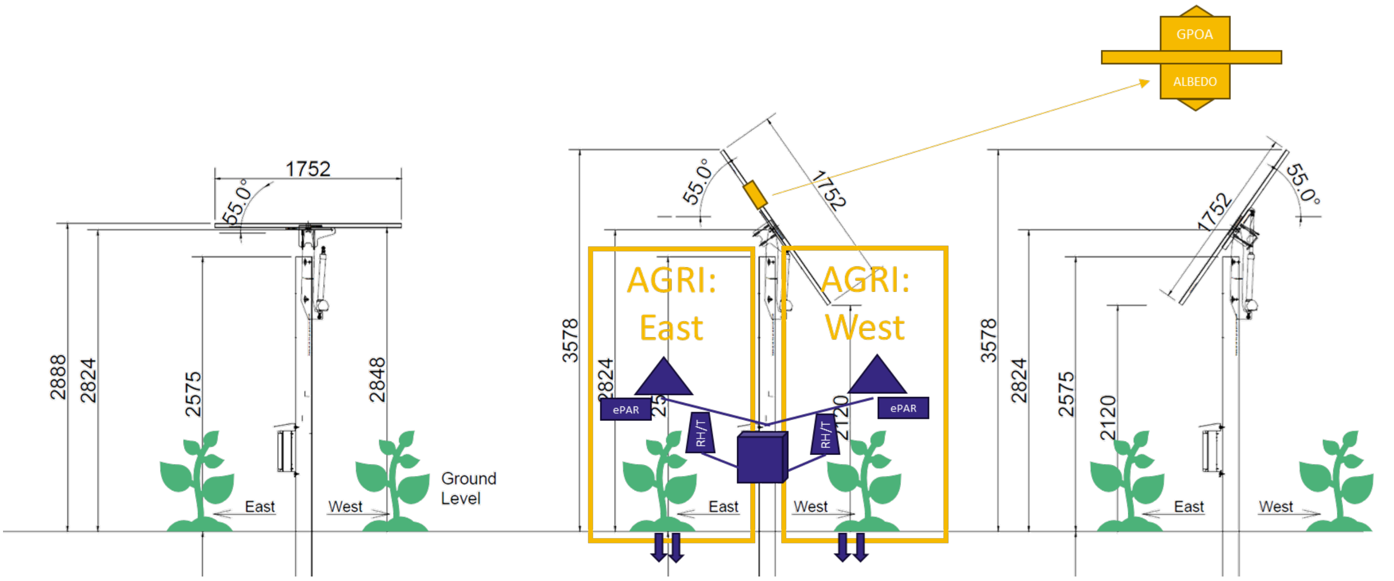


Figure 28 Qualitative mounting diagram of the probes in the Barcelona demo case (detail of plant section 2 with 2 row of vegetables between each rows of PV).

Table 16 and Table 17 summarize the sensors to be installed on S1 and S2 stations.

Table 16: 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 17: S1 and S2 Stations – PV Part

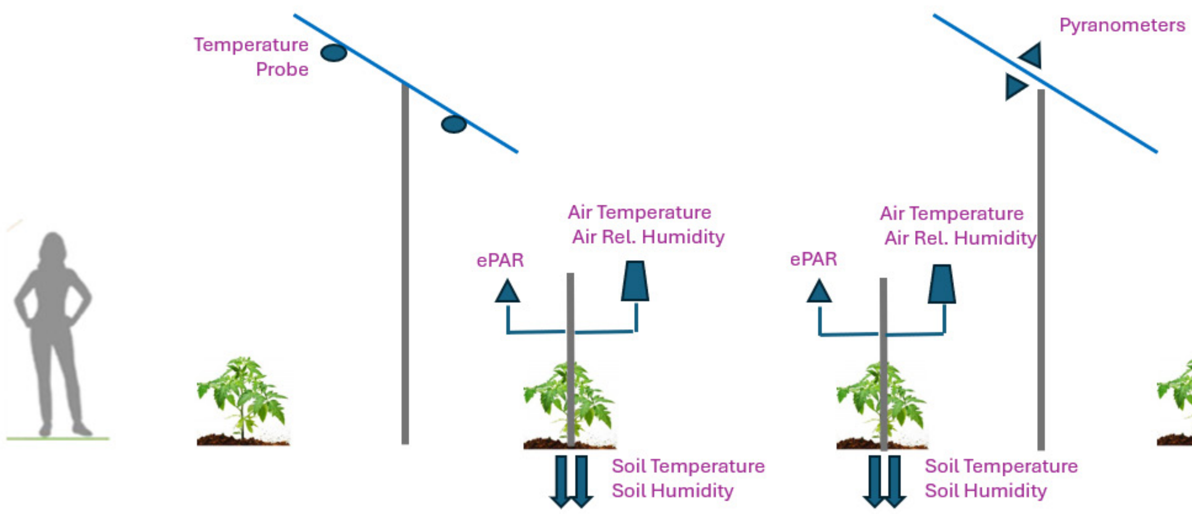
Domain	Measured Parameter	Type	Accuracy
PV MODULES	G_POA	Pyranometer	< 2.4 %
	Albedo	Pyranometer	< 2.4 %
	Module Temperature		

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 18 shows the list of sensors mounted on the Reference station.

Table 18: 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 below shows the position of the sensors in relation to the support post.
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).



4. AGRIVOLTAIC DEMONSTRATOR 3 – NETHERLANDS

4.1. AGRIVOLTAIC PROJECT DESCRIPTION

The demo driver owns a typical existing greenhouse structure in which vegetables such as tomatoes, cucumbers, peppers, lettuce, and many other varieties, can be grown. At the moment there is a large demand for 'extra' energy, and same is expected from Agrivoltaic systems. However, the greenhouse market is very hesitant to install PV- panels above the vegetation area. The common idea is that all the available sunlight should be available for the maximization of crop yield. In this Demo the aim is to measure how much light is blocked by the PV-panels when they are installed in intervals above the growing area. With the DLI (Daily Light Integral) data of this test, it is of the interest to determine the number of PV panels that could be installed without losing crop yield. The coordinates of the site where the prototype will be located are 51.997963, 4.313927.

Figure 29 displays the existing greenhouse with the SYMBIOSYST test area.

Figure 29: Existing greenhouse and display of the SYMBIOSYST test area

Figure 30 shows a closer view over the VENLO greenhouses.

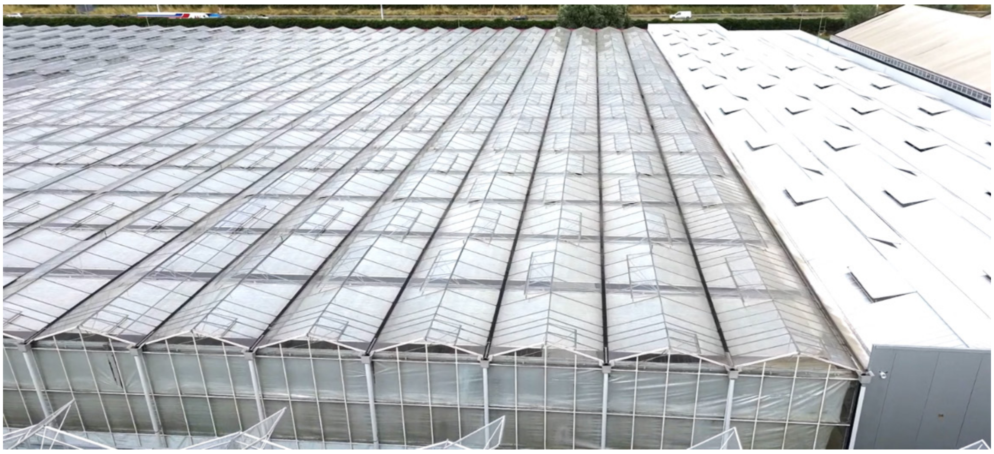


Figure 30: Closer view over the VENLO greenhouses

Figure 31 shows a view of the greenhouse with dimensions indicated. The total size of the test area is 51 m x 86 m.

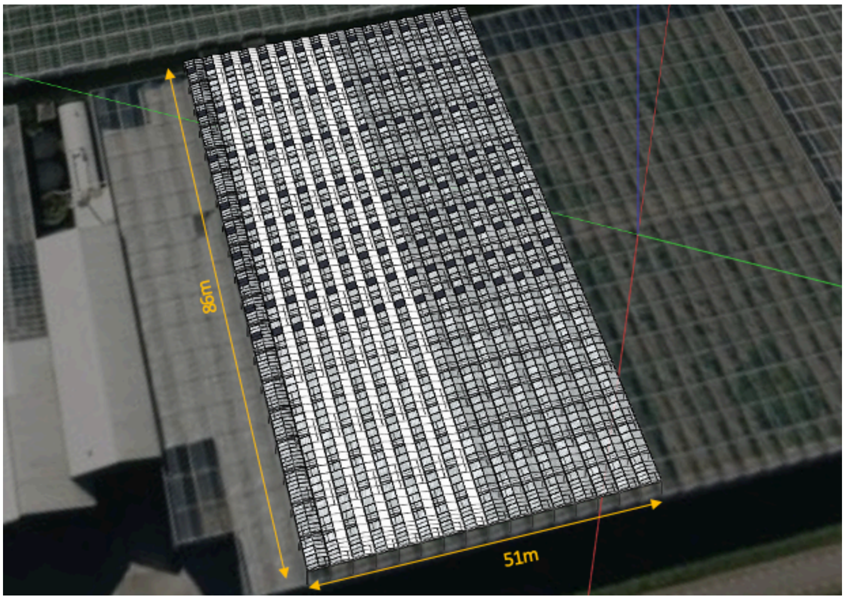


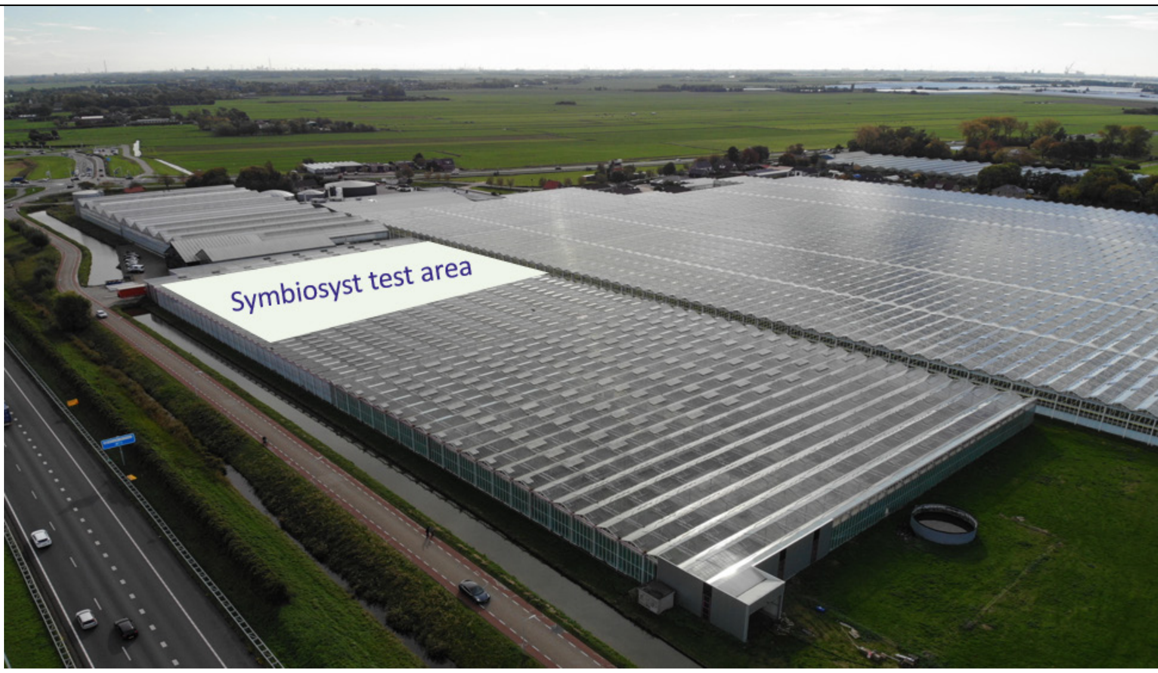
Figure 31: View of the greenhouse with dimensions indicated

4.2. GENERAL TECHNICAL SPECIFICATIONS

Table 19 describes the envisioned features of the demo of Schipluiden (Netherlands) and the updates in terms of Technical Specifications at M12 and M18 of the project.

Table 19: Envisioned features of the demo in the Netherlands and the updates in terms of Technical Specifications at M12 of the project

Use case 4	Greenhouse retrofit and KUBO bluelab
Unique Value Proposition	Retrofit of existing greenhouse fully equipped with sensors to correlate crop yield with incident light depending on presence of surrounding uncoated and coated glazing.
Location	Schipluiden, Netherlands.
Replication potential	Use validated modelling to perform simulations for other countries (MEDA) and other crops (lettuce, berries) and check business models.
Crop	Tomatoes

Solutions implemented in the demo	 The available area is of 86 x 51 m. The size of the SYMBIOSYST PV deployed solution will be of around 50 kWp (around 100-150 PV modules distributed in different patterns in the greenhouse roof. Start with PV panel of standard size to keep cost down, make special Aluminium profile for easy mounting. Use of semi-transparent agri-PV modules. Optimize PV module layout (cell/string spacing) and bill of materials (encapsulant, glass coating, etc.). Optimize PV system layout (horizontal/landscape orientation, rows vs chessboard pattern, etc.). Optimize PV system integration in landscape in general (visual key performance indicators to increase acceptance like with BIPV). The testing will compare the crop yield with clear glass, with PV modules, with coated PV modules.
Use of electricity	The PV system will be connected under the same Point of Delivery of the greenhouse. Although the size of the demonstrator will not allow for the coverage of the electrical demand, through modelling and validation with field data we will demonstrate the possibility to achieve nearly zero energy greenhouse.

This prototype is located at Lotsweg 3, 2636 JH, in the municipality of Schipluiden (near Delft), in the Netherlands.

4.3. LAYOUT

The test area is distinctively divided in six zones, as seen in Figure 32, which shows the top view of the demo site with 6 distinct zones, where zones 1, 2, 3 and 4 will generate electricity. These four zones will feature south-west facing PV panels that are installed in a specific repetitive pattern covering the vegetation. More specifically zone 1 and 2 will feature 24 panels each, that are placed in intervals of 9 m, while zones 3 and 4 will showcase 48 panels each, placed in 4.5 m apart.

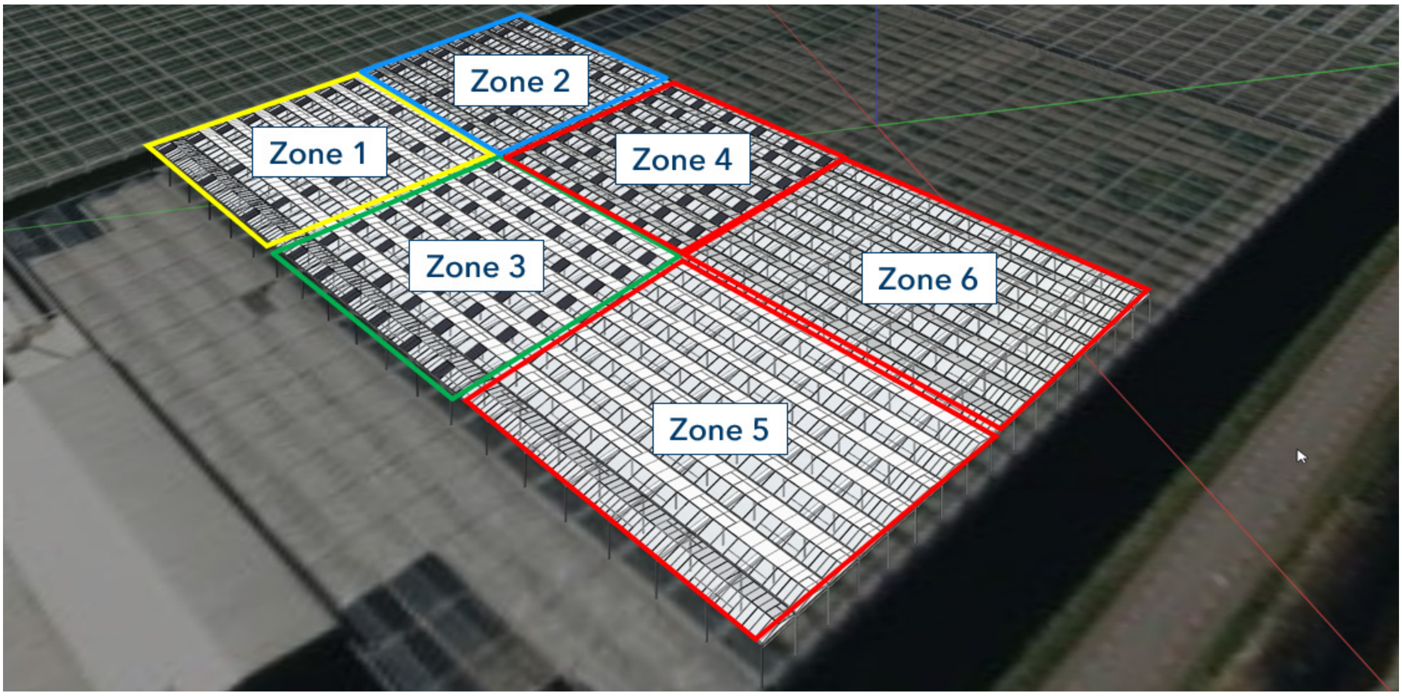


Figure 32: Top view of the demo site on the greenhouse with 6 distinct zones

To better visualise the zones, Figure 33 and Figure 34 offers a closeup view for the four zones featuring PV panels.

Figure 33: Closeup view for the four zones featuring PV panels

Figure 34: Closeup drone view of the six zones featuring PV panels, all six zones included

The detailed string arrangement is depicted in the Figure 35 and Table 20 shows the details of the envisaged wiring of the PV arrays to be installed on the greenhouse. Congruently, it is planned to have 1 inverter for every six strings containing 24 PV panels each. The inverter selected to be installed has been the SMA STP 50.

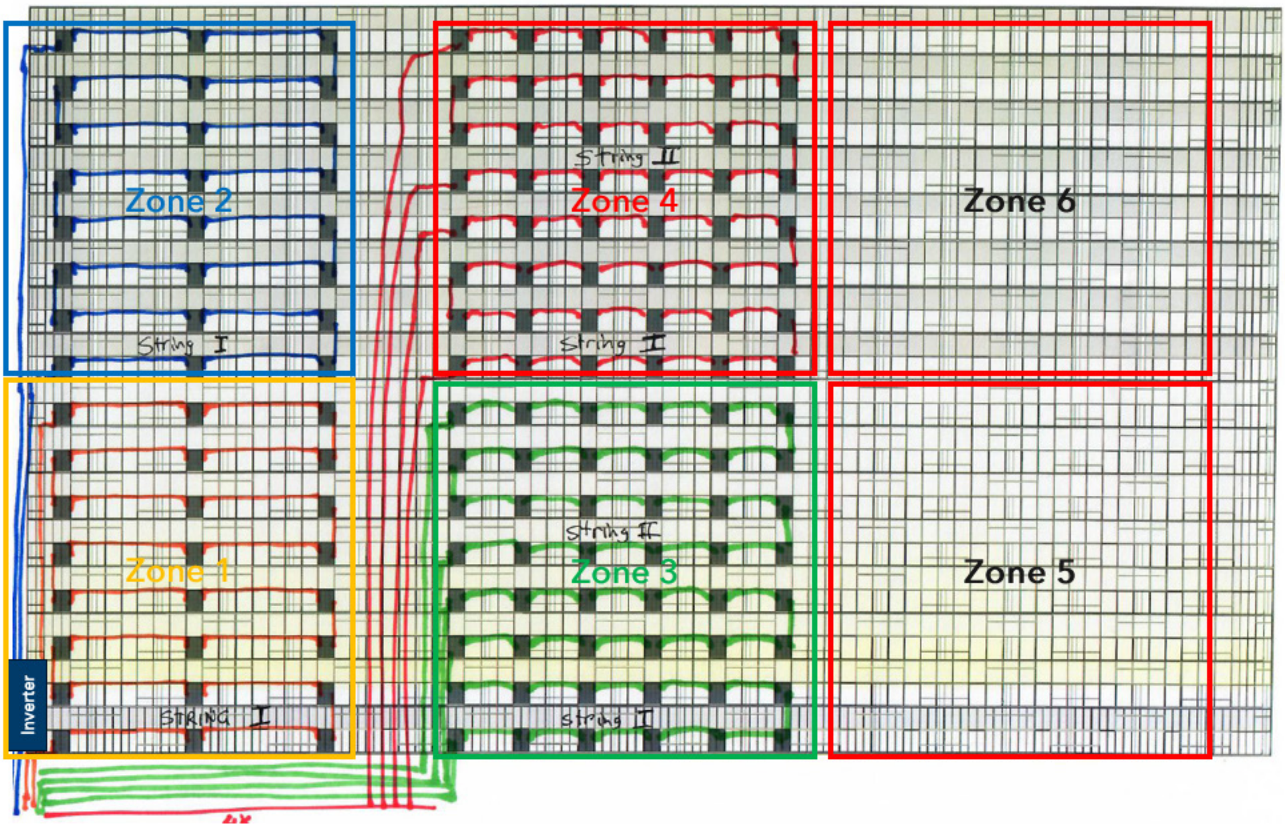


Figure 35: Detailed string arrangement for the PV arrays on the greenhouse

Table 20: Details of the envisaged wiring of the PV arrays to be installed on the greenhouse

Zone 1

String 1		Length (m)	Amount #	Totaal amount of meters
	Post (paal)	5	2	10
	1st panel	3	1	3
	ridge (nok)	10	16	160
	traverse (oversteek)	4	7	28
	last panel	24	1	24
				225

Zone 2

String 2		Length (m)	Amount #	Totaal amount of meters
	Post (paal)	5	2	10
	1st panel	30	1	30
	ridge (nok)	10	16	160
	traverse (oversteek)	4	7	28
	last panel	51	1	51
				279

Zone 3

String 3		Length (m)	Amount #	Totaal amount of meters
	Post (paal)	5	2	10
	1st panel	30	1	30
	ridge (nok)	5.5	20	110
	traverse (oversteek)	4	3	12
	last panel	42	1	42
				204
String 4		Length	#	totaal
	Post (paal)	5	2	10
	1st panel	42	1	42
	ridge (nok)	5.5	20	110
	traverse (oversteek)	4	3	12
	last panel	55	1	55
				229

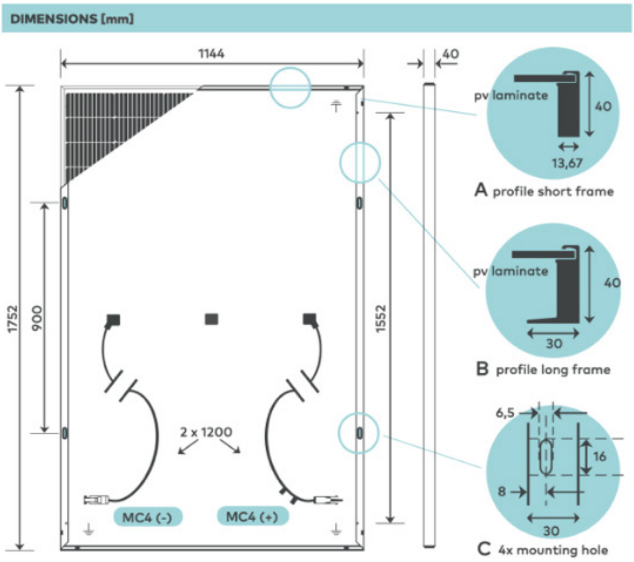
Zone 4

String 5		Length (m)	Amount #	Totaal amount of meters
	Post (paal)	5	2	10
	1st panel	55	1	55
	ridge (nok)	5.5	20	110
	traverse (oversteek)	4	3	12
	last panel	66	1	66
				253
String 6		Length	#	totaal
	Post (paal)	5	2	10
	1st panel	66	1	66
	ridge (nok)	5.5	20	110
	traverse (oversteek)	4	3	12
	last panel	78	1	78
				276

4.4. PV MODULES

Fully opaque, frameless, 365 W PV panels by aleo with dimensions 1,557 mm x 1,137 mm will be used for the Agrivoltaic prototype.

Figure 36 below show the dimensions and other related modules for the mentioned aleo PV panel.



BASIC MODULE DATA		
Length x width x height	[mm]	1752 x 1144 x 40
Weight	[kg]	22
Number of cells		108
Cell size	[mm]	182 x 91
Cell material		Monocrystalline Si, PERC
Number of Busbars		10
Front sheet		3.2 mm Solar glass (TSG)
Back sheet		Polymer sheet, white
Frame material		Al alloy, black

BASIC DATA JUNCTION BOX		
3 parts junction box acc. to IEC 62790	[mm]	left & right: 62 x 58 x 14 middle: 49 x 55 x 14
Bypass diodes		3 (one per box)
IP class		IP68
Cable	[mm]	1200 (+), 1200 (-) acc. to EN 50618
Connectors		genuine MC4 acc. to EN 62852

Figure 36: dimensions and other related modules for the mentioned aleo PV panel

Furthermore, Figure 37 showcases the image of the PV panel to be installed (left) and the first PV panel being installed (right).

Figure 37: PV panel to be installed (left) and the first PV panel being installed (right)

4.5. COATING TECHNOLOGY AND GREENHOUSE COVERING FEATURES

Additionally, zone 1, 3 and 5 will have, Fotoniq diffusive PAR+ coating while the remaining zones 2, 4 and 6 will contain normal clear glass. FOTONIQ (Delft, the Netherlands) developed PAR+, a water-acrylic based, semi-permanent, retro-fit diffusive coating aimed to glass greenhouses. Figure below depicts the zones containing coating and clear glass, respectively. Its main attribute is to bring the benefits of light scattering while minimizing light loss to existing glass greenhouses. It is a more sustainable solution than existing seasonal coatings because of its higher durability, designed to be of 8 years.

Diffuse covering materials have proven to increase yield in many crops . By scattering the light through translucent and diffusive coatings, both the vertical and horizontal light distributions is expected to be improved which results in a more homogenous light distribution over the leaves. This promotes crop growth as it increases light use efficiency.

Another expected effect is the reduction of the complex shading effects introduced by the presence of multiple PV panels under direct light conditions. During light peaks an imbalance can occur between absorption and utilization of light energy. Diffuse materials decrease the amplitude and the rate of light intensity peaks on top leaves which, therefore, absorb less light. This results in less photoinhibition and lower leaf temperatures.

Within the context of this field test, a version of PAR+ coating will be sprayed on top of the greenhouse using conventional spraying processes known to the industry so the effects of a light diffusive material can be directly compared to clear glass under the Agri-PV context. In terms of coating application, the goal will be to spray an uniform looking film that gives to the greenhouse panels an average hemispherical transmittance of (80 ± 1)% and a horticatter of (35 ± 5)%. For comparison, low iron clear glass and the common float glass have hemispherical transmittances respectively of 84% and 82 ± 1%. Both with small horticatter values.

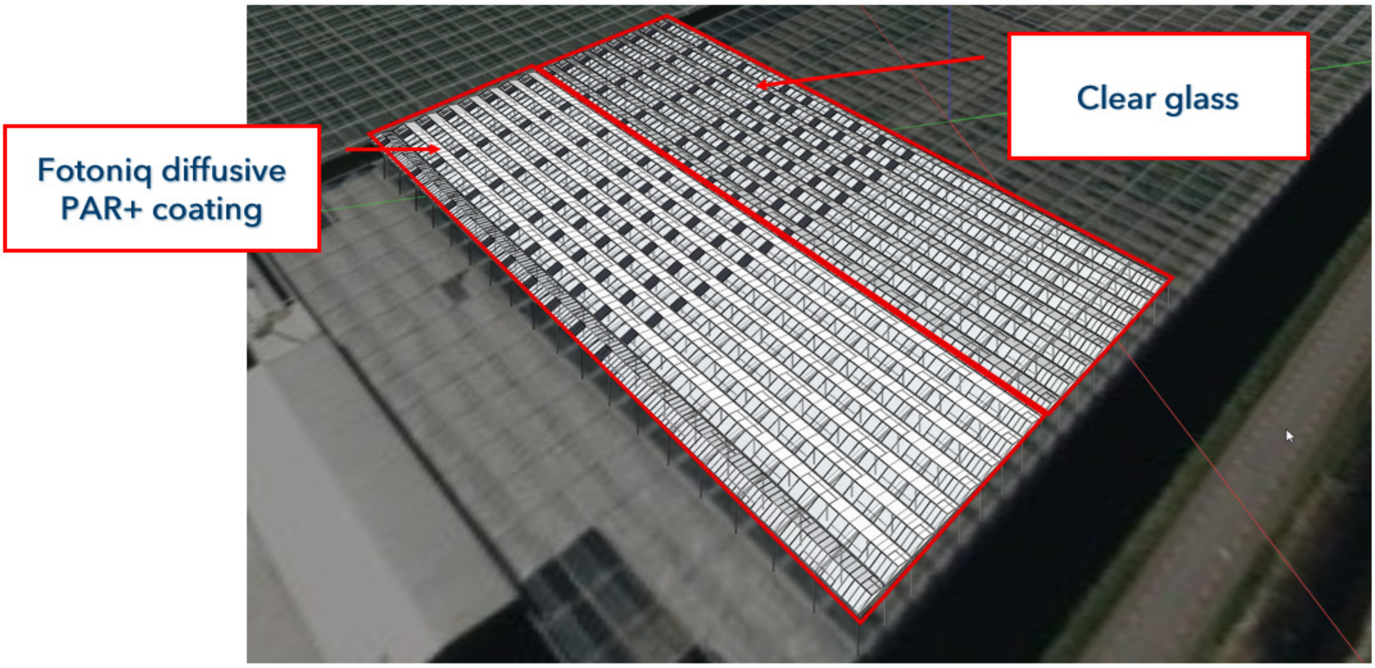


Figure 38: Layout of the zones containing coating and clear glass, respectively

4.6. INVERTER – STRINGS DESIGN

Selected PV inverter is SMA Sunny Tripower Core 1 (50 KW) that provides 6 MPPT with 2 input strings for each one. In this project each inverter manages 6 strings, each one composed by 24 strings.

4.7. MONITORING SYSTEM AND SENSORS

For on-field Daily Light Integral (DLI) measurements, a total of 90 Quantified PAR light sensors will be employed. Figure 39 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 40 and Figure 41.

Figure 39: Quantified sensor attached to a tomato plant

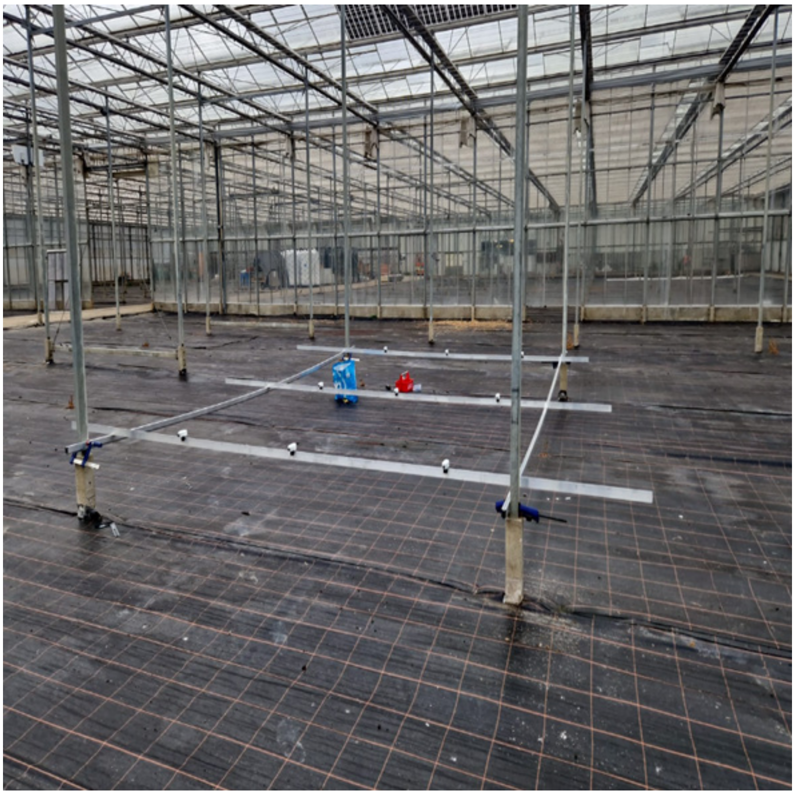


Figure 40: each zone containing 9 to 16 sensors placed in a grid-like formation

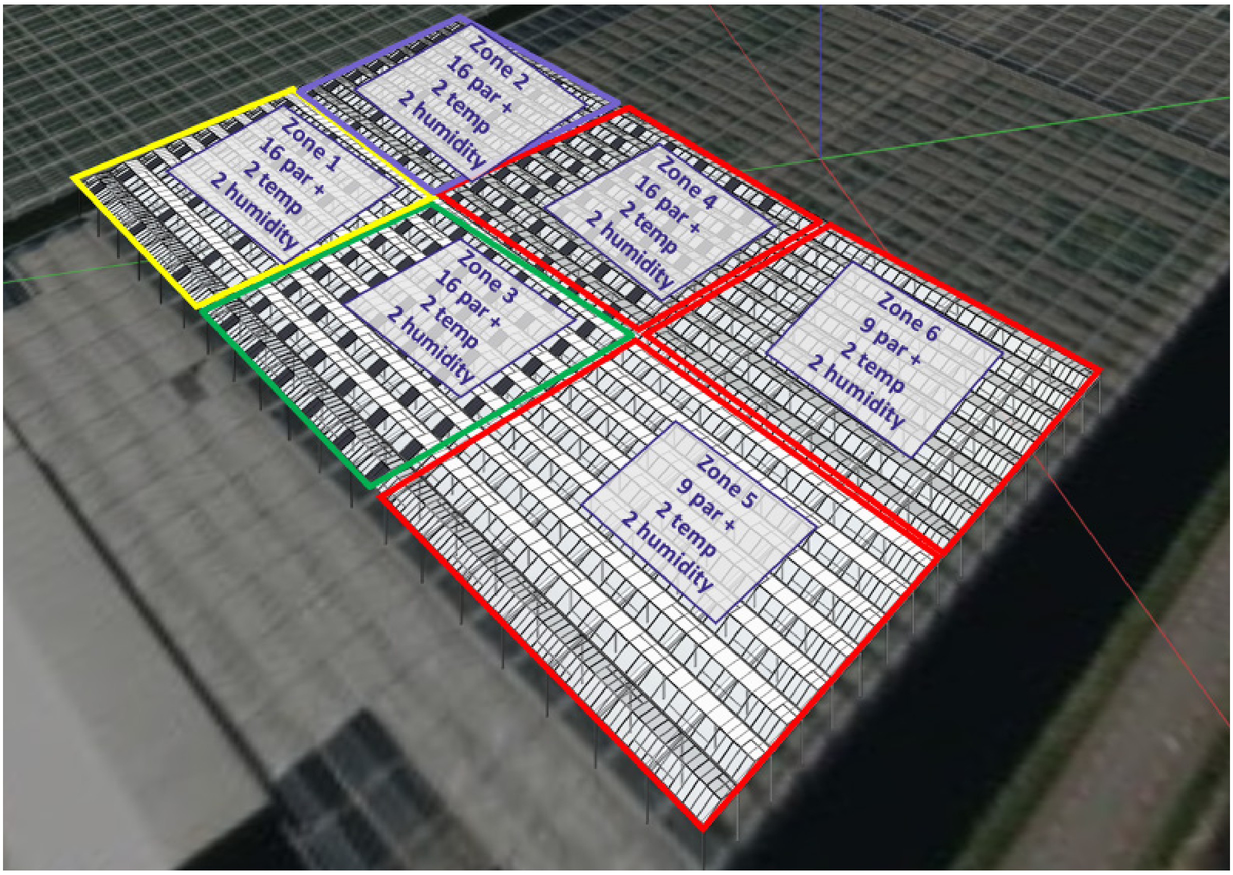


Figure 41: A sensor grid in every zone in the greenhouse

DLI (Daily Light Integral)
For every sensor we are going to measure the daily amount of light.
These values are different in every zone.

We want to measure the effects on the DLI of the:

- PV-panels (shadow)
- PAR coating (diffusiveness)

Figure 42: Clear glass versus PAR+coating Fotoniq

Figure 43: The effect of diffusive PAR+ coating with PV-panels on top of the greenhouse. The shadows appear to be less hard due to the 35% hortiscatter.

By measuring the DLI in every zone we want to determine which crops can be grown with a certain number of PV-panels. This know how can be beneficial for the whole greenhouse industry.

5. AGRIVOLTAIC DEMONSTRATOR 4 - SCALEA

5.1. AGRIVOLTAIC PROJECT DESCRIPTION

The Demo plant in Scalea in his first release has been realized in November 2021, for this reason it also plays a role of Demo Drivers for the SYMBIOSYST project. It has been designed with single-axis solar tracking technology to modulate irradiation and reduce fixed-shadowing. PV Modules are elevated up to 3.20 meters from the ground and installed in rows at a distance of 5 m, to allow the operations of agricultural machinery.

5.2. GENERAL TECHNICAL SPECIFICATIONS

Table 20 below describes the envisioned features of the demo of Scalea and the updates in terms of Technical Specifications at M12 of the project.

Table 210: Envisioned features of the demo in the Scalea and the updates in terms of Technical Specifications at M12 of the project

Use case 2	SCALEA
Unique Value Proposition	Innovative citrus orchard solution that can integrate irrigation, frost and snow protection, hail protection systems; together also with agronomic sensors and insect detection systems.
Location	SCALEA (Cosenza) Italy. The coordinates where the prototype is located are as follows (nearby the existing greenhouses owned by EF Solare Italia): • 39°46'22.95''N; 15°48'23.02''E; 
Replication potential	The replicability of the solution is high, thanks to the planned renewal of plantations in south Italy, together with new plantations in the Mediterranean area.
Crop	The Scalea Demo is focused on citrus fruit trees (mainly citruses, in particular the type White Zagaria and 2KR Citrus Limon, famous for its properties such as its pleasant parfum, medium shape, and generally +30% of juiciness with respect to other varieties) in a "Classic" 3D configuration, with trees height ≤ than 2.5 m (at maximum grow), in four rows with mutual distance of 5.0m. This choice is particularly useful for the proposal, as it is complementary to the demonstrator planned in the Bolzano area (apple tree).

Solutions implemented in the demo	 The Scalea Demo involves approximately 42 m trackers designed and manufactured by CONVERT. The useful height of the trackers is 3.20 m (at rotating axis), ensuring the free movement of agricultural machinery. All four rows of the orchard (10.40m each) are covered by trackers: one tracker line N-S for each row of trees (with interspace W-E of 5.0m). Weathering steel is used to manufacture the trackers, as a low environmental and visual impact in an agri-PV field. To meet both agricultural and electricity production optimisation needs, a specific tilting and weather emergency programme will be developed and implemented within the SCADA system, aimed at the Scalea Demo. This system can be networked with the monitoring systems (digital platform) developed within the project.
Water catchment / irrigation	Precision irrigation systems are provided to increase water saving. The type tested is a drip sub-irrigation system.
Health &Safety	To overcome the lack of specific safety standards for agri-PV plants, the current electrical and fire safety standards developed for utility scale PV plants will be applied.
System integration	Approximately 70% of the crops area is covered by photovoltaic panels; to ensure complete protection of the remaining 30%, the Demo of Scalea will also be integrated by hail protection systems as nets.
Use of electricity	The complete use of the electrical PV energy produced within the Scalea Demo plant is foreseen, ensuring the power supply of the cultivation electric equipment as new tractors, pumps, compressors, etc.

Figure 45 shows a photograph from the Demo Plant in Scalea, showing the lemon orchard within the Agri-PV system.

Figure 44: Demo Plant in Scalea – lemon orchard within the Agri-PV demo plant

5.3. LAYOUT

The figure below describes the layout of the agrivoltaic system in Scalea.

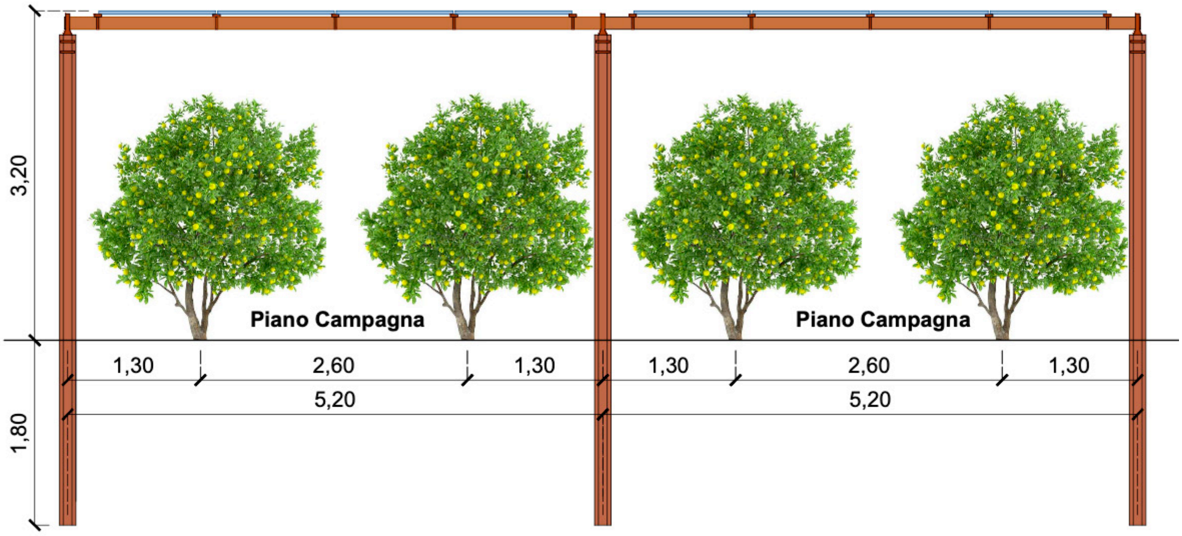


Figure 45: Layout of SCALEA

5.4. PV MODULES

PV modules: n.40 x JA Solar P6-60 Poly 240 W 1650 x 991 x 40 mm (Ptot = 9.6 kW) – to be revamped.

5.5. STRUCTURES

The structure is composed by single-axis tracker 1P, Height: 3.2 m, Span 5.2 m, Pitch: 5 m.

5.6. MONITORING SYSTEM AND SENSORS

Figure 46 illustrates the Demo Plant in Scalea, through a top view, with the position of sensors. The weathering steel mounting structures are ground-fixed without the use of concrete. The irrigation is controlled in order to improve water consumption thanks to non-fixed shadowing and a digital watering control system, together with aerial irrigation systems. The monitoring system allows to measure temperature, humidity, crop growth, and PAR. On the Eastern side of the Agri-PV plant, a Control area is in place, with two rows of orchard in open field and PAR sensor, for comparing the results versus in-PV-plant one.

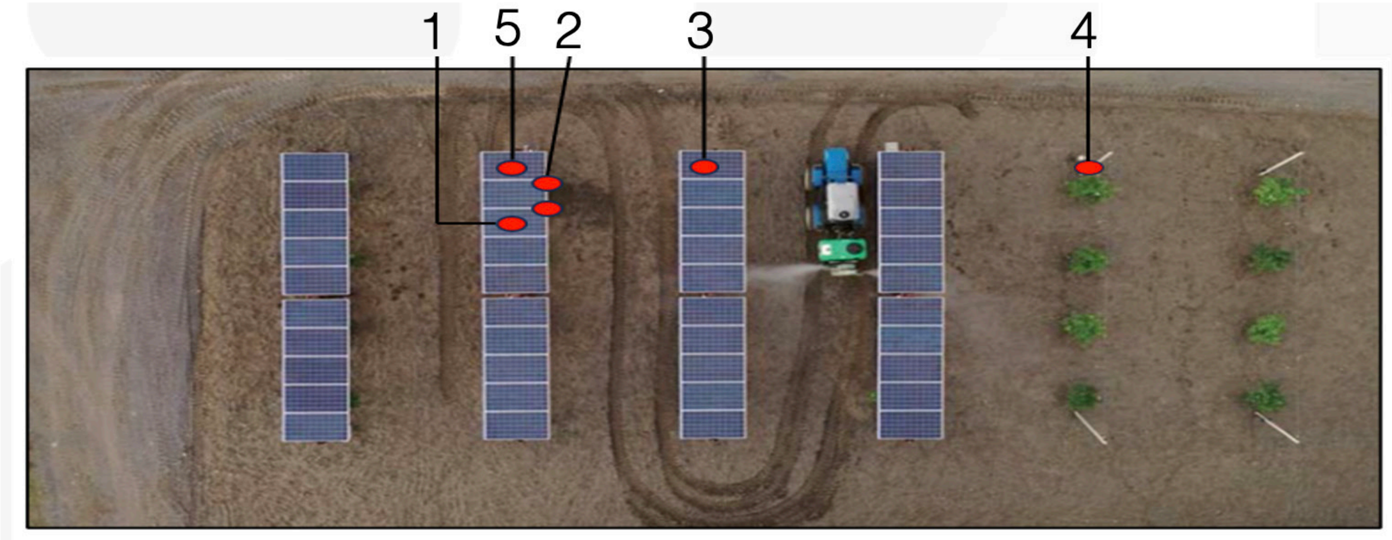


Figure 46: Demo Plant in Scalea – Top view, with the position of sensors

The agri-sensors indicated in the figure above are:

- Ground Temperature (1),
- Humidity at -20 cm and -40 cm (2),
- PAR1 (3) and PAR2 (4) (Photosynthetically Active Radiation) respectively in Agri-PV plant and in Open field plant (i.e. the Control plant, at Est side of Agri-PV plant),
- Dendrometer (5).

5.7. SCHEDULED REVAMPING OF PV MODULES

By Q3 2024 is planned a revamping of PV modules with more efficient ones. The 4 trackers will receive 8 new PV modules each instead of the current smaller PV modules. The power of new PV modules is 550 Wp (JA Solar JAM72D30 – 525-550/MB or similar one) so the new PV plant power will be 17.6 KWp.