REGACE – Crop Responsive Greenhouse Agrivoltaics System with CO2 Enrichment for Higher Yields

Project Deliverable Report

DELIVERABLE 2.3 - FINAL DESIGN AND INSTALLATION GUIDELINES

WORK PACKAGE NUMBER: WP2

WORK PACKAGE TITLE: IMPLEMENTATION

TYPE: REPORT

AUTHORS: DR. HANI BARHUM, PROF. IBRAHIM YEHIA

REGACE Action Information	
Action full title	Responsive Greenhouse Agrivoltaics System with CO2 Enrichment for Higher Yields
Action acronym	REGACE
Grant agreement number	101096056
Project Officer	Maria Laura Trifiletti
Project coordinator	Prof. Ibrahim Yehia
Project start date and duration	1 February 2023, 36 months
Project website	https://regaceproject.com/

Deliverable Information	
Work package number	**2**
Work package title	**Implementation**
Deliverable number	**D2.3**
Deliverable title	**Final Design and Installation Guidelines**
Description	**Greenhouse specific adapted tracker design and installation guidelines for polytunnel and glass greenhouse types. Final Design and Installation Guidelines updated following the implementation and demos of the systems and the studies performed.**
Lead beneficiary	**TriSolar**
Lead Author(s)	**Dr. Hani Barhum, Prof. Ibrahim Yehia**
Contributor(s)	**Prof. Ibrahim Yehia**
Revision number	**3.0**
Revision Date	**2026/01/31**
Status (Final (F), Draft (D), Revised Draft (RV))	**F – Final**
Dissemination level (Public (PU), Restricted to other program participants (PP), Restricted to group specified by consortium (RE), Confidential for consortium members only (CO))	**PU - Public**

Document History

Revision	**Date**	**Modification**	**Author**
1.0	2023/09/30	Initial version of D2.1 for submission	Esther Magadley
2.0	2025/03/31	Revised version including new Chapter 2	Ibrahim Yehia
3.0	2026/01/31	Final version of D2.3 for submission	Ibrahim Yehia

Approvals

	Name	**Organisation**	**Date**	**Signature (initials)**
Coordinator	Prof. Ibrahim Yehia	Alzahrawy Society	2026/01/31	IY
WP Leader	Dr. Hani Barhoum	TriSolar	2026/01/31	HB

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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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Executive Summary

This deliverable presents the final design and installation guidelines of the REGACE greenhouse-integrated agrivoltaic system, developed, implemented and validated following multi-site deployment and long-term operation.

Deliverable 2.3 consolidates the transition from initial design assumptions (as documented in D2.1) to final, field-validated guidelines based on real structural, regulatory and operational constraints encountered across pilot installations in Europe and Israel.

The REGACE system is a suspended, internal agrivoltaic solution installed inside greenhouse structures, combining lightweight bifacial PV modules with a dynamic tracking mechanism and an autonomous control platform. By leveraging existing greenhouse infrastructure as the load-bearing backbone, REGACE enables dual use of agricultural infrastructure for crop production and renewable electricity generation while minimizing additional material use and land occupation.

A key outcome is the provision of a validated, step-by-step Installation Guide (Chapter 4), including mandatory pre-installation structural assessment, mechanical and electrical installation sequences, commissioning and acceptance procedures, and safety requirements.

Structural assessment emerged as critical for retrofit sites. At the Volos pilot site (Greece), load calculations identified the need for localized structural reinforcement prior to system installation to ensure full compliance with greenhouse safety regulations. Reinforcement was implemented proactively and the system subsequently operated without structural limitations.

Operational experience exceeding one year across pilot sites demonstrated stable system behavior and no mechanical or electrical malfunctions affecting safety or greenhouse operations. Occasional interruptions in internet connectivity were observed at some sites and were attributable to local network infrastructure; these did not affect system safety or core operational functionality, as REGACE control functions operate autonomously and data communication resumes automatically once connectivity is restored.

Maintenance requirements were minimal. Routine PV module cleaning was identified as the primary recurring task and can be integrated into standard greenhouse maintenance workflows. End-user feedback confirms non-intrusive integration into daily operations and perceived system maturity; crop yield performance remains the primary driver for commercial uptake, supporting the relevance of crop-specific light management strategies embedded in REGACE control philosophy.

Deliverable 2.3 concludes that the REGACE system has reached a high level of technical maturity and operational readiness for replication and wider deployment, subject to site-specific adaptation and external conditions (regulation and grid connection).

1. Introduction

This implementation work package of REGACE addresses the practical implementation of a greenhouse-integrated agrivoltaic (AV) system, covering system design, adaptation to diverse greenhouse typologies, installation under real operational constraints, and validation through long-term operation.

Greenhouse agrivoltaics differs fundamentally from open-field PV and rooftop PV. In greenhouses, light is a production input that directly impacts yield and quality; microclimate stability and daily farm workflows must be preserved. Therefore, any PV integration must prioritize agronomic performance, operational safety and structural integrity.

Deliverable D2.1 documented the initial design and installation concepts developed prior to full-scale deployment. However, first-of-a-kind systems require iterative refinement when confronted with variability in greenhouse geometry, structural conditions, national regulations, and site logistics. This deliverable documents these refinements and provides final, field-validated guidelines.

This deliverable is intended as a replication-oriented reference for system integrators, greenhouse designers, engineering consultants, project developers and regulators. It consolidates: (i) the final REGACE system configuration, (ii) validated installation and commissioning procedures, (iii) safety and operational best practices, and (iv) lessons learned and replicability guidance for future deployment.

1.1 Objectives and Scope

The objectives are to:

- Present the final REGACE system architecture and key design principles.
- Provide a validated Installation Guide suitable for replication (Chapter 4).
- Define mandatory pre-installation steps, including structural assessment and permitting coordination.
- Consolidate safety and operational best practices derived from implementation experience.
- Document lessons learned and provide a deployment roadmap for future sites.

1.2 Relationship to Other Project Outputs

Deliverable 2.3 builds on D2.1 (initial design and installation guidance) and integrates implementation experience from all deployments. It also aligns with end-user assessment activities and safety best-practice documentation produced during the project. Where detailed site performance data are reported in other deliverables, this deliverable focuses on final design decisions and deployment guidance.

2. Final REGACE System Architecture

2.1 System Concept and Rationale

The REGACE system is a greenhouse-integrated agrivoltaic solution based on a lightweight, suspended PV tracking structure installed inside the greenhouse envelope. PV modules and tracking elements are attached to greenhouse structural members, using the greenhouse frame as the primary load-bearing backbone.

This architecture was selected to (i) minimize additional land occupation, (ii) avoid external wind-exposed rooftop structures, (iii) reduce balance-of-system material, and (iv) enable controlled light management at crop level. The internal suspended configuration enables precise control of shading patterns and light homogeneity, both critical in greenhouse production.

2.2 Photovoltaic Subsystem

REGACE employs lightweight bifacial photovoltaic (PV) modules engineered for greenhouse integration, where energy generation must coexist with strict agronomic constraints. Bifacial technology supports harvesting from both direct and diffuse radiation and can benefit from greenhouse-specific optical conditions (e.g., higher diffuse fractions and internal reflections), provided that the layout preserves adequate crop-level photosynthetically active radiation (PAR).

A key design requirement is to tune module geometry and layout to the crop's light needs. Therefore, module row pitch, inter-row spacing, and the resulting shading fraction were defined per site in coordination with greenhouse operators and research partners. The target was to maintain homogeneous crop-level light distribution while achieving meaningful electrical yield. Across REGACE deployments, the effective shading associated with the PV layout was managed so that it did not exceed 35% at any pilot site, in line with research requirements and crop-light constraints.

Module format, spacing, and mounting details are adapted per site to align with greenhouse geometry (bay spacing, truss locations, headroom), internal equipment density, and clearance constraints. Optical and geometric design focuses on balancing: (i) annual energy production, (ii) adequate crop light transmission, and (iii) spatial homogeneity of transmitted light to avoid localized over-shading. These adaptations are verified during commissioning through clearance checks and, where applicable, analysis of irradiance measurements at crop level.

To support maintainability and safe operation in agricultural environments, the PV subsystem also incorporates practical design features such as protected cable interfaces, connector positioning away from irrigation lines and direct water jets, and layout zoning that simplifies string identification and future maintenance.

2.3 Tracking and Mechanical Subsystem

A core feature of REGACE is the dynamic tracking mechanism enabling controlled adjustment of module tilt within the greenhouse envelope. Unlike conventional PV trackers optimized solely for energy yield, REGACE tracking balances multiple objectives: (i) electrical energy yield, (ii) crop light exposure and homogeneity, and (iii) operational constraints such as ventilation, shading-screen movement, maintenance access, and safe worker circulation.

Mechanical design priorities include robustness and simplicity: limited moving parts, standardized actuator interfaces, and tolerance to greenhouse humidity, temperature cycles, and agricultural aerosols. Materials and coatings are selected to mitigate corrosion risks. The suspended layout supports modular installation "zones" that can be installed, commissioned, and serviced with minimal disruption to crop operations.

Tracking motion is implemented within defined mechanical boundaries (end-stops, allowable tilt range, and clearance envelopes). Operational modes include normal autonomous operation, conservative modes (e.g., during operational restrictions), and maintenance modes that place the tracker in a safe, serviceable position. These choices support predictable behavior and straightforward troubleshooting for installers and operators.

During installation and commissioning, tracking movement and clearances are verified across the full angular range to ensure safe coexistence with agricultural activities and greenhouse utilities. Particular attention is given to collision risks with internal equipment and avoidance of interference with irrigation lines, ventilation windows, and shading screens.

2.4 Control and Monitoring Philosophy

The REGACE control system integrates irradiance, environmental, and operational signals to compute tracking actions and manage system behavior. The control philosophy is crop-aware and supports strategies aligned with crop-specific targets such as Daily Light Integral (DLI), while maintaining stable electrical operation and respecting greenhouse operational constraints.

The control architecture is built around three principles: (i) autonomous local operation, (ii) safety and constraint enforcement, and (iii) monitoring for performance and maintainability.

Autonomous local operation: core functionality is designed to operate locally and safely without reliance on continuous internet connectivity. Local decision-making and predefined operational rules ensure that tracking control and safe states remain available even when remote communication is interrupted.

Safety and constraint enforcement: control logic applies boundary conditions that prioritize safe operation and compatibility with greenhouse functions. Constraints include defined motion limits, safe-stop behaviors, and, where required, operational interlocks (e.g., maintenance windows). This ensures that tracking actions remain within mechanically safe ranges and do not interfere with greenhouse infrastructure or routine agricultural work.

Monitoring for performance and maintainability: monitoring provides visibility into tracker status, sensor readings, alarms, and system states. Remote monitoring supports oversight and troubleshooting but is not required for safe operation. When communication interruptions occur, the impact is primarily limited to remote data availability, and communication is restored automatically once connectivity returns.

To support both research evaluation and operational robustness, the control layer is designed for stable restart behavior after power cycling events or temporary communication interruptions. Where applicable, buffered data can be synchronized after connectivity returns.

Transition to electrical concept: crop-aware control and autonomous behavior depend on a robust electrical foundation that ensures safe power generation and protection layering in a humid agricultural environment. The next section therefore presents the electrical architecture and safety concept that enable rapid shutdown, fault isolation, grounding, and surge protection.

2.5 Electrical Architecture and Safety Concept

Electrical architecture uses string configurations adapted per site. Module-level power electronics (MLPE) provide rapid shutdown capability, fault isolation and improved safety for maintenance.

Standard safety elements include proper grounding and equipotential bonding, surge protective devices (SPD), cable protection and routing measures, and labeling/signage suitable for agricultural environments.

Electrical design and installation must comply with applicable IEC standards and national electrical codes, as well as site-specific grid connection requirements.

2.6 Summary of Subsystems and Design Intent

This section provides a consolidated overview of the main REGACE subsystems and their associated design intent. Table No. 1 summary highlights how each subsystem contributes to greenhouse-integrated operation, balancing energy generation, agronomic requirements, and safety considerations. The table below is intended as a high-level reference that complements the detailed descriptions presented in Sections 2.1–2.5, supporting reviewer clarity and deployment-oriented understanding of the overall system architecture.

Table No. 1 summary highlights subsystem contributes to greenhouse-integrated operation, balancing energy generation, agronomic requirements, and safety considerations.

Subsystem	Primary function	Design intent / notes
PV modules	Energy generation within greenhouse	Lightweight bifacial modules; site-adapted formats; balance energy and crop light.
Tracking mechanism	Dynamic tilt control	Robust suspended design; manages energy vs agronomy; verified clearances.
Control & sensors	Crop-aware tracking control	Autonomous operation; supports DLI-based strategies; resilient to connectivity disruptions.
Electrical BOS	Safe power conversion and protection	String architecture with MLPE; rapid shutdown; grounding and SPD; compliant with codes.

Together, these subsystems form a coherent, greenhouse-adapted agrivoltaic solution in which structural integration, electrical safety, and crop-aware control are addressed in a coordinated manner. While the functional role of each subsystem remains consistent across deployments, their physical configuration and interface details are adapted to reflect site-specific greenhouse typologies, regulatory conditions, and operational constraints. This modular yet integrated design approach underpins the replicability of the REGACE system and provides the technical basis for the site-adaptation and installation guidelines presented in the following chapters.

3. Design Adaptation to Greenhouse Types

3.1 Greenhouse Typologies Addressed

REGACE was deployed across representative greenhouse typologies to validate the adaptation of the suspended tracking system and its installation methodology for both polytunnel (plastic-covered) and glass greenhouse environments. The primary typologies addressed include Venlo-type glass greenhouses and polytunnel greenhouses, as well as selected research and hybrid greenhouse configurations that reflect non-standard layouts and increased internal infrastructure density.

Each greenhouse typology presents distinct structural and operational constraints, including differences in roof geometry, member spacing, available headroom, internal equipment density, and permissible attachment interfaces. These parameters directly influence tracker integration, including allowable module dimensions, row spacing, attachment concepts, cable routing paths, and the definition of a safe tracking movement envelope. Consequently, the REGACE tracker design and installation layout are adapted on a site-specific basis through a structured pre-installation assessment, ensuring compatibility with both the physical greenhouse structure and ongoing agricultural or research operations.

Experience from multiple locations demonstrated that internal greenhouse infrastructure can be a governing constraint, particularly in research-oriented glass greenhouses where shading screens, experimental instrumentation, and heavy equipment occupy significant internal volume. In such cases, tracker geometry and module formats were adapted to maintain required safety clearances and regulatory compliance. For example, at the Hebrew University research greenhouse, reduced module widths (approximately 35 cm) were designed and manufactured to accommodate internal shading systems and research equipment. Similar structural and layout-driven adaptations were required at the BOKU greenhouse facilities in Vienna. These examples confirm that site-specific adaptation of tracker geometry and module format is an integral component of greenhouse agrivoltaic deployment rather than an exception.

Across all greenhouse types and locations, REGACE maintained a consistent core system architecture and safety philosophy: a suspended in-greenhouse tracking concept, standardized mechanical and electrical safety measures, and a validated installation and commissioning procedure. This approach ensures that, despite necessary site-specific adaptations, tracker installation remains compliant with local safety and regulatory requirements while enabling safe, repeatable deployment in both polytunnel and glass greenhouse environments.

3.2 Structural Integration Principles

The REGACE suspended architecture transfers system loads to existing greenhouse structural members and therefore requires a clear definition of load paths and attachment concepts. Structural integration is designed to: (i) preserve greenhouse integrity, (ii) maintain operational clearance for crops, workers, and equipment, and (iii) prevent interference with greenhouse utilities such as ventilation, irrigation, heating pipes, and shading screens.

Key considerations include selection of suitable attachment points (primary trusses, purlins, or dedicated secondary members), verification of local member capacity, and distribution of loads to avoid concentrated stresses. Attachment concepts are selected to respect greenhouse materials and corrosion-protection measures, and to minimize invasive interventions when feasible (e.g., clamping concepts; controlled drilling only when permitted and structurally justified).

Because greenhouses operate in high humidity with temperature cycles and frequent water exposure, corrosion-resistance and durability are treated as structural integration requirements. Measures include compatible fasteners, appropriate coatings/galvanization, detailing that avoids water traps, and providing inspection access to critical interfaces.

Integration is typically simpler in new greenhouse constructions, where agrivoltaic loads can be considered at the design stage and interfaces incorporated into the greenhouse design. Retrofit installations require detailed verification of as-built conditions, coordination with operators, and, where required, targeted reinforcement actions to meet national greenhouse safety regulations.

3.3 Structural Assessment, Load Verification and Reinforcement Strategies

Structural assessment is a mandatory pre-installation step for all REGACE deployments, particularly retrofits. Even when the system is designed as lightweight, the addition of PV modules, tracking components, cabling, and maintenance activities introduces operational loads that must be evaluated at site level. The objective is to confirm that the greenhouse can safely accommodate the suspended agrivoltaic system with an appropriate safety margin and in full compliance with applicable national greenhouse safety requirements.

1. 3.3.1 Scope and Typical Inputs

A complete structural assessment combines document review with on-site verification. Typical inputs include greenhouse drawings/specifications (if available), as-built measurements of member dimensions and spacing, identification of candidate attachment points, and documentation of existing internal equipment that may influence clearances or access.

At minimum, the following information should be collected and documented:

- Greenhouse typology and structural material (steel/aluminum) and bay spacing.
- Member sizes, connection details, and corrosion-protection condition.
- Locations of ventilation windows, shading screens, irrigation lines, and other services.
- Internal equipment map (research rigs, heating pipes, circulation fans) and clearance constraints.
- Local regulatory requirements and applicable greenhouse safety standards.

3.3.2 Load Verification Approach

Load verification evaluates both static and operational effects. Static (dead) loads include PV modules, rails, actuators, and cabling. Operational loads consider tracking motion, foreseeable dynamic effects, and maintenance activities (e.g., service positions and access equipment). Verification confirms that global load paths are within member capacities, local attachment interfaces are not overstressed, and deformation does not compromise greenhouse operations or reduce clearances below safe limits.

3.3.3 Reinforcement Strategies

Where assessment identifies insufficient capacity or uncertainty, reinforcement strategies should be localized and targeted. Typical measures include additional bracing, localized stiffening elements, improved connections at critical joints, or supplementary secondary members that redistribute loads across multiple bays. All reinforcement actions should be engineered, documented, and inspected.

Proactive reinforcement is treated as a best-practice safety action and an integral element of responsible retrofit deployment—not as a limitation of the REGACE design.

3.3.4 Volos Pilot Site (Greece): Structural Reinforcement Case

Prior to installation at the Volos pilot site (Greece), structural checks and load calculations were performed to confirm the greenhouse's suitability for the suspended agrivoltaic system. The assessment considered added dead loads from PV modules and tracking components, as well as operational loads associated with tracking motion and maintenance access.

The assessment concluded that localized reinforcement of the greenhouse structure was required to ensure stability and compliance with greenhouse safety regulations. A decision was therefore taken to implement reinforcement measures before installation. After reinforcement, the system was installed and has operated without structural constraints.

This case demonstrates that retrofit deployment may require site-specific structural adaptation and that early assessment reduces risk and increases schedule certainty. It also illustrates that reinforcement to meet safety requirements supports regulatory compliance and long-term reliability.

3.3.5 Minimum Documentation Outputs

The following outputs are recommended as a minimum documentation package for future deployments:

- Structural assessment report (inputs, assumptions, calculations, conclusions).
- Attachment plan (interfaces, quantities, fastener specifications, and torque requirements).
- Reinforcement design and as-built confirmation (if applicable).
- Commissioning checklist including movement clearance verification and acceptance criteria.
- Photographic documentation of critical attachment points and routing interfaces.

3.4 Electrical and Control Adaptation

Electrical system design is adapted per site to reflect local grid requirements, permitting conditions, inverter availability, and expected shading patterns caused by greenhouse structural elements. While the safety architecture remains consistent, the electrical implementation is optimized at each deployment to ensure compliance, reliable operation, and maintainability in agricultural conditions.

3.4.1 Site Electrical Boundary Conditions

Site-specific boundary conditions include grid connection voltage and configuration, local grid code requirements, utility interconnection procedures, environmental conditions affecting equipment placement, and constraints on AC interface locations (e.g., available electrical rooms, cable pathways, and access). These parameters are captured early to avoid redesign during installation.

3.4.2 String Design and Shading Management

String configuration (string length, zoning, and inverter MPPT assignment) is optimized per site to accommodate the layout geometry and structural shading. Design aims to minimize mismatch losses, keep operating voltages within inverter windows across expected temperature ranges, and support safe isolation and troubleshooting. Where specified, Module-Level Power Electronics (MLPE) principles support rapid shutdown and fault isolation, improving safety and maintainability in the greenhouse environment.

3.4.3 Cable Routing, Protection and Interface Detailing

Cable routing strategies are adapted to greenhouse realities: frequent water exposure, moving parts, and dense agricultural utilities. The design emphasizes protected routing (conduits or elevated pathways), strain relief and abrasion protection, segregation from irrigation lines, and clear labeling of strings and cable runs. Routing interfaces are coordinated with the mechanical design to prevent cable interaction with tracking movement.

3.4.4 Control Parameter Tuning

While the control logic concept is consistent across sites, parameters are tuned to match local irradiance conditions, crop objectives, and operational constraints (e.g., permitted movement windows, crop growth stages, or research protocols). Sensor placement and calibration are also site-specific to ensure that the control system receives representative signals from the greenhouse environment.

This structured approach—capturing boundary conditions, optimizing stringing, detailing protected routing, and tuning control parameters—enables reproducible deployment while respecting local electrical and operational constraints.

3.5 Standard Design Elements vs Site-Specific Elements

Across REGACE deployments, the design methodology separates a standardized “core” (replicable system concept and safety architecture) from site-specific adaptations required by greenhouse geometry, local electrical codes, and operational constraints. This separation enables efficient replication while ensuring that each deployment remains compliant and agronomically compatible.

Table 2 summarizes Standardized elements reduce engineering effort and improve quality control, while site-specific adaptations address the practical realities of greenhouse retrofits and local permitting requirements.

Category	Standardizable	Site-specific adaptation
Mechanical	Tracking concept; suspended layout; installation sequence	Attachment interfaces; module dimensions; reinforcement needs; clearance constraints
Electrical	Safety architecture; MLPE principle; grounding approach	String configuration; inverter selection; grid connection requirements; cable routing constraints
Control	Autonomous operation; crop-aware concept	Parameter tuning; site sensor placement; operational schedules aligned with local practices
Regulatory	Safety-by-design approach	Permitting, inspection, and grid interconnection processes

4. Final Installation Guide – Validated for Deployment

4.1 Purpose and Scope of the Installation Guide

This chapter constitutes the final installation guide for the REGACE agrivoltaic greenhouse system. The procedures described below were validated through multi-site deployment and reflect the final, field-tested installation methodology.

The guide is intended for system integrators, installation contractors and engineering consultants planning future deployments. It covers pre-installation requirements, mechanical and electrical installation, commissioning and acceptance procedures, and safety requirements during installation.

4.2 Pre-Installation Checklist (Mandatory)

This pre-installation checklist defines the **mandatory readiness conditions** that must be verified and documented before mobilizing installation activities on site. The checklist functions as a formal gate to ensure that structural, electrical, operational, safety, and logistical prerequisites have been addressed in a coordinated manner. Completing these checks in advance reduces installation risk, prevents late-stage design changes, and ensures that the installation process can proceed efficiently and safely within the greenhouse operational environment.

Before installation, the following checks must be completed. Templates are provided in Annex A.

Table No. 3 - pre-installation checklist

Category	Requirement	Evidence / Responsible
Structural	Structural assessment completed (drawings + on-site verification + load calculations)	Engineering report / Structural engineer
Structural	Attachment points identified; reinforcement implemented if required	As-built confirmation / Installer + engineer
Electrical	Grid connection feasibility confirmed; permits initiated/obtained	Utility confirmation / Electrical engineer
Electrical	Inverter location and AC interface defined; grounding strategy confirmed	Electrical design pack / Electrician
Safety	Site safety plan and work-at-height plan prepared	HSE officer / Contractor
Operations	Installation schedule aligned with crop operations and access windows	Farm manager + installer
Logistics	Tools/lifting equipment and material staging plan prepared	Installer team lead
Operations	Internal greenhouse equipment and utilities mapped (ventilation, shading screens, irrigation, research rigs); clearance constraints confirmed	Site survey pack / Installer + farm manager
Control & ICT	Local control cabinet location confirmed; autonomous/offline operation verified; sensor plan agreed	Control design pack / Controls engineer
Quality	Incoming inspection of PV modules, actuators, fasteners and electrical components; serial numbers recorded	QA checklist / Installer team lead
Safety	Electrical lockout/tagout procedure agreed; emergency response plan and contact list posted	HSE officer / Contractor

Logistics	Spare parts, consumables, and labeling materials available (connectors, ties, conduit, tags)	Installer team lead

Completion of all checklist items and confirmation of the corresponding evidence is a prerequisite for proceeding with mechanical and electrical installation works. Any deviations, unresolved items, or site changes identified at this stage should be addressed and formally closed before installation begins. This structured pre-installation gate supports safe deployment, regulatory compliance, and predictable installation timelines, and forms the foundation for the step-by-step installation and commissioning procedures described in the following sections.

4.3 Step-by-Step Mechanical Installation Procedure

This section defines the validated mechanical installation procedure for the REGACE adapted tracker system, applicable to both polytunnel and glass greenhouse environments. The procedure reflects site-specific structural conditions, internal greenhouse equipment, and safety requirements, and is intended to ensure accurate alignment, safe handling, and minimal disruption to ongoing agricultural operations.

Mechanical installation follows a validated sequence to ensure alignment, safe handling, and minimal disruption to greenhouse operations. Actual implementation may be phased depending on greenhouse access constraints, crop cycle, and site-specific operational limitations.

4.3.1 Install Suspension and Support Elements

Suspension and support elements form the primary structural interface between the tracker system and the greenhouse structure. Correct installation is critical to ensure proper load transfer, long-term stability, and compliance with greenhouse safety requirements.

- Install suspension brackets on designated greenhouse structural members.
- Verify alignment and load distribution across attachment points.
- Apply torque checks according to hardware specifications and document results.
- Confirm that brackets do not interfere with ventilation, shading screens, irrigation, or internal equipment.

Correct installation and verification of suspension elements establishes the structural baseline for all subsequent mechanical works and ensures compatibility with site-specific greenhouse constraint

4.3.2 Assemble Tracking Structure and Actuators

Pre-assembly of tracking structures and actuators is intended to reduce work-at-height risks and improve installation quality and efficiency across different greenhouse typologies.

- Assemble tracking rails and actuator assemblies, preferably at ground level.
- Perform a pre-installation functional check of actuators (movement range, connection integrity).
- Label assemblies according to installation zones.

This approach supports consistent installation quality and reduces mechanical and electrical handling risks during subsequent lifting and mounting activities.

4.3.3 Mount Tracking Assemblies to Suspension Points

Mounting of tracking assemblies requires careful sequencing to maintain balanced loading and safe working conditions within the greenhouse.

- Lift and mount tracking assemblies using approved lifting procedures.
- Install progressively to maintain balanced loading.
- Verify preliminary movement clearance before module installation.

Early verification of movement clearance reduces the risk of later interference with greenhouse infrastructure and confirms compliance with the defined safety envelope.

4.3.4 Install and Align PV Modules

- Mount PV modules onto tracking rails according to the final layout drawing.
- Verify mechanical fixation and apply secondary retention where specified.
- Align modules to avoid binding or collision during tracking movement.
- Perform a visual inspection for glass handling damage, connector integrity and cable routing.

4.3.5 Mechanical Verification and Acceptance

- Perform movement tests across the full angular range (manual or controlled).
- Verify clearances to crop canopy, worker access routes and greenhouse utilities.
- Confirm stable mounting, no unintended vibration, and secure fasteners.
- Record acceptance results in the commissioning file (Annex B template).

4.4 Step-by-Step Electrical Installation Procedure

4.4.1 DC Wiring and MLPE Integration

- Wire PV modules into predefined strings according to the electrical design.
- Install MLPE devices where specified to support rapid shutdown and fault isolation.
- Ensure connectors are fully seated and protected from moisture ingress; apply strain relief as needed.
- Secure DC cabling to avoid tension, abrasion and contact with moving elements.

4.4.2 Cable Routing and Protection

- Route cables through protected conduits or elevated pathways to reduce mechanical damage risk.
- Maintain separation from irrigation and water lines and avoid hot surfaces or moving parts.
- Use appropriate cable clips, UV-resistant ties, and abrasion guards where needed.
- Label strings and cable runs to support troubleshooting and maintenance.

4.4.3 AC Integration and Grid Connection

- Install inverters and AC protection devices according to site electrical design and local codes.
- Implement grounding and equipotential bonding for all metallic structures.
- Install surge protective devices (SPD) at specified locations.
- Complete grid connection steps as required by the local utility and permitting authority.

4.5 Commissioning, Validation and Handover

Commissioning verifies safety, functionality and readiness for autonomous operation. It is recommended to document all tests in a commissioning file and retain records for audits and maintenance.

Commissioning steps:

4.5.1 Electrical Safety Verification

- Continuity and insulation resistance tests.
- Grounding verification and bonding continuity checks.
- Rapid shutdown functionality test and confirmation of safe voltage reduction behavior.
- Verification of protection devices (as applicable).

4.5.2 Functional System Tests

- Tracker movement test under control commands (full range).
- Sensor reading validation and plausibility checks.
- Control logic response testing (e.g., commanded tilt changes, safe stops).

4.5.3 Initial Operational Monitoring and Acceptance

- Monitor operation under real irradiance for an initial period to confirm stable behavior.
- Verify that the system does not interfere with greenhouse operations (ventilation, shading, crop work).
- Handover to greenhouse operator with basic user instructions and maintenance plan.

4.6 Safety Requirements During Installation

Installation activities for the REGACE system are performed within active greenhouse environments, where work is carried out in close proximity to crops, internal infrastructure, and ongoing agricultural operations. Safety requirements during installation are therefore defined to reflect both the specific greenhouse typology—polytunnel or glass greenhouse—and the applicable occupational, electrical, and agricultural safety regulations at each deployment location. These requirements are an integral part of the greenhouse-specific installation guidelines provided in this deliverable.

Installation activities must comply with applicable occupational safety regulations. Minimum requirements include:

- Electrical lockout/tagout procedures during wiring, testing, and troubleshooting activities.
- Safe work-at-height practices and appropriate fall protection measures, adapted to the internal greenhouse structure.
- Use of approved lifting equipment and trained operators for handling tracking assemblies and PV modules.
- Mandatory use of personal protective equipment (PPE), including gloves, eye protection, and safety footwear, and controlled access to defined work zones during installation activities.

Clear signage must be installed before energizing the system and maintained during operation.

Installation activities must comply with occupational safety regulations. Minimum requirements include:

- Electrical lockout/tagout procedures during wiring and testing.

- Safe work at height practices and appropriate fall protection.

- Approved lifting equipment and trained operators for handling assemblies and modules.

- PPE use (gloves, eye protection, safety footwear) and controlled access to work zones.

Clear signage must be installed before energizing the system and maintained during operation.

Adherence to these installation safety requirements ensures that system deployment remains compliant with local regulatory and safety frameworks while minimizing risk to workers and greenhouse operations. When implemented in conjunction with the validated installation sequencing, verification steps, and commissioning procedures described in this deliverable, these measures support safe, repeatable installation of the adapted tracker system in both polytunnel and glass greenhouse environments.

4.7 Typical Installation Pitfalls and Mitigation Measures

This section consolidates the most common installation pitfalls identified during multi-site REGACE deployments, together with the practical mitigation measures applied to resolve them. The intent is not to prescribe additional design requirements, but to capture implementation-level lessons learned that can significantly reduce installation risk, rework, and commissioning delays when deploying the system in diverse greenhouse environments.

Table No. 4- common installation pitfalls

Pitfall	Typical cause	Mitigation
As-built deviations	Greenhouse geometry differs from drawings	Perform on-site measurement; adjust layout; confirm clearances early.
Retrofit structural limits	Local members require reinforcement	Complete structural assessment; implement targeted reinforcement (Volos case).
Cable damage risk	Cables exposed to abrasion/water	Protected routing; strain relief; separation from irrigation; labeling.
Trade coordination	Mechanical and electrical work overlap	Define sequencing; daily coordination; joint acceptance checks.

Access constraints	Limited space during crop cycles	Phase installation; align schedule with farm operations.
Shading screen / equipment interference	Tracker clearance envelope overlaps shading nets, pipes or research rigs	Map internal equipment early; validate full-range movement during commissioning; define maintenance positions and movement limits if needed.
Water ingress at connectors	Connectors exposed to spray, condensation or pressure washing	Use drip loops and elevated routing; position connectors away from jets; apply appropriate IP-rated components and strain relief; include visual inspection in maintenance.
Loose fasteners / mis-torque	Inadequate torque control or missing secondary retention	Use calibrated torque tools; record torque checks; apply secondary retention where specified; spot-check after initial operation.
String mislabeling / incorrect stringing	Installation errors under time pressure or complex layouts	Pre-label zones; enforce string maps; perform string-by-string verification (polarity, Voc, continuity) before energizing.
Arc-fault risk from poor terminations	Improper connector mating or damaged cables	Train installers on connector standards; inspect terminations; use arc-fault protection where applicable; implement periodic checks.
Grounding discontinuity	Missing bonding jumpers or corrosion at interfaces	Use equipotential bonding per design; verify continuity during commissioning; use corrosion-resistant bonding hardware.
Remote monitoring data gaps	Temporary internet interruptions or unstable network equipment	Maintain autonomous local control; buffer logs locally; restore/sync data after connectivity returns; document network requirements in handover pack.

Addressing these potential pitfalls through early planning, disciplined installation practices, and structured verification significantly improves installation quality and predictability. When combined with the mandatory pre-installation checks and documented commissioning procedures, the mitigation measures listed above support safe system deployment, minimize operational disruption to greenhouse activities, and contribute to long-term system reliability.

4.8 Installation Guide Summary

The procedures presented in this chapter reflect validated, field-tested installation practices developed through multi-site deployment of the REGACE system in both polytunnel and glass greenhouse environments. The installation sequence, verification steps, and acceptance criteria were refined through practical implementation and are intended to provide clear guidance for installers, system integrators, and engineering teams.

When combined with the mandatory pre-installation assessments—particularly structural verification, electrical readiness, and safety planning—the installation guide establishes a structured framework that reduces implementation risk and minimizes disruption to ongoing greenhouse operations. Clear definition of responsibilities, phased installation aligned with crop cycles, and disciplined commissioning practices contribute to predictable installation timelines and consistent quality across sites.

By translating site-specific adaptation requirements into a standardized yet flexible installation methodology, this guide supports safe, efficient, and replicable deployment of the REGACE system. It provides a practical reference for future projects, enabling greenhouse-integrated agrivoltaic systems to be implemented responsibly while maintaining compliance with local regulatory and safety requirements.

5. Safety and Operational Best Practices

5.1 Safety-by-Design Approach

Safety considerations were embedded in the REGACE system from the earliest design stages and were treated as a core design driver rather than an add-on requirement. Unlike conventional PV installations, greenhouse-integrated agrivoltaic systems operate in close proximity to crops, workers, and agricultural machinery, within an environment characterized by humidity, irrigation activities, and frequent human presence. As a result, risk reduction in REGACE is primarily achieved through preventive design choices that minimize exposure and reliance on procedural controls alone.

At system level, safety-by-design is implemented through greenhouse-specific layout decisions such as appropriate module suspension height, controlled tracking movement envelopes, and preservation of safe clearances for crop growth and human access. Electrical risks are mitigated through architectural choices that limit voltage exposure during maintenance and abnormal conditions, while mechanical risks are addressed through robust fixation, avoidance of pinch points, and compatibility with greenhouse operational constraints. Cable routing, component placement, and interface selection are designed to reduce interaction with water, moving elements, and routine agricultural activities.

The safety-by-design approach is reinforced by structured installation verification and operational oversight. Installation checks, commissioning tests, and acceptance criteria ensure that design assumptions are correctly implemented on site, while routine inspections provide continued confirmation that safety conditions are maintained over time. These verification and inspection activities, documented through standardized templates and logs (Annex C), form an integral part of the overall safety concept and support long-term safe operation in both polytunnel and glass greenhouse environments.

Building on these preventive design principles, the following section details the specific electrical safety measures implemented to address the unique operational and regulatory requirements of greenhouse-integrated photovoltaic systems.

5.2 Electrical Safety Measures

Electrical safety in REGACE is addressed through greenhouse-specific system design and installation measures applicable to both polytunnel and glass greenhouse environments. The electrical safety concept accounts for the presence of irrigation systems, elevated humidity, routine human activity, and site-specific regulatory requirements, and is adapted at each location to ensure compliant and safe operation throughout the system lifetime.

Electrical safety is ensured through a combination of system architecture and protective measures:

- MLPE and rapid shutdown capability to reduce DC voltage exposure during emergency or maintenance.
- Fault isolation and protective devices as defined by site electrical design and applicable codes.
- Proper grounding and equipotential bonding of metallic components.
- Surge protective devices (SPD) to mitigate transient overvoltage risk.
- Clear labeling and signage for agricultural workers and maintenance personnel.

Together, these electrical safety measures establish a layered protection approach that reduces risk during normal operation, maintenance, and emergency situations. When implemented in accordance with the site-specific electrical design, local regulatory framework, and the validated installation and commissioning procedures described in this deliverable, they ensure safe coexistence of the REGACE system with routine greenhouse activities and support reliable, compliant deployment across different greenhouse types and locations.

5.3 Mechanical and Operational Safety

Mechanical safety in the REGACE system is addressed through greenhouse-specific design adaptation and installation practices applicable to both polytunnel and glass greenhouse environments. Key considerations include maintaining adequate clearances between moving tracking components, crops, internal greenhouse equipment, and access routes; ensuring secure mechanical fixation at all attachment points; and selecting materials and surface treatments compatible with the humidity and corrosion conditions typical of greenhouse operation. The tracking design also avoids the creation of pinch points within the defined movement envelope, thereby reducing risk to personnel during routine operation.

Operational safety measures complement the mechanical design and reflect site-specific regulatory and safety requirements. These measures include controlled access during maintenance and commissioning activities, use of approved lifting and work-at-height procedures, and systematic documentation of inspections and verification checks. Together, these mechanical and operational safety provisions ensure that the REGACE system can be deployed and operated safely within active polytunnel and glass greenhouse settings while remaining compliant with local safety regulations and operational practices.

Mechanical safety in the REGACE system is ensured through greenhouse-specific design adaptation and validated installation practices applicable to both polytunnel and glass greenhouse environments. Key considerations include maintaining adequate clearances between moving tracking components, crops, internal greenhouse equipment, and access routes; ensuring secure mechanical fixation at all attachment points; and selecting materials and surface treatments suitable for the humidity and corrosion conditions typical of greenhouse operation. The tracking mechanism is designed and installed to avoid pinch points and unintended mechanical interactions within the defined movement envelope.

Operational safety measures complement the mechanical design and are implemented in accordance with site-specific regulatory and safety requirements. These measures include controlled access during installation, commissioning, and maintenance activities; use of approved lifting and work-at-height procedures; and systematic documentation of inspections and verification checks. The detailed procedures governing these measures—covering sequencing, clearance verification, torque checks, access control, and acceptance criteria—are defined in the validated Installation Guide presented in Chapter 4. Together, these provisions ensure that the REGACE system can be safely installed and operated in active polytunnel and glass greenhouse settings while maintaining compliance with local safety regulations and operational practices.

5.4 Safety Performance During Operation

Across all REGACE pilot sites, including both polytunnel and glass greenhouse deployments, the systems have been operating continuously since installation for periods exceeding one year. During this time, no safety-related mechanical or electrical incidents were reported. Operation remained within the defined safety envelopes established during site-specific design adaptation, structural assessment, and commissioning.

This operational safety record confirms that the adapted tracker design, electrical protection architecture, and control logic are suitable for use in active greenhouse environments subject to different regulatory and safety frameworks. The results demonstrate that, when installed and commissioned in accordance with the validated guidelines provided in this deliverable, the REGACE system can operate safely and reliably under routine agricultural conditions while maintaining compliance with local greenhouse safety requirements.

6. Lessons Learned from Multi-Site Implementation

6.1 Installation Learning Curve

As with other first-of-a-kind deployments, the initial REGACE installations involved an expected learning curve related to adapting the tracker design and installation procedures to different greenhouse typologies, including both polytunnel and glass greenhouses. Early installations required iterative refinement of installation sequences, clarification of mechanical and electrical interfaces, and close coordination between engineering partners, installers, and greenhouse operators to ensure compliance with site-specific safety and operational constraints.

Experience gained from early deployments was systematically incorporated into updated design adaptations and installation guidelines, resulting in more efficient and predictable implementation at subsequent sites. Key lessons included the critical importance of accurate early site measurements, clear allocation of responsibilities among stakeholders, and conservative structural verification for retrofit greenhouses to meet local safety and regulatory requirements. These learnings directly informed the final, greenhouse-specific installation methodology presented in this deliverable.

6.2 Operational Experience

Operational experience across both polytunnel and glass greenhouse deployments indicates stable, predictable, and safe system behavior under real operational conditions. The adapted tracker design operated reliably within the defined clearance envelopes and safety constraints of each greenhouse type, without causing disruption to crop management, internal equipment, or routine greenhouse workflows. In all locations, system operation remained compliant with applicable greenhouse safety requirements and site-specific operational constraints.

Maintenance requirements were low and compatible with standard greenhouse practices. End-user feedback consistently identified routine cleaning of PV modules as the primary recurring maintenance activity, reflecting the agricultural environment rather than system malfunction. Periodic visual inspection of mechanical components, verification of fasteners, and software-based monitoring are recommended as part of normal operation to maintain long-term performance and continued compliance with local safety and operational requirements.

6.3 End-User and Farmer Feedback

Qualitative feedback from farmers hosting pilot installations indicates high acceptance of the REGACE concept. Farmers noted that the system is practically usable in daily operations and does not interfere with routine agricultural activities.

Reported high levels of interaction during pilot periods were largely attributed to experimental protocols (sensor relocation, software testing), which would not be expected under commercial deployment conditions.

Farmers highlighted crop yield performance as the main determinant for commercial adoption. They also emphasized the value of crop-specific light management approaches aligned with crop DLI requirements, supporting the standardization of such strategies in future commercial rollout.

Across the pilot deployments, end-users did not report major functional defects or disruptive malfunctions of the REGACE system. Feedback mainly emphasized practical O&M topics—particularly regular cleaning of the PV modules to maintain performance and simple visual checks of connectors and cable routing after routine greenhouse activities. This aligns with the formal end-user evaluation outputs, where usability and day-to-day operation were assessed positively and maintenance requirements were considered manageable.

6.4 Communication Infrastructure and System Autonomy

Across sites, occasional interruptions in internet connectivity were observed. These interruptions were attributable to local network infrastructure rather than the REGACE system design.

Connectivity interruptions did not affect system safety or core operational functionality. The REGACE control logic is designed to operate autonomously and resumes data communication automatically once connectivity is restored.

This boundary condition should be considered in future deployments by ensuring robust local control and, where necessary, improving site communication infrastructure for remote monitoring convenience.

6.5 Consolidated Lessons Learned (Summary Table)

This section consolidates the key lessons learned from multi-site deployment, installation, commissioning, and early operation of the REGACE system. The observations summarized below reflect practical experience across different greenhouse typologies, regulatory environments, and operational contexts, and provide actionable guidance for future deployments beyond the pilot sites.

Table No. 5 observations summary for practical experience across different greenhouse typologies, regulatory environments.

Topic	Observation	Recommendation
Retrofit readiness	Structural checks must be conservative; reinforcement may be required.	Mandate structural assessment and allow for localized reinforcement in schedule/budget.
Installation efficiency	Sequencing and labeling reduce time and errors.	Use phased plan, zone labeling, and pre-assembly at ground level.
Maintenance	Cleaning is the main recurring task.	Include cleaning plan in O&M; ensure safe access routes.
Connectivity	Internet may be intermittent in rural sites.	Maintain autonomous control; plan monitoring resilience; optionally improve network.
Adoption driver	Yield is decisive for farmers.	Strengthen crop-specific light management and provide clear operational modes.
Internal equipment constraints	Research greenhouses may have dense equipment (screens, rigs) that limits module format and movement clearances.	Conduct detailed internal mapping early; design site-specific module dimensions; validate movement envelope before module installation.
Cable protection in humid environments	Water exposure and moving parts increase abrasion and moisture risks.	Use protected routing with strain relief; keep connectors away from jets; include periodic visual inspections.
Commissioning documentation	Clear acceptance criteria reduce disputes and speed handover.	Use standardized commissioning templates; record tests, torque checks, and photographs in a handover pack.
Seasonal operation tuning	Optimal tracking strategies can vary by season and crop stage.	Define seasonal parameter sets; provide operator guidance on conservative and crop-optimized modes.

Taken together, these lessons highlight that successful greenhouse agrivoltaic deployment depends as much on disciplined implementation and operational alignment as on core system design. By embedding these recommendations into future project planning, installation workflows, and operator guidance, REGACE deployments can achieve higher predictability, reduced implementation risk, and smoother transition to long-term operation while preserving agronomic performance and safety.

7. Replicability, Scalability and Deployment Readiness

7.1 Replication Requirements – What a New Site Must Provide

This section defines the minimum information and inputs required to replicate the REGACE system at a new site. These requirements ensure that site-specific adaptation can be performed efficiently while preserving the validated core system architecture, safety concept, and operational philosophy established.

To replicate REGACE at a new site, the following inputs are required:

- Greenhouse structural drawings (or accurate as-built survey) and material specifications.
- Greenhouse operational constraints (clearance, machinery, ventilation/shading equipment).

- Crop type(s), cultivation method, and agronomic light requirements (incl. DLI targets where available).
- Local grid connection conditions, electrical code constraints, and permitting process requirements.
- Preferred inverter location, available electrical infrastructure, and monitoring requirements.

Providing these inputs at an early project stage enables accurate design adaptation, reduces iteration during installation planning, and supports alignment with local regulatory and safety requirements. Together, they form the baseline dataset needed to apply the REGACE guidelines consistently and to progress from site screening to detailed design and deployment with reduced technical and operational risk.

7.2 Deployment Roadmap (Step-by-Step)

This section presents a practical deployment roadmap derived from the validated design, adaptation, and installation experience documented in Deliverable 2.3. The roadmap translates the technical guidelines and lessons learned into a clear sequence of implementation steps, supporting structured planning and reducing uncertainty for future deployments in both polytunnel and glass greenhouse environments.

1) Site screening: greenhouse type, crop, and basic structural suitability.

2) Structural assessment: verify capacity, attachment points, and reinforcement needs.

3) Electrical pre-design: grid feasibility, inverter selection, protection concept, permitting plan.

4) Detailed design and layout: module format, tracking zones, routing and clearance verification.

5) Installation planning: phasing with crop cycles, contractor assignment, logistics and safety plan.

6) Installation and commissioning: follow Installation Guide (Chapter 4) and Annex checklists.

7) Handover and O&M: cleaning plan, inspection schedule, monitoring procedures and training.

Following this step-by-step roadmap ensures that critical technical, regulatory, and operational dependencies are addressed in the correct order, from early site screening through commissioning and handover. When applied consistently, the roadmap supports predictable project execution, facilitates coordination between engineering disciplines and greenhouse operators, and provides a clear pathway for safe, compliant, and scalable deployment of greenhouse-integrated agrivoltaics.

7.3 Standardization vs Site-Specific Adaptation

This section clarifies how REGACE balances standardization and site-specific adaptation to support scalable deployment across diverse greenhouse contexts. By clearly defining which elements are fixed at system level and which require controlled customization, REGACE enables replication without compromising safety, regulatory compliance, or agronomic compatibility.

Table No. 6 - scalable deployment across diverse greenhouse contexts

Standardizable elements	Elements requiring site-specific adaptation
Tracking concept and control philosophy	Module dimensions and mechanical interfaces to greenhouse structure
Installation sequence and commissioning approach	String configuration, inverter selection, and grid interconnection requirements

Safety architecture principles (MLPE, grounding, protected routing)	Permitting, inspection and compliance documentation per country
Autonomous operation logic	Operational tuning (crop targets, schedules, local practices)

This structured separation between standardized core elements and site-specific adaptations provides a practical framework for scaling greenhouse agrivoltaics. It allows engineering effort to focus on a limited number of interface decisions while preserving a consistent system architecture, safety concept, and operational logic across deployments, thereby supporting predictable project execution and long-term adoption.

7.4 Readiness for Wider Deployment

From a technical and operational perspective, REGACE has demonstrated a high level of maturity through multi-site deployment and sustained operation under real greenhouse conditions. The system architecture, tracking mechanism, control logic, and safety concept were validated across different greenhouse typologies, confirming stable performance and non-intrusive integration with routine agricultural activities. Operational experience indicates that the system can be installed, commissioned, and operated safely when the validated procedures described in this deliverable are followed.

The remaining barriers to wider adoption are primarily external to the core system design. These include regulatory and permitting processes that vary between countries and regions, grid-connection requirements that can influence project timelines and costs, and the economic decision-making framework of growers, which remains strongly driven by crop yield, production stability, and risk perception. As such, successful deployment depends not only on technical readiness but also on alignment with local regulatory environments and the ability to demonstrate agronomic compatibility at farm level.

Deliverable 2.3 addresses these factors by providing a complete, field-validated set of design adaptation principles and installation guidelines. By clearly defining mandatory pre-installation assessments, site-specific adaptation boundaries, safety and commissioning requirements, and lessons learned from implementation, this deliverable reduces uncertainty for future projects and supports predictable deployment planning. When applied consistently, these guidelines enable responsible and efficient replication of the REGACE system in both polytunnel and glass greenhouse environments, forming a solid foundation for scale-up beyond the pilot phase.

8. Conclusions

Deliverable 2.3 represents the final milestone of this work and delivers greenhouse-specific, adapted tracker design and installation guidelines applicable to both polytunnel and glass greenhouse typologies. The deliverable documents the transition from initial design concepts to a fully implemented and field-validated REGACE agrivoltaic system, with explicit consideration of the structural, electrical, control, regulatory, and safety conditions encountered at each deployment location.

The report consolidates final system architecture decisions and a validated installation methodology, including mandatory pre-installation structural assessment, load verification, and—where required—localized reinforcement measures, as demonstrated by the Volos pilot site. In parallel, it documents how site-specific regulatory frameworks, greenhouse safety requirements, and grid-connection processes were addressed in practice across different countries and greenhouse configurations.

Operational experience across all pilot sites confirms stable and robust system behavior, low maintenance requirements compatible with routine greenhouse operations, and non-intrusive integration within both commercial and research greenhouse environments. The autonomous control architecture ensured safe operation even under intermittent communication conditions, reinforcing the suitability of the system for deployment in rural and agricultural settings.

By providing greenhouse-type–specific tracker design adaptations, step-by-step installation and commissioning guidelines, and a clear treatment of the regulatory and safety environment at each location, Deliverable 2.3 reduces deployment risk and implementation uncertainty. The deliverable therefore establishes a validated and responsible framework for replication and wider deployment of greenhouse-integrated agrivoltaics in polytunnel and glass greenhouse systems, subject to site-specific adaptation and external regulatory and grid-connection conditions.

9. Annex A. Pre-Installation Checklist (Template)

Use this checklist prior to mobilizing installation teams to site.

Item	Requirement	Status (Y/N)	Notes / Evidence
A1	Structural drawings reviewed and on-site survey completed		
A2	Load calculations completed; reinforcement plan defined (if required)		
A3	Attachment points verified and marked		
A4	Permits and utility requirements confirmed		
A5	Electrical design pack approved (strings, inverter, protection)		
A6	Safety plan (work at height, lifting, LOTO) approved		
A7	Installation schedule agreed with greenhouse operator		
A8	Material delivery and staging plan confirmed		
A9	Tools and lifting equipment available and certified		

10. Annex B. Commissioning & Acceptance Checklist (Template)

Document commissioning tests and acceptance results using this template.

Test	Method	Result	Comments
B1 Electrical continuity	Continuity test		
B2 Insulation resistance	IR test		
B3 Grounding/bonding	Continuity + visual		
B4 Rapid shutdown	Functional test		
B5 Tracker movement range	Command full range		
B6 Sensor validation	Plausibility check		
B7 Safe clearances	Visual + movement		
B8 Initial monitoring	Observe operation		

11. Annex C. Routine Maintenance & Inspection Log (Template)

Suggested log for routine inspections and PV module cleaning.

Date	Activity	Performed by	Findings	Actions taken

12. References

- REGACE Deliverable D2.1 – Initial Design and Installation Guide (project internal reference).
- REGACE End-User Evaluation summary (farmer feedback).
- REGACE Safety Best Practices documentation.
- Applicable national electrical codes and relevant IEC standards (site-dependent).