Project Deliverable Report

DELIVERABLE 2.1

INITIAL DESIGN AND INSTALLATION GUIDELINES

WORK PACKAGE NUMBER: WP2

WORK PACKAGE TITLE: IMPLEMENTATION

TYPE: REPORT

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REGACE
Using Co2 for Green Energy

Deliverable Information	
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Description	**Greenhouse specific adapted tracker design and installation guidelines for polytunnel and glass greenhouse types. Regulatory and safety environment for each location.**
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Contributor(s)	**Prof. Ibrahim Yehia**
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Table of Acronyms

Acronym	Full Term	Explanation
PV	Photovoltaic	Technology converting sunlight into electricity
GH	Greenhouse	Controlled environment for crop cultivation
MLPE	Module-Level Power Electronics	Devices ensuring safety and monitoring at panel level
EAG	Renewable Expansion Act (Austria)	National law promoting renewable energy deployment
PNRR	Piano Nazionale di Ripresa e Resilienza (Italy)	National Recovery and Resilience Plan
HEDNO	Hellenic Distribution Network Operator	Manages electricity distribution in Greece
DoA	Description of Action	Core document defining project objectives in Horizon Europe
GA	Grant Agreement	Contract between consortium and the EU Commission
IEC	International Electrotechnical Commission	Sets international safety and performance standards
UL	Underwriters Laboratories	Safety certification organization
CO2	Carbon Dioxide	Gas used in greenhouse enrichment systems

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1. Introduction

The TriSolar PV tracking system is designed as a sun-tracking bifacial photovoltaic (PV) array integrated within greenhouses of various structures and dimensions. Its lightweight components are optimized for easy installation, minimizing structural reinforcement while ensuring high mechanical integrity. The system leverages the greenhouse’s existing framework as a load-bearing structure, substantially reducing material costs and installation complexity.

The mechanical and electrical design of the system guarantees optimal sunlight exposure for both panels and crops, achieving a balanced synergy between energy generation and plant growth. The bifacial modules capture reflected and transmitted light, increasing total yield while maintaining adequate Photosynthetically Active Radiation (PAR) for vegetation.

This deliverable outlines the design principles, system configurations, and installation procedures for each participating site under the REGACE project. The guidelines include:

- Solar module adaptation per country and greenhouse type
- Electrical and mechanical PV system designs
- Tracking system optimization
- Installation Guide, step-by-step

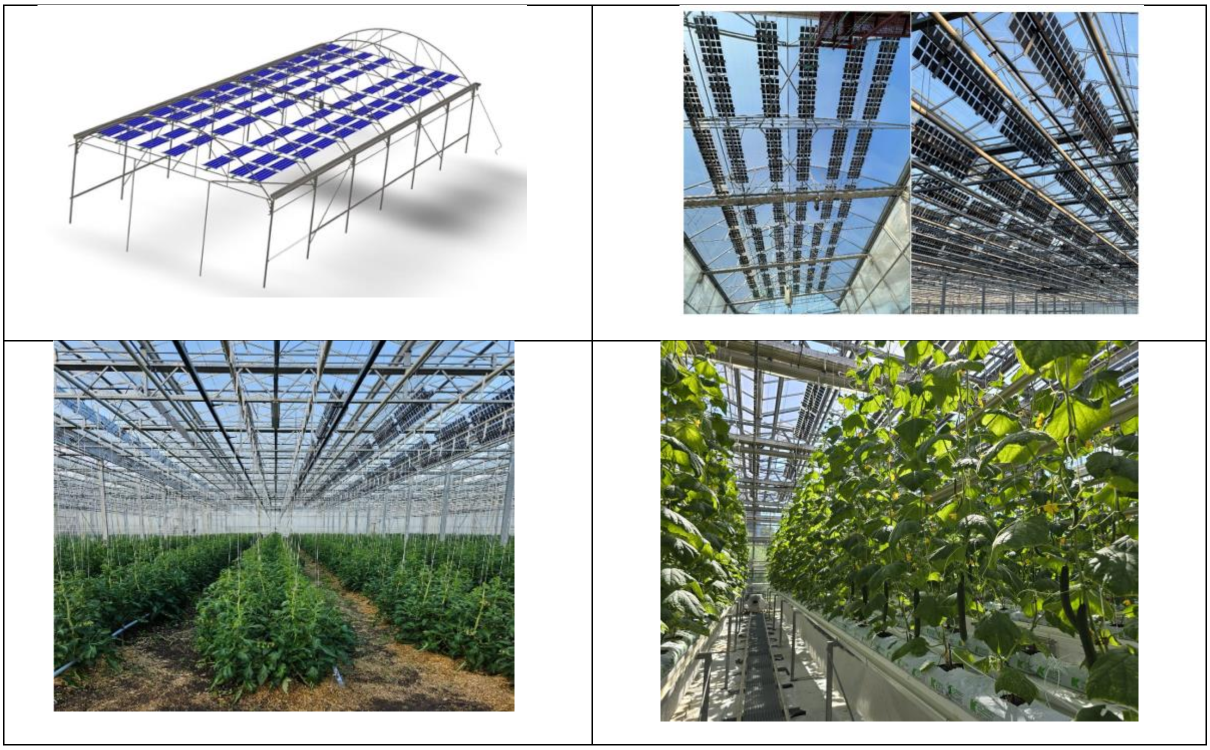

Figure 1 Examples of TriSolar PV tracking systems integrated in REGACE test sites

The figure above illustrates multiple greenhouse system sizes and configurations tested under different climatic conditions in Germany, Greece, Israel, Italy, and Austria. Each variant reflects adjustments in module spacing, tilt range, and actuator type to match greenhouse geometry and local irradiance.

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2. Regulatory and Safety Environments Per Location

Regulatory and Safety Compliance

In compliance with Article 17 of the Grant Agreement (GA No. 101096056) and the Description of the Action (DoA), TriSolar ensures that all Agri-PV system operations respect national and regional regulatory and safety requirements in each participating country:

- Germany: Systems must comply with EEG legislation and BNetzA grid-connection standards. Mechanical structures conform to local agricultural zoning and safety norms.

- Italy: All deployments must adhere to national land-use laws and PV-specific permitting pathways. Regional authorities were consulted for integration with farm infrastructure.

- Greece: Installations must be compliant with agricultural land classification laws and regulated via the Ministry of Energy and Ministry of Rural Development.

- Austria: TriSolar must operate in accordance with E-Control Austria's green energy guidelines, land allocation rules, and building codes for PV integration.

- Israel: Installations must be compliant with the Ministry of Agriculture, Ministry of Environment Protection, the Regulatory Authority for Energy and the Planning and Construction Department regulations.

National Regulatory Contexts

The following section briefly introduces the national regulatory and legal frameworks that influence Agri-PV implementation in REGACE pilot countries. These initial contextual factors will be greatly expanded upon in **Deliverable D7.1 – Recommendations for Improved Regulations**.

Germany

Germany's regulatory environment for Agri-PV is defined by the Renewable Energy Sources Act (EEG), administered by the Federal Network Agency (BNetzA). Agri-PV installations must comply with land use regulations, ensuring agricultural productivity is maintained. Projects must also conform to building and electrical safety codes, with mandatory grid-connection procedures and feed-in tariffs contingent on location and technology. Additional restrictions exist on federal land and nature conservation zones.

Italy

In Italy, the development of Agri-PV must adhere to both national and regional laws governing land use and energy deployment. Regional authorities play a significant role in permitting and zoning. Recent incentives under the National Recovery and Resilience Plan (PNRR) promote dual-use solar systems, provided they do not hinder crop production or irrigation. Environmental impact assessments (EIA) are often required based on the scale of installation.

Greece

Greek regulations distinguish between permitted agricultural and energy uses of land. Agri-PV installations must be approved by the Ministry of Rural Development and Food and the Regulatory

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Authority for Energy. Specific conditions apply to avoid conflicts with arable land preservation and rural development programs. Technical requirements for grid-connection, metering, and licensing are managed through the HEDNO (Hellenic Distribution Network Operator).

Austria

Austria's support for Agri-PV is embedded in the Renewable Expansion Act (EAG), overseen by E-Control and regional planning authorities. Projects must align with agricultural zoning and avoid interference with biodiversity conservation. Grid integration is governed by provincial energy strategies and the national electricity market framework. Public funding is available, but project designs must balance agricultural and photovoltaic objectives.

Israel

Israeli regulations distinguish between permitted agricultural and energy uses of land. Agri-PV installations must be approved by the Ministry of Agriculture, Ministry of Environment Protection, the Regulatory Authority for Energy and the Planning and Construction Department.

In the future, Israel's National Planning and Building Committee plans a dedicated regulation allowing the construction of agrivoltaic systems above agricultural land. The new regulation for agrivoltaics is suggested to change the regulations so that PV placement under the canopy of greenhouses will be generally allowed (beyond the current allowance only for experimental and testing facilities). The regulation will permit the installation of solar infrastructures above crops, as long as meaningful agricultural activity is maintained and environmental and planning conditions are met.

Enhanced Safety Protocols at REGACE Testing Sites

TriSolar will comply with all national and safety regulations at each testing site. It has developed and will implement a robust safety framework for Agri-PV installations, harmonizing both European (IEC) and American (UL) standards. The systems are designed to protect farmers, maintenance personnel, and emergency responders. Electrical cables are either elevated or routed through protective conduits to avoid accidental contact and mechanical damage.

Module-Level Power Electronics (MLPE), including arc fault detection and SafeDC™ emergency shutdown features, enable rapid voltage reduction during faults or maintenance, ensuring that high DC voltages do not pose risks. Strategic signage, voltage isolation plans, and emergency protocols are integrated from the design phase.

Modules are mounted at heights that prevent accidental contact, even by large agricultural equipment, while maintaining optimal agronomic light penetration. These best practices have been tested in live environments without incident, demonstrating the maturity and safety of the TriSolar Agri-PV concept. The mechanical stability and robust electrical procedures uphold a safe environment for all those who interact with the system.

General Electrical Safety Guidelines

1. Signage

- Clearly post safety signs around the site to remind farmers and visitors that live electrical equipment is present.
- Basic but highly effective for maintaining awareness, especially where people and machinery move frequently.

2. Cable Placement

- Wherever possible, bury or safely elevate DC/AC cables.
- In some cases,, overhead cabling is used to avoid damage from animals and equipment. Ensure cables remain taut or properly secured to prevent abrasion and reduce trip hazards.

3. Module Height

- Mount modules at an appropriate height above the crops to minimize accidental contact by large machinery or farm workers.
- Align this height with agronomic considerations (e.g., plant growth and sunlight requirements).

4. Fire & Shock Prevention with MLPE

- Use module-level power electronics (MLPE) to detect and isolate faults at the panel level.
- Utilise SolarEdge's SafeDC™, which automatically drops each panel's voltage to 1V in emergencies or inverter shutdown. This protects farmers, firefighters, and maintenance crews from high DC voltage.
- Built-in arc detection further reduces the chance of fire from frayed cables or poor connections.

5. Integrating Safety Early

- Addressi safety in the design phase (e.g., wiring routes, signage, module height) avoids expensive retrofits.
- Properly plan so that if the inverter shuts down (e.g., during a grid or AC outage), the system voltage will be safe for any onsite responders.

6. Knowing the Basics of PV Operation

- Solar panels produce high DC voltage in daylight even if the circuit breaker is off.
- For added assurance, ensure the system meets recognized safety standards (e.g., UL 1699B for arc detection in the U.S., or up-and-coming IEC 63027 in Europe), and consider insurance requirements.

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By combining clear signage, protective cable routing, correct module height, and the advanced monitoring and rapid shutdown capabilities of MLPE-based solutions, REGACE sites will meet the heightened safety demands of co-locating solar equipment with daily farm activities—ultimately benefiting both agricultural output and renewable energy generation.

3. Solar Module Designs

The solar module design was adapted to suit each installation location. Specific attention was given to the requirements in each installation location to achieve a suitable panel size and configuration of cells within the panels to achieve as homogenous light distribution as possible at crop level. All those requirements were communicated with the manufacturer to meet and obtain the required CE, TUV and ISO standards, ensuring electrical and mechanical safety requirements. The panel voltage was also optimized to be connected to the grid, as is the case with standard PV modules on the market. The modules were designed especially for agrivoltaic applications, by minimizing their weight, ensuring their stability in a greenhouse environment as well as their light transparency to ensure good crop development. Solar module cells with high efficiencies of 22.5% were used and the modules were designed to be bifacial modules, aiming to maximize the energy yield in the greenhouses.

The following section includes the panel specifications for each location.

1) *2.1 PV panel specifications*

A PV panel specification booklet was prepared, detailing the different panel types used in this project. Each panel type was custom designed according to the different types of greenhouse construction.

- 135W module is for Bio-Gaertnerei Watzkendorf, Germany
- 105W module is for TRDC, Israel
- 85W module is for Thessaly University, Greece and FSC, Italy
- 90W module is for BOKU, Austria
- 120W module is for Humboldt University Berlin, Germany

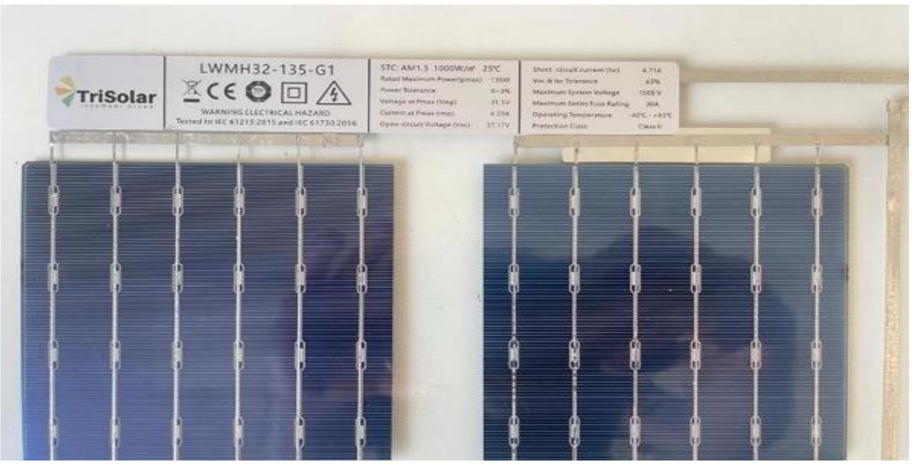

Figure 2 Mechanical and electrical specifications of photovoltaic panels

The figure above illustrates the mechanical and electrical specifications of the photovoltaic panels as presented in the dedicated specification booklet.

(1) Example PV panel specifications

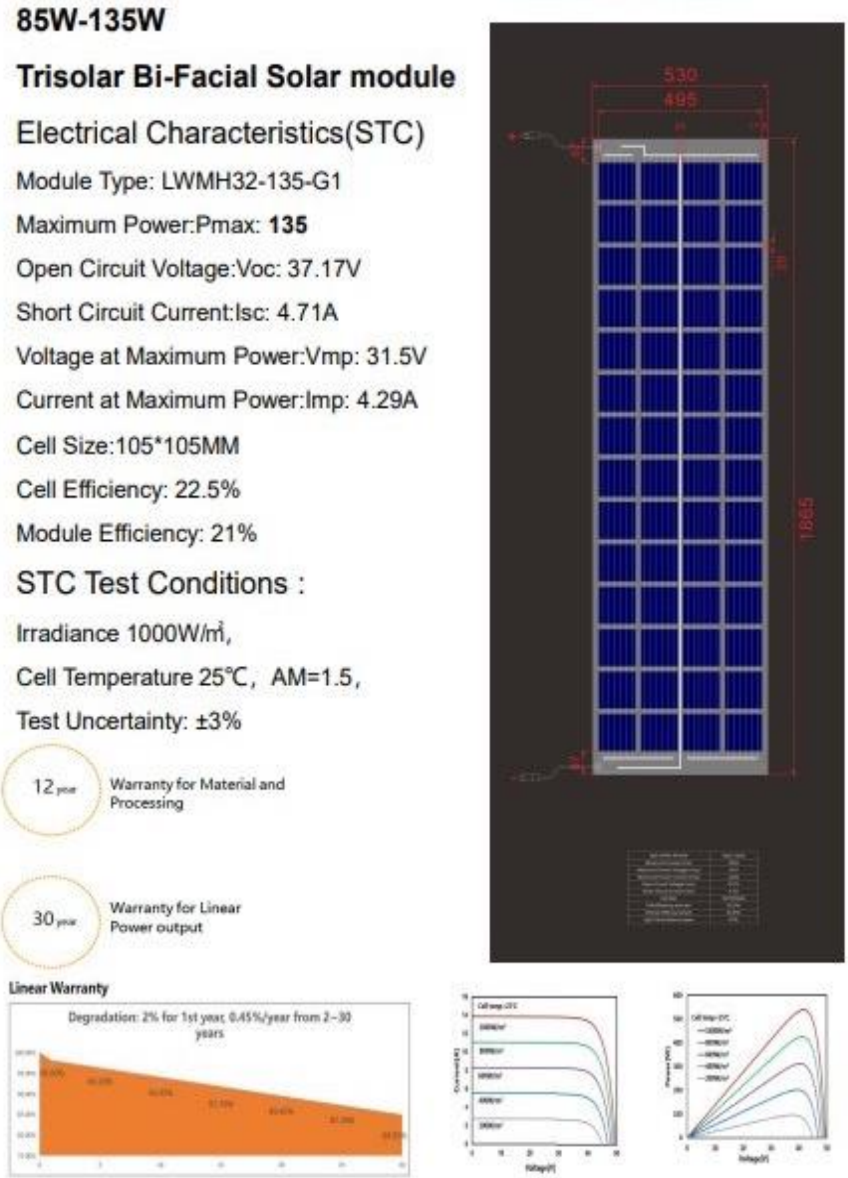

Figure 3 Mechanical and electrical specifications at Watzkendorf in Germany

The figure above illustrates the mechanical and electrical specifications of the PV-panels used at Bio Gärtnerei Watzkendorf Farm system with 135 Wp power output.

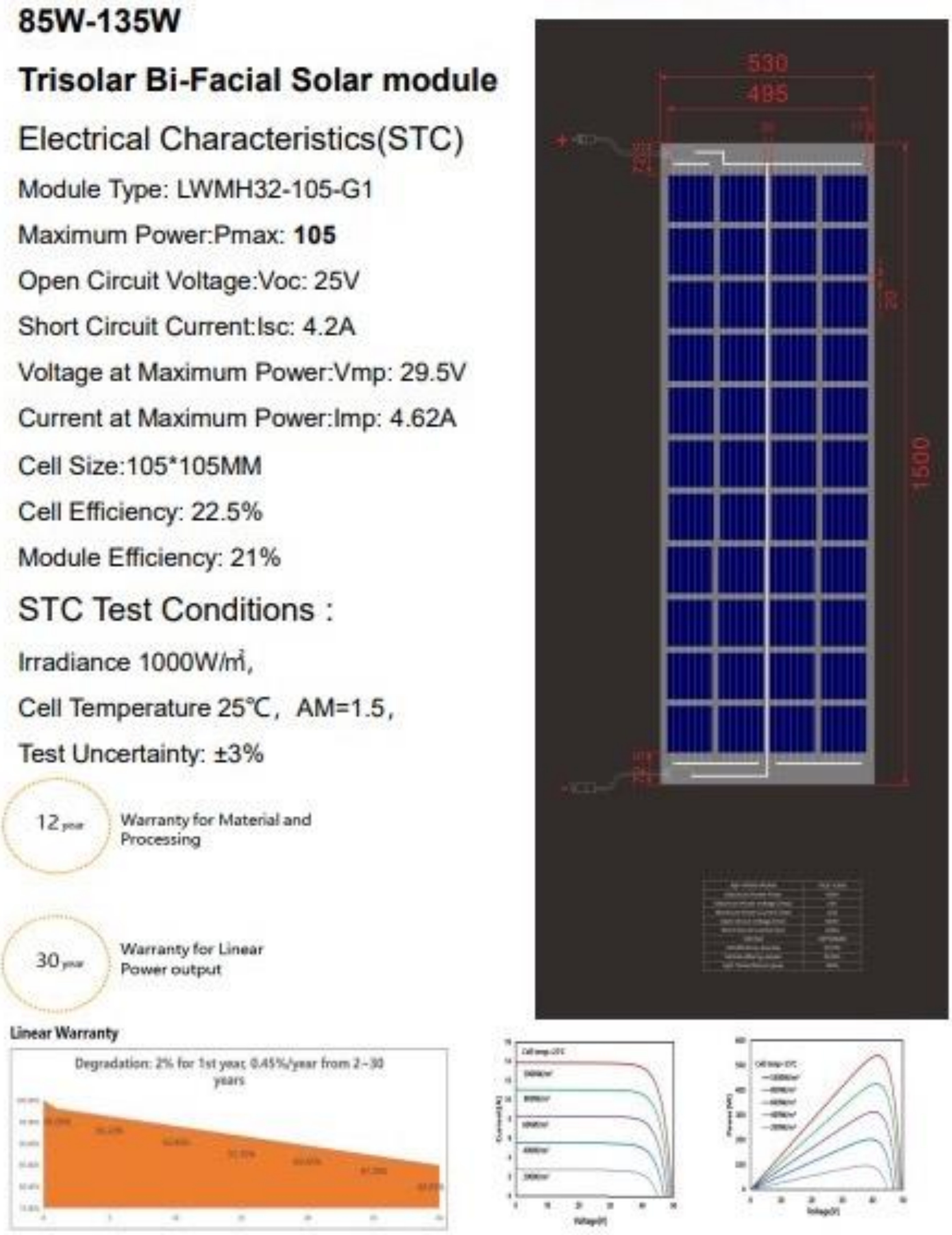

Figure 4 Mechanical and electrical specifications at Al-Zahrawy in Israel

The figure above illustrates the mechanical and electrical specifications of the PV-panels used at Al-Zahrawy system with 105 Wp power output.

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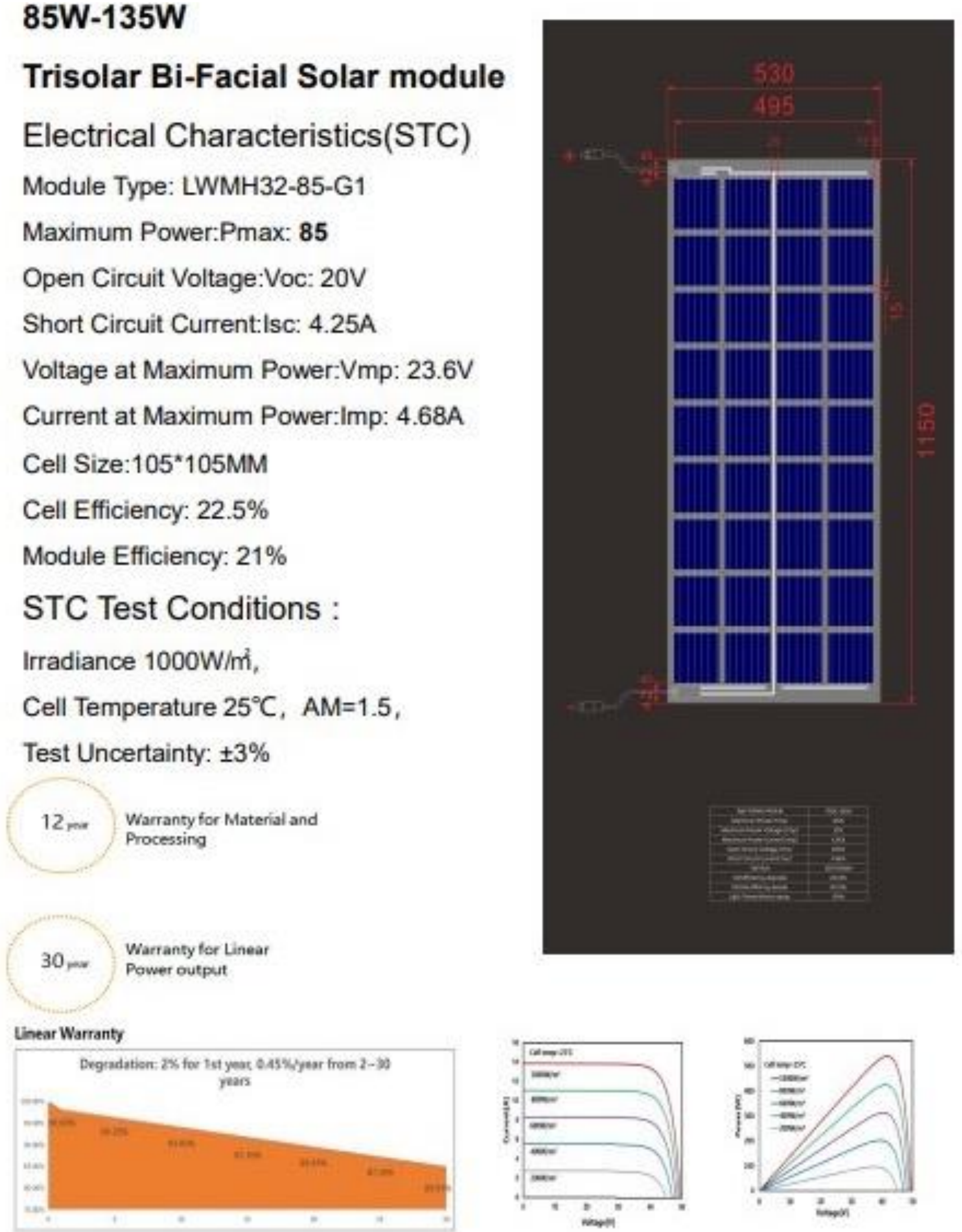

Figure 5 Mechanical and electrical specification at FSC in Italy

The figure above illustrates the mechanical and electrical specifications of the PV-panels used at FSC Farm system with 85 Wp power output.

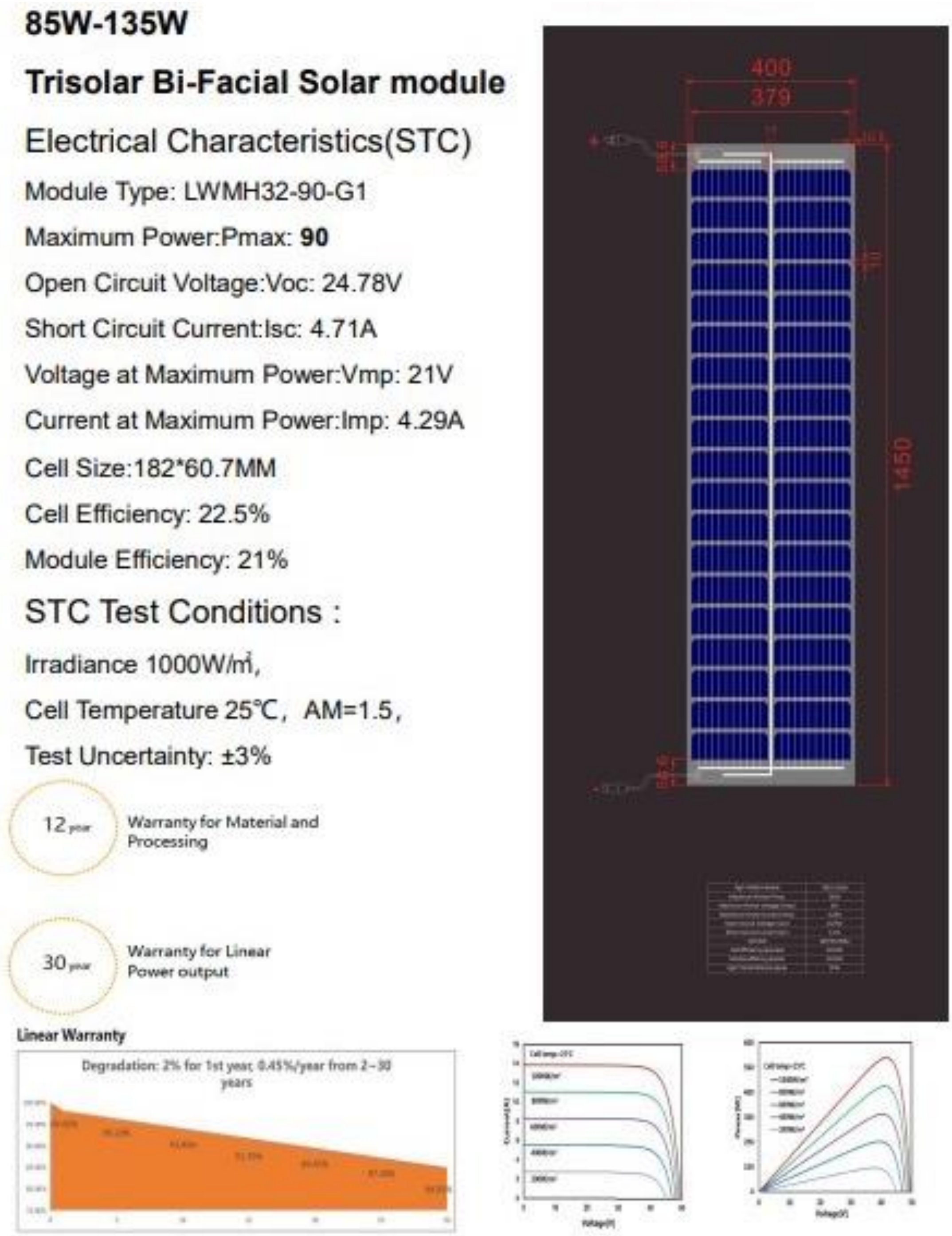

Figure 6 Mechanical and electrical specifications at BOKU in Vienna

The figure above illustrates the mechanical and electrical specifications of the PV-panels used at the BOKU university system with 90 Wp power output.

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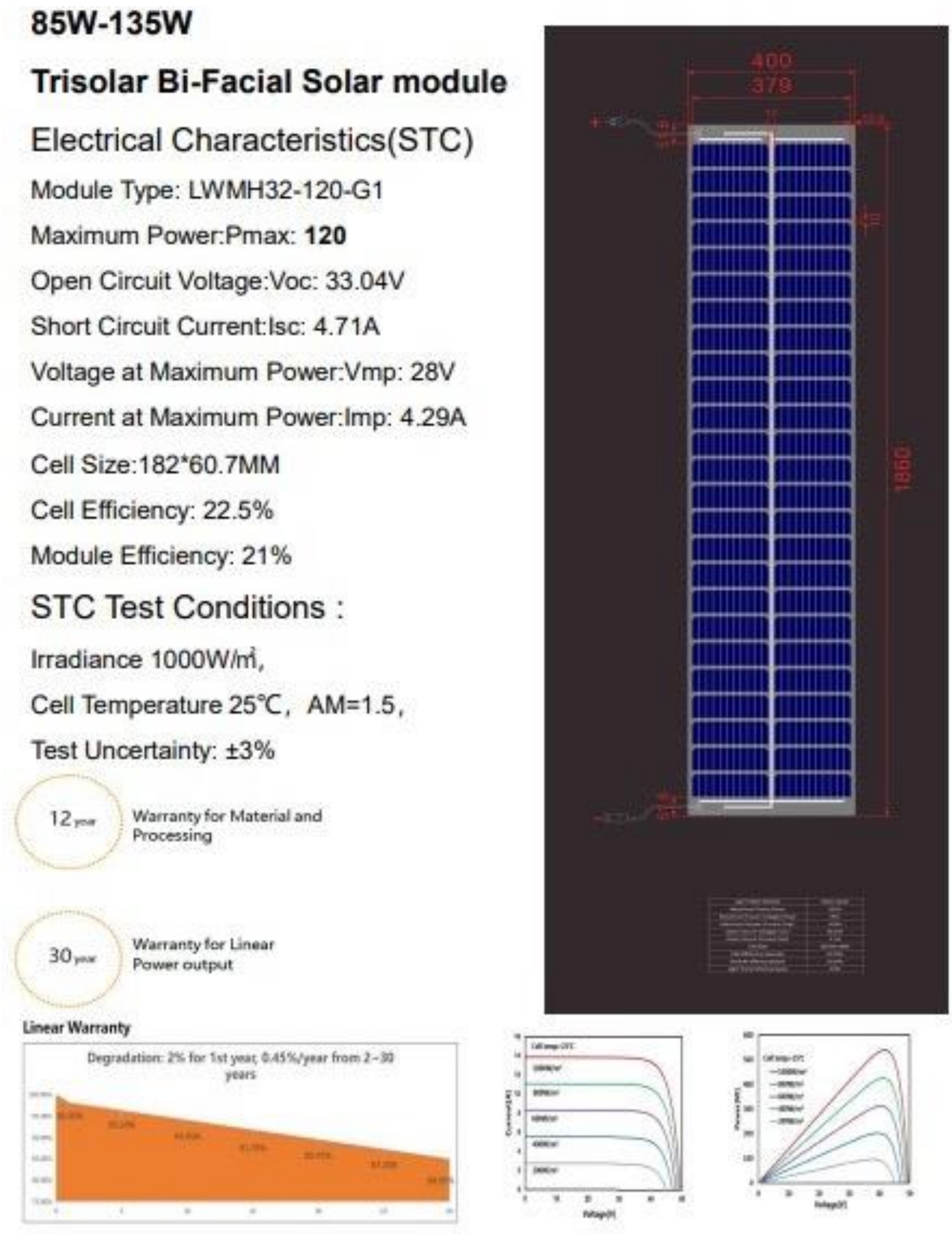

Figure 7 Mechanical and electrical specifications at Humboldt in Berlin

The figure above illustrates the mechanical and electrical specifications of the PV-panels used at Humboldt university system with 120 Wp power output.

Within the REGACE project, five distinct photovoltaic (PV) panel types were specifically designed and engineered to meet the mechanical and structural requirements of each greenhouse installation site. This customization was necessary due to the significant variations in greenhouse architecture across the different locations, which imposed unique mechanical and spatial constraints that required precise structural adaptations.

In addition to the differences in greenhouse geometry, internal equipment layouts—such as ventilation systems, irrigation infrastructure, and CO_2 enrichment pipelines—necessitated further modifications to the physical dimensions and framing design of the panels to enable safe and efficient integration within each greenhouse.

As a result, the REGACE installations feature site-specific PV modules that vary in both mechanical configuration (e.g., frame thickness, mounting interface, and support spacing) and electrical design (e.g., voltage, current, and cell arrangement), ensuring full compatibility with the respective greenhouse environment while maintaining optimal light transmission and energy performance.

2.2 Sample manufacturing and testing

Samples of the PV modules were manufactured and tested before manufacturing all the panels for all locations. The sample modules were sent to the Alzahrawy research center and were tested mechanically and electrically in the field. In addition, the light distribution at crop level was tested, to ensure an even light distribution for the crops.

Figure 8 Testing process of photovoltaic panels

The figure above illustrates the testing process of the photovoltaic panels conducted prior to their delivery to the installation sites

Sample modules were shipped to the Alzahrawy Research Center, where they underwent comprehensive mechanical and electrical field testing to verify their structural integrity, performance stability, and compliance with design specifications.

In addition to standard performance evaluation, light distribution measurements at crop level were performed inside experimental greenhouse setups. These tests ensured uniform illumination across the cultivation area, confirming that the panels provide balanced photosynthetically active radiation (PAR) necessary for optimal crop growth while maintaining high electrical efficiency.

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(2) PV module samples

Figure 9 PV modules sample testing

All photovoltaic modules have now been fully manufactured in accordance with the finalized mechanical and electrical specifications. A set of sample modules has been shipped to the University of Rome Tor Vergata for advanced testing and performance validation under Work Package 3 (WP3)**,** focusing on optical transmission, electrical efficiency, and thermal behavior inside greenhouse conditions.

The remaining production batches are securely stored at the manufacturer's facility under controlled conditions, awaiting coordinated shipment alongside the tracking system components. This ensures synchronized delivery and installation at each REGACE pilot site, maintaining system integrity and minimizing logistical risks.

4. PV System Designs

The following sections present the detailed system designs developed for each REGACE installation site. To ensure design precision and compatibility**,** 3D digital models of all greenhouse structures were created, enabling accurate spatial verification of mechanical, electrical, and control components. These models were used to validate the integration of PV modules, tracking actuators, wiring routes, and mounting interfaces, ensuring seamless adaptation to the geometric and operational characteristics of each greenhouse type (Venlo, polytunnel, and research-scale units).

Furthermore, these high-resolution models serve as the foundation for a dynamic simulation video, currently under development within the Dissemination and Communication Work Package (WP7)**.** The simulation visually demonstrates the operational principles of the TriSolar tracking system, including real-time solar angle adjustment, shading behavior, and its impact on light transmission to the crops. This visualization supports outreach activities, helping stakeholders and policymakers understand the agronomic and energy synergies of the REGACE technology.

The system technology implemented in REGACE represents patent-protected intellectual property (IP) **of** TriSolar InnoWadi Group Ltd**.**, a consortium partner and technological leader in agrivoltaic integration. The design and control logic of the dynamic tracking mechanism are covered under multiple international patents, ensuring both innovation protection and compliance with European regulatory and safety standards.

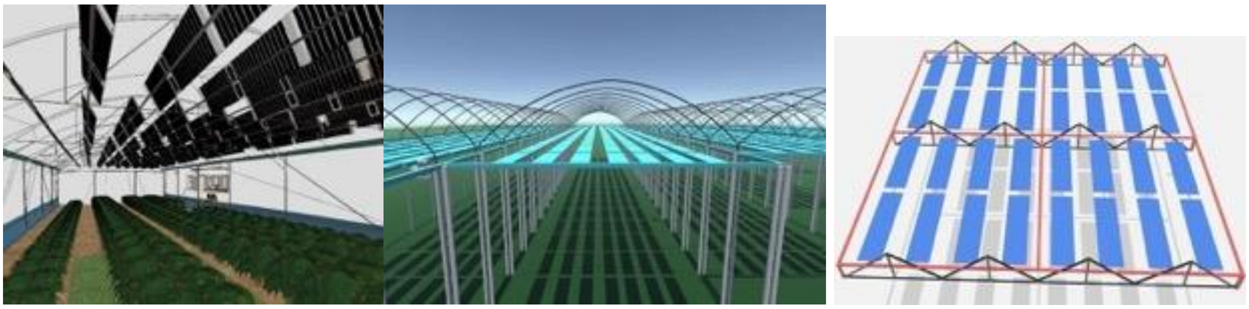

Figure 10 Sample 3D models of greenhouse structures

The figure above shows sample 3D models of the greenhouse structures integrated with the TriSolar dynamic tracking system.

These models illustrate how the photovoltaic panels, actuator mechanisms, and support components are spatially arranged within each greenhouse type, ensuring structural compatibility and optimal solar exposure.

The electrical design of each installation was developed according to the specific operational, climatic, and grid-connection requirements of each pilot location. Detailed electrical schematics were prepared to define inverter selection, cable routing, grounding, and protection systems in compliance with both national regulations and IEC safety standards.

The complete REGACE system will be deployed across six pilot sites, each featuring a customized electrical and mechanical layout designed to reflect the local greenhouse configuration, energy demand profile, and environmental conditions. The corresponding system designs for these sites are outlined in the following subsections.

1) *Bio-Gaertnerei Watzkendorf – commercial Venlo type greenhouse*

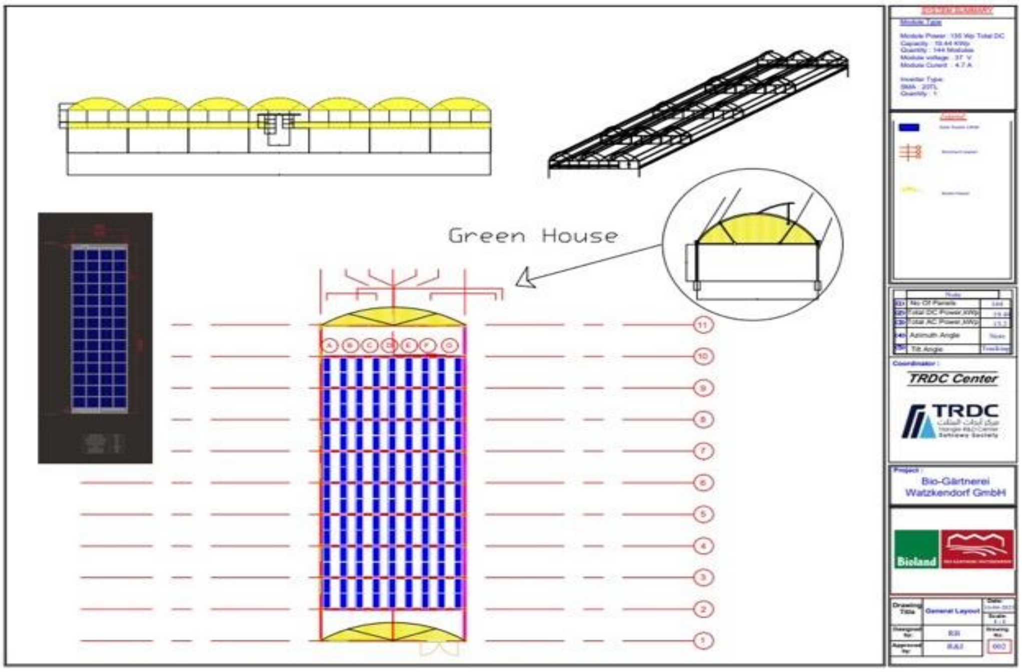

Figure 11 Module arrangements

The figure above shows the modules arrangements in the roof of BW greenhouse.

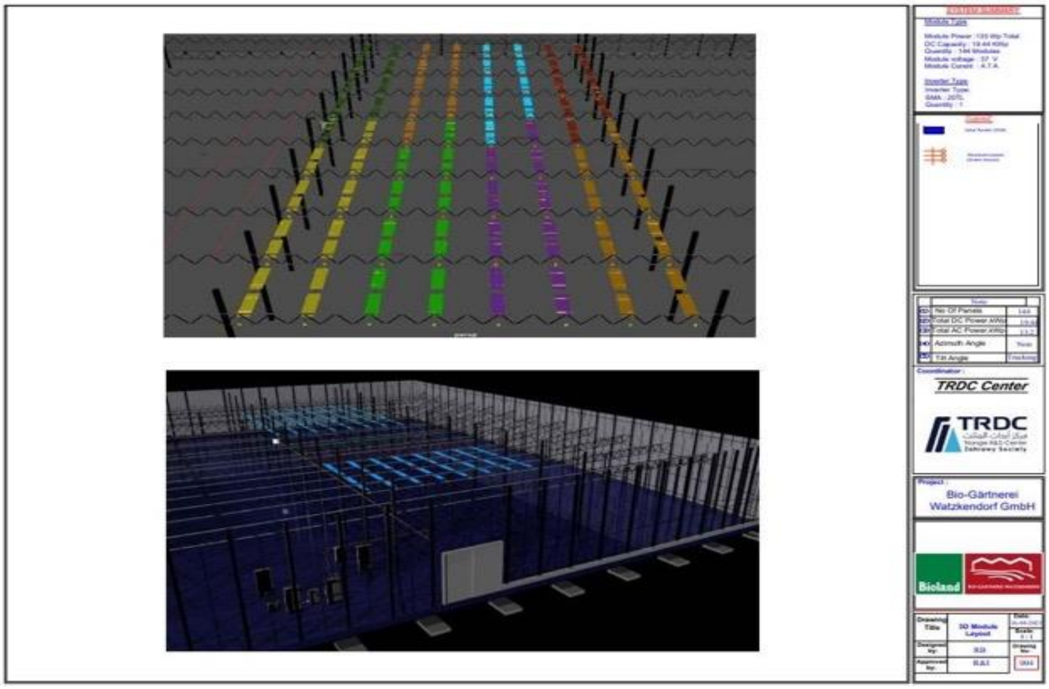

Figure 12 3D models of BW greenhouse

The figure above displays sample 3D models of the BW greenhouse structures integrated with the TriSolar dynamic tracking system.

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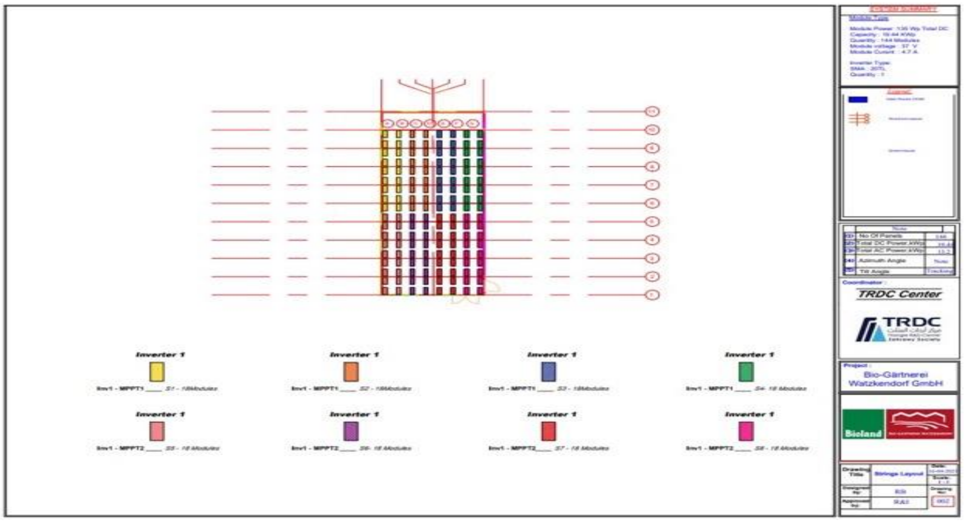

Figure 13 Electrical grounding

The figure above presents the schematic electrical grounding plan.

The plan was developed in full compliance with international safety and electrical protection standards. The diagram illustrates the layout and interconnection of all grounding elements, including PV module frames, support structures, actuator housings, and inverter cabinets, all bonded to a common earth potential to ensure personnel and equipment safety.

This grounding configuration minimizes the risk of electric shock, equipment damage, or fire hazards caused by insulation faults or lightning strikes. The design also incorporates surge protection devices (SPD) and equipotential bonding across metallic components, guaranteeing safe dissipation of fault currents.
By implementing this robust grounding system, all REGACE installations comply with the highest safety requirements for combined agricultural and photovoltaic environments, where human activity and electrical infrastructure coexist in close proximity.

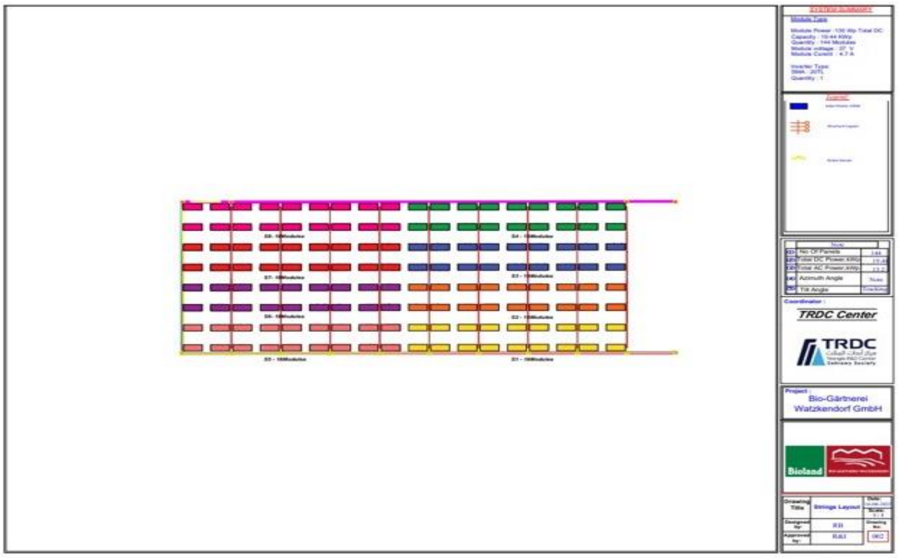

Figure 14 Module string layout

The figure above illustrates the schematic module string layout.

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The figure illustrates the configuration that defines the operating voltage and current characteristics of the PV system installed at the Bio-Gärtnerei Watzkendorf (BW) site.

The string design plays a critical role in determining the overall electrical performance and efficiency of the photovoltaic system. Proper string configuration ensures that the system operates within the inverter’s optimal voltage window, maximizing energy yield and power stability. Conversely, incorrect string sizing or imbalance can lead to voltage drops, inverter inefficiencies, or thermal losses.
In greenhouse-integrated PV systems such as REGACE, partial shading effects—caused by greenhouse frames, ventilation openings, or roof curvature—can significantly impact power output. Therefore, the string layout must be carefully engineered for each specific site, taking into account the geometry of the greenhouse, panel orientation, expected shading patterns, and irradiance conditions throughout the day and across seasons.
To mitigate shading-related losses, module-level power electronics (MLPE) and bypass diode configurations are applied, ensuring consistent performance even under non-uniform illumination conditions. The final string configuration for each site was validated through electrical simulation and field testing, ensuring compliance with safety standards and optimal energy performance.

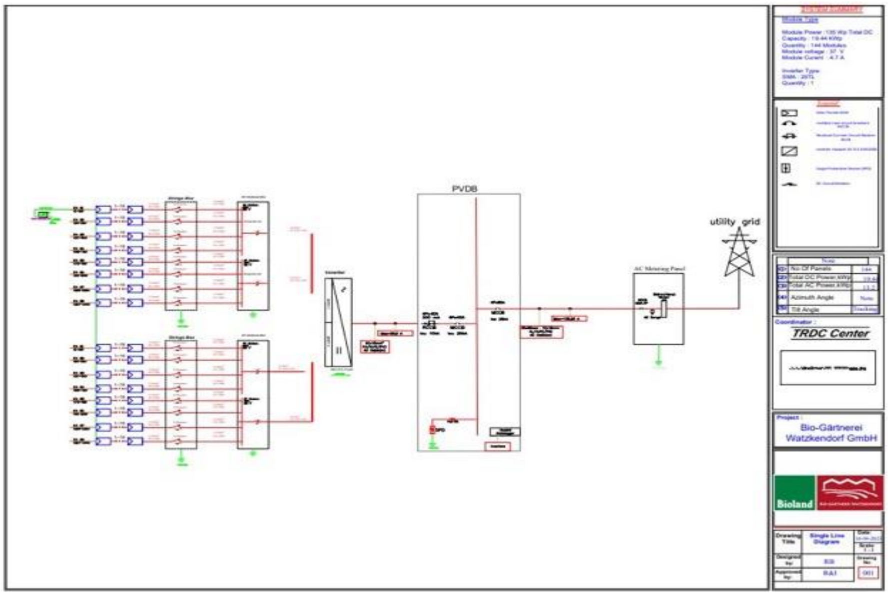

Figure 15 Electrical system design

The figure above presents the comprehensive electrical system design.

The design encompasses both the DC and AC sections of the photovoltaic installation and their interconnection with the local power grid at the Bio-Gärtnerei Watzkendorf (BW) site.

The design adheres fully to international safety and electrical protection standards, including IEC 60364, IEC 62548, and relevant VDE (Germany) regulations governing PV system installation and grid integration.
The DC section includes the photovoltaic module strings, combiner boxes, fuses, surge protection devices (SPDs), and cable routing up to the inverters. The AC section covers the inverter output, switchgear, overcurrent protection, grounding network, and the grid-connection interface.
This configuration ensures safe operation, optimal power conversion efficiency, and reliable synchronization with the utility grid. Additional features, such as isolation monitoring, residual current

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detection, and automatic disconnection in fault conditions, guarantee maximum system safety and compliance with both EU and national electrical codes for greenhouse-integrated solar systems.

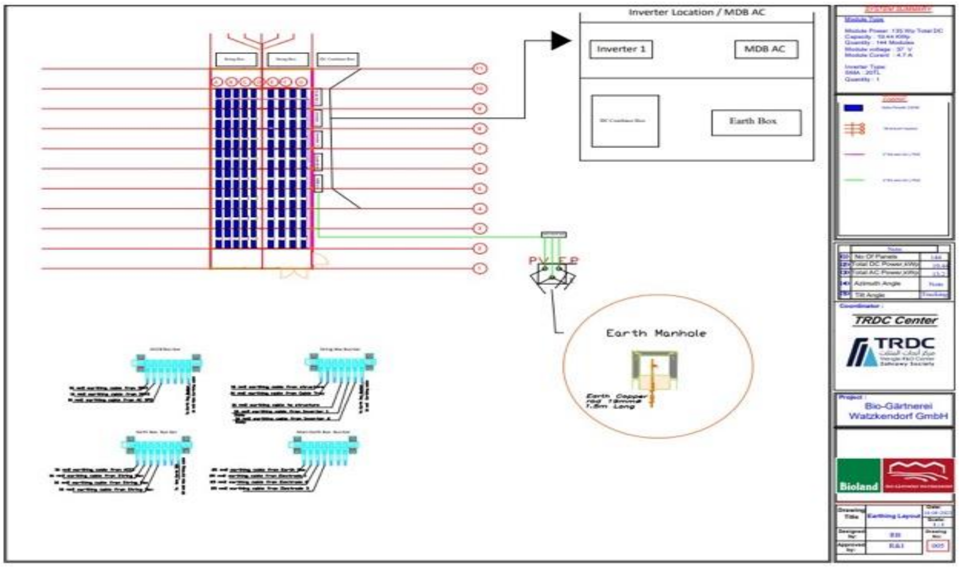

Figure 16 Electrical safety system

The figure above shows the comprehensive electrical safety system design.

The schematic details the AC interconnection and protection architecture for the photovoltaic installation at the Bio-Gärtnerei Watzkendorf (BW) site.

The schematic illustrates the integration of protective devices, including residual current circuit breakers (RCCBs), surge protection devices (SPDs), and isolation switches, ensuring full compliance with IEC 60364, IEC 62109, and VDE 0100 safety standards.
This configuration guarantees safe operation during normal conditions and provides rapid fault isolation and disconnection in case of overcurrent, insulation failure, or grid disturbances. The design also incorporates equipotential bonding and ground-fault monitoring systems to prevent electrical hazards and ensure reliable protection for both personnel and equipment within the greenhouse environment.

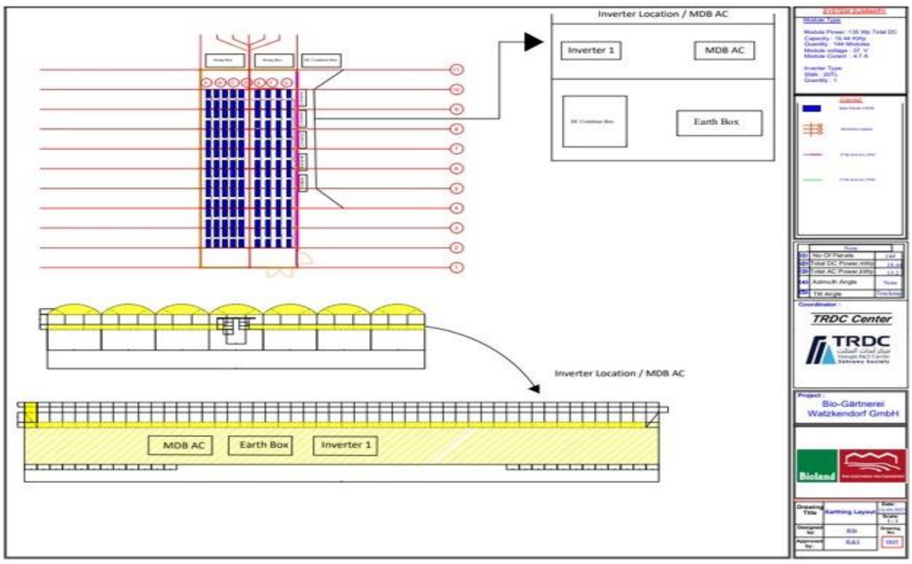

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Figure 17 Spatial integration in Watzkendorf

The figure above displays the location and spatial integration of the photovoltaic (PV) system in Watzkendorf.

The figures shows the integration of the PV system within the greenhouse, highlighting its physical relationship with the greenhouse control and automation components at the Bio-Gärtnerei Watzkendorf (BW) site.

This illustration demonstrates how the PV modules, actuators, and electrical conduits are positioned relative to key greenhouse infrastructure—such as climate control units, irrigation systems, and sensor networks—to ensure efficient coexistence and operational safety. The layout was carefully designed to maintain uninterrupted agricultural activities while optimizing sunlight exposure and minimizing shading interference with the greenhouse's environmental control systems.
By aligning the PV installation with the existing control architecture, the REGACE system achieves seamless integration between energy generation and greenhouse management, enabling coordinated operation, real-time monitoring, and improved overall system efficiency.

2) BOKU- small scale research greenhouse with unique construction

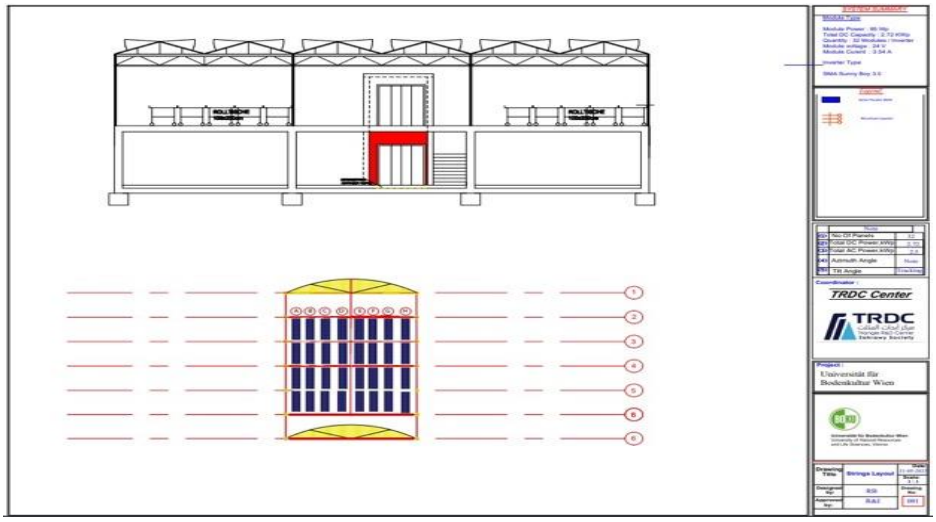

Figure 18 Spatial integration in BOKU

The figure above presents the location and spatial integration of the photovoltaic (PV) system in BOKU.

The figure highlights its physical relationship with the greenhouse control and automation components.

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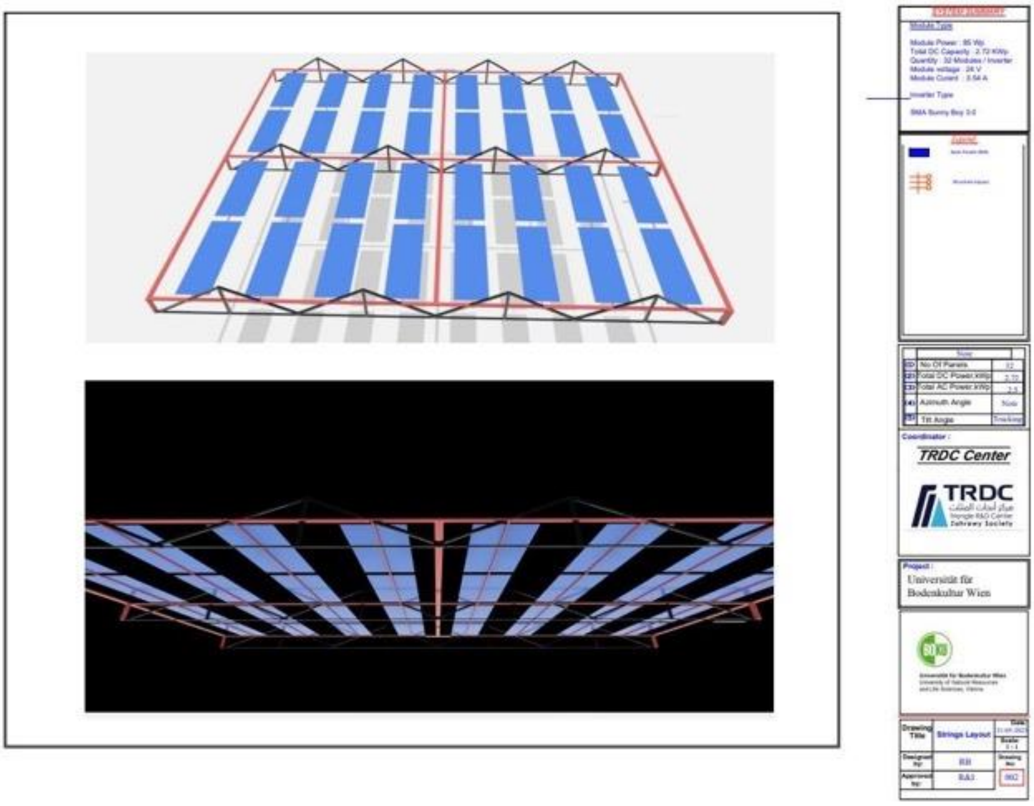

Figure 19 Sample 3D models of BOKU greenhouse

The figure above shows sample 3D models of the BOKU greenhouse structures integrated with the TriSolar dynamic tracking system.

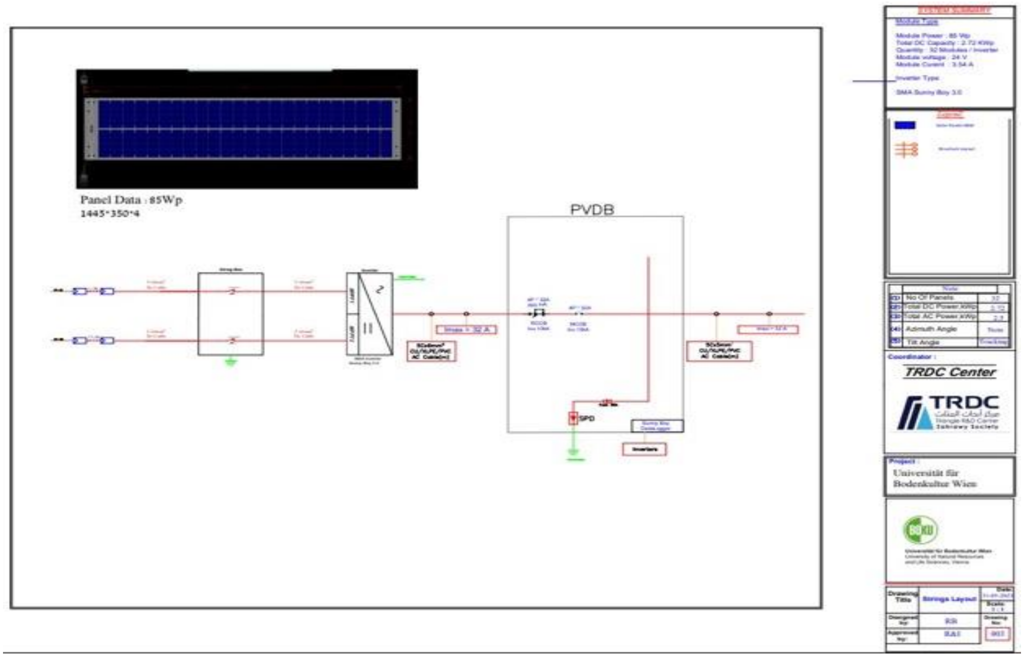

Figure 20 Electrical system design at BOKU

The figure above displays the comprehensive electrical system design, encompassing both the DC and AC sections of the photovoltaic installation and their interconnection with the local power grid at the BOKU site.

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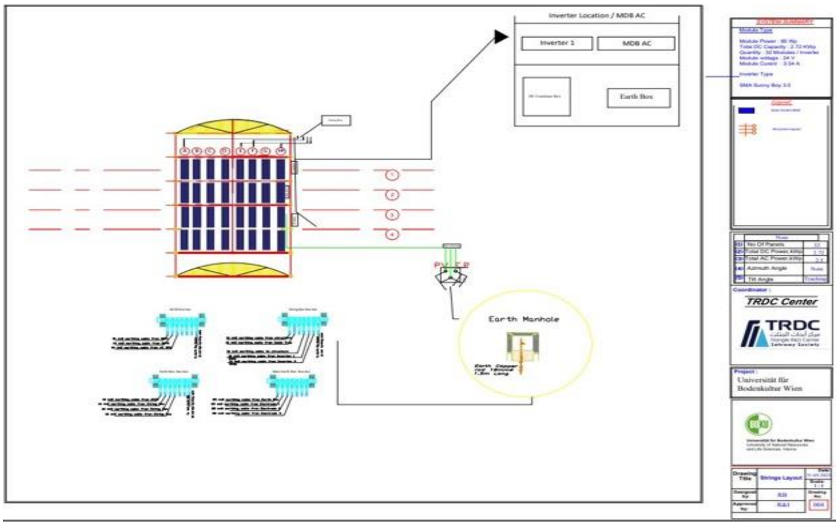

Figure 21 Electrical safety system design at Boku

The figure above provides the comprehensive electrical safety system design, detailing the AC interconnection and protection architecture for the photovoltaic installation at BOKU site.

The PV system installed at the BOKU site represents the smallest installation among all REGACE testing locations, designed primarily for research and performance validation under controlled greenhouse conditions.

The system consists of two independent subsystems, with a combined total DC capacity of 1.320 kWp. Each subsystem comprises 24 photovoltaic modules, rated at 85 Wp per module, connected to form optimized strings that match the inverter's operational voltage range.

Despite its modest scale, the BOKU installation plays a crucial role in the comparative analysis of system performance, particularly in assessing light transmission, temperature effects, and crop–energy interactions within small-scale research greenhouses. The modular design also allows flexible configuration adjustments to support ongoing experimental studies on dynamic tracking behavior and bifacial module efficiency in agrivoltaic environments.

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3) *Humboldt University- standard Venlo type research greenhouse*

The PV system installed at Humboldt University (HU) is composed of three distinct sections, each designed with a different spatial coverage configuration to evaluate the effects of varying shading levels and light transmission on crop growth. The sections consist of 8 rows, 6 rows, and 4 rows of photovoltaic modules, respectively, as illustrated in the accompanying figure.

In total, the system integrates 36 high-efficiency bifacial PV modules, providing a nominal DC capacity of 3.78 kWp. This modular layout enables comparative analysis of energy yield, light distribution, and microclimate behavior across sections with different coverage ratios.

The design also facilitates academic experimentation within the REGACE framework, allowing Humboldt University researchers to investigate the interaction between PV coverage density, photosynthetically active radiation (PAR), and greenhouse climate control. Data collected from this site contribute significantly to developing optimized AgriPV configurations for research and commercial greenhouses across Europe.

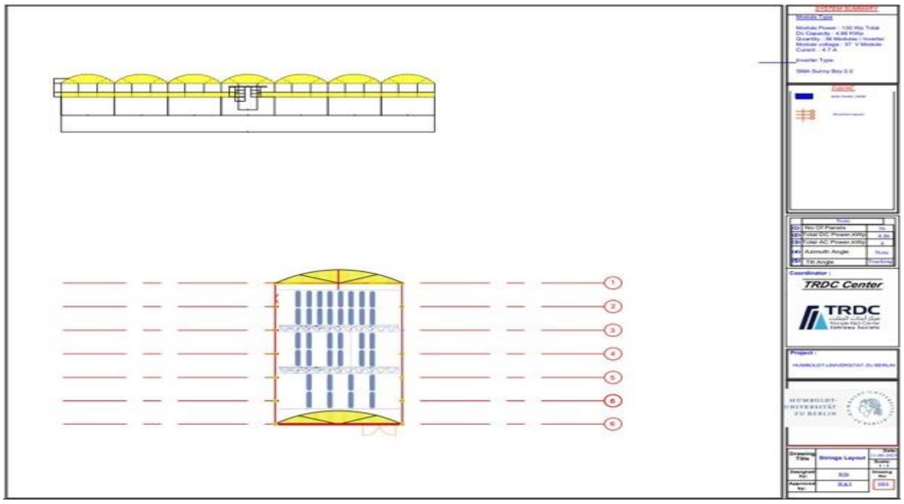

Figure 22 Spatial integration of the photovoltaic system at Humboldt University of Berlin

The figure above represents the location and spatial integration of the photovoltaic (PV) system within the HB greenhouse, highlighting its three PV coverage section.

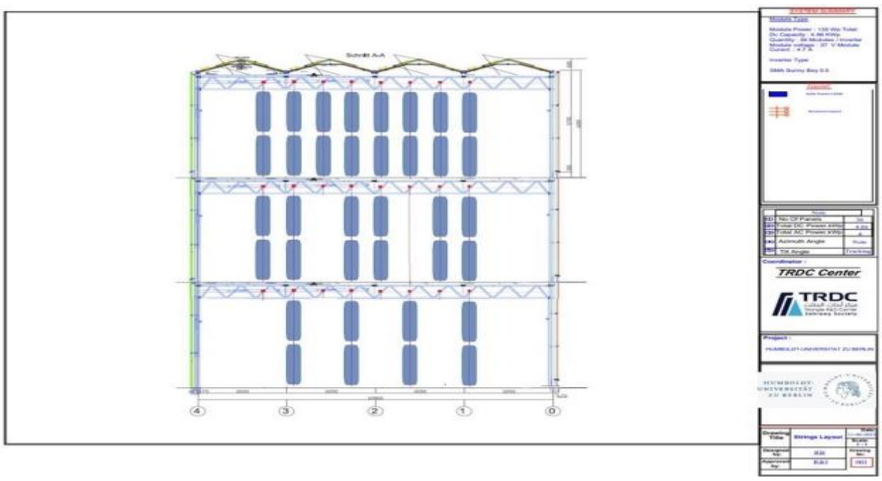

Figure 23 Distribution of photovoltaic modules at Humboldt University of Berlin

The figure above shows the distribution of photovoltaic modules within the greenhouse and highlights the complex installation process that was required due to the limited height and structural constraints in the upper section of the greenhouse.

The confined space imposed mechanical and logistical challenges during installation, particularly in aligning the module rails, actuator connections, and support frames without interfering with the existing greenhouse infrastructure such as ventilation ducts and shading systems.
To overcome these limitations, customized mounting brackets and adjustable fixtures were designed to ensure precise alignment and secure attachment of the modules while maintaining the required tilt and spacing for optimal solar performance. The installation process at this site demonstrates the adaptability of the TriSolar tracking system to diverse greenhouse geometries, ensuring both mechanical stability and efficient energy generation even under restricted vertical clearance conditions.

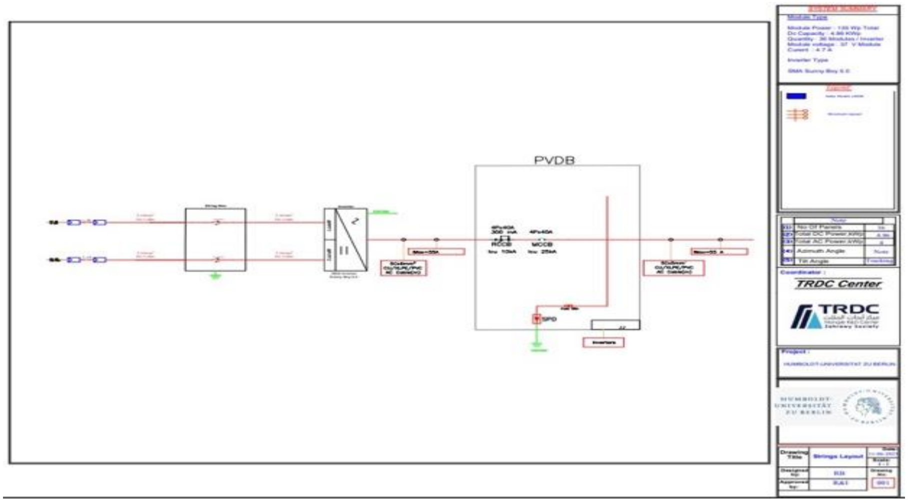

Figure 24 Electrical system design at Humboldt

The figure above illustrates the comprehensive electrical system design, encompassing both the DC and AC sections of the photovoltaic installation and their interconnection with the local power grid at HB site.

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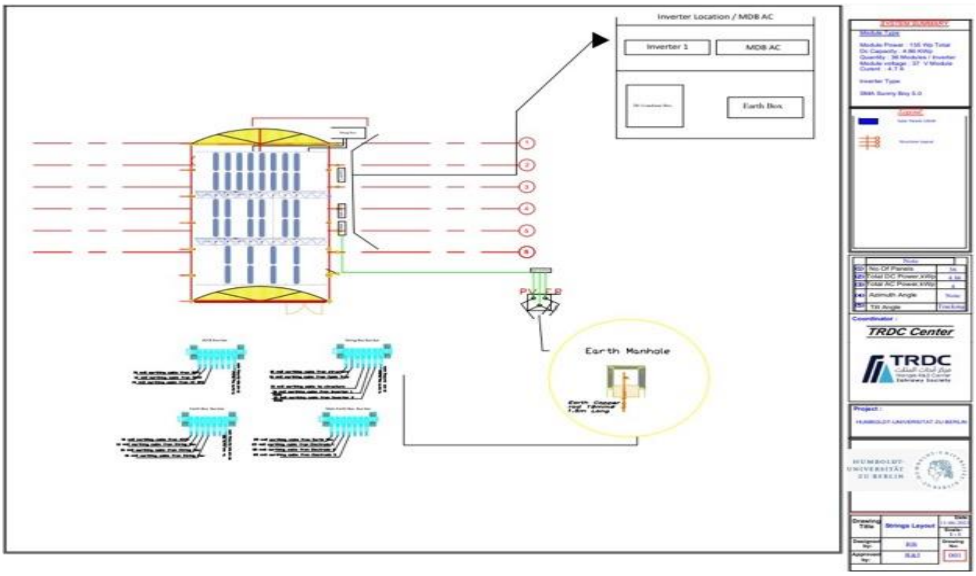

Figure 25 Interconnection and protection architecture at BOKU

The figure above represents the comprehensive electrical safety system design, detailing the AC interconnection and protection architecture for the photovoltaic installation at BOKU site.

4) University of Thessaly – standard polytunnel type research greenhouse

The PV system installed at the University of Thessaly (UTH) site consists of two independent subsystems, installed in two separate greenhouse compartments — one equipped with CO_2 enrichment and the other operating under standard atmospheric conditions. This dual-compartment configuration enables direct comparative analysis of crop performance, energy yield, and environmental parameters under differing agronomic scenarios.

Each subsystem was electrically identical in design, comprising 96 photovoltaic modules rated at 75 Wp each, resulting in a nominal DC output of 7.2 kWp per subsystem. Combined, the total DC system capacity reaches 14.4 kWp, covering approximately 35% of the greenhouse roof surface. This coverage ratio was carefully selected to balance light transmission for crops with maximized energy production and minimal thermal load.

The UTH installation serves as a key research platform within the REGACE project, providing valuable data on how PV integration and CO_2 enrichment jointly influence microclimate, photosynthetic activity (PAR), and crop productivity. Insights gained from this site contribute to refining AgriPV design principles for both research-oriented and commercial-scale greenhouse systems across Europe.

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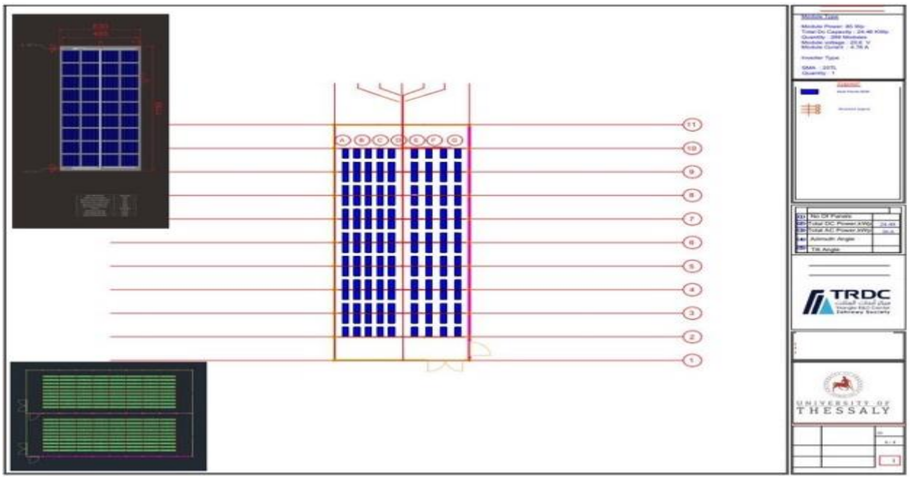

Figure 26 Module arrangement at UTH

The figure above indicates the modules arrangements in the roof of UTH greenhouse with two compartments.

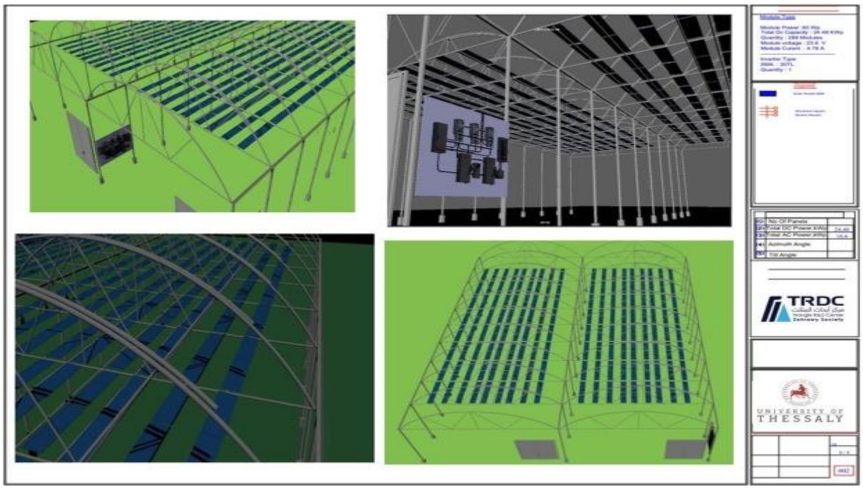

Figure 27 Sample 3D models of the BOKU structures

The figure above provides sample 3D models of the BOKU greenhouse structures integrated with the TriSolar dynamic tracking system.

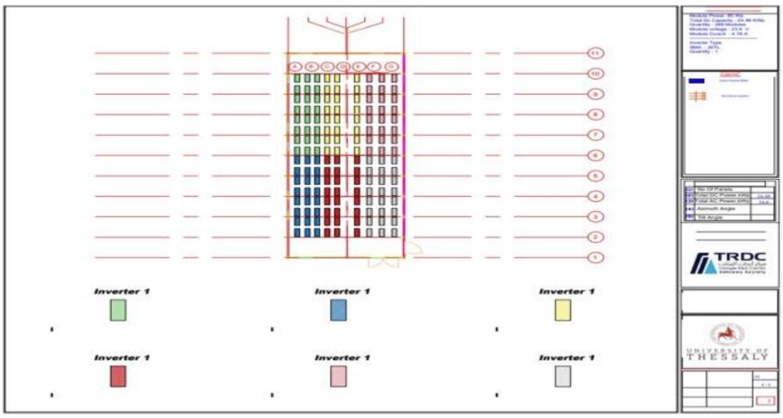

Figure 28 Schematic module string layout at UTH

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The figure above illustrates the schematic module string layout, illustrating the configuration that defines the operating voltage and current characteristics of the PV system installed at UTH site.

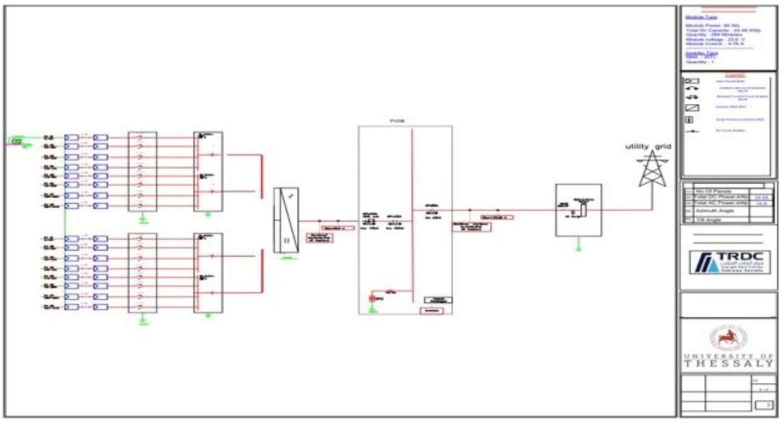

Figure 29 Electrical system design at UTH

The figure above represents the comprehensive electrical system design, encompassing both the DC and AC sections of the photovoltaic installation and their interconnection with the local power grid at the UTH site.

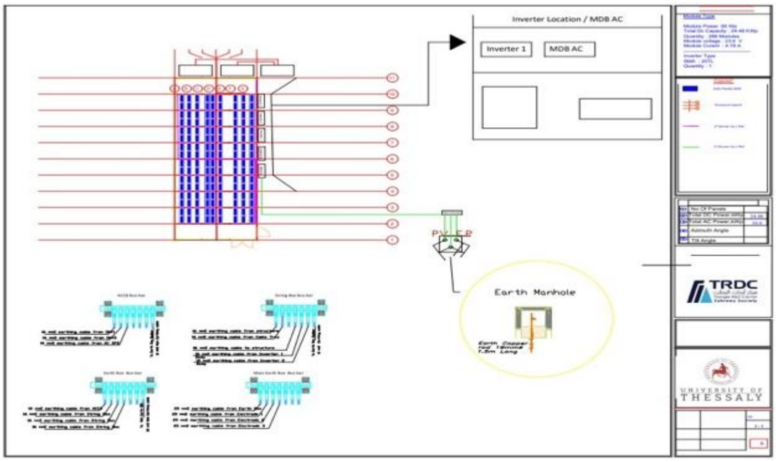

Figure 30 Interconnection and protection architecture at UTH

The figure above denotes the comprehensive electrical safety system design, detailing the AC interconnection and protection architecture for the photovoltaic installation at UTH site.

5) FSC - standard polytunnel type commercial greenhouse

The PV system installed at the FSC site consists of two independent subsystems, installed in two separate greenhouse compartments. This dual-compartment configuration enables direct comparative analysis of crop performance, energy yield, and environmental parameters under differing agronomic scenarios.

Each subsystem was electrically identical in design, comprising 32 photovoltaic modules rated at 85 Wp each, resulting in a nominal DC output of 2.72 kWp per subsystem. Combined, the total DC system capacity reaches 5.44 kWp, covering approximately 30% of the greenhouse roof surface. This coverage

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ratio was carefully selected to balance light transmission for crops with maximized energy production and minimal thermal load.

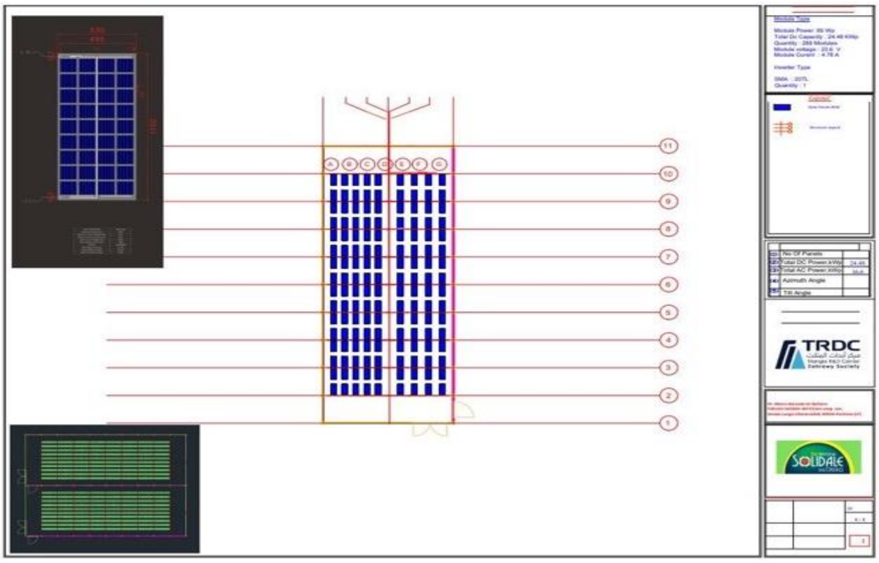

Figure 31 Module arrangement at FSC

The figure above shows the modules arrangements in the roof of FSC greenhouse with two compartments.

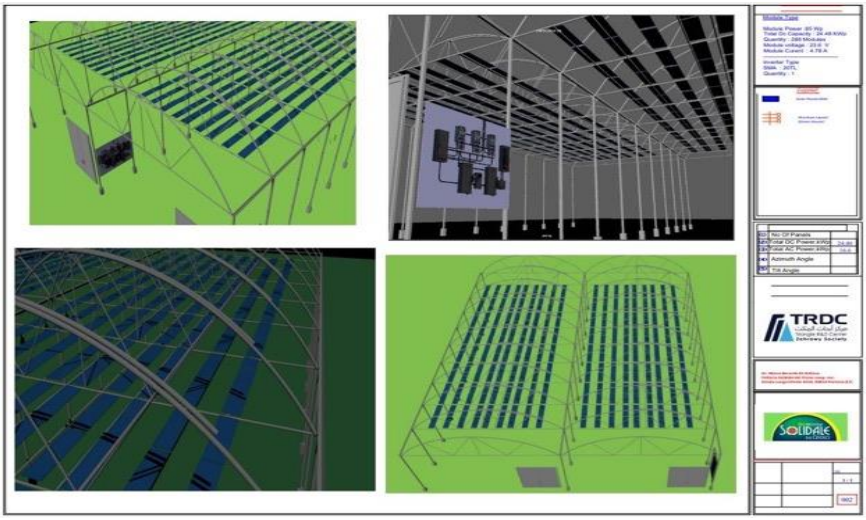

Figure 32 Sample 3D models of FSC greenhouse

The figure above illustrates sample 3D models of the FSC greenhouse structures integrated with the TriSolar dynamic tracking system.

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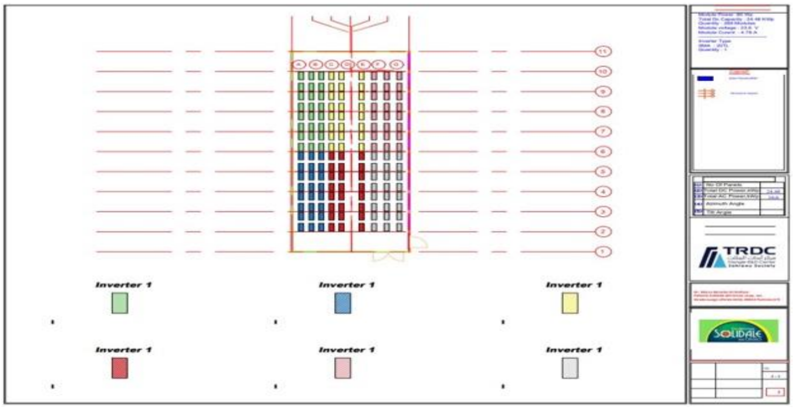

Figure 33 Schematic string layout at UTH

The figure above represents the schematic module string layout, illustrating the configuration that defines the operating voltage and current characteristics of the PV system installed at UTH site.

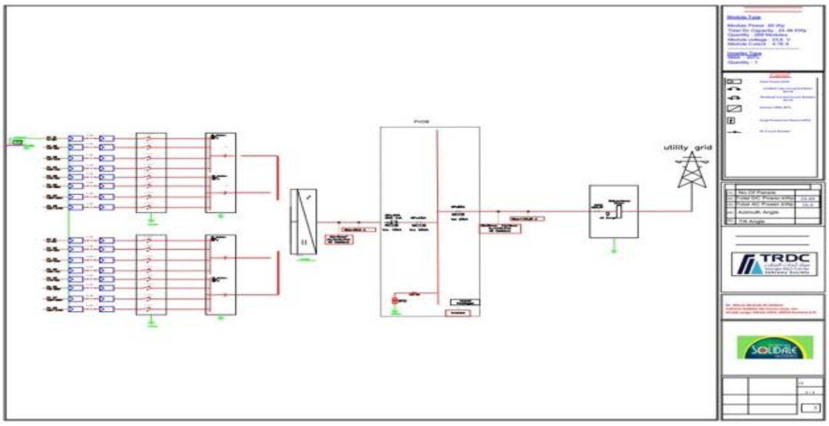

Figure 34 Electrical system design at FSC

The figure above illustrates the comprehensive electrical system design, encompassing both the DC and AC sections of the photovoltaic installation and their interconnection with the local power grid at FSC site.

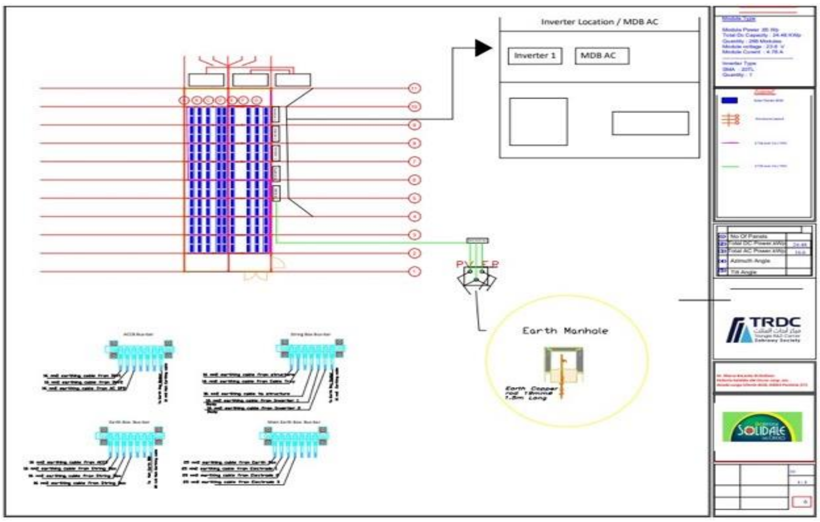

Figure 35 Electrical safety system design at FSC

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The figure above provides the comprehensive electrical safety system design, detailing the AC interconnection and protection architecture for the photovoltaic installation at FSC site.

6) Alzahrawy- research greenhouse

The PV system installed at Al-Zahrawy site consists of two independent subsystems, installed in two separate greenhouse compartments. This dual-compartment configuration with and without CO2 enrichment system, enables direct comparative analysis of crop performance, energy yield, and environmental parameters under differing agronomic scenarios.

Each subsystem was electrically identical in design, comprising 60 photovoltaic modules rated at 105 Wp each, resulting in a nominal DC output of 6.30 kWp per subsystem. Combined, the total DC system capacity reaches 12.60 kWp, covering approximately 29% of the greenhouse roof surface. This coverage ratio was carefully selected to balance light transmission for crops with maximized energy production and minimal thermal load.

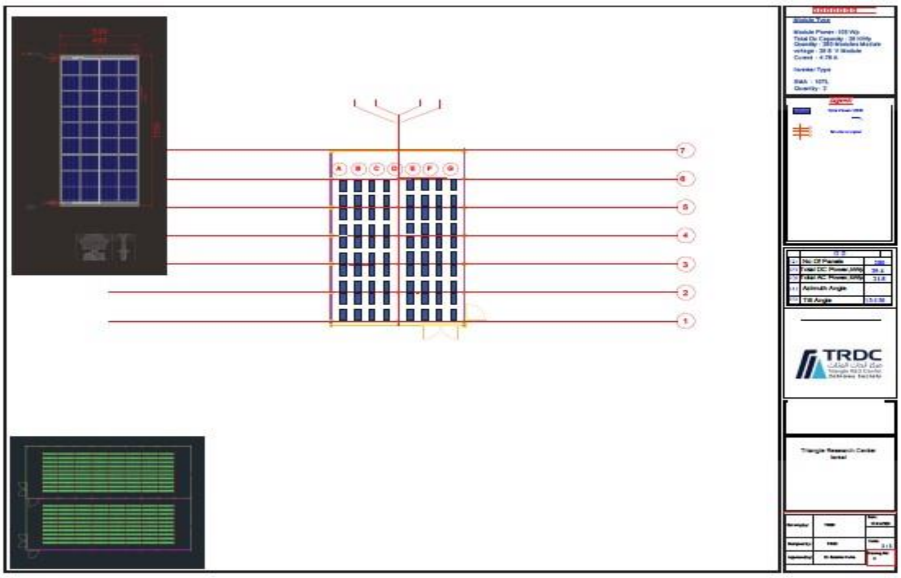

Figure 36 Module arrangement at the Alzahrawy greenhouses

The figure above shows the modules arrangements in the roof of Alzahrawy greenhouses with two sperate compartments.

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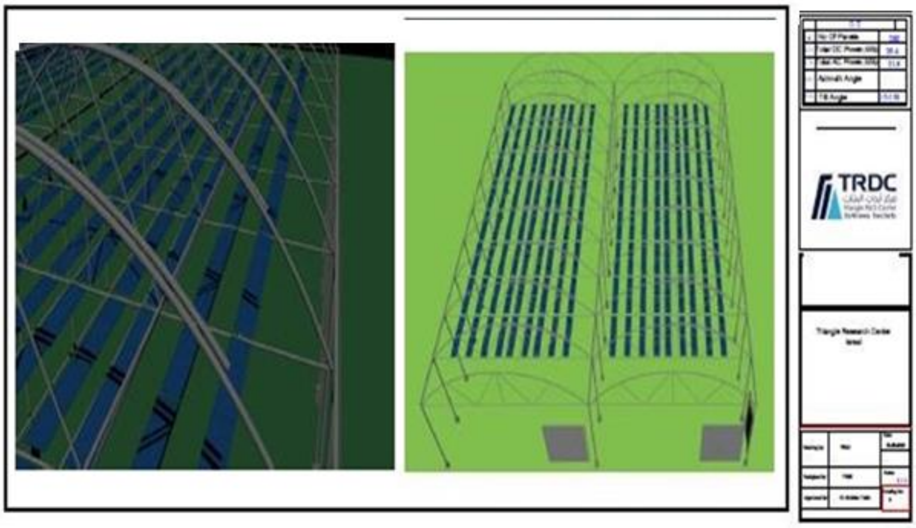

Figure 37 Sample 3D models of FSC greenhouse structures

The figure above illustrates sample 3D models of the FSC greenhouse structures integrated with the TriSolar dynamic tracking system at Alzahrawy site.

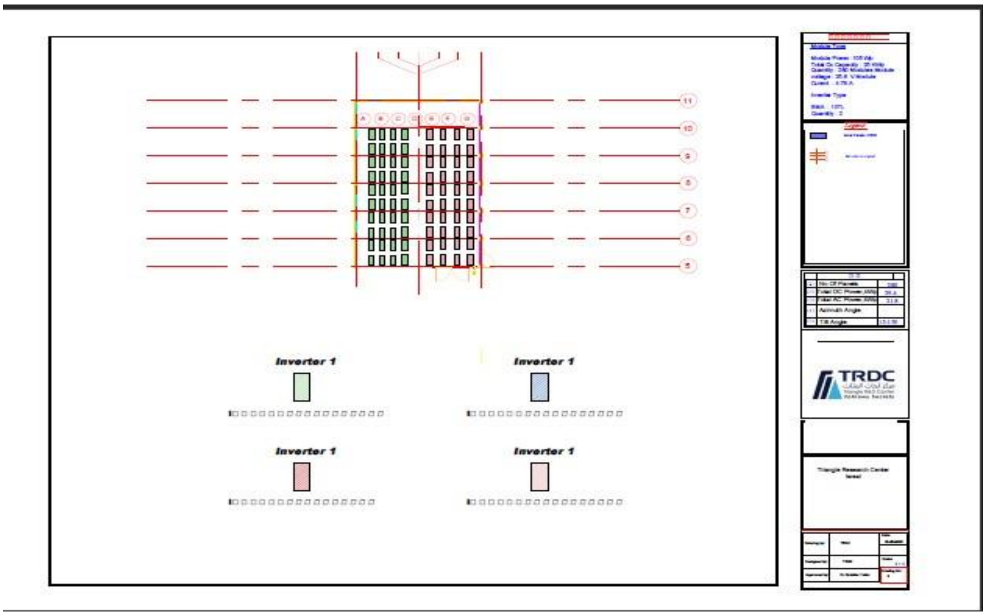

Figure 38 Schematic module string layout at Alzahrawy

The figure above provides the schematic module string layout, illustrating the configuration that defines the operating voltage and current characteristics of the PV system installed at Alzahrawy site.

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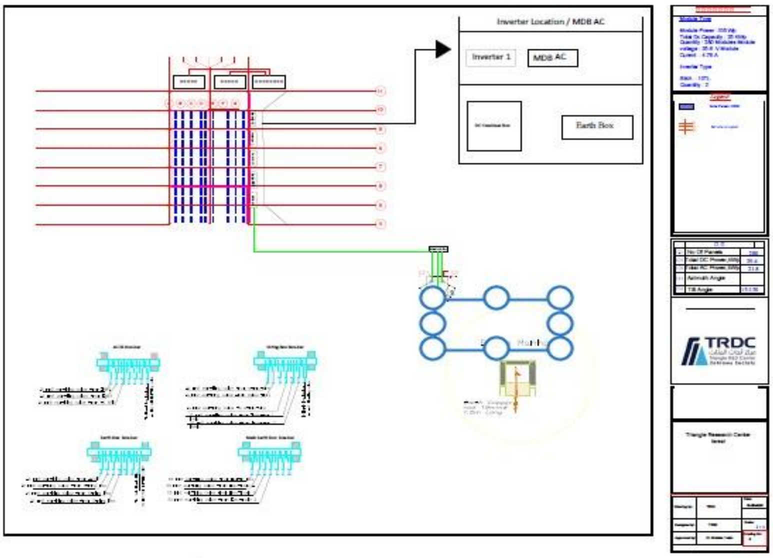

Figure 39 Electrical safety system design at Alzahrawy

The figure above represents the comprehensive electrical safety system design, detailing the AC interconnection and protection architecture for the photovoltaic installation at Alzahrawy site.

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5. Trisolar Tracking System Adaptation

The tracking system was carefully adapted and customized to enable seamless installation across the various REGACE pilot sites, each characterized by different greenhouse types, structural geometries, and environmental conditions. The mechanical configuration, actuator alignment, and mounting interfaces were adjusted for each location to ensure optimal compatibility, reliability, and performance within the constraints of the respective greenhouse frameworks.

To guarantee full compliance with European and national safety standards, the system underwent a series of mechanical stability, load-bearing, and operational safety tests. For this purpose, a specialized mechanical engineer was subcontracted to conduct **a** comprehensive review of the initial design, perform structural optimization, and validate the final adapted design through both analytical simulations and on-site testing.

This process ensured that the TriSolar dynamic tracking system meets all required mechanical, electrical, and occupational safety criteria, providing a robust, field-proven solution suitable for diverse greenhouse environments while maintaining the precision and efficiency required for agrivoltaic operation.

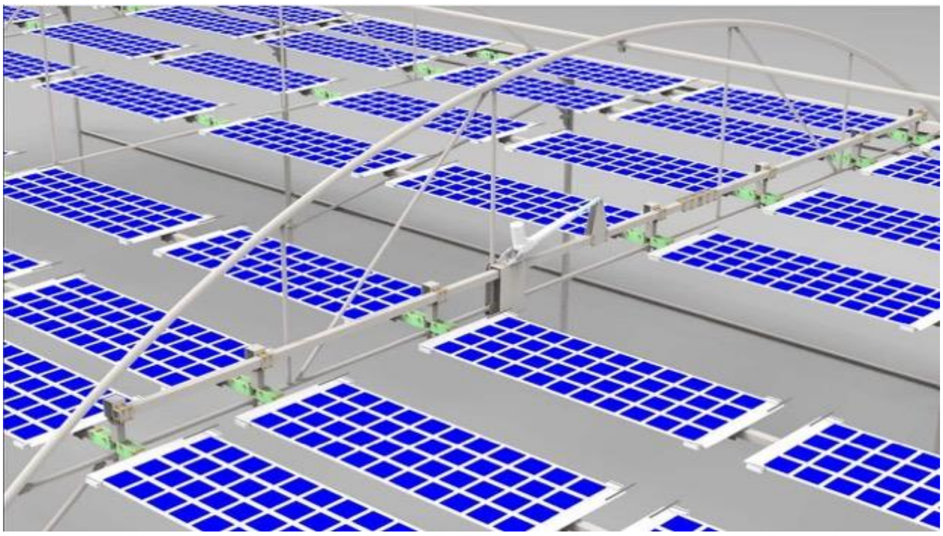

Figure 40 TriSolar dynamic tracking system

The figure above illustrates the design of the TriSolar dynamic tracking system, detailing the mechanical configuration and integration of all key components within the greenhouse structure.

For each system element, a comprehensive bill of materials (BOM) and a set of manufacturing drawings were prepared to ensure precise fabrication and assembly consistency across all REGACE sites. These include the panel holders, actuator units, drive beams, connecting joints, and support brackets, all engineered to meet the structural and environmental requirements of greenhouse installations.

The design process emphasized lightweight construction, corrosion resistance, and ease of on-site assembly, enabling efficient production and installation under varying greenhouse geometries. Each component underwent mechanical stress analysis and prototyping, ensuring reliable operation and long-term durability under real agricultural and climatic conditions.

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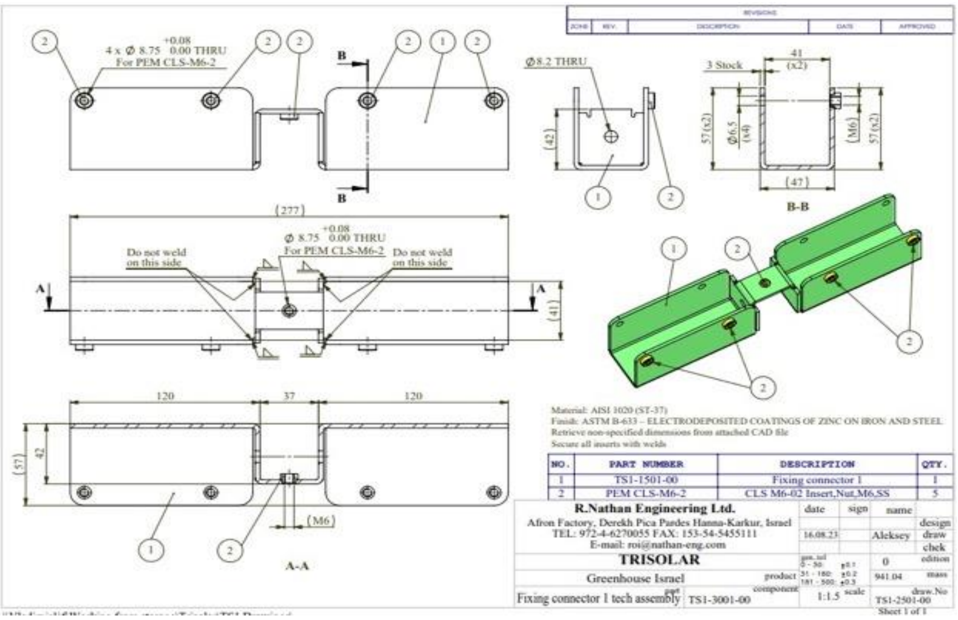

Figure 41 Example manufacturing drawing

The figure above illustrates an example of a manufacturing drawing for one of the mechanical system components—the *middle connector*, which is designed to securely hold the metal profile supporting the PV modules within the greenhouse structure.

This component represents a critical part of the TriSolar dynamic tracking system, ensuring both mechanical stability and precise alignment of the moving elements. The detailed technical drawing specifies the dimensions, material properties, tolerances, and connection interfaces, enabling accurate and repeatable fabrication across different manufacturing batches.

The design reflects TriSolar's engineering approach of combining robust mechanical performance with lightweight construction, allowing the connector to withstand dynamic loads generated during actuator movement while maintaining high structural integrity. Such detailed manufacturing documentation ensures consistent quality control and facilitates efficient assembly and maintenance across all REGACE greenhouse installations.

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5.1 Tracking System Component lists

The following figures designate the different components of the mechanical parts of the tracking system.

Main Picture	Serial Number	Separate Components Picture	Separate Components Name	Dimension	Production Process	Material
	TS1-2510-00		panel holder link	165•70•2 MM (Length•Width•Thickenes)	1-Press tapping 2-Bending machine 3-Bending&pressing 4-Riveting 5-Spray coating 6-Packing & transportation	SPCC steel
	TS1-1009-00		panel holder	493•64•8.0MM (Length•Width•Height)	Mold making 1-Extrusion processing 2-CNC machining 3-Material processing 4-Surface treatment/Long material oxidation 5-Packaging & transportation	6063-T5 Aluminum
			panel clamp (bottom part)	60•34.55•8.5MM (Length•Width•Height)		6063-T5 Aluminum
			panel clamp (top part)	60•65•8.5MM (Length•Width•Height)		6063-T5 Aluminum
			panel holder's siclicone cushion		Mold making 1-Extrusion processing 2-Material processing 3-Surface treatment 4-Packaging & transportation	silica gel
			panel Clamp's siclicone cushion			silica gel
			Bolt M6x13 (without cap)			304 stainless steel
			Bolt M5x16 (without cap)			304 stainless steel
			Bolt M6x60 (without cap)			304 stainless steel

Figure 42 Panel holder components

The figure above shows the list of the panel holder components.

Main Picture	Serial Number	Separate Components Picture	Separate Components Name	Dimension	Production Process	Material
	TS1-2503-00		fixing connector (2pcs CLS-M6-2)	250•165•3 MM (Length•Width•Thickenes)	1-Press tapping 2-Bending&pressing 3-Riveting 4-Spray coating 5-Packing & transportation	SPCC steel
	TS1-2502-00		holder (2pcs CLS-M6-2)	135•90•3MM (Length•Width•Thickenes)	1-Press tapping 2-Bending&pressing 3-Riveting 4-Spray coating 5-Packing & transportation	SPCC steel
	TS1-1001-00		spacer		CNC	304 stainless steel
	MCM-12-03		igus dry clamp bearing plastic			Iglidur™ M250 plastic
	DIN 912		Bolt M6x60 (without cap)			stainless steel
	DIN 912		Bolt M8x65 (without cap)			

Figure 43 End fixing connector components

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The figure above provides the list of the end fixing connector components.

Main Picture	Serial Number	Separate Components Picture	Separate Components Name	Dimension	Production Process	Material
	TS1-2501-00		fixing connector (5pcs CLS-M6-2)	365×165×3 MM (Length×Width×Thickenes)	1-Press tapping 2-Bending&pressing 3-Riveting 4-Spray coating 5-Packing & transportation	SPCC steel
	TS1-2502-00		bottom holder (2pcs CLS-M6-2)	135×90×3MM (Length×Width×Thickenes)	1-Press tapping 2-Bending&pressing 3-Riveting 4-Spray coating 5-Packing & transportation	SPCC steel
	TS1-1504-00		crank 1	168×142×3MM (Length×Width×Thickenes)	1-Press tapping 2-Bending&pressing 3-Riveting 4-Spray coating 5-Packing & transportation	SPCC steel
	TS1-2505-00		Drive beam ear (4pcs CLS-M6-2)	275×70×3MM (Length×Width×Thickenes)	1-Press tapping 2-Bending machine 3-Bending&pressing 4-Riveting 5-Spray coating 6-Packing & transportation	SPCC steel
	TS1-1508-00		Drive beam clamp plate	96×74×3MM (Length×Width×Thickenes)	1-Press tapping 2-Spray coating 3-Packing & transportation	SPCC steel
	TS1-1001-00		spacer	60×34.55×8.5MM (Length×Width×Height)	CNC	304 stainless steel
	MCM-12-03		igus dry clamp bearing			iglidur™ M250 plastic
	DIN 912		Bolt M6x60 (without cap)			
	DIN 912		Bolt M8x65 (without cap)			
	DIN 912		Bolt M8x80 (without cap)			
			Bolt M6x16 (without cap)			
			Bolt M6x45 (without cap)			Stainless Steel

Figure 44 Actuator fixing connector components

The figure above lists the actuator fixing connector components.

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Main Picture	Serial Number	Separate Components Picture	Separate Components Name	Dimension	Production Process	Material
	TS1-2501-00		fixing connector (5pcs CLS-M6-2)	365*165*3 MM (Length*Width*Thickenes)	1-Press tapping 2-Bending&pressing 3-Riveting 4-Spray coating 5-Packing & transportation	SPCC steel
	TS1-2502-00		holder (2pcs CLS-M6-2)	135*90*3MM (Length*Width*Thickenes)	1-Press tapping 2-Bending&pressing 3-Riveting 4-Spray coating 5-Packing & transportation	SPCC steel
	TS1-1001-00		spacer	60*34.55*8.5MM (Length*Width*Height)		304 stainless steel
	MCM-12-03		igus dry clamp bearing Model:MCM-12-03			Iglidur™ M250 plastic
	DIN 912		Bolt M6x60 (without cap)			304 stainless steel
	DIN 912		Bolt M8x65 (without cap)			304 stainless steel

Figure 45 Middle fixing connector components

The figure above shows the list of the middle fixing connector components.

Main Picture	Serial Number	Separate Components Picture	Separate Components Name	Dimension	Production Process	Material
	TS1-1506-00		Drive beam link plate 2	310*80*3 MM (Length*Width*Thickenes)	1-Press tapping 2-Spray coating 3-Packing & transportation	SPCC steel
	TS1-2504-00		Drive beam link plate	310*80*3 MM (Length*Width*Thickenes)	1-Press tapping 2-Bending&pressing 3-Riveting 4-Spray coating 5-Packing & transportation	SPCC steel
	DIN 912		Bolt M6x60(without cap)			304 Stainless Steel

Figure 46 Drive beam link plate components

The figure above provides the list of the drive beam link plate components.

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Main Picture	Serial Number	Separate Components Picture	Separate Components Name	Dimension	Production Process	Material
	TS1-2505-00		Drive beam ear (4pcs CLS-M6-2)	275*70*3MM (Length*Width*Thickenes)	1-Press tapping 2-Bending&pressing 3-Riveting 4-Spray coating 5-Packing & transportation	SPCC steel
	TS1-1508-00		Drive beam clamp plate	96*74*3MM (Length*Width*Thickenes)	1-Press tapping 2-Spray coating 3-Packing & transportation	SPCC steel
	DIN 912		Bolt M6x60(without cap)			304 Stainless Steel

Figure 47 Drive beam ear components

The figure above lists the drive beam ear components.

Main Picture	Serial Number	Separate Components Picture	Separate Components Name	Dimension	Production Process	Material
	TS1-2511-00		Drive beam ear 3 tech assembly (4pcs CLS-M6-2)	265*130*3 MM (Length*Width*Thickenes)	1-Press tapping 2-Bending&pressing 3-Riveting 4-Spray coating 5-Packing & transportation	SPCC steel
	TS1-1518-00		Drive beam ear 31	135*90*3MM (Length*Width*Thickenes)	1-Press tapping 2-Bending&pressing 3-Spray coating 4-Packing & transportation	SPCC steel
	TS1-1012-00		Actuator spacer 1			POM
	MCM-12-03		igus dry clamp bearing plastic			
	TS1-1011-00		Actuator axle 1		CNC	304 Stainless Steel
			Flat Washer			304 Stainless Steel
			Bolt M6x60(without cap)			304 Stainless Steel

Figure 48 Drive beam system

The figure above shows the drive beam system.

Main Picture	Serial Number	Separate Components Name	Dimension	Production Process	Material
	TS1-2509-00	Fixed fork tech assembly (2pcs CLS-M6-2)	95*65*2 MM (Length*Width*Thickenes)	1-Press tapping 2-Bending&pressing 3-Riveting 4-Spray coating 5-Packing & transportation	SPCC steel

Figure 49 Fixed fork components

The figure above depicts the drive beam system fixed fork components.

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5.2 Component testing (Revised and Expanded Version)

7) *Samples representing multiple design iterations of the key mechanical components were manufactured and rigorously tested through a combination of laboratory simulations and field experiments. The objective of this testing phase was to validate the mechanical integrity, operational reliability, and environmental resilience of each part under real-world agrivoltaic conditions.*

8) *The testing campaign was designed to systematically optimize the geometry, material composition, and assembly interfaces of components such as the actuator joints, panel holders, drive beams, and connector brackets. By refining these parameters, the TriSolar engineering team ensured that the final design achieved maximum stability with minimum structural weight, facilitating easier installation and reduced maintenance requirements.*

9) *Comprehensive evaluations included:*

- *Static and dynamic load tests to verify resistance to bending and torsional stress;*
- *Fatigue and cyclic motion simulations to assess long-term mechanical endurance during continuous daily tracking;*
- *Corrosion and UV resistance testing, replicating the humid and high-irradiance conditions typical of greenhouse environments; and*
- *Field validation trials to confirm assembly precision and interaction between components under operational loads.*

10) *Following these iterative improvements, the final component versions were produced and are now undergoing on-site validation at the REGACE pilot facilities. These final trials focus on confirming operational safety, actuator synchronization accuracy, vibration stability, and structural reliability prior to large-scale implementation across all REGACE testing sites.*


Figure 50 Samples of first-generation mechanical components

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The figure above presents samples of the first-generation mechanical components developed for the TriSolar dynamic tracking system. These prototype elements were produced during the initial design phase to validate manufacturing feasibility, dimensional accuracy, and assembly compatibility within the greenhouse structure.

The first version included early models of actuator connectors, drive beam fixers, and panel holder assemblies, fabricated using the initially proposed aluminum alloy profiles and joint configurations. Visual inspection and mechanical testing of these components revealed several areas for optimization, including reinforcement of stress points, reduction of overall weight, and improvement of the assembly interfaces to facilitate faster on-site installation.

The insights gained from this prototype series played a crucial role in guiding the second design iteration, leading to enhanced structural performance, mechanical stability, and operational precision in the final version of the tracking system now deployed at the REGACE pilot sites.

5.3 Software System Adaptation

The control system and software platform were specifically adapted and optimized by TriSolar to meet the operational and research requirements of the REGACE project. The software serves as the central intelligence of the dynamic tracking system, managing real-time actuator movements, monitoring environmental inputs, and ensuring coordinated operation between the photovoltaic modules and the greenhouse climate-control systems.

The current version of the software incorporates automated solar tracking algorithms, designed to adjust panel tilt angles based on solar position, crop light requirements, and greenhouse shading dynamics. These algorithms are enhanced with feedback loops from irradiance and temperature sensors, allowing dynamic fine-tuning of the tracking behavior to maximize both energy generation and crop photosynthetic efficiency.

The system design is being continuously expanded to accommodate the different greenhouse typologies used across REGACE sites—ranging from Venlo-type glasshouses to polytunnel structures—each requiring unique calibration parameters. In addition, the next software update will integrate the CO_2 enrichment control interface, enabling synchronized regulation of light, energy, and CO_2 concentration to support optimal crop growth conditions.

Ultimately, the software adaptation ensures that the TriSolar system operates as a fully integrated AgriPV platform, combining renewable energy management with precision-controlled agricultural processes in line with REGACE's multidisciplinary objectives.

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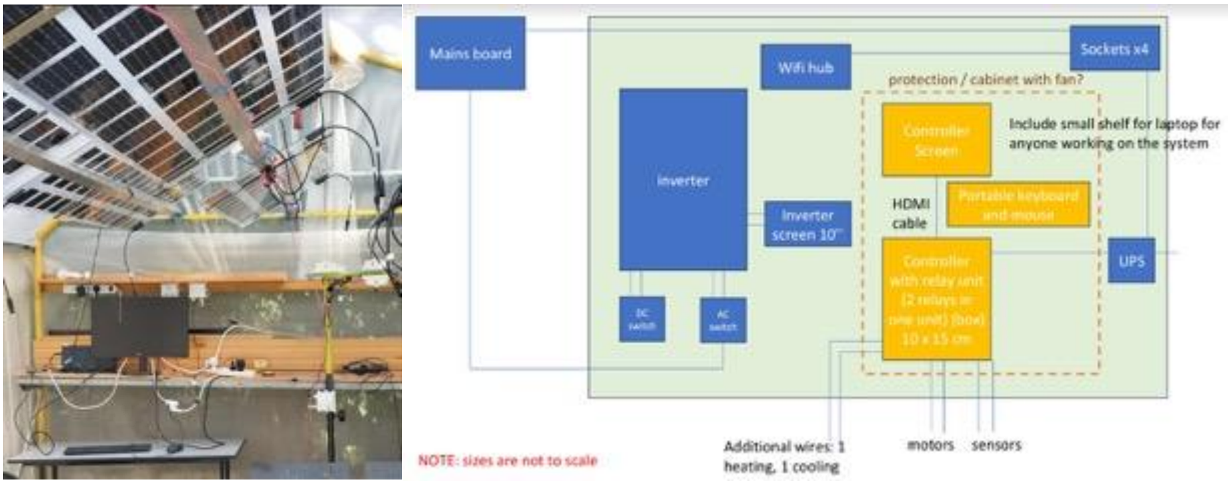

Figure 51 Software design and testing framework

The figure above illustrates the software design and testing framework developed for the TriSolar dynamic tracking system within the REGACE project. The diagram outlines the interaction between the hardware components (actuators, sensors, inverters, and control units) and the software layers responsible for data acquisition, processing, and real-time decision-making.

The software architecture is composed of several integrated modules, including the tracking algorithm, safety and fault-detection system, data logging and visualization interface, and remote monitoring dashboard. Each module was subjected to rigorous testing and validation, both in simulated laboratory conditions and during field deployment at the pilot greenhouses. Testing procedures included verification of communication protocols (Modbus, RS485, and IoT-based systems), calibration of sensor inputs for irradiance, temperature, and actuator position, and performance evaluation of the automatic shading and light-optimization routines. This systematic testing ensures stable, responsive, and safe operation of the tracking system under varying environmental conditions. The results confirm that the TriSolar control software is capable of synchronizing mechanical motion with environmental feedback, achieving high reliability and precision required for agrivoltaic integration within greenhouse environments.

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6. Installation Guide

To facilitate the installation of the REGACE systems across the different pilot locations, a comprehensive TriSolar System Installation Guide was developed. This guide provides a standardized framework and step-by-step methodology for assembling and commissioning the dynamic PV tracking systems within diverse greenhouse structures and environmental conditions.

The installation manual was prepared to ensure consistency, safety, and quality control across all partner sites while allowing necessary adjustments to accommodate local construction practices and greenhouse typologies. It includes detailed procedures for mechanical assembly, electrical wiring, actuator alignment, and system calibration, along with safety instructions and maintenance recommendations.

While the following sections summarize the main installation phases, they do not include all the technical drawings, torque specifications, and electrical schematics provided to certified installers. It is strictly mandatory that all installation activities comply with national and local regulatory frameworks, as well as applicable European safety standards (IEC, EN, and national equivalents).

Adherence to these protocols ensures that every REGACE installation achieves optimal operational safety, mechanical stability, and electrical performance, supporting the long-term reliability of the TriSolar AgriPV systems deployed within the project.

TriSolar System

Installation Guide for Installers

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This guide provides a detailed, step-by-step instruction manual for the installation of the TriSolar Responsive Tracking System, developed and implemented within the REGACE project. It is designed to assist installation teams in correctly assembling and commissioning the system inside greenhouse environments while maintaining full compliance with safety and regulatory standards.

The following list outlines the main system components to be installed in sequence, each accompanied by dedicated procedures and visual references in the complete manual:

1. Solar Panels (PV Modules) – customized bifacial modules designed for greenhouse integration.
2. Panel Holders – structural fixtures securing the PV modules to the supporting rail system.
3. Panel Rails – longitudinal profiles connecting multiple panels and distributing mechanical loads evenly.
4. Middle Connectors – components linking adjacent panel rails, ensuring alignment and structural rigidity.
5. Side Connectors – end fixtures anchoring the panel rows to the greenhouse structure.
6. Actuator Connectors – mechanical interfaces linking the actuators to the moving panel arrays.
7. Actuator Rails – motion-guiding elements that transfer actuator movement to the drive beams.
8. Drive Beam Fixers – components connecting the actuator rail to the drive beam for synchronized motion.
9. Drive Link Plates – coupling plates that transmit mechanical motion between adjacent rows.
10. Actuator Units – electromechanical devices controlling the tilt and orientation of the PV modules.
11. Fixed Forks – stabilizing elements that maintain alignment and restrict excessive lateral movement.

Each component must be assembled and aligned precisely according to the project-specific 3D design drawings and engineering specifications. Proper installation of these parts ensures the accurate motion tracking, mechanical stability, and long-term reliability of the TriSolar system across all REGACE greenhouse sites.

Item No.	Item Name	Image
1	Solar Panel	
2	Panel Holder	
3	Panel Rail	

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4	Middle connector	
5	Side connector	
6	Actuator connector	
7	Actuator Rail 	
8	Drive Beam fixer	
9	Drive link plate	
10	Actuator Unit	
11	Fixed fork 	

Figure 52 List of system components to be installed

The figure above provides the list of system components to be installed step by step.

Step -1 – Panel holder installation
(complete on the ground)

1x item no 1 (panel)	2x item no 2 (panel holder)
	

Figure 53 solar module and aluminum holders

The figure above shows the solar module with the two aluminum holders.

Step 1 – Installation of the Panel Holder

Begin by installing the panel holders approximately 5 cm from each edge of the photovoltaic panel to ensure correct weight distribution and secure attachment during operation.

1. **Loosen** the bolt located on one side of the panel holder.
2. **Insert** the PV panel carefully into the holder slot, ensuring the panel frame is fully seated and aligned.

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3. **Retighten** the bolt firmly to secure the holder in place. Use a torque wrench as specified in the technical manual to prevent over-tightening or slippage.
4. **Repeat** this procedure for all panels that will be integrated into the system.

Proper positioning of the panel holders is essential to maintain mechanical stability, prevent torsion during tracking movement, and ensure uniform load transfer along the mounting rail. Verifying alignment at this stage facilitates accurate assembly in subsequent installation steps.

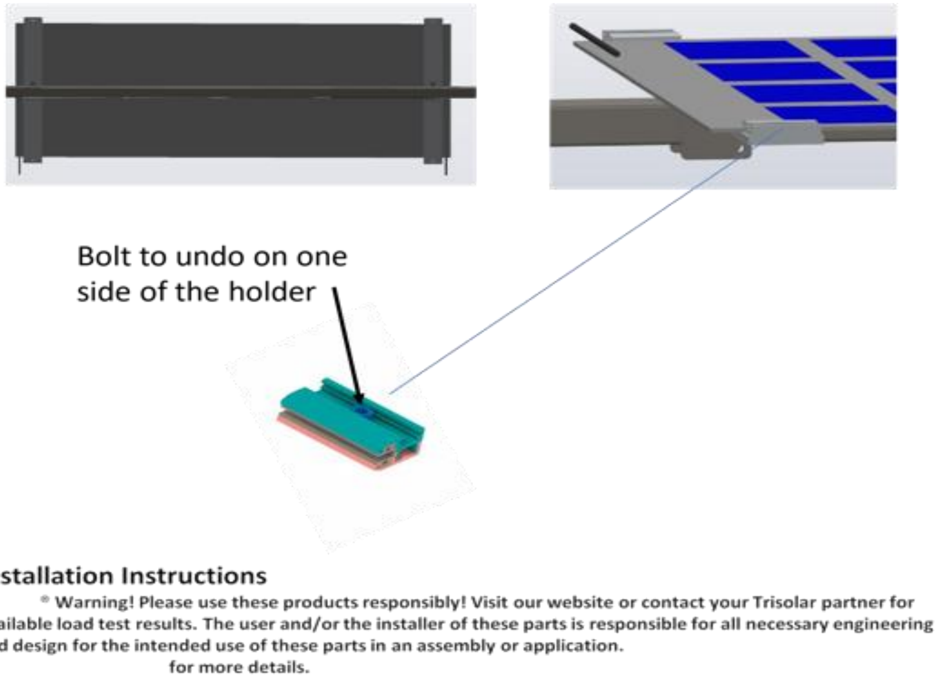

Figure 54 Connection of the module holders

The figure above depicts the connection of the module holders with the metal profile.

Step -2 – Panel to rail installation (complete on the ground)

2x panel with fitted holders	1x panel rail (item no. 3)

(The length of the rail depends on the project greenhouse and the number of holes in the rail is determined by the solar module type used)

Figure 55 Module with the metal rail

The figure above shows installing the module with the metal rail.

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Step 2 – Fixing the Panel Elements to the Panel Rail

To assemble the panel units onto the supporting rail, follow the procedure below carefully to ensure correct positioning and secure mechanical attachment:

1. Loosen and remove the M6 bolts from the panel fixer elements.

2. Position the panel fixer elements along the panel rail, maintaining a minimum clearance of 15 cm between the edge of the PV panel and the end of the rail on both sides. This spacing is critical to allow for thermal expansion, actuator motion, and structural flexibility.

3. Reinsert the M6 bolts into the panel fixer elements and tighten them securely using the appropriate torque setting as defined in the installation manual. Ensure all bolts are evenly fastened to prevent uneven loading or misalignment.

4. Repeat this process for each rail segment required for the project, confirming consistent spacing and alignment across all module rows.

Proper installation of the panel fixers ensures stable module positioning, minimizes vibration during actuator movement, and contributes to the long-term mechanical integrity of the TriSolar tracking system.

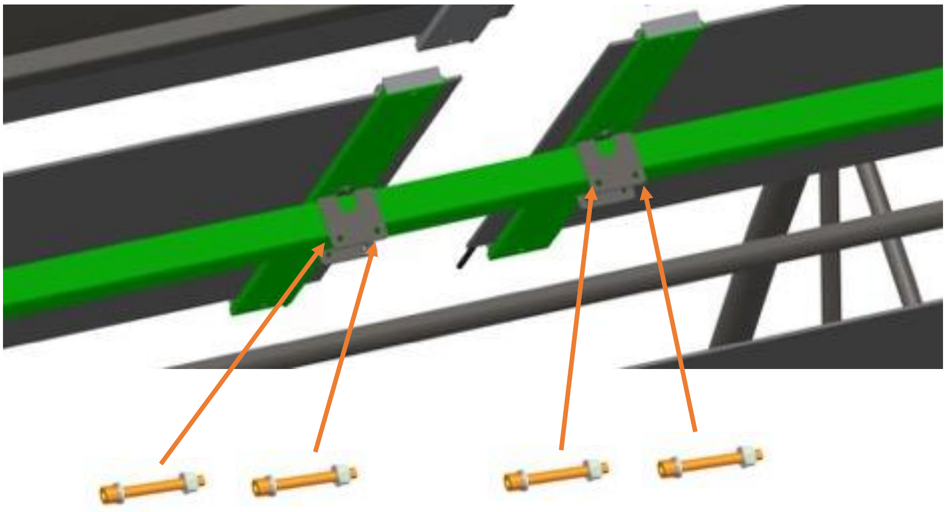

Figure 56 Fixing of panel elements

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The figure above illustrates the fixing of panel elements to the panel rail.

Installation Instructions

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Step -3 – Connector fixing to greenhouse structure (complete at height inside the greenhouse)

side connector (5)	actuator connector (6)	middle connector (4)

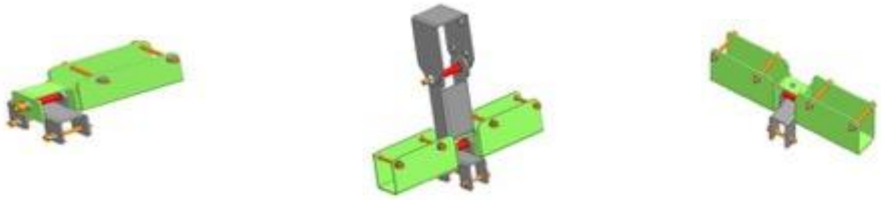

Figure 57 Connectors and motor holder

The figure above shows the middle, side connector and the motor holder.

Step 3 – Installing the Connectors to the Greenhouse Structure

Before beginning this step, consult the specific system design drawings for your project to determine the exact number and positioning of each connector type inside the greenhouse.

- Side connectors are typically installed at each end of the system.
- Actuator connectors are positioned along the row containing the actuator rail.
- Middle connectors are used in all remaining intermediate positions of the system.

Follow the installation procedure below:

- Loosen and remove the M8 bolts from the connector elements.
- Position each connector according to the project-specific layout drawings. To ensure precise alignment across all rows, use a laser level or laser alignment device before fastening.
- Once aligned, reinsert and tighten the M8 bolts securely to attach the connectors to the greenhouse structure. Confirm that each connector sits flush and firmly against the structural frame without gaps or tilting.
- Repeat this process for all connectors required in the system, checking alignment consistency along the entire installation row.

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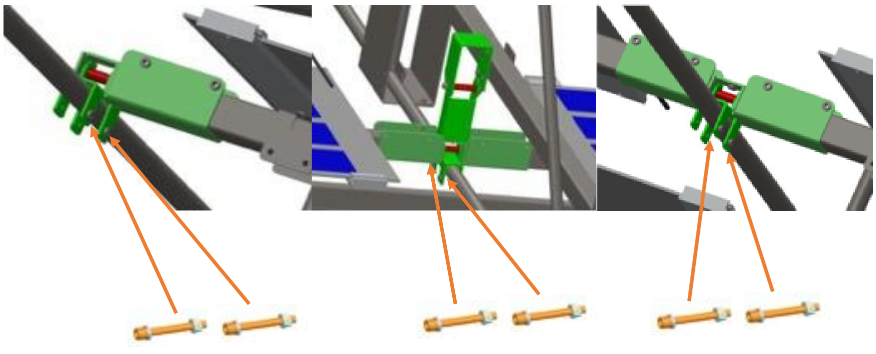
Accurate placement and alignment of the connectors are critical to maintaining mechanical balance, smooth actuator motion, and uniform load distribution throughout the TriSolar responsive tracking system.



Installation Instructions

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Figure 58 Connectors to greenhouse structure

The figure above illustrates the installation of the connectors to the greenhouse structure.

Step -4 – Mounting of panel rails inside the greenhouse (complete at height inside the greenhouse)

Panel rails with panels

This step involves lifting and securing the assembled panel rails (with mounted PV panels) into position within the greenhouse structure. Proceed carefully and follow proper safety procedures when working at height.

1. Loosen and remove the M8 bolts from the panel connector elements that were previously installed on the greenhouse frame.
2. Lift the panel rails, with the PV panels already mounted, into position. Ensure that both ends of each rail are properly seated inside the connector elements. Use mechanical lifting equipment if necessary to maintain safety and prevent panel damage.
3. Reinsert and tighten the M8 bolts to firmly secure each rail within its connector. Verify that the rails are level and aligned with the reference lines or laser alignment used during connector installation.
4. Repeat this procedure for all panel rails included in the project, ensuring consistent alignment and structural stability across the entire system.

Proper and precise mounting of the panel rails is essential for maintaining system integrity, smooth actuator movement, and optimal solar tracking performance of the TriSolar dynamic greenhouse installation.

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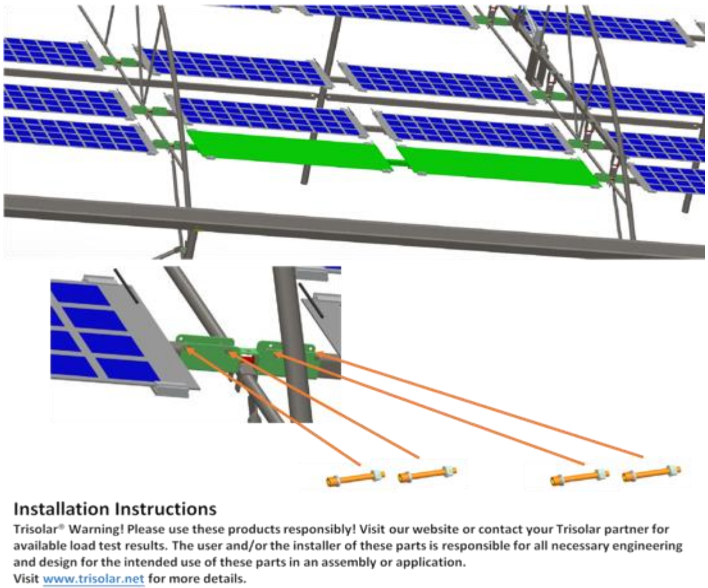

Figure 59 Securing the assembled panel rails

The figure above depicts how to secure the assembled panel rails (with mounted PV panels) into position within the greenhouse structure.

Step -5 – Mounting of the actuator unit inside the greenhouse (complete at height inside the greenhouse)

Actuator unit (item no 10)

Figure 60 Mounted actuator part

The figure above shows the actuator part mounted on the GH profile structure.

Mounting of Panel Rails Inside the Greenhouse

(To be completed at height inside the greenhouse)

This step involves lifting and securing the assembled panel rails (with mounted PV panels) into position within the greenhouse structure. Proceed carefully and follow proper safety procedures when working at height.

1. Loosen and remove the M8 bolts from the panel connector elements that were previously installed on the greenhouse frame.

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2. Lift the panel rails, with the PV panels already mounted, into position. Ensure that both ends of each rail are properly seated inside the connector elements. Use mechanical lifting equipment if necessary to maintain safety and prevent panel damage.
3. Reinsert and tighten the M8 bolts to firmly secure each rail within its connector. Verify that the rails are level and aligned with the reference lines or laser alignment used during connector installation.
4. Repeat this procedure for all panel rails included in the project, ensuring consistent alignment and structural stability across the entire system.
5.

Proper and precise mounting of the panel rails is essential for maintaining system integrity, smooth actuator movement, and optimal solar tracking performance of the TriSolar dynamic greenhouse installation.

Step 4 – Mounting the Panel Rails Inside the Greenhouse

(To be completed at height inside the greenhouse)

This operation installs the **assembled panel rails—already fitted with PV modules—**onto the greenhouse frame. Work only with approved lifting and safety equipment.

1. Loosen and remove the *M8 bolts* from the panel-connector elements attached to the greenhouse structure.
2. Lift each panel rail carefully so that both ends are seated inside the connector elements. Use mechanical hoists or scaffolding to avoid stress on the modules.
3. Reinsert and tighten the M8 bolts to secure the rail within the connectors. Check that each rail is level and aligned with the installation reference lines or laser alignment system.
4. Repeat for all panel rails until the entire row assembly is complete.

Accurate installation and alignment of the panel rails are vital for maintaining mechanical stability, proper load distribution, and smooth tracking motion of the TriSolar responsive system.

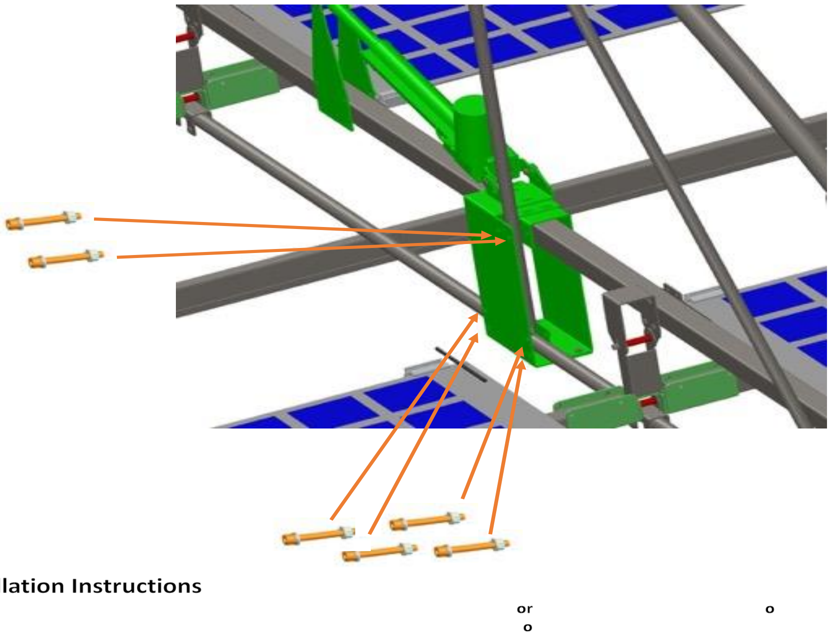

Figure 61 Mounting of panel rails in greenhouse

The figure above illustrates the mounting of panel rails inside the greenhouse.

Step -6 – alignment of panels before installing the actuator rail (complete at height inside the greenhouse)

Fixed forks (item no 11)

Figure 62 Fixed forks

The figure above shows the fixed forks structure.

Step 5 – Alignment of Panel Rails Before Actuator Installation
(To be completed at height inside the greenhouse)
Before connecting the actuator rail, it is essential to ensure that all panel rails are perfectly aligned and leveled to guarantee smooth motion and proper mechanical synchronization of the tracking system.

1. Insert the fixed forks onto each actuator connector installed along the actuator rail line.
2. Use the fixed forks to stabilize and align the panel rails, ensuring that every rail is positioned in a horizontal orientation (tilt angle = 0°).
3. Verify alignment along the entire row using a laser level or spirit level to confirm uniform height and parallelism between all rails.
4. Make minor adjustments if necessary to eliminate deviations before proceeding to the actuator rail installation.

This alignment step is critical for achieving accurate actuator motion, uniform panel tracking angles, and long-term mechanical stability of the TriSolar system inside the greenhouse.

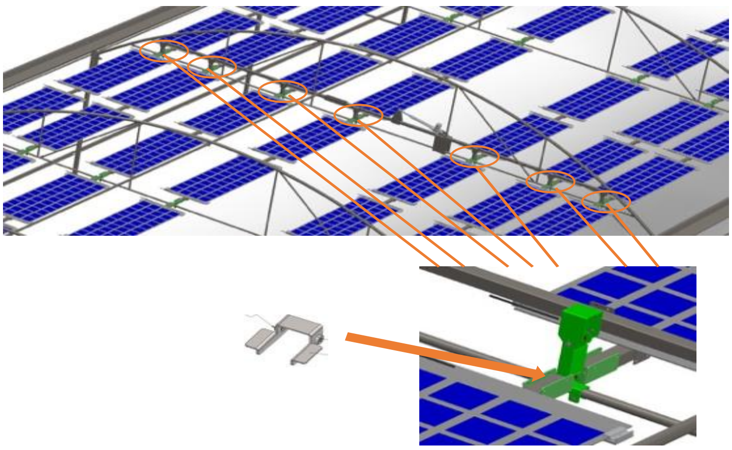

Figure 63 Actuator motion and panel tracking

The figure above illustrates the accurate actuator motion with uniform panel tracking angles.

Step -7 – installing the actuator rail (complete at height inside the greenhouse)

2x actuator rails (item no 7) drive beam fixers (item no 8) drive link plate (item no 9)

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Figure 64 Rail parts and drive beam fixers

The figure above depicts the connecting rail parts with the drive beam fixers.

Slide the first **rail** through the actuator unit as shown below.

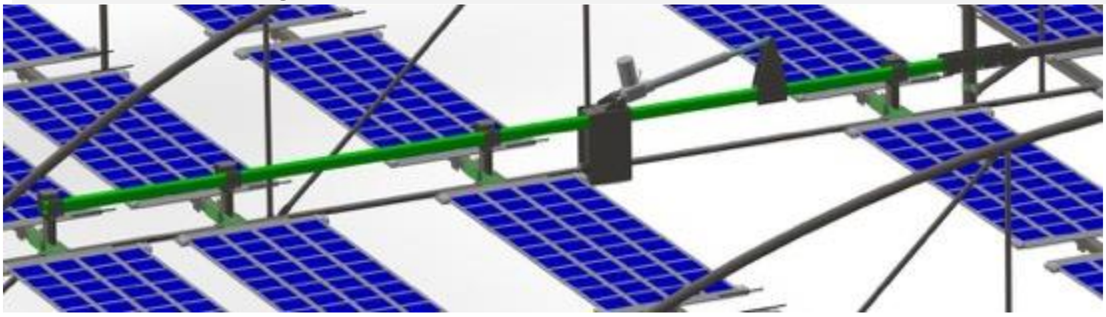

Figure 65 Rail connection to actuator

The figure above shows the connection of the rail to the actuator.

Connect the **drive beam fixer plates** and the actuator ears to the actuator rail, by undoing and reconnecting the relevant bolts as shown below.

Step -8 – installing the actuator rail (complete at height inside the greenhouse)

Place the second actuator rail into position and fasten using the drive beam fixers as shown above. Then connect to the first rail using the drive link plate.

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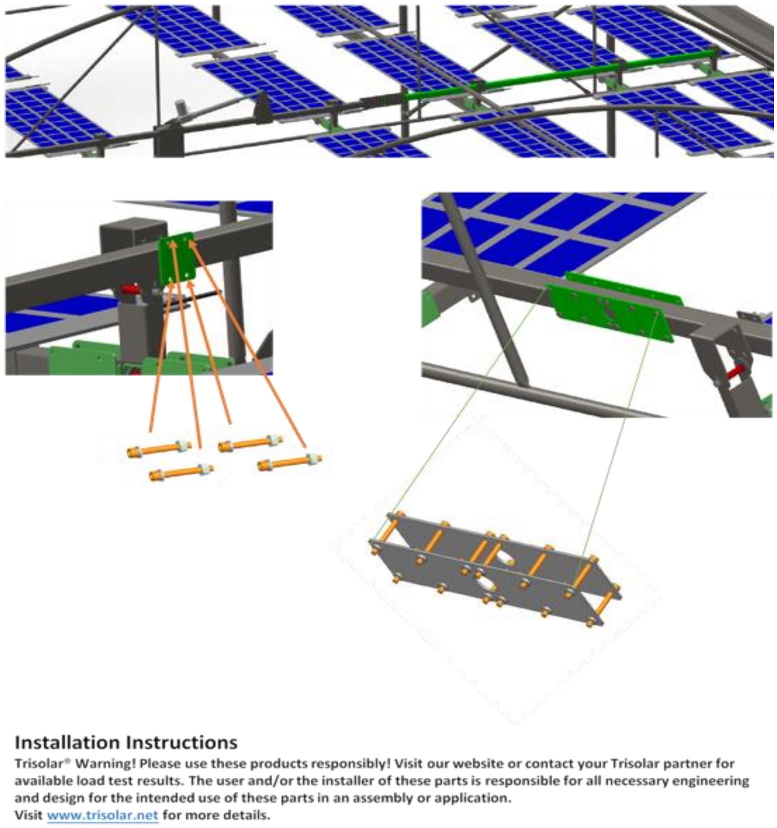

Figure 66 Final step of installation

The figure above illustrates the final step to complete the installation the system.

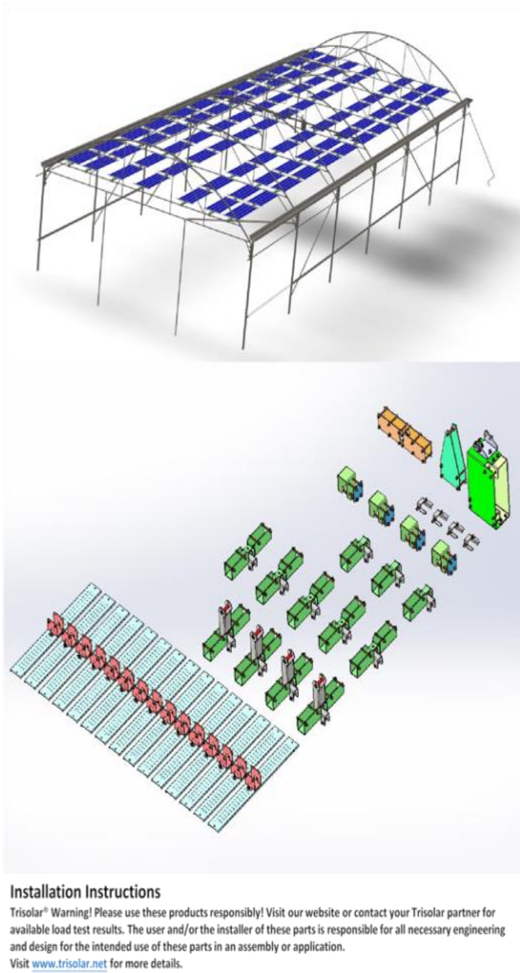

Figure 67 Final installed system

The figure above illustrates the installed system inside the greenhouse with all the components.

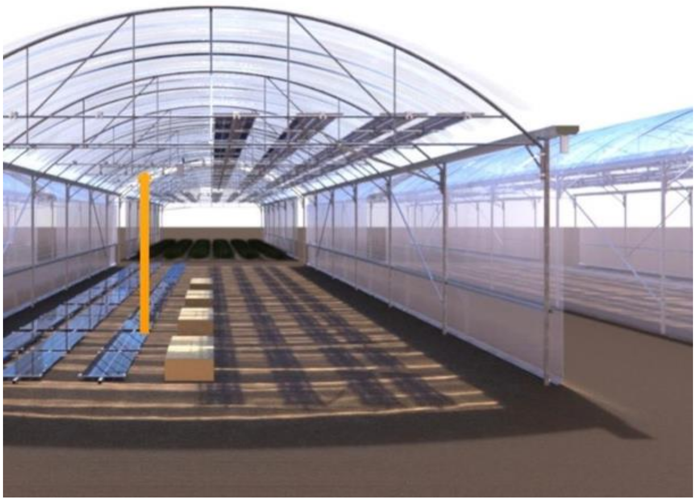

Figure 68 Final installed system inside view

The figure above depicts the PV system after complete installation inside the greenhouse.

7. Conclusion

This report has presented the comprehensive design, optimization, and installation guidelines developed for the REGACE Responsive Greenhouse Agrivoltaics System (AgriPV)—a pioneering integration of solar energy and greenhouse cultivation tailored to diverse structural types and climatic conditions across Europe and Israel.

By systematically addressing the mechanical and electrical design of solar modules, system configuration and layout, tracking mechanism adaptation, and stringent regulatory and safety frameworks, the REGACE consortium ensures the deployment of safe, efficient, and agronomically compatible AgriPV solutions. These solutions not only enhance renewable energy generation but also maintain, and in many cases improve, crop productivity and environmental balance within the greenhouse ecosystem.

The custom-engineered bifacial PV panels and TriSolar dynamic tracking system underwent rigorous laboratory and field testing to validate their structural reliability, energy performance, and long-term durability. The resulting design represents a highly adaptive and modular technology capable of functioning effectively across different greenhouse geometries, agricultural practices, and regulatory contexts.

The installation guide included in this deliverable provides clear, step-by-step procedures ensuring standardized, safe, and efficient deployment across all REGACE pilot sites. It supports installers, researchers, and policymakers in replicating the system under real agricultural conditions with consistency and precision.

Looking ahead, these guidelines provide a solid foundation for large-scale implementation and replication of the REGACE system. Continuous monitoring, data collection, and performance feedback from the operational pilot sites will drive iterative improvements, reinforcing the project's contribution to the European Green Deal and to the advancement of sustainable agriculture integrated with renewable energy production.

In conclusion, the REGACE project demonstrates a transformative model for future AgriPV systems, harmonizing energy generation, food production, and environmental stewardship—a crucial step toward achieving climate-resilient and resource-efficient farming across Europe.

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