# Project Deliverable Report

## DELIVERABLE 3.1 NAME

## DELIVERABLE

**WORK PACKAGE NUMBER: WP D3.1**

**WORK PACKAGE TITLE: TEST PROTOCOL FOR BIFACIAL PV CHARACTERISATION**

**TYPE: REPORT**

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| **Action acronym** | REGACE |
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| **Lead beneficiary** | BOKU |
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## Executive Summary

This deliverable summarises the different measurement protocols used in the REGACE project. The PV tracking technology will be combined with $CO_2$ enrichment under greenhouse conditions at different locations. For each location, the crops will be selected based on the crops typically cultivated in the respective locations. The choice should also consider crops with high and low light demand. The project will cover both soil-based and hydroponic cultivation. In a first approach, it is aimed to create basic knowledge that will enable to evaluate the introduction of the PV tracker system in low, medium and high insolation environments. To enable efficient and precise data collection, protocols are developed for PV electrical performance, greenhouse microclimate assessment, and crop performance.

Samples of the PV bifacial modules will be studied at ESTER lab, in Rome, Italy to evaluate the PV module's main parameters to be used as input in the semiempirical model. Concerning the response of the bifacial module to solar radiation, pyranometers will be mounted on the front and rear side of the module, and the bifaciality coefficients and bifaciality gain will be measured according to IEC 60904 1-2 (2019). The testing protocol also includes a test procedure to evaluate the angle of incidence and the spectral coefficient for the bifacial PV modules. The electrical performance of the photovoltaic system will be measured in the different locations in two ways, the second only at AZS greenhouses in Israel: firstly, the general output data will be collected from the webbox of the inverter at each location, and, secondly, more detailed PV performance data will be collected at 10-min intervals using an automated measurement and data collection system. Measurements will include: current-voltage (IV) curves, open circuit voltage, short circuit current,

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maximum power point, efficiency, fill factor, panel temperature and incident irradiance (on both sides of the bifacial modules). The annual as well as the diurnal performance of the PV modules will be assessed.

In addition to assessing PV module performance, the micro-climate of the greenhouses will be recorded, both in the control greenhouse and in that affected by shading due to the PV panels. Measurements include air temperature, humidity, radiation level and distribution, irradiance spectrum, air velocity within the canopy, root medium temperature, and heat fluxes. External conditions will also be measured.

To quantify the effect of the PV system on crop growth, crop monitoring protocols are worked out by BOKU taking into consideration the available capacities especially of the non-academic farming partners. From the beginning of sawing or planting till harvest growth parameters will be assessed, in addition to deficiencies, pests and diseases. The elaborated systematic and methodical recording of the crops' performances is expected to provide the necessary information for assessing the size of the harvest per $m^2$ and quality of harvested crops. The collected data will be used for modelling the influence of the PV tracking system and elevated atmospheric $CO_2$-concentrations on growth and yield. In addition to these yield physiological studies, the intrinsic and consumer quality of the produces from selected partners will be determined at BOKU (carbohydrates, organic acids, carotenoids, polyphenolics, lycopene, nitrate).

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# 1 Introduction

The REGACE consortium is composed of 11 partners from 6 Member States and Associated Countries, offering a broad range of multidisciplinary expertise in order to characterise the efficiency of an Agrivoltaic system in polytunnel and conventional greenhouses. The participants may be subdivided into

(1) Academic partners providing European scientific expertise and knowledge for the project: Alzahrawy Society **AZS**, Tel Aviv University **TAU,** University of Rome Tor Vergata **UR**, University of Thessaly **UTH**, Humboldt University of Berlin **HU** and University of Natural Resources and Life Sciences, Vienna **BOKU**;

(2) Industrial partners and technology developers providing relevant industrial experience, know-how and technologies to the project: Trisolar - Innowadi Group Ltd. **TS**, Fattoria Solidale del Circeo **FSC** and Bio-Gärtnerei Watzkendorf GmbH **BW**); and

(3) partners providing specific skills (Interteam Project Management **IT**, Time.lex **TL**).

The **Alzahrawy Society** (AZS) acts as the Coordinator of the REGACE project. In addition, AZS has its core competence in the field of agrivoltaics, especially in the integration of PVs into polytunnel greenhouses. With respect to their previous work, AZS is well equipped to focused on the electrical performance and lifetimes of PV modules in a greenhouse application. For the experiments, they offer two polytunnel greenhouses, located in Kfar Qari (central Israel), where they record the electrical yields of the PV system of the responsive tracking system. In addition, AZS is involved in testing the responsive tracking system.

There are further three partners in Israel: **TriSolar Ltd** (TS), **Tel Aviv University**

(TAU), and **Interteam Project Management** (IT). TS main task is in close cooperation with AZS to adapt the tracking system to the different test locations of the project. The tracking system, panels, sensors and controllers will be installed by TS in the trial greenhouses in all locations and the system will be introduced in Europe. The **Tel Aviv University** competences are in the economics and environmental aspects of this form of agrivoltaics and also in the sociological work on easing its introduction. **Interteam Project Management** is responsible for project management and undertakes the essential communication and dissemination tasks, thus taking responsibility for assuring all deliverables, milestones and reports.

The **University of Rome Tor Vergata** (UR) contributes with two units to the PVproject. The **Ester lab** (Solar Energy TEst and Research) offers its expertise in PV evaluation and solar energy modelling. The ESTER lab group characterises the PV system to be tested in order to enable a more widespread utilisation of renewable energy conversion technology. In addition, the University of Rome Tor Vergata with their experts in social sciences accompanies and studies the introduction of the new PV technology. The test of the PV panels under practice conditions in Italy is realised in the farming greenhouse of the **working social/cooperative farm at Fattoria Solidale del Circeo Cooperativa Sociale di Produzione e Lavoro** (FSC), which has already experience in agrivoltaic systems installed in open fields.

The working team at the **University of Thessaly** (UTH) is in charge of the microclimate measurements inside the greenhouses. Here, in contrast to other partners, the cultivation of hydroponically grown crops is studied. In addition, the UTH has the competence to apply elevated $CO_2$ levels in the greenhouse atmosphere.

**Humboldt University of Berlin** (HU) provides the consortium with the key expertise for the strategy to compensate shading by the PV system with $CO_2$

enrichment. They are also well experienced in efficient greenhouse water management and offer so-called phytoboxes for controlled environment experiments. HU also supports the **Bio-Gärtnerei Watzkendorf** (BW), which has extensive practical experience in the application of elevated $CO_2$-concentrations in their working greenhouses.

The **University of Natural Resources and Life Sciences Vienna** (BOKU) is responsible for the assessment of the horticultural product quality and yield physiology. In addition, cultivation experiments under different light intensities in the BOKU greenhouses contribute to the knowledge on the responses of crop plants to light stress. BOKU also share their experience in photosynthesis and growth analyses under different light and eventually $CO_2$-concentrations.

**Time.lex** (TL) is a niche law firm based in Brussels, specialised in emerging technology in the broadest sense, covering all legal issues encountered in the creation, management and exploitation of information and technology, in all of its diverse forms. The new solutions proposed in the REGACE project cannot be evaluated solely from a technological point of view, but must also be seen in the legal and social context in which it will be operating. Based upon the present regulatory landscape and the underlying ethical principles, TL will identify to what extent REGACE presents advantages and/or challenges to the regulatory regime and the underlying ethical principles.

The main competences of the project partners are summarized in Tab. 1

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Table 1: Main competences of the research partners. AZS: Alzahrawy Society; TS: Trisolar - Innowadi Group Ltd.; BOKU: University of Natural Resources and Life Sciences, Vienna; UTH: University of Thessaly; UR: University of Rome Tor Vergata; HU: Humboldt University of Berlin; FSC: Fattoria Solidale del Circeo; BW: Bio-Gärtnerei Watzkendorf GmbH; TL: Time.lex; IT: Interteam Project Management; TAU: Tel Aviv University

| | AZS | TS | BOKU | UTH | UR1 | UR2 | HU | FSC | BW | TL | IT | TAU |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agrivoltaics | x | | | | | | | | | | | |
| Responsive tracking system | | x | | | | | | | | | | |
| Greenhouse horticulture | | | x | | | | | | | | | |
| Greenhouse microclimate | | | | x | | | | | | | | |
| $CO_2$-enrichment | x | | x | | | | x | | x | | | |
| Solar energy modelling & PV panel testing | | | | | x | | | | | | | |
| Farmer sociology | | | | | | x | | | | | | |
| Environmental analyses | | | | | | | | | | | | x |
| Communication dissemination | | | | | | | | | | | x | |
| Regulations | | | | | | | | | | x | | |
| Greenhouse farming | x | | | x | | | x | x | x | | | |
| Greenhouse $CO_2$farming | x | | x | x | | | x | | x | | | |

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# 2 Research Tasks

## 2.1 Task 3.1 Bifacial PV characterization (M6 – M34)

Task Leader: UR (ESTER lab); Participants: AZS

Photovoltaic (PV) panels are widely used in the various case studies of our project. The purpose of this task is to evaluate and establish guidelines for a standardised protocol procedure evaluating the performance and reliability of bifacial photovoltaic panels under real-world conditions. We have divided the protocol into three consecutive phases. Phase one is necessary to verify the functioning and main characteristics of the delivered Bifacial PV panels. In phase two we explain how to perform a comprehensive analysis of the panel characteristics to determine the device's response to the environmental variables. The results of this phase are compared with those of the manufacturer. In phase 3, we describe how to evaluate the long-term performance of PV panels, focussing on their reliability and stability under different environmental conditions. The main objective is to compare the performance of these devices with its monofacial counterpart over an extended period of time. In this phase, the durability of the panels in generating energy and possible degradation can be assessed.

This document also includes in the **Annexes** the templates of the protocols and the registration documents that will be used during the project activities.

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### 2.1.1 Description of the ESTER Laboratory Testing Facilities

The local experimental data used for the model characterisation come from the ESTER outdoor Laboratory - University of Rome 'Tor Vergata'.

The ESTER lab has i) a complete weather station, ii) a tracker stand, iii) a variable tilt and south orientated stand, and iv) a variable tilt and orientation stand. The weather station measures the global and diffuse horizontal irradiance and the reflected irradiance by 3 Kipp & Zonen CM21 pyranometers; the direct normal irradiance by Kipp & Zonen CH1 pyrheliometer; the air temperature and relative humidity by a Rotronic Hygroclip thermo-hygrometer; the pressure and the rain gage by Skye Instruments Ltd air pressure sensor model SKPS-810 and EM Ltd model ARG-100. All the data are recorded by a Campbell Scientific CR1000 with a scan rate of 0.1 Hz providing average data with one-minute time rate. The sun tracker, onto which the diffuse pyranometer and the pyrheliometer are mounted, has been renewed for the purpose of the project and is a EKO STR-22G.

On the tracker and on the tilt and fixed stands, we measure the following variables: the back of module (BOM) temperature using a PT100, the plane of array (POA) irradiance using a EKO MS-802F pyranometer, along with the maximum power electrical (MPP) values and the IV curves using the MPPT 3000 provided by SUPSI laboratory. Furthermore, on the tracker stand, the incident spectrum is also measured using two EKO spectroradiometers MS-710 and MS-712.

On the fixed stand (South oriented, variable tilt) two EKO MS-80 pyranometers have been added to measure front and rear irradiance on the POA.

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The Campbell Scientific CR1000 records the BOM temperature, POA irradiance, and MPP data every minute, while the spectrum data and IV curves are acquired every 10 minutes.

The employment of a portable station allows for the measurement of temperature coefficients and angles of incidence. The portable station collects data on horizontal and POA irradiance, temperatures, and module IV curves. In this case, a Campbell Scientific CR1000 records the data every 20 seconds.

Table 2: Uncertainties of the ESTER laboratory sensors

| **Parameter** | **Uncertainty** |
|---|---|
| Pyranometer irradiance | +/- 8% at 100 $Wm^{-2}$<br>+/- 3% at 1000 $Wm^{-2}$ |
| Pyrheliometer irradiance | +/- 2 % on hourly totals<br>+/- 1% on daily totals |
| Spectral irradiance | 15% for 335–450nm, 5% for 450–1600nm, 24% 16001700 nm |
| Reference cells irradiance | +/- 4% |
| Reference cell temperature | +/- 0.12°C at 25°C<br>+/- 0.15°C at 50°C |
| MPPT Voltage and Current | +/- 0.2% |
| MPPT Power | +/- 0.5% |
| PV Module temperature | +/- 0.16°C |
| Wind speed | Range: 0 to 60 m/s Accuracy: ±2% @ 12 m/s Resolution: 0.01 m/s |
| Wind direction | Range: 0º to 359° (no dead band) Accuracy: ±3° Resolution: 1° |
| Air temperature | +/-0.2 K |
| Relative Humidity | ±0.8 % |
| Rain gauge | 1% up to 120 mm/hr. |

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| Air pressure | Typically, less than 1.0 mbar. Max 3.0 mbar at 1000 mbar and 20 °C |

The measurement uncertainties relating to the instruments used at the station are shown in Tab. 2. All instruments apart from the spectroradiometer have been calibrated in July 2023.

### 2.1.2General Testing Procedure

ESTER Lab provides the instrumentation necessary to accept, characterise, and monitor the performance of photovoltaic panels. Each device will be connected to a MPPT3000 (ISAAC - SUPSI laboratory, 2011) device for tracking the maximum power point and plotting the IV curves at regular intervals. The use of this device is standard practice for commercial PV modules.

The data acquired automatically in the 24 hours will be as follows:

- Every minute the system will measure the following environmental and device parameters:
  1. solar radiation on the plane of the devices by means of a ventilated pyranometer;
  2. air temperature;
  3. wind speed and direction;
  4. components of solar radiation (direct, scattered, reflected);
  5. maximum current of the device;

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6. maximum voltage of the device;

7. maximum power of the device;

8. device temperature.

- Every ten minutes the system will measure:

1. all parameters previously mentioned in the per-minute capture;

2. I and V parameters related to the IV curve of the device (256 points);

3. short-circuit current of the device;

4. open-circuit voltage of the device.

The following details our testing procedure, which is divided into three phases.

Phase 1: PV panels acceptance

Phase 2: PV panels characterization

Phase 3: PV panels performance and degradation

At each phase, we carefully inspect various aspects related to the functionality of the panel.

- Phase 1: PV panels acceptance

In Phase 1, the primary objective is to conduct an initial technical, physical, and optical inspection and testing of the PV panels compatible with the weather conditions upon receiving them from the manufacturer. This inspection allows us to ensure that the panels meet the necessary quality standards and specifications before proceeding to further testing. Overall,

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the goal of Phase 1 is to guarantee that the PV panels are in good condition and meet the necessary quality standards to proceed with the subsequent testing phases. At this stage also the Bifacility coefficients will be evaluated.

By conducting a thorough physical, optical, and technical inspection, we can address any potential issues early on and ensure accurate and reliable performance evaluation throughout the testing process.

- Phase 2: PV panels characterization

This phase involves conducting a comprehensive analysis of the panels' parameters useful to identify the response of the device to the environmental variables. IV curves, temperature coefficients (response to temperature), parameter to evidence the spectral dependence and the Angle of Incidence (AOI) dependence will be investigated. These measurements will be carried out in real operating conditions, outdoor. Where necessary, the findings will be reported to standard test conditions (STC). This stage allows us to thoroughly understand the panels' capabilities and limitations, providing valuable insights into their potential performance in real-world conditions. By conducting this detailed analysis, we can gather essential data that will later be used to make accurate predictions and comparisons during performance monitoring and evaluation in Phase 3. ○ Phase 3: PV panels performance and degradation

In Phase 3, our focus shifts towards assessing the long-term performance and reliability of the photovoltaic (PV) panels. By following this approach, we can track the stability and performance of the panels under real environmental

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conditions, such as temperature fluctuations, varying light intensities, and exposure to different weather conditions.

The primary objective of Phase 3 is to evaluate the performance of the device in comparison with its monofacial counterpart. Moreover, by evaluating the panels' performance over an extended duration, we can gauge their ability to maintain consistent energy generation levels and assess any potential degradation or loss of efficiency over time. This information is crucial for understanding the panels' long-term reliability and durability, as well as for making informed decisions regarding their implementation and maintenance.

Through continuous monitoring and evaluation, we gain valuable insights into how the photovoltaic panels perform under real-world conditions. This data allows us to make more accurate predictions about their performance in specific environments and helps us identify potential areas for improvement.

### 2.1.3 Operative Procedures (PO) and Registration Documents (DR)

For all the measurement protocols in ESTER, we have established two series of documents: the protocols documents referred to as PO and the registration documents referred to as DR. Below, you will find a list of the PO and DR used specifically for the Bifacial PV protocols (see also Annexes).

Having protocols documents (PO) and registration documents (DR) is crucial in the testing of photovoltaic panels for multiple reasons: protocols documents establish

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a standardized set of procedures and guidelines, ensuring consistent and reproducible tests. This consistency is essential for obtaining reliable and comparable results across different testing sessions and laboratories, regardless of the operator or testing location. On the other hand, protocols documents outline specific methodologies and techniques to be followed during the testing process. They provide step-by-step instructions for conducting measurements, calibrations, and data collection accurately, adhering to industry best practices. Following these protocols minimizes the risk of errors or inaccuracies in the results. Additionally, registration documents serve as a record of the testing process and provide traceability for each tested panel. These documents include information such as the panel's test dates, test results, and any observations or comments. Having this documentation is crucial for tracking the history of each panel, identifying potential issues, and ensuring regulatory compliance.

List of Protocols Documents

| Document Number | Description |
| --- | --- |
| **PO – 01** | Measurement protocol for Bifacial PV outdoor testing |
| **PO – 02** | Mapping for device cell identification |
| **PO – 03** | IV curve translation protocol |

List of Registration Documents

| Document Number | Description |
| --- | --- |
| **DR-00 PO-01** | Device acceptance receipt |
| **DR-01 PO-01** | Device acceptance sheet |
| **DR-02 PO-01** | Device test sheet |
| **DR-03 PO-01** | Attachments |

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In the subsequent sections, we will provide more specific details and information about the three phases including the documents we use to track these steps, all the instruments used for this analysis and any performance evaluation techniques employed.

### 2.1.3 PV panels acceptance

The delivery of the Bi-facial PV panels shall be recorded on the appropriate form (DR-00 – PO-01).

The panels shall be subjected to an acceptance test, the results of which shall be recorded on the acceptance sheet attached to this Protocol (DR-01 – PO-01), including a report on the visual inspection of the material on receipt and a report on three functionality tests ○ Full functionality test

The full functionality test shall be carried out by orienting the units at normal solar incidence ± 5° at solar midday with optimum tilt towards the South on a clear and stable day (irradiance ≥ 800 W $m^{-2}$, irradiance variations within ± 1 %).

Under the above conditions, the IV curves are recorded and shifted to STC (the procedure is described in PO-03). The short-circuit current ($I_{sc}$), opencircuit voltage ($V_{oc}$) and maximum power ($P_{max}$) parameters are evaluated. ○ Front functionality test

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The front functionality test shall be carried out in the same position and irradiance conditions as the full functionality test. The rear side of the units shall be covered to evaluate the front side's monofacial functionality.

Under the above conditions, the IV curves are recorded and shifted to STC (the procedure is described in PO-03). The short-circuit current ($I_{sc}$), open-circuit voltage ($V_{oc}$) and maximum power ($P_{max}$) parameters are evaluated and compared with the values provided by the manufacturer.

- Rear functionality test

The rear functionality test shall be carried out in the same position and irradiance conditions as the two tests above. The units shall be flipped over compared to the previous test, so that the rear side is now exposed to sunlight, with the front side covered. This allows to evaluate the rear side's monofacial functionality.

Under the above conditions, the IV curves are recorded and shifted to STC (the procedure is described in PO-03). The short-circuit current ($I_{sc}$), opencircuit voltage ($V_{oc}$) and maximum power ($P_{max}$) parameters are evaluated.

The units will be equipped with a temperature sensor on the back for the duration of all three functionality tests.

The functionality tests are carried out in the manner described above, depending on the weather conditions that occur in the time window provided for this activity.

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The values of short-circuit current ($I_{sc}$), open-circuit voltage ($V_{oc}$) and maximum power ($P_{max}$) obtained for the front and rear sides shall be used to evaluate the following bifaciality coefficients:

$$\varphi_{Isc} = \frac{I_{scr}}{I_{scf}} \quad (1)$$

$$\varphi_{Voc} = \frac{V_{ocr}}{V_{ocf}} \quad (2)$$

$$\varphi_{Pmax} = \frac{P_{maxr}}{P_{maxf}} \quad (3)$$

where the *f* and *r* subscript refer to the front and rear side respectively. The value of these bifaciality coefficients shall be expressed as a percentage (IEC, 2019).

The visual inspection shall be accompanied by a photographic report and mapping of anomalies. The photographic report is included in the acceptance sheet.

Furthermore, a thermographic inspection shall be performed, the report of which shall be included in the acceptance sheet.

### 2.1.4 PV panels characterization

The performance of PV modules is affected by four phenomena: temperature, irradiance, spectral and reflection effects. They take into account the change of the

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modules efficiency at cell temperature, irradiance, spectrum, and angle of incidence (AOI) different from the Standard Test Conditions (STC): 25°C, 1000 W $m^{-2}$, AM1.5G and 0°. To evaluate these effects on the module performance it is necessary to evaluate the following parameters:

1. Temperature Coefficients (TC), temperature effect;
2. Mismatch factor (MMF), spectral effect;
3. Incidence Angle Modifier (IAM), angle of incidence effect;

- Temperature coefficients

The modules temperature coefficients will be measured in outdoor conditions following the CEI EN 61215 procedure (CEI, 2021).

The module is placed on the tracker stand to be at normal incidence. During a sunny day at plane of array irradiance G ≈ 1000 W $m^{-2}$, the module is completely shaded until the back of module temperature ($T_{bom}$) reaches the ambient temperature value. Then, the module is uncovered and the IV curves are recorded every 20 seconds until the $T_{bom}$ is stabilized. At the same time, also plane of array and horizontal irradiance, air and back of module temperature, wind speed are recorded.

- Mismatch factor

The Spectral Mismatch Factor (MMF) can be measured as (Pierro et al., 2015):

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$$\text{MMF} \cong \frac{(I_{sc}(AM)/G)}{I_{sc}0/G0}; \quad (4)$$

where $I_{sc}(AM)$ and $I_{sc0}$ are the short circuit currents measured at a specific AM and $AM = [1.45G\text{-}1.55G]$ and $G = [950\text{-}1050]\ W\ m^{-2}$, at $AOI = 0$, and corrected in temperature to translate them at $T_{cell} = 25°C$.

The module is placed on a tracker stand. The IV curve, the incident spectrum, the POA irradiance, together with the horizontal irradiance, the air and back of module temperature and wind speed and direction, relative humidity, diffuse and direct normal irradiance are recorded every ten minutes.

The minimum period to calculate the spectral mismatch fit coefficients is one month. MMF is then related to the spectral irradiance through the Average Photon Energy (APE) and AM.

- Incidence Angle Modifier

The angle of incidence effect on the PV module can be evaluated through the Incidence Angle Modifier (IAM) parameter that could be measured as (Pierro et al., 2015):

$$\text{IAM} = \frac{(I_{sc}(AOI)/G)}{I_{sc}0/G0}; \quad (5)$$

where $I_{sc}(AOI)$ and $I_{sc0}$ are the short circuit currents measured at a specific AOI and $AOI = 0$ corrected in temperature to translate them at $T_{cell} = 25°C$. Moreover, to avoid spectral influences all the current measurements should be done near AM1.5G.

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Thus, the module is placed on a stand with variable tilt ad orientation. A suitable orientation of the stand to provide AM near 1.5 is fixed and $I_{sc0}$ is measured at AOI = 0° and AM = 1.5G. The tilt is then changed, starting from AOI = 87° until AOI = 0°. For each angle, the IV curve together with the plane of array and horizontal irradiance, the air and back of module temperature and wind speed are recorded every 20 seconds, for 10 minutes. During the same 10 minutes also the diffuse and direct normal irradiance are recorded at a time rate of one minute. Finally, for each minute the 20 seconds measurements are averaged, and the data obtained are graphed with respect to the AOI.

### 2.1.3 PV panels performance and degradation ○

Performance test

The Performance test has the function of determining the performance of the units over an extended period of time. For this purpose, the units will be oriented towards the South with a 30° tilt angle (optimum angle to maximize yearly production at the ESTER lab latitude).

Phase 3 of the testing procedure will be carried out for a total period of one year. Degradation (D) and Performance (P) tests will be performed alternately and will provide information about the units' behaviour over time.

Measuring devices and sensors will be inspected and cleaned three times a week and the functioning of the acquisition system will be checked daily.

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PV systems of different configurations and at different locations can be readily compared by evaluating their normalised system performance indices such as yields and efficiencies. Yields are energy quantities normalised to rated power. Efficiencies are normalised to panel area (IEC, 2021). During the test the following parameters will be evaluated: PV panel yield ($Y_p$), Reference Yield ($Y_{ref}$) and Performance Ratio (PR). The panel yield $Y_p$ is defined as the annual, monthly, or daily net energy output of the PV panel per kW of installed PV panel (kWh/kWp).

The panel yield can be calculated as follows:

$$Y_p = \frac{E_p}{P_0} \quad \left[\frac{kWh}{kW_p}\right] \tag{6}$$

Where $E_p$ is the total energy produced by the panel in the reference time period and $P_0$ is the nominal power of the module. Reference yield is defined as the total irradiation divided by the reference irradiance ($G_{stc} = 1\ kW\ m^{-2}$). The reference yield can be expressed in unit of h and defined as:

$$Y_r = \frac{H_t}{G_{STC}} \quad [h] \tag{7}$$

where $H_t$ is total in-plane irradiation, kWh $m^{-2}$ and $G_{STC}$ is the irradiance at STC (1000 W $m^{-2}$).

The performance ratio (*PR*) is used to access the quality of PV module, which is widely reported on a daily, monthly, or yearly basis. *PR* is typically expressed in percentage and can be defined by the following equation as:

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$$PR = \frac{Y_p}{Y_r} = \frac{\eta_p}{\eta_0} \quad [-] \tag{8}$$

It represents the ratio of the efficiency of the panel in real operating conditions over the efficiency at STC.

The mentioned parameters can also be evaluated using the instantaneous value more than the energy values over a prescribed period of time.

For the calculation of PR for a bifacial module, it is necessary to consider the contribution of irradiance on the rear side of the module, which results in an increase in generated power. This calculation method follows the standard defined by IEC 61724-1 (IEC, 2021), where the additional irradiance contribution on the rear side of the PV modules is added to the global incident irradiance.

The IEC standard implies that the sum of front-side and backside irradiances should be considered and indicate that the bifaciality factor may be included in the definition as a multiplicative factor for the backside irradiance. Therefore, an equivalent value of irradiance GE is calculated as follows.

$$G_E = G_f + \varphi * G_r \tag{9}$$

$$\varphi = \min\{\varphi_{Isc}; \varphi_{Pmax}\} \tag{10}$$

$\varphi$ corresponds to the bifaciality factor, calculated as the minimum value between $\varphi_{Isc}$ and $\varphi_{Pmax}$, both of which are computed as defined by the IEC TS 60904-1-2 standard.

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This is why a correct value of the total in-plane irradiation ($H_t^{bi}$) is defined using the following formula.

$$H_t^{bi} = \sum_k [G_{Ek} * t_k] \quad (11)$$

From the definition of ($H_t^{bi}$), a reference yield $Y_r^{bi}$ is calculated, considering the additional component derived from rear irradiance, using the following formula.

$$Y_r^{bi} = \frac{H_t^{bi}}{G_{STC}} \left[\frac{kWh/m^2}{kW/m^2}\right] \quad (12)$$

Ultimately, we arrive at the conclusive Performance Ratio formula for bifacial modules, which is as follows.

$$PR^{bi} = \frac{Y_p}{Y_r^{bi}} \quad (13)$$

IEC standard 61724-1 (2021) suggests the use of the bifaciality factor in the calculation of GE, but also does not exclude the possibility of calculating it as a simple sum of the two irradiance contributions. This is the solution applied by PVSyst simulation software (PVSyst SA, 2021).

During this phase the abovementioned parameters will be evaluated starting from the power and irradiance collected measurements, considering the bifaciality of the PV modules under test. The parameters will be calculated on a minute, hourly, daily, monthly, and yearly basis. During the long term

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test a quantitative check of panels degradation will be carried out as described in the detailed section.

- Degradation test

  To assess the degradation of the units over time, Degradation tests will need to be performed before and after their outdoor exposure for a comparative analysis. These tests consist in orienting the units at normal solar incidence ± 5° at solar midday with optimum tilt towards the South, measuring their parameters for three days and obtaining the I-V curves.

Table 3: Performance and degradation tests timeline over the one-year test period. In yellow the period for degradation tests, in green the period for performance tests.

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**P&D tests timeline**

| Days | D | P | Days | D | P |
|---|---|---|---|---|---|
| 1 – 3 | | | 199 – 201 | | |
| 4 – 33 | | | 202 – 231 | | |
| 34 – 36 | | | 232 – 234 | | |
| 37 – 66 | | | 235 – 264 | | |
| 67 – 69 | | | 265 – 267 | | |
| 70 – 99 | | | 268 – 297 | | |
| 100 – 102 | | | 298 – 300 | | |
| 103 – 132 | | | 301 – 330 | | |
| 133 – 135 | | | 331 – 333 | | |
| 136 – 165 | | | 334 – 363 | | |
| 166 – 168 | | | 364 - 366 | | |
| 169 – 198 | | | | | |

Degradation tests will be carried out outdoors, so it is required to shift the resulting I-V curves to STC to render the test results comparable with each other (the procedure is described in PO-03). In this way, it will be possible to identify any variations in the characteristic parameters of the curves due to

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degradation. It is worth pointing out that this procedure cannot be considered as reliable as comparing I-V curves measured in indoor conditions under a solar simulator. However, it allows to test the variation of reference conditions without dismounting the devices.

The first Degradation test will take place before the start of the Performance tests and will serve as a reference for the units "as good as new". The following Degradation tests will be performed at the end of each Performance test. For each device, a device test sheet (DR-02 – PO-01) will be filled out where the characteristics of the test and any degradation information will be recorded.

A detailed timeline of the Performance and Degradation tests over the full one-year duration of Phase 3 of the testing procedure is shown in Tab. 3.

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## 2.2 Task 3.2 PV electrical monitoring in greenhouses (M6 – M34)

Task Leader: AZS; Participants: BOKU, HU, UTH, FSC, BW, UR

The electrical yields of the photovoltaic system of the responsive tracking systems with and without $CO_2$ enrichment added to the greenhouse will be measured in different locations. The electrical measurement protocol for the PV systems installed on the tracking systems inside the greenhouses as part of the REGACE project is prepared for two different groups:

- a data collection strategy for all locations and
- a data collection strategy for the AZS greenhouses, involving more detailed measurements.

The data collected will be used to carry out the following tasks, as listed in the project proposal:

- Task 3.2.1; AZS: A PV electrical performance testing and data collection protocol for the PV systems for all locations will be developed to collect the relevant data needed for WP4 and WP5.
- Task 3.2.2; AZS, UTH: Training of the researchers from each growing site to ensure the reproducibility of collected data on the ground.
- Task 3.2.3; AZS, UTH, BOKU, FSC, HU, BW: Data collection in all test locations.
- Task 3.2.4; AZS, UR: The ageing behaviour of the PVs in the greenhouse environments.

There are interactions between tasks 3.1 (outdoor PV module characterisation) and 3.2 (PV electrical monitoring in greenhouses) to compare the tracking systems PV modules in standard outdoor conditions compared to their installation on the TriSolar tracking system inside the greenhouses.

The collected data will also be used for work packages 4 (Digital Twins) and 5 (Validation) (Figs 1-2).

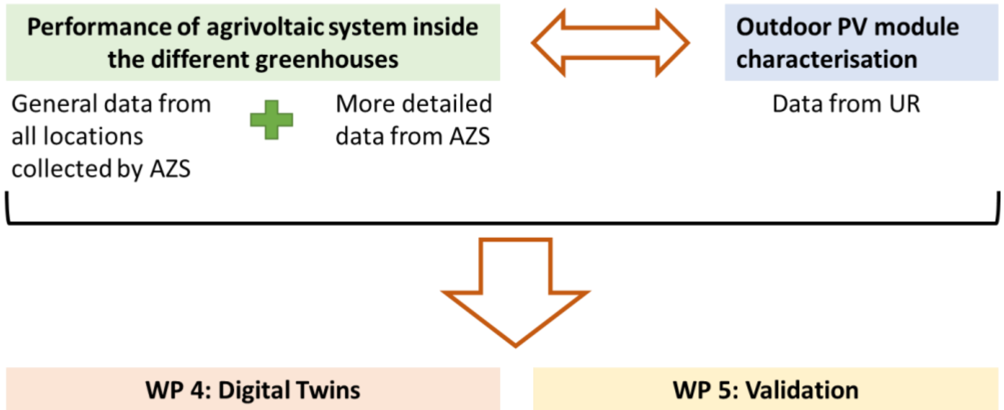


Fig. 1: Summary of data flow from PV electrical performance testing

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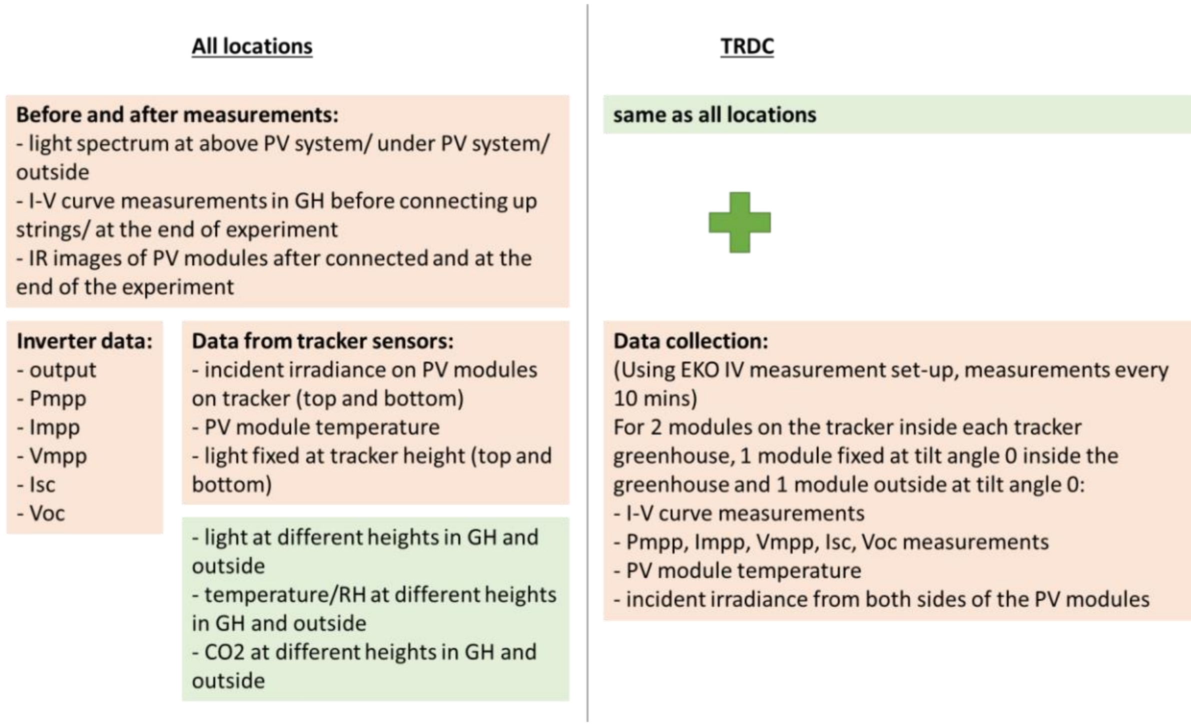


Fig. 2: Summary of Data collection strategy for PV electrical performance testing

The electrical performance of the modules will be measured in two different ways (Task 3.2.1):

1. In the first option, general output data will be collected from the webbox of the inverter at each location. This will supply overall output data of the system for each location. Additional sensors and dataloggers will be sent with the TriSolar tracking system to collect additional irradiance data and PV module temperature data in each location. A training session will be provided to a representative of each installation site to explain the measurement system and its components (Task 3.2.2). However, the data will be collected automatically using a datalogger and therefore will only need intervention in the event of a problem occurring with the measurement

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system or sensors. In addition, some measurements will be carried out to characterise a couple of PV modules at the time of installation in each location and at the end of the project. This task will be carried out by AZS.

2. In the second option, more detailed PV performance data will be collected at 10-minute intervals during daylight hours using an automated measurement and data collection system. This will only be carried out at AZS greenhouses in Israel, where the appropriate measurement equipment is available. These measurements will be compared with outdoor measurements taken as part of the PV module characterization at UR (task
3. 1).

In order to ensure the reproducibility of the collected data, training of the research groups will be performed for each growing site, which will be documented (Fig. 3) (Task 3.2.2; AZS).

| | | Trainee --Name | | | | | |
|---|---|---|---|---|---|---|---|
| SUBJECT | Trainer ORG+NAME | AZS | HU | UTH | BOKU | FSC | BW |
| Photovoltaics | AZS (E. Magadley) | | NN | NN | E. Cziszczon, N. Keutgen | NN | NN |
| Horicultural measurements | BOKU (N. Keutgen) | Alaa Haj-Yahya | NN | NN | | NN | NN |
| Microclimate | UTH (C. Papaioannou) | Madhat Matar | NN | | E. Cziszczon, N. Keutgen | NN | NN |
| $CO_2$ enrichment | HU (T. Rocksch) | Alhan Abasi | | NN | E. Cziszczon | NN | NN |

Fig. 3: Grid for the documentation of the training

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### 2.1.3 PV system measurements in all locations ○

Inverter data

All installation locations will include an inverter as part of the PV system installed. The data from the inverter will form part of the data collection method for the project. The same inverter type will be used in all locations to ensure ease of data collection and analysis. In addition, each tracker installation will include some additional light and module temperature sensors to evaluate the PV performance in each location.

The inverters installed at all installation sites will provide the following data for each string connected to the inverter (with and without $CO_2$ if tested):

-  Output (kWh), power at maximum power point ($P_{mpp}$) (W), current at maximum power point ($I_{mpp}$) (A), voltage at maximum power point ($V_{mpp}$) (V), short circuit current ($I_{sc}$) and open circuit voltage ($V_{oc}$) (V).

  This data will be collected continuously for specified intervals from each inverter. The data will be accessible on the inverter portal and downloaded periodically by AZS to analyse the data (Fig. 4).

Fig. 4: Example inverter data screen

(https://www.sma.de/en/products/monitoring-control/sunny-portal)

- Initial measurements (at installation) & end of project measurements

At least one member of the AZS team will be present at installation and will carry out the following measurements:

- A spectroradiometer will be used to measure the light spectrum outside the greenhouse, inside the greenhouse, and under the PV system inside the greenhouse.
- A couple of PV modules will be selected and marked for measurements before and after use in the tracking system. For these

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PV modules, IV measurements together with incident irradiance will be taken inside the greenhouse: to evaluate the module performance before and after use inside the greenhouse. A portable IV curve measurement device will be used for these measurements and the results will be converted to STC values.

- For the same two modules, photographic records before and after will provide information with respect to visual degradation of the PV panels and measurements of the panel temperature distribution will be taken using an IR camera to identify any defects or hot spots in the panels at the beginning and end of the measurement period.

Table 4: Equipment used for the measurements

| Parameter | Unit | Measuring instrument | Model |
| --- | --- | --- | --- |
| temperature T | °C | Infrared camera | Fluke TiS20+ |
| Current-Voltage I-V | A/V | Portable I-V checker | EKO MP-11 |
| Spectral irradiance | $W/m^2/nm$ | Spectroradiometer | EKO LS100 |

- Additional sensor data collection

In addition, each tracker installation will include some additional light and module temperature sensors to evaluate the PV performance in each location. These sensors will be provided by AZS together with the tracking system components.

Irradiance sensors will be installed on the tracking system to measure incident irradiance on the PV modules from above and below the panels. This

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enables the calculation of efficiency of the PV modules in the system when installed in the greenhouse. The installation of a fixed irradiance sensor at panel height inside the greenhouse and one outside the greenhouse to measure global horizontal irradiance (GHI), will enable a comparison of a fixed system inside and outside the greenhouse and the effect of the greenhouse cover on available light inside the greenhouse over time. PV module temperature sensors will also be included for a couple of modules installed in each location. These sensors will be part of the tracking system controller set-up and the data will be collected using the tracking system controller system. This enables similar data to be collected in all locations for ease of comparison. These sensors will be installed together with the tracking system in each location, and the data will be collected automatically every minute and remotely accessible via the TriSolar system data collection cloud.

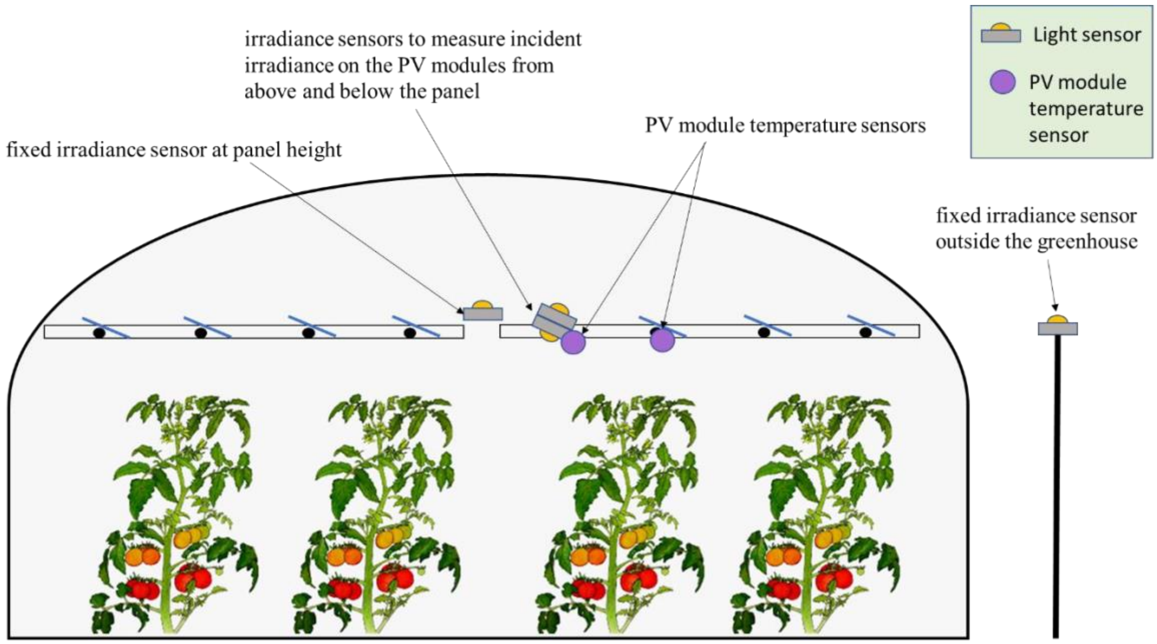


Fig. 5: Additional sensor locations for each installation location

Table 5: Equipment used for the measurements

| Parameter | | | Model |
| --- | --- | --- | --- |
| **Unit** | | | **Measuring instrument** |
| PV module temperature | °C | Flat probe temperature sensor | Shandong Renke RS-WS-2 |
| Irradiance | W/m$^2$ | Solar radiation sensor | RS-RA-N01 |

- Training

As detailed in task 3.2.2, a training session will be provided to each partner that has an installation site. The purpose of the training is for a member of the research team in each location to understand the measurement systems (inverter and additional sensors), in case of a problem. The data will be collected automatically by the measurement systems. However, this researcher will be the contact point for AZS in case of a problem with the electrical data collection described above. The training sessions will be

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carried out over zoom, straight after installation or in person at the installation location, if a member of the AZS team is present at installation.

### 2.1.3 Detailed measurements – Kfar Qara

At the AZ installation site, additional more detailed measurements will be carried out on module level to understand the PV performance in a greenhouse environment in more detail. These measurements will be carried out using the existing measurement set-up at AZ and is therefore not possible in the other locations where the appropriate equipment is not available (Fig. 6).

Fig. 6: PV I-V measurement system, including I-V measurement blocks, irradiance block and module temperature block

At AZS greenhouses, in addition to the above measurements the following measurements will be carried out on a PV module level rather than system level: current-voltage (I-V) curves, open circuit voltage, short circuit current, maximum power point, efficiency, fill factor, panel temperature and incident irradiance (on both sides of the bifacial modules). These measurements will be taken every

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minute, except for the I-V curve measurements that will be taken every 10 minutes. The I-V measurement system includes loads attached to the measured modules, to keep the PV modules at maximum power point in between measurements.

This system will measure a couple of PV modules mounted on each tracking system (with and without $CO_2$ enrichment), a module fixed at a tilt angle of 0˚ inside the greenhouse and a module at a tilt angle of 0˚ outside the greenhouses, giving detailed data on the module performance. The performance of the modules on the tracker can then be compared to modules in a fixed position, both inside and outside the greenhouse. The PV modules will be monitored throughout the project over a period of 24 months to evaluate their annual performance as well as their diurnal performance throughout the year. The effect of temperature, irradiance and humidity on the panels will also be investigated using the microclimate data collected from the AZS greenhouses.

A weather station next to the AZS greenhouses will measure ambient outdoor temperature, relative humidity, wind speed and direction and rain. It also includes a pyranometer and DNI sensor.

In addition, at the AZS site, weekly photographic records will provide information with respect to visual degradation of the PV panels. A thermal imaging camera will also be used to identify any localised shorts (hotspots). Changes in spectral transmittance of the glass parts of the panels will be measured using a spectroradiometer.

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To evaluate dust accumulation on the panels inside the greenhouse, their electrical performance and light transmittance through the glass parts of the panel will be recorded before and after cleaning of the modules.

Table 6: Equipment used for the measurements

| **Parameter** | **Unit** | **Measuring instrument** | **Model** |
|---|---|---|---|
| I-V curves of PV modules | A/V | I-V tracer | EKO PV blocks |
| Irradiance | $W/m^2$ | Silicon irradiance sensor | Si-mV-85 |
| PV module temperature | ˚C | PT-100 | EKO MP-Temp |
| DNI | $W/m^2$ | DNI sensor | EKO MS-90 |
| GHI Irradiance | $W/m^2$ | pyranometer | EKO MS-80S-E |
| Spectral irradiance | $W/m^2/nm$ | spectroradiometer | EKO LS-100 |
| PV module temperature distribution | ˚C | Infrared camera | Fluke TiS20+ |

### 2.1.3 Data evaluation

For evaluation of the TriSolar tracking system performance in the different locations with and without $CO_2$ enrichment and PV module degradation inside the greenhouses, the data will be compiled as shown below (Fig. 7).

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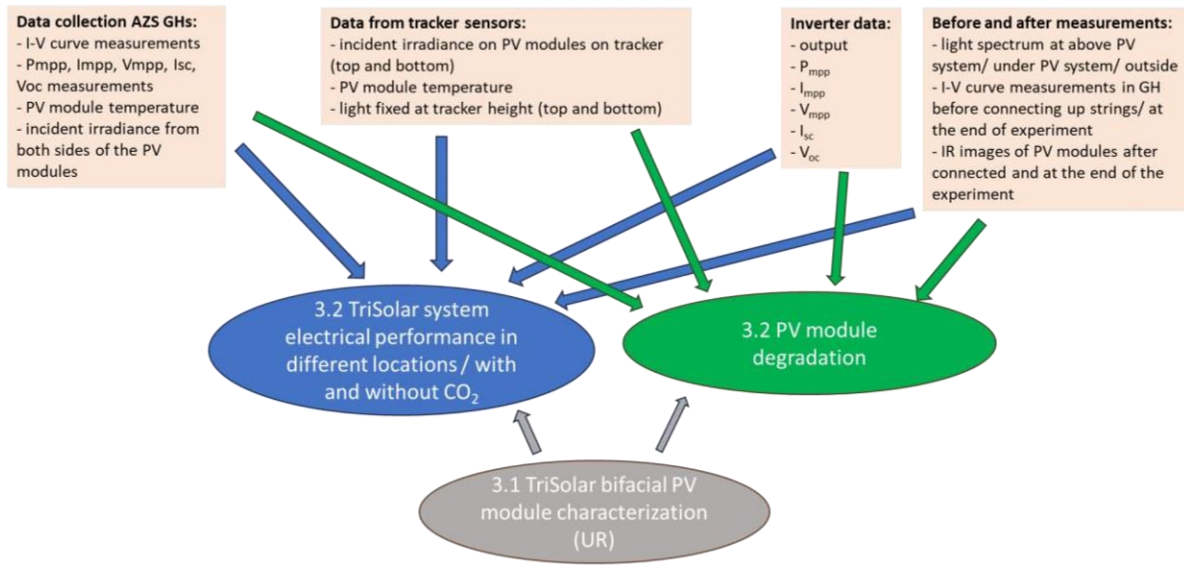


Fig. 7: Data flow diagram for task 3.2

The data collected using the above-described methods will be used to evaluate the system output and PV module performance and degradation inside the greenhouse.

In addition to the above measured values, efficiency and fill factor values will be calculated as follows:

- Efficiency (%), $\eta = P_{max} / (E \times A_c) \times 100$ ○ Fill factor, $FF = P_{max} / (V_{oc} \times I_{sc})$, where, $P_{max}$ = maximum power point (W), E = incident irradiance (W/m$^2$), $A_c$ = collector active area (m$^2$), $I_{sc}$ = short circuit current (A) and $V_{oc}$ = open circuit voltage (V).

System output data from the inverters in the different installation locations will enable yearly, monthly and daily output data to be compared for the different


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locations. In addition, a comparison of the different locations will be done by evaluating the yields and the performance ratios as described in the previous Task 3.1. This information will be used in WP5 Validation to evaluate the viability of the system for different climatic regions. The system data collected will be used in combination with energy demand data of the greenhouses to assess how much energy demand can be covered by the PV system and what times of day, month or year might require some storage or energy imports. The inverter data in combination with the additional irradiance sensor data in each location will be used to calculate system efficiencies. In addition, the amount of light available inside the greenhouse compared to outside and on the tracking system will be compared to understand the potential effect on output of the PV modules mounted on the TriSolar tracking system compared to other installation methods.

PV module performance data together with the data from the greenhouse microclimate measurements allow for assessment of the internal conditions of the greenhouse on the PV electrical output. This will be investigated in more detail in AZS greenhouses, where modules installed on the TriSolar tracker can be compared to ones installed outside the greenhouse in the same location. The installation of a couple of modules outside the greenhouse will also allow for a comparison of any degradation rates of the modules in both installation locations (inside and outside the greenhouse). Changes in module/system efficiency and fill factor will be monitored over the project time to identify any changes and thermal imaging will indicate the formation of any hot spots.

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PV module performance data will be collected at all test locations (Task 3.2.3; AZS, UTH, BOKU, FSC, HU, BW) in line with the planned cultivation (Task 3.4) and also in times that are unsuitable for cultivation. In the control greenhouse without PVs the consumed energy will we recorded. For comparison in the test greenhouse with PVs in addition to the energy consumed, the energy produced by the solar panels in the greenhouse is recorded in order to assess, whether energy supplementation is needed in order to sustain the yields. This might not be possible at all localities due to the arrangement of the measuring devices for determining consumption in accordance with local requirements (e.g. BOKU), or simply, because the greenhouse does not consume electricity (AZS). Preferably, the data should be summarized and delivered for further analyses to TAU at the end of each growing season (2-3 times per year).

## 2.3 Task 3.3 Greenhouse microclimate measurements inside the greenhouses (M6 – M34)

Task Leader UTH; Participants: AZS, BOKU, HU, FSC, BW

2.3.1 Climate related parameters affecting crop performance in a greenhouse ○

Solar radiation

Solar radiation is the most important parameter related to crop development and production and can be measured by pyranometers in the range of total (400-1100 or 2800 nm) or photosynthetically active radiation (PAR 400-700 nm). An accuracy of 5-10 W $m^{-2}$ would be appropriate for the above parameter taking into account that the maximum total solar radiation

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during summer inside the greenhouse could be around 750 W $m^{-2}$. It has to be noted that the distribution of solar radiation inside the greenhouse can be considered as uniform and one or two sensors can give a clear view of the solar radiation level in the greenhouse environment.

- Air temperature

Temperature is the most important parameter of the greenhouse climate that has to be recorded and controlled. The majority of plants grown in greenhouses are warm-season species adapted to average temperatures of the range 17-27 °C, with no negative effect on yield and quality between the range of mean monthly minimum and maximum values of 12 and 32 °C. However, optimal control of air and crop temperature in the greenhouse environment is very important not only for the maximisation of crop production but also for the reduction of energy inputs (heating and cooling) in greenhouses.

Temperature and irradiation conditions during fruit development greatly influence fruit development and quality. Chronic mild heat stress limits pollen release and fruit set (Sato et al., 2000). After fruit set, fruit growth is also strongly related to fruit temperature (Pearce et al., 1993). Temperature may influence the distribution of photoassimilates between fruits and vegetative parts (Dorais et al., 2001). During fruit maturation, changes in fruit temperature can affect carotenoid and vitamin C biosynthesis (Liptay et al., 1986).

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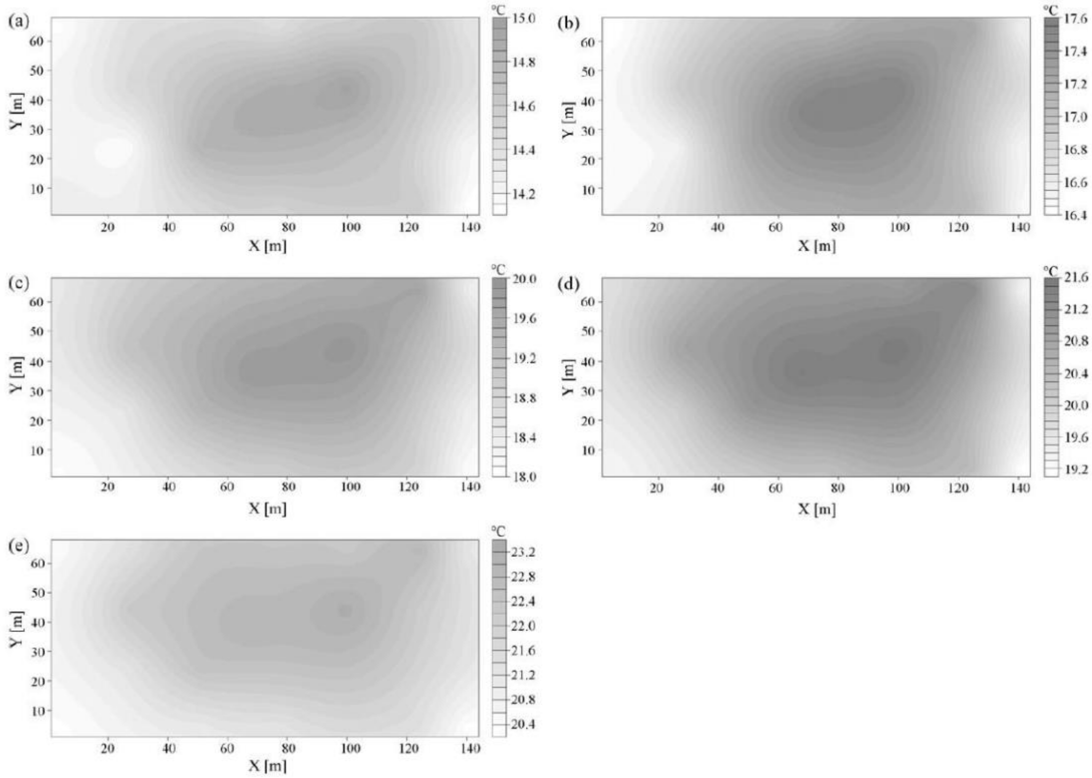


Fig. 8: Greenhouse temperature distribution maps as a function of outside global radiation levels: (a) 177, (b) 177–381, (c) 381–567, (d) 567–753 and (e) >753 W $m^{-2}$; maps represent horizontal distribution at 1.5 m height above soil surface; the semivariogram was fitted to the spherical model and prediction for unsampled locations were performed by block ordinary kriging technique. Average temperatures for sampled grid points are (a) 14.5, (b) 17.0, (c) 19.1, (d) 20.5 and (e) 21.8 °C, respectively (Bojaca et al., 2009)

Bojaca et al. (2009) used 25 temperature sensors to monitor the air temperature in 1 ha greenhouse and produced the temperature distribution maps shown in Fig. 8. Then, they used a crop growth model to model the

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growth performance of a tomato crop and produced the final fruit weight maps shown in Fig. 9.

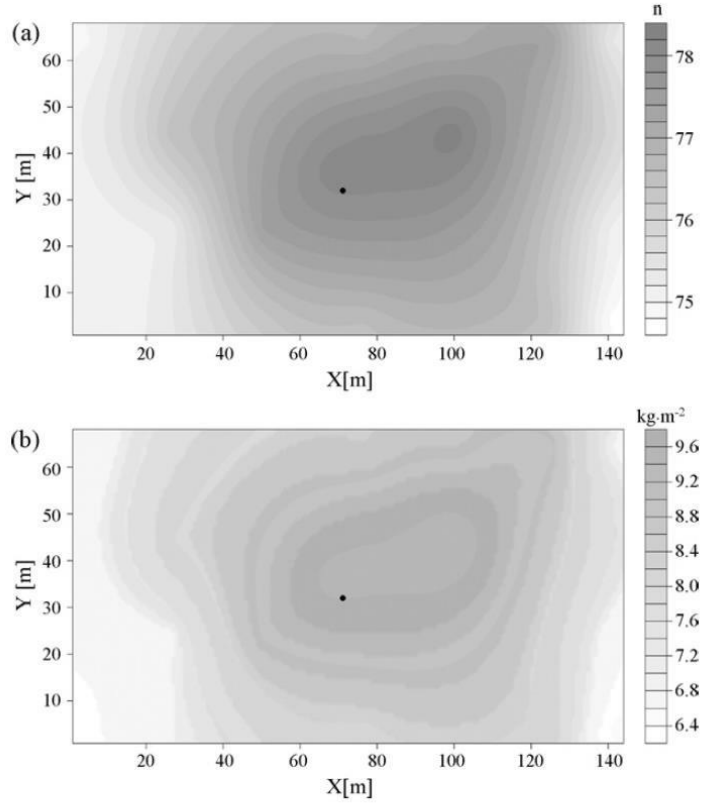


Fig. 9: Simulated final nodes number per plant (a) and final fruit fresh weight (b) distribution maps (Bojaca et al., 2009).

They observed average temperature differences of 1 °C at radiation intensities below 170 W m$^{-2}$ (Fig. 8a), but when the global radiation reached levels above 750 W m$^{-2}$, average temperature variations were as high as 2.2 °C (Fig. 8e). A consistent temperature distribution pattern can be observed for all the prediction maps. Higher temperatures were predicted around the centre, but with a little displacement to the top left zone of the greenhouse.

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Cooler zones were established near the greenhouse walls. The temperature differences between extreme locations, although only 1 °C higher during the day, can potentially determine differential behaviours on plant growth and development.

The warmer zone of the greenhouse registered the highest yields with a maximum of 9.7 kg $m^{-2}$. This result represents an increment of 3.3 kg $m^{-2}$ in comparison with the cooler zones of the greenhouse. An important difference of 34.5% in production was determined between the points where maximum and minimum yields were achieved according to the simulations.

Except the above effects, the greenhouse air temperature inside the greenhouse is related to the greenhouse heating cost, since the latter is related to the inside to outside air temperature difference, to the greenhouse heat loss coefficient and the greenhouse cover area. Accordingly, accurate measurement and control of the greenhouse air temperature is necessary. It could be shown that for a temperature difference between inside and outside air of 0.5ºC, the energy needed to heat a 1 ha polyethylene covered greenhouse during 24 hours is about 4000 MJ. If the greenhouse heating is performed using diesel as a fuel, it can be estimated that about 100 kg of diesel are needed for the above heating energy needs, which may cost more than 150 euro per day.

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Accordingly, it is important to accurately monitor and control the greenhouse air temperature in the greenhouse with an acceptable accuracy in air temperature measurement of at least 0.20 °C to 0.15 °C or higher.

With respect to the number of sensors needed for an accurate measurement of the greenhouse air temperature distribution in the greenhouse, it has been shown that with about 20 sensors per ha the uncertainty in temperature measurement is about 0.5 °C (Balendonck et al., 2011, 2013). ○ Air relative humidity

The third important variable of the greenhouse climate is the air relative humidity.

Relative humidity values within the range 60-90% have little effect on plants (Grange and Hand, 1987). Values below 60% may occur during ventilation in arid and semi-arid climates, or when plants are young with small leaves, and this can cause water stress. Serious problems can also occur if the relative humidity exceeds 95% for long periods, particularly at night as this favours the rapid development of fungal diseases e.g. *Botrytis cinerea* (O'Neill et al., 1997). The increased interest in maintaining adequate transpiration to avoid problems associated with calcium deficiency has resulted in humidity being expressed in terms of the vapour pressure deficit (VPD) or the moisture deficit, both of which are directly related to transpiration. Maintaining the VPD above some minimum value helps to ensure adequate transpiration and also reduces disease problems.

Since the problem of Botrytis is usually the most important problem related to greenhouse air humidity control and is usually one of the most important problems in the greenhouse related to humidity control, an accuracy of about 3% in humidity measurements is needed at the total range of air relative humidity, but especially on the range between 90% and 97%. Concerning the density of relative humidity sensors, this will have to be in accordance with the air temperature sensors.

- Air velocity and direction

A fourth characteristic of the greenhouse air, which is also very important for the greenhouse climate and its distribution, is air velocity. The air velocity inside the greenhouse does not only affect the convective heat exchanges of the greenhouse air with the cover and the soil, but also the energetic and physiological behaviour of the canopy, and more precisely the sensible and latent heat fluxes exchanged between the canopy and the internal atmosphere at the canopy level (Kittas et al., 2001).

Thus, measurement of air velocity in the greenhouse would also help in regulating irrigation in the greenhouse, since the air velocity is related to crop transpiration. Furthermore, air velocity is also related to the relation of the air relative humidity in the air and at the leaf level. Consequently, the higher the air velocity, the lower the difference between greenhouse air and leaf boundary layer air relative humidity.

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Since the air velocity inside the greenhouse is relatively low (between 0.05 and 1 m $s^{-1}$) a high accuracy in the measuring devises is needed of the level of 0.05 m $s^{-1}$ or higher.

- $CO_2$-concentration

Finally, the last greenhouse environmental parameter important to be measured would be the $CO_2$-concentration, since it affects an important crop process, the crop photosynthesis. Many research papers have demonstrated the beneficial effects of atmospheric $CO_2$ enrichment in greenhouse crop production (Long et al., 2004). The current ambient level of atmospheric $CO_2$ (about 420 ppm in 2022) is a limiting factor for maximum photosynthesis (Tolbert & Zelitch, 1983). Therefore, any increase in $CO_2$ above the ambient level has the potential to increase the rate of photosynthesis, especially in $C_3$-plants. This increased rate of photosynthesis will directly affect plant growth (Yelle et al., 1990; Lawlor & Mitchell, 1991; Islam et al., 1996; Das et al., 2000).

At one time it was a common practice to enrich greenhouses to 2000-3000 ppm $CO_2$, because it was believed that the higher the concentration the better. Later, a $CO_2$-concentration of 1000-1500 ppm was recommended. In the last few years, it has been shown in a number of experiments that concentrations above 900 ppm very rarely have any beneficial effect (Heij & Uffelen, 1984; Mortensen & Ulsaker, 1985). For most species, it is impossible to give the exact optimal $CO_2$-concentration, because most experiments with $CO_2$ enrichment include only a few $CO_2$-concentrations. However, from the

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literature, it might be concluded that the optimal $CO_2$-concentration for plant growth lies between 600 and 900 ppm for most species.

Taking into account the above, an accuracy of 30-20 ppm would be appropriate for optimal control and modelling of greenhouse crop photosynthesis and production. Concerning the density of sensors, information in literature is limited, but we consider that a density of 5 sensors per hectare will be appropriate. At least one $CO_2$-sensor should be situated near the ground, a second between 1.5 – 2.0 m above, preferably at medium plant hight.

### 2.3.2 Evaluation of the effect of tracking PV panels on microclimate conditions and crop performance

In the framework of Work Package 3 (WP3) of the REGACE project, UTH will evaluate the effect of tracking PV panels mounted above the crop on microclimate conditions and crop performance inside a greenhouse.

The experiments will take place at the greenhouse park of UTH facilities at Velestino, central Greece (N 39° 54’ 43’’, E 22° 37’ 21’’, alt 65 m), in a commercial scale multispan Gothic greenhouse, consisting of six separated compartments, each of which with an area of 240 $m^2$ (9.60 m x 25.00 m), gutter height at 4.00 m and top at 6.20 m (Fig. 10).

Three separate greenhouse compartments will be used for the three treatments of the project:

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1. Treatment 1 - Greenhouse compartment 1: Control treatment, where only the crop is cultivated.
2. Treatment 2 - Greenhouse compartment 2: PV tracking system mounted above the crop, no $CO_2$ enrichment.
3. Treatment 3 - Greenhouse compartment 3: PV tracking system mounted above the crop, $CO_2$ enrichment.

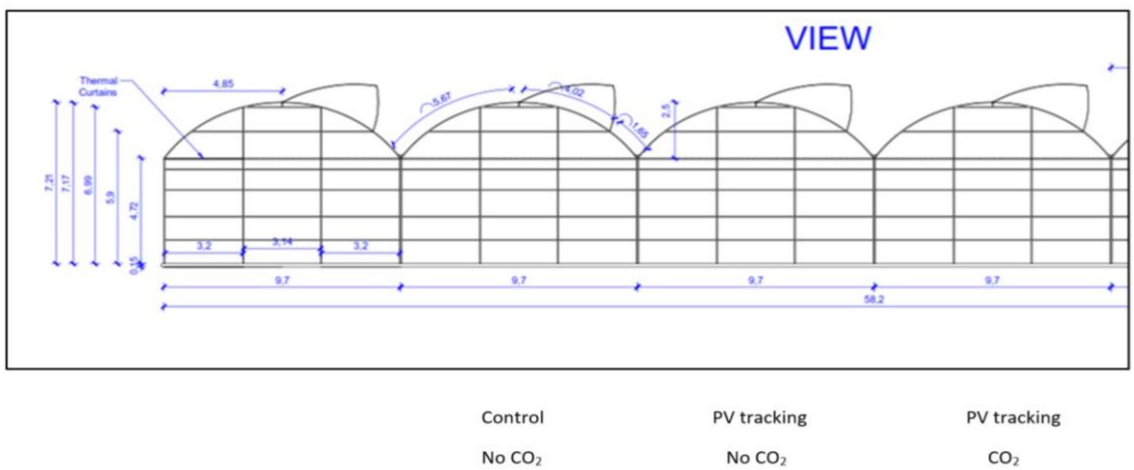


Fig. 10: Section view from the multi-tunnel Gothic type greenhouse at the greenhouse park of UTH at Velestino, central Greece. Three separate compartments will be used for the three treatments of the project. Compartment 1: Control treatment – no PVs, no $CO_2$ enrichment; Compartment 2: PV tracking – no $CO_2$ enrichment; Compartment 3 - PV tracking – $CO_2$ enrichment.

### 2.3.3. Hydroponic greenhouse cultivation at UTH

A two-period experiment will be conducted in each greenhouse compartment for the three treatments of the project. Cucumber and lettuce are selected as crops under investigation. The cultivation will be hydroponic, where cucumber and

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lettuce plants will grow on perlite slabs on hydroponic channels (Fig. 11), pruned in one stem cultivation system. Water and nutrition supply will be managed automatically and drainages will be reused (closed hydroponic system).

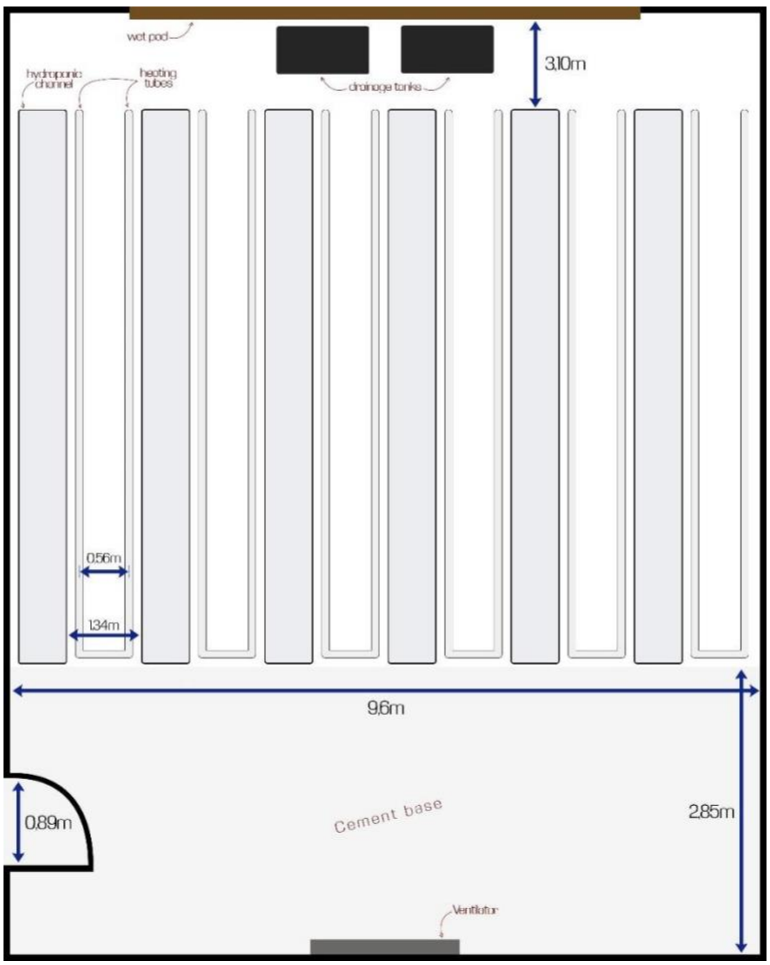


Fig. 11: Plan view of a greenhouse compartment showing the position of the hydroponic slabs and the hydroponic channels.

A series of measurements regarding the morphological and physiological parameters of the cucumber and lettuce crops will take place during cultivation periods. The plant height, the number of leaves, flowering height, number and size of flowering clusters or flowers, fruit set, the number of fruits, and the leaf area index (LAI) will be determined on a weekly basis, in addition to the final yield (kg $m^{-2}$), as well as the deficiencies, pests and diseases. Moreover, the photosynthetically active radiation (PAR) will be measured once per week using the LCpro T (ADC Bioscientific Ltd., Hoddesdon, Hertfordshire) instrument.

Measurements of the spectral transmittance of the cover material will be executed in the laboratory using a portable spectroradiometer equipped with a 10 W glass halogen lamp and an external integrating sphere internally coated with barium sulphate. After the installation on the greenhouse roof, measurements will be taken throughout the experimental period by means of a portable spectroradiometer.

The electrical consumed energy will be measured in UTH greenhouses in two levels, in the main switchboard and in the secondary switchboard feeding the individual machines.

In the main electrical switchboard, a three-phase power analyser will be installed in parallel with a set of one sub-metering kit equipped with one transmitter and 3 current sensors.

The main switchboard feeds five (5) chambers. From them the three chambers will be used for the REGACE project measurements (one will be equipped with PV and $CO_2$ injection system, one equipped only with PV and one will be the conventional cultivation without PV and/or $CO_2$ injection system). In these three chambers the basic energy consumption devices are:

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a) one ventilation fan in each chamber,
b) one opening motor in each chamber,
c) one curtain motor in each chamber,
d) an oil burner for hot water preparation for heating for the whole greenhouse,
e) a circulation pump for the hot water for the whole greenhouse,
f) a fertigation system with different pumps for each chamber,
g) a water pump for the evaporative pad system for the whole greenhouse and
h) a dc motor for the evaporative pad flap.

These devices are distributed in 5 sub-switchboards. So, the individual devices consumption will be measured in the sub-switchboards.

In the ventilation fans sub-switchboard, the 3 3P fans and the 3P evaporative pad pump will be measured. In the two sub- switchboards feeding the opening and curtain motors 6 1P motors will be measured (two for each chamber). In the DC sub-switchboard, the evaporative pad flap motor will be measured. In the fertigation system sub-switchboard, the 3P switchboard feeding will be measured. This corresponds to the irrigation as well as to the preparation of the feeding mixture. Since there is monitoring of the feeding mixture pumps operation it will be able to assess the consumption of the three chambers from the whole system consumption. Finally in the boiler sub-switchboard the electrical energy consumed for heating will be measured as a whole since this switchboard feed the circulation pump and the burner.

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For the measurement a wireless ‘efergy’ architecture will be used consisted by 1 sub-metering kit for every five transmitters. The sub-metering kit sends through internet the measured data in a ‘efergy’ center. These data can be downloaded with a friendly user interface application via a simple web browser. There will be one energy monitoring transmitter (Efergy Elite E2 type) for each 3P or 1P consumption which will send wirelessly the measured consumption. Finally, the in each consumption line 3 sensors in the case of 3P consumption and 1 sensor in the case of 1P consumption will measure the electrical current.

### 2.3.4 Climate related parameters measurements

In order to evaluate the effect of tracking PV panels mounted above the crop on microclimate conditions and crop performance, a monitoring system consisting of sensors recording climate-related parameters and data loggers collecting the data will be used.

The following climatic parameters will be measured inside and outside the greenhouse compartments:

- Global radiation (Rs, in W $m^{-2}$) by means of pyranometers connected to a sensor node/data logger.
- Air temperature (T, in °C), Air Relative Humidity (RH, in %) and $CO_2$-concentration (C, in %) by means of temperature, humidity and carbon dioxide sensors in a sensor node/data logger.

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- Air velocity and air direction (Ws, in m $s^{-1}$ and WD, in Rad, respectively) by means of an Ultrasonic Wind Speed & Direction sensor connected to a sensor node/data logger.

All the above-mentioned nodes/data loggers will be connected to a gateway connected with the cloud, showing the data online in real-time in a web-based database.

### 2.3.5 Sensor's and Data logger's specification characteristics

- Irradiance sensors

  SP Lite2 (KIPP & ZONEN, the Netherlands) pyranometers located above and below the PV tracking systems and outside the greenhouse, connected to a sensor node/data logger.

  Specifications of the SP Lite2:

  - Spectral range (overall): 400 to 1100 nm
  - Sensitivity: 60 to 100 µV $W^{-1}$ $m^{-2}$
  - Response time (95%): < 500 ns
  - Directional response (up to 80° with 1000 W $m^{-2}$ beam): < 10 W $m^{-2}$
  - Temperature response: < -0.15 % $°C^{-1}$
  - Operational temperature range: -40 to +80 °C
  - Maximum solar irradiance: 2000 W $m^{-2}$  Field of view: 180°.

- Temperature, humidity and carbon dioxide ($CO_2$) data logger

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LoRaWAN (DELTA OHM, Italy) temperature, humidity, and carbon dioxide ($CO_2$) node/data logger. The sensors are all inside a housing. Temperature sensor integrated in the RH Module.

Measuring ranges:

- Temperature: -40 to +105 °C
- Relative humidity: 0 to 100% RH
- $CO_2$: 0 to 5.000 ppm
- Instrument operating temperature / humidity:
  -10 to +70 °C / 0 to 85% RH.

Calculated quantities: dew point, wet bulb temperature, absolute humidity, mixing ratio, partial vapour pressure. Min. 44,000/ Max. 120,000 samples.

Supplied with 3.6 V non-rechargeable Li-SOCL2 battery and HD 35.

- Air velocity and air direction sensor

RK 120-07 (RIKA, China) ultrasonic wind speed & direction sensor.

RK 120-07 uses the time difference of ultrasonic wave on the air to measure the wind speed and direction. RK 120-07 uses a low-power chip with low power consumption of only 0.2 W, which is especially suitable for a solar or battery powered environment with high power consumption requirements.

- Power supply: 12-24 V DC
- Power consumption: 1.7 W

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- Output signal: 4-20 mA
- Operating temperature: -30 to +60 °C
- Dimension: F82*108 mm

Table 7: Characterisation of the air velocity and air direction sensor

| **Item** | **Range** | **Resolution** | **Accuracy** |
|---|---|---|---|
| Wind Speed | 0-40 m s$^{-1}$ | 0.1 m s$^{-1}$ | +/- 3% |
| Wind Direction | 360˚ | 1˚ | +/- 3% |
| Starting Threshold | 0.1 m s$^{-1}$ | 0.1 m s$^{-1}$ | |
| Extreme Wind Speed | | 60 m s$^{-1}$ | |

- Data logger with four terminal header inputs

  LoRaWAN (DELTA OHM, Italy) data logger with four terminal header inputs for the connection of:

  - transmitters with 0 ÷ 20 mA, 4 ÷ 20 mA, 0 ÷ 1 / 0 ÷ 10 V or 0 ÷ 50 / -50 ÷ 50 mV output,
  - Pt100/Pt1000 sensors K, J, cT, N, E thermocouples,  Sensors with voltage free contact output (max, one sensor)  Potensiometric sensors.

  Min. 28,000 / Max. 58,000 samples.

  Instrument operating temperature / Humidity:

  -20 to +70 °C / 0 to 100% RH.

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Supplied with 3.6 V non rechargeable Li-SOCL2 battery.

### 2.3.6 Measurements points in the greenhouse

For the three treatments at the relevant greenhouse compartments, the sensors will be placed at 8 measurement positions as follows (Fig. 12):

1. Treatment 1 - Greenhouse compartment 1: Control treatment. One measurement position at the centre of the greenhouse, monitoring Rs, T, RH, C, Ws and WD.
2. Treatment 2 - Greenhouse compartment 2: PV tracking system mounted above the crop, no $CO_2$ enrichment. One measurement position at the centre of the greenhouse, monitoring Rs, T, RH, C, Ws and WD. Additionally, solar radiation will be measured above the PV tracking system with an additional pyranometer.
3. Treatment 3 - Greenhouse compartment 3: PV tracking system mounted above the crop, $CO_2$ enrichment. Six measurement positions monitoring Rs, T, RH, C, Ws and WD, in the following cross arrangement: on the long side of the axis of the greenhouse, one measurement position in front of the evaporative pad, two measurement positions in the centre of the green house at two height levels and one measurement position in front of the fan, and on the short side of the axis of the greenhouse, one measurement position to the left of the center points and one measurement position to the right of the center points. Additionally, solar radiation will be measured above the PV tracking system with an additional pyranometer.

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Finally, a set of sensors will be placed outside the greenhouse measuring Rs, T, RH, C, Ws and WD.

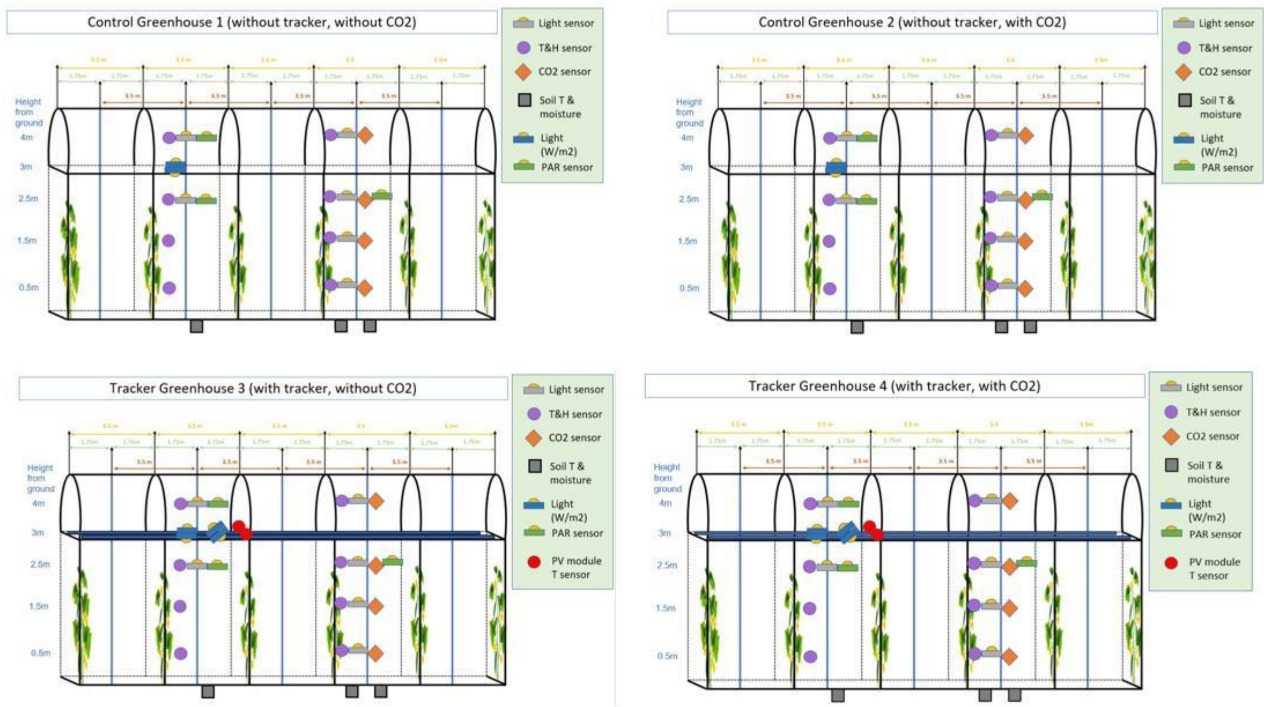


Fig. 12: Sensor layout for greenhouse microclimate monitoring at AZS

## 2.3.7 Training

Training of the researchers from each growing side will be performed by Zoom to the extend necessary to ensure the reproducibility of the locally collected data (Task 3.3.2; UTH).

## 2.3.8 Literature cited

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## 2.4 Task 3.4 Crop monitoring inside the greenhouses (M6 – M34)

Task Leader: BOKU; Participants: AZS, HU, FSC, BW,

Crops are selected based on the experience of the local stations ("typically grown") based on the daily light integral ideally for a year-round production. Cultivars with high and low light demand are selected and the cultivation of similar cultivars for all or most localities is considered in order to receive comparable data sets (though this is not the main goal of the study, but an optimized cultivation practice under the local conditions). The following crop plants are considered by the partners (Fig. 13) as locally typical:

- AZS: cucumber, bell pepper (two polytunnel greenhouses) ○ FSC: courgette, lettuce, melon, cucumber (farming greenhouse) ○ UTH: cucumber, lettuce (greenhouses; hydroponics)
- HU (& BW): lettuce, tomato, cucumber, basil (phytobox & farming greenhouses) ○ BOKU: basil, bell pepper, cucumber (greenhouse)

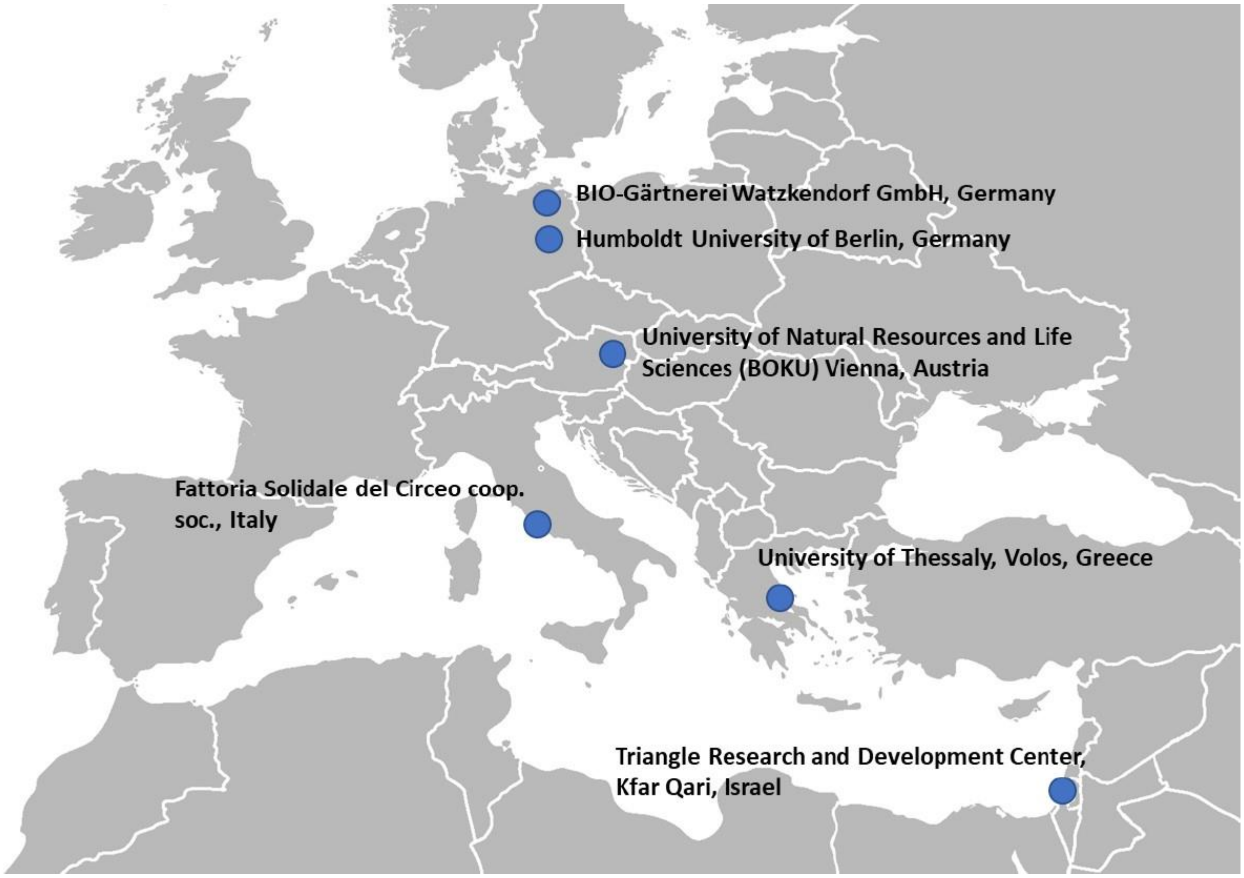


Fig. 13: Locations of REGACE experimental greenhouses

The experiments will start when the PVs are installed and commenced as long as the local conditions (decisive factor is temperature) allow cultivation. The results will be submitted to the task leader (BOKU) by each partner immediately after the cultivation of a crop is finished. Locally (BOKU) selected questions will be studied applying shading nets in order to simulate the effects of reduced light intensities. Depending on the local conditions, crops will be cultivated in the local soil, in pots (9-11 cm diameter, eventually larger depending on the crop) with the locally preferred growing medium, for instance rock wool slabs or alternative substrate

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slabs (coconut fiber, sphagnum), or garden soil (Task 3.4.1; BOKU under consultation with each partner).

### 2.4.1 Data collection strategy and crop monitoring protocols

The crop monitoring protocols have been established for basil, courgette, fruit vegetables (tomato, cucumber, bell & chili pepper), lettuce, and melon and are attached to this report (see Annexes). Following the crop monitoring protocol, five steps can be distinguished (Task 3.4.2; BOKU):

- The first data set represents the variety information, which is normally given together with the seeds or seedlings. It should be recorded immediately.
- The second data set covers the general growing parameters, such as planting date and density, substrate, harvest date, plant protection treatments. These should be recorded on demand.
- The third data set evaluates the appearance of the plant on the field. These data cover aspects such as plant growth vigour and vitality, uniformity of growth in the stand, leaf mass and colour, flower and fruit set, fruit ripening, appearance of pests, diseases and insects. These as well shall be recorded on demand, latest at harvest.
- Finally, the produce will be evaluated at harvest by recording the amount harvested, Ø weight of individual plant or fruit, uniformity of the fruit size and form, fruit/plant colouring, appearance of spots/spoiled produce, cause of non-marketable fruits, Brix measurements when possible.

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The partners will be trained by BOKU personnel on demand via Zoom. In the case of questions for certain crops, this is considered most effective at the beginning of the culture (Task 3.4.3; BOKU).

### 2.4.2 Growth analysis

Selected partners (BOKU, HU, AZS) will participate in growth analyses in order to quantify crop performance. However, the plant height, the number of leaves, flowering height, number and size of flowering clusters or flowers, fruit set, the number of fruits, and the leaf area index (LAI) will be determined on a weekly basis, in addition to the final yield (kg $m^{-2}$), as well as the deficiencies, pests and diseases by all partners. Photo-documentation will be performed on a weekly basis as well. Weight measurements have to be performed in different scaling, requiring different kinds of balances. For growth analyses single plants (5-14 individuals per variant depending on availability and sampling interval) have to be separated into root, stems, leaves and fruits. Fresh and dry weight of these fractions have to be determined with a balance. For the assessment of final yield, fresh weight of the harvested compound(s) should be expressed per $m^2$ – even in case the fruits are sampled over a longer period of time. The larger the sampled area (in the centre of the cultivation area) the better, but a minimum of 2 $m^2$ is required. The following parameters will be measured in case of the more detailed growth analysis:

- Plant height [m]
- Stem diameter at the basis [cm] ○ Canopy diameter [m] ○ Leaf number [--]
- Leaf area [$cm^2$]

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- Leaf area index (LAI) [--] = one-sided green leaf area per unit ground surface area [$m^2/m^2$] in broadleaf canopies
- Specific leaf area (SLA) = amount of leaf area per unit of leaf dry mass [$m^2$ $kg^{-1}$]
- leaf weight ratio (LWR) = leaf dry weight per plant dry weight [kg $kg^{-1}$]; this measurement in fact is part of the dry weight ratios, which are the dry weights of each plant organ relative to plant dry weight.
- Calculating dry weight ratios of roots, stems and fruits is also necessary in order to assess plant's vegetative-generative balance. The "fresh" (see above) and dry weight of leaves shed during the measuring interval per plant must be recorded as well.
- Leaf area ratio LAR = SLA x LWR [$m^2$ $kg^{-1}$]
- Net assimilation rate (NAR) = net increment in plant dry mass per unit of mean leaf area during the experiment [kg $m^{-2}$ $days^{-1}$]
- Absolute growth rate (AGR) = $(DM_2\text{-}DM_1)/(t_2\text{-}t_1)$, where $DM_2$ and $DM_1$ are the mass of the plant at time $t_2$ and $t_1$, respectively [kg $days^{-1}$]
- Relative growth rate (RGR) may be calculated from the dry mass difference at the beginning ($DM_1$) and end ($DM_2$) assuming an exponential growth of the plants: RGR = $(Ln(DM_2) – Ln(DM_1))/(t_2\text{-}t_1)$; another definition of RGR = LAR x NAR [kg $m^{-2}$ $days^{-1}$]
- For the determination of leaf area, a "simple" method is suggested:

  Leaf area determination: Leaf area ($cm^2$) can be recorded as follows:

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1. Option: Destructive analysis as harvesting of leaves is necessary

   The leaves can be placed on a photocopier. The resulting copies of the leaves shall be cut out. The weight of the paper copies will be compared with the weight of a DinA4 sheet, of which the area (210 mm x 297 mm) is known.

2. Option: Leaf area can be estimated from measurements of leaf length and width on attached leaves

   Step 1: Create a calibration curve

   The aim is to infer the leaf area from the measurement of length and maximum leaf width, which can be recorded non-destructively with a ruler or caliper (if the shape of the leaf is not too complicated). To do this, different leaf sizes must be recorded from a test plant of the same species (variety). These leaves are placed on the photocopier after harvesting and copied. The leaf copies are then cut out and weighed. The weight of a DinA4 leaf, whose area is known, serves as a reference. Taking into account the leaf shape, a calibration curve is created from the measured values of leaf length, width and area (BOKU).

   Step 2: Measurement of leaf area of all (!) leaves on selected (reference) plants during cultivation. This approach is attractive in the case leaf area should be assessed once a week or every two weeks, depending on the duration of cultivation.

As a minimum, the interval for measurements is from the beginning to the end. In this case, the first harvest is at the beginning, before any treatment; the second is at the end of the experiment. It is desirable to harvest plants

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during the experiment every week or second week depending on the life of the crop, which should be planned in advance, because additional plants for harvest are needed. This increases the information of the weather/environmental effects. Noteworthy, as a minimum requirement, mean daytime temperature per week, mean nighttime temperature per week and mean humidity per week should be recorded per cultivation environment in combination with the corresponding means for atmospheric $CO_2$ concentration and light intensity in order to assess environmental effects on weekly plant growth. For the growth analysis, it would be interesting to assess leaf growth (leaf area) in more detail by measurement of leaf length and leaf width on a so-called master plant more regularly in case growth analysis only at the beginning and end of crop cultivation is considered.

The following partners plan growth analyses:

- BOKU – growth analyses with more than one sampling interval
- HU – growth analyses with more than one sampling interval
- AZS – growth analyses with one sampling interval

The growth analyses will contribute to the assessment of crop and yield development under PVs, considering eventual growth retardation, ion imbalances, nitrate accumulation, the appearance of stress symptoms, and the sensitivity of plants to diseases. Together with the different kinds of cultivation systems that are in use and the results of the quality assessment, the data will contribute to the identification of the special needs of plants under the PV tracking system (Task

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3.4.4; each partner)

### 2.4.3 Determination of produce quality

Produce quality characterizing ingredients will be assessed by BOKU from freezedried and milled material send to Vienna immediately after harvest and freezedrying from the following partners: BOKU, HU, BW, TS immediately after freezedrying. The following will be analysed: carbohydrates & organic acids by HPLC, chlorophyll a, b & carotionoid contents (Sumanta et al. 2014), total phenolic compounds (Keutgen & Pawelzik, 2007), total flavonoids (Keutgen et al., 2019), total anthocyanin content (Lee et al., 2005; Purbaningtias et al., 2017), lycopin (in the case of tomatoes: George et al., 2004), antioxidant capacity (Keutgen & Pawelzik, 2007), nitrate content (Miranda et al., 2001) and eventually selected mineral nutrients in case of suspicion of nutrient deficiencies (Task 3.4.5; BOKU).

The advanced Phytomonitoring Systems of the HU Berlin will be used for long time analyses of light and water use efficiency by gas exchange on single leaves of selected crops. Ten leaf cuvettes are available for measuring a representative average of the gas exchange of younger and older leaves under shaded and nonshaded conditions. The cuvettes are constantly attached for about one week on the single leaves, then are allocated to different leaves in the canopy. For the evaluation of the light - photosynthesis interaction under PVs, the light use efficiency (LUE) will be calculated, i.e. the ratio of net photosynthesis to the outside PAR. The Phytomonitoring System with the leaf cuvettes also measures transpiration, photosynthetic efficiency, and leaf temperature, which will contribute to the modelling approach for this location. The data will be analysed and interpreted by HU and submitted when the analysis is finished.

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## 2.5 Task 3.5 Greenhouse water efficiency (M6 – M34)

Task Leader: HU; Participants: AZS, BOKU, FSC, BW, UTH

Water consumption of crops during cultivation will be recorded by the mentioned participants. The data should be sent to HU after harvest of each single crop together with the information on the cultivation system and yield. Water consumption will be calculated as the amount of water supplied expressed by plants per $m^2$ or ha. In the case of container/pot cultivation, water supply will be related to the planting density, too. For this purpose, the irrigation areas under PV modules and corresponding reference areas will be equipped with separate water metres. Finally, water consumption will be expressed in relation to crop production, as the ratio of consumed water to total yield.

In addition, at the Berlin site (HU), the yield performance under different PV coverage rates will be measured as the ratio of fixed carbon to transpired water measured on singe leaves.

Berlin will also measure the water use efficiency in the highly efficient fully closed recirculating irrigation system (Task 3.5.1; HU).

An immediate comparisons of water consumption per yield unit with and without PVs will be performed by BOKU, UTH, HU, and AZS (Task 3.5.2).

## 2.6 Task 3.6 $CO_2$-enrichment as compensation possibility (M6 – M34)

Task Leader: HU; Participants: AZS, HU, BOKU, FSC, BW, UTH

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$CO_2$ may be added to compensate for the yield losses caused by the light reduction due to PVs. This general statement needs in practice more detailed considerations. For instance, in the case of high light intensities such as during summer time in Israel, PVs provide only limited shading and the remaining light intensity is sufficiently high so that a broad range of atmospheric $CO_2$-concentrations will promote photosynthesis. By contrast, during low light intensities in winter for instance in Austria, light is the limiting factor for photosynthesis. Consequently, an increase of atmospheric $CO_2$-contentrations is expected to have only a limited effect. These interactions, which are basic for assessing the applicability of $CO_2$enrichment strategies from a plant cultivation and economic point of view, may be addressed by measuring $A/C_i$- and light curves on selected crop cvs (basil and/or cucumber) (BOKU). In practice, the experiments with elevated atmospheric $CO_2$levels are embedded in the previous described experiments and time frames for data submission.

Experiments on selected crops (tomato, cucumber and lettuce) under different light and $CO_2$ levels in phytoboxes (phytotrones) will be performed by HU in order to evaluate the parameters from task 4.4, which will be connected with the climatic conditions in the greenhouse (radiation, $CO_2$-concentration, air temperature, humidity) and used to model the growth and yield performance of tested crops. The phytoboxes enable performing exact experiments under different $CO_2$-, light- and temperature-conditions. In addition, water and nutrient consumption will also be recorded (Task 3.6.1; HU).

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Experiments will be conducted, which investigate the effect of additional $CO_2$concentrations in the greenhouse under PV modules (Task 3.6.2; AZS, HU, BOKU, FSC, BW, UTH). Different approaches for $CO_2$-enrichment are tested under practical conditions, among which are considered the application of gas from $CO_2$-cylinders (HU), $CO_2$-bags ($CO_2$BAG®Finland $CO_2$ Products Oy; BOKU), dry ice (BOKU), mushroom cultivation (BOKU) and compost (AZS). The $CO_2$-concentration within the greenhouse and outside as well as in the control greenhouses with and without PV but without $CO_2$-enrichment will be monitored with a $CO_2$-gas analyser at least once a day. Where available, a second control with $CO_2$-enrichment but without PV will be included (AZS).

## 2.7 Task 3.7 Additional lighting as compensation possibility (M8 – M34)

Task Leader: BOKU; Participants: -

Because the natural light level is at least temporarily too low to support the proper production of crops in the greenhouse at the location in Vienna in the autumn/winter time, an additional light supply may become essential. Thus, the experiments under PV modules in the greenhouse in late autumn and winter will be conducted under additional lighting of the production area, when the natural light intensity drops below a critical level, which depends on the chosen crop (probably basil and/or lettuce). This task intends investigating the possible elasticity of the intelligent PV system under low light levels.

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## 2.8 Task 3.8 Social aspects and acceptance of first user (M8 – M34)

Task Leader: UR; Participants: AZS, BOKU, FSC, BW, UTH, HU

The sociological section of this Work Package is dedicated to conducting an initial and qualitative survey to understand how farmers perceive solar energy sources and whether they can be utilized profitably in the agricultural sector. Since this research is in its preliminary and methodological phase, our approach involves several key steps. First, we identified 10 key individuals with significant experience in agriculture from each of the partner states. Subsequently, we conducted indepth interviews with these 10 selected experts in each state. These interviews were designed and led by Andrea Volterrani, who oversaw the interview process. To ensure the interviewers were well-prepared from a sociological perspective, they underwent training within the Spring School held in May 2023 at the Fattoria Solidale del Circeo, organized by our project partners. The following stage involved identifying interview subjects, conducting the interviews, transcribing the collected data, and translating it. This phase was executed by participants in the Summer School program, in collaboration with our project partners. The interviews took place between June and September 2023, and the entire dataset is now available for social analysis. In addition to the interview-based research, we also conducted 5 focus groups in all partner states. These focus groups were facilitated by the same teams who received training during the Spring School. Their objective was to explore farmers' perceptions and opinions on various topics related to technological innovation, the accessibility of solar energy sources, and their potential use in agriculture. Focus groups are considered a more dynamic and

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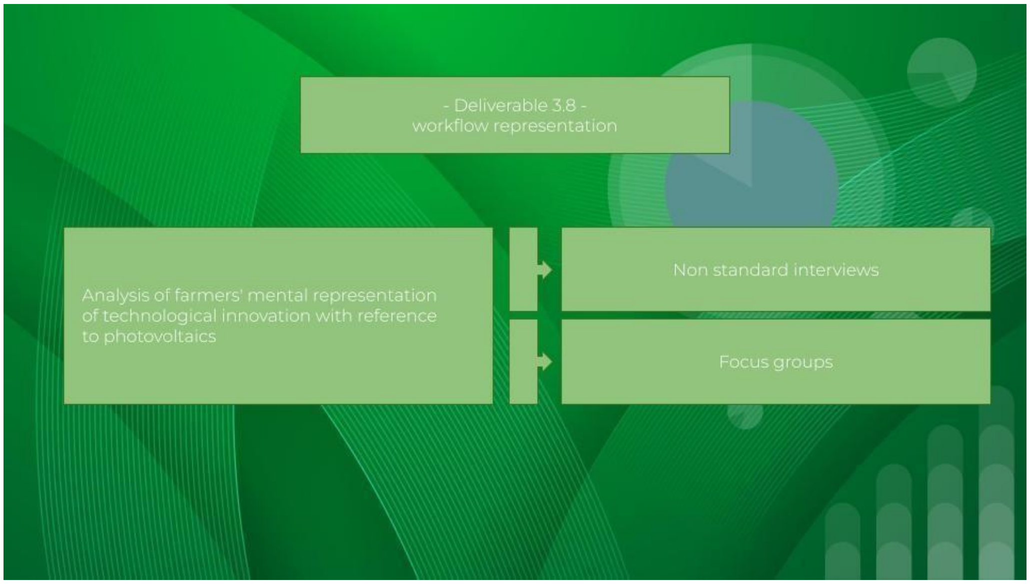
responsive method for understanding group dynamics and exploring the issues discussed during interviews. This approach allows us to uncover both obvious and subtle trends, risks, and opportunities within the group's collective thinking when it comes to disruptive innovations.




The methodology for this WP section consists of two distinct components with different purposes:

1. Initial Survey with In-Depth Interviews:

   This segment involves conducting in-depth interviews with select experts in the field, providing insights into how farmers perceive technological innovations in energy, both in their personal and professional lives. The goal is to construct a comprehensive profile of their perceptions, with contextual understanding, exploring diverse perspectives, obtaining qualitative rich data, and uncovering unconscious beliefs and attitudes. Using in-depth interviews in this section of the research process enables

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to gather in-depth qualitative data regarding the insights, perspectives, and ideas of the interviewees. Simultaneously, this approach allows us to explore aspects of analysis that may not have been spontaneously addressed by the interviewees but can be probed through specific questions from the interviewers.

### 2.8.1 Focus Group Analysis

In the second part, we use focus groups to uncover trends, perspectives, and potential perception biases related to technological innovation in the solar energy sector within the group dynamic. The research using focus groups, specifically centered on the innovation aspect of agriphotovoltaic energy, aims to spotlight the collective perspective held by the participating group. It delves into participants' views, attitudes, and experiences regarding this topic and explores the group dynamics that evolve when discussing it. In this context, focus groups serve to supplement and enhance the qualitative data obtained from in-depth interviews, providing an additional layer to the project's social research perspective.

### 2.8.2 Long interview outline

Sociological qualitative, in-depth interviews involve the research practice of posing a series of questions to the interviewee, granting them the broadest opportunity to express their ideas, opinions, and perspectives regarding the topics under discussion. Open-ended and adaptable inquiries provide a gateway to the interviewees' perspectives, insights into events, personal encounters, and

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viewpoints. When conducted effectively, qualitative interviews have the potential to delve into profound and intricate layers of understanding that surpass the capabilities of alternative methodologies.

Our in-depth interview scheme considers the following items:

1. What is your overall **opinion** of **technological innovation** and its impact on our lives?
2. How do you view **technological innovation within your work** in nature and agriculture?
3. There is currently a global debate on the use of **renewable energy sources** with lower environmental impact, as well as **limiting energy consumption**. What is **your stance** on these positions?
4. In the past, some **cultivable land has been allocated for the installation of solar panels** for energy production. **How do you feel** about this practice?
5. **Agrivoltaics** is an innovative technology that involves the installation of solar panels over greenhouses to enable plant cultivation without sacrificing farmland for energy production. What is your view on this technology?
6. **If this technology was readily available, would you be willing to try it** out on your farm?
7. **Based on the context** in which you live and work, **what are the primary reasons** that would cause you **to delay the adoption of this new technology**?

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### 2.8.3 Focus group outline

Focus groups are a research technique that involves bringing together a small, diverse group of participants to engage in open and structured discussions on a specific topic, concept, product, or idea. The primary goal of a focus group is to gather qualitative data by encouraging participants to share their thoughts, opinions, and experiences in a group setting. A skilled moderator guides the discussion, ensuring that key research questions are addressed and allowing participants to mutually interact, which can lead to a deeper understanding of their collective perceptions and insights. Focus groups are an established research technique in social science studies, and are useful to explore ideas, test concepts, and gain insights into the target group attitudes and preferences.

In each partner state of the project, the research design involves conducting one focus group with a number of participants ranging from 8 to 15. Each partner will subject the focus group participants to the same general questions to initiate the group discussion. A transcription of the interactions must be produced for each focus group, which is essential for subsequent qualitative analyses.

Our focus group scheme considers the following items:

1. **Technological innovation** brings about an **improvement** in living and working conditions, with specific reference to agriculture. What do you believe are the main advantages and risks?

2. **Green energy**, understood as clean and environmentally sustainable energy, is making significant strides with new technologies. How and to what extent do you think it can be important for your work?
3. I**nvestment in green energy in agriculture** may entail **costs** and **constraints**. To what extent, both financially and in a general sense, are you willing to support these burdens?

### 2.8.4.Literature used

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# 3 Annexes

## 3.1 Annex 1: DR-00 PO-01: Acceptance receipt

**MODULE ACCEPTANCE RECEIPT**

| | Date | Receipt N° |
|---|---|---|
| | | |

| It is hereby declared that the device has been received: | |
|---|---|
| Brand | |
| Model | |
| Technology | |
| Serial N°/Name | |

Annotations:

**Signature of the recipient**

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## 3.2 Annex 2: DR-01 PO-01: Device acceptance sheet

**ACCEPTANCE SHEET**
**BF PV MODULES**

*REGACE PROJECT n°*________

| OPERATOR | RECEIPT DATE | SHEET NUMBER |
|---|---|---|
| | | SA |

| DEVICE | | | |
|---|---|---|---|
| **Brand** | **Model** | **Code N.** | |
| | | | |
| **Type** - Module ☐ - String ☐ - Panel ☐ | **Technology** | **Serial N°** | |
| **Dimensions L x H** *(cm)* | Frame | Active area | |

| STC ELECTRICAL PARAMETERS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| G *(W/m²)* | T *(°C)* | VMAX *(V)* | IMAX *(A)* | PMAX *(W)* | Voc *(V)* | Isc *(A)* | FF | η *(%)* |
| | | | | | | | | |

**FUNCTIONALITY TEST** PASS ☐ FAIL ☐

| BIFACIALITY COEFFICIENTS (STC) | | | | | |
|---|---|---|---|---|---|
| Voc | | Isc | | PMAX | |

| Picture | Notes |
|---|---|
| | |

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## FULL FUNCTIONALITY TEST

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **DATE** | | | **HOUR** | | | | **TEST 1** |
| ***G*** *(W/m²)* | ***T*** *(°C)* | $V_{MAX}$ *(V)* | $I_{MAX}$ *(A)* | $P_{MAX}$ *(W)* | $V_{OC}$ *(V)* | $I_{SC}$ *(A)* | ***FF*** |
| | | | | | | | |
| **STC** | | | | | | | |
| | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **DATE** | | | **HOUR** | | | | **TEST 2** |
| ***G*** *(W/m²)* | ***T*** *(°C)* | $V_{MAX}$ *(V)* | $I_{MAX}$ *(A)* | $P_{MAX}$ *(W)* | $V_{OC}$ *(V)* | $I_{SC}$ *(A)* | ***FF*** |
| | | | | | | | |
| **STC** | | | | | | | |
| | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **DATE** | | | **HOUR** | | | | **TEST 3** |
| ***G*** *(W/m²)* | ***T*** *(°C)* | $V_{MAX}$ *(V)* | $I_{MAX}$ *(A)* | $P_{MAX}$ *(W)* | $V_{OC}$ *(V)* | $I_{SC}$ *(A)* | ***FF*** |
| | | | | | | | |
| **STC** | | | | | | | |
| | | | | | | | |

*I-V Curve*

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REGACE Using Co2 for Green Energy | ESTER Energia Solare TEst e Ricerca, Laboratori di Fisica Tecnica Ambientale, Università degli Studi di Roma 'Tor Vergata' | TOR VERGATA UNIVERSITY OF ROME

## FRONT FUNCTIONALITY TEST

| **DATE** | | | **HOUR** | | | | **TEST 1** |
|---|---|---|---|---|---|---|---|
| ***G*** *(W/m²)* | ***T*** *(°C)* | $V_{MAX}$*(V)* | $I_{MAX}$*(A)* | $P_{MAX}$*(W)* | $V_{OC}$ *(V)* | $I_{SC}$ *(A)* | ***FF*** |
| | | | | | | | |
| | | | **STC** | | | | |
| | | | | | | | |

| **DATE** | | | **HOUR** | | | | **TEST 2** |
|---|---|---|---|---|---|---|---|
| ***G*** *(W/m²)* | ***T*** *(°C)* | $V_{MAX}$*(V)* | $I_{MAX}$*(A)* | $P_{MAX}$*(W)* | $V_{OC}$ *(V)* | $I_{SC}$ *(A)* | ***FF*** |
| | | | | | | | |
| | | | **STC** | | | | |
| | | | | | | | |

| **DATE** | | | **HOUR** | | | | **TEST 3** |
|---|---|---|---|---|---|---|---|
| ***G*** *(W/m²)* | ***T*** *(°C)* | $V_{MAX}$*(V)* | $I_{MAX}$*(A)* | $P_{MAX}$*(W)* | $V_{OC}$ *(V)* | $I_{SC}$ *(A)* | ***FF*** |
| | | | | | | | |
| | | | **STC** | | | | |
| | | | | | | | |

*I-V Curve*

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## REAR FUNCTIONALITY TEST

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **DATE** | | | **HOUR** | | | | **TEST 1** |
| *G (W/m$^2$)* | *T (°C)* | *$V_{MAX}$ (V)* | *$I_{MAX}$ (A)* | *$P_{MAX}$ (W)* | *$V_{OC}$ (V)* | *$I_{SC}$ (A)* | *FF* |
| | | | | | | | |
| | | | **STC** | | | | |
| | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **DATE** | | | **HOUR** | | | | **TEST 2** |
| *G (W/m$^2$)* | *T (°C)* | *$V_{MAX}$ (V)* | *$I_{MAX}$ (A)* | *$P_{MAX}$ (W)* | *$V_{OC}$ (V)* | *$I_{SC}$ (A)* | *FF* |
| | | | | | | | |
| | | | **STC** | | | | |
| | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **DATE** | | | **HOUR** | | | | **TEST 3** |
| *G (W/m$^2$)* | *T (°C)* | *$V_{MAX}$ (V)* | *$I_{MAX}$ (A)* | *$P_{MAX}$ (W)* | *$V_{OC}$ (V)* | *$I_{SC}$ (A)* | *FF* |
| | | | | | | | |
| | | | **STC** | | | | |
| | | | | | | | |

*I-V Curve*

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## VISUAL INSPECTION

*(If checked specify and attach photo)*

| | |
|---|---|
| - Presence of broken, bent, misaligned, torn, or scratched outer surfaces | |
| | |
| - Broken or cracked cells | |
| | |
| - Faulty interconnections or joints | |
| | |
| - Cells in contact with each other or with the frame | |
| | |
| - Defects in sealants | |
| | |
| - Bubbles or delaminations that form a continuous path between any part of a cell and the edge of the device | |
| | |
| - Surfaces of plastics or other material notched | |
| | |
| - Faulty terminations, exposed live electrical parts | |
| | |
| - Loss of mechanical integrity such that device installation and/or operation becomes difficult | |
| | |
| - Other conditions that may negatively affect performance | |
| | |

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## THERMOGRAPHIC INSPECTION

| | |
|---|---|
| ATTACHMENTS N. | |

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## 3.3 Annex 3: DR-02 PO-01: Device test sheet

**DEVICE TEST SHEET** *REGACE PROJECT n°*__________

| OPERATOR |
|---|
| |

| SHEET N° |
|---|
| SPM |

| DEVICE | | | | | |
|---|---|---|---|---|---|
| **Brand** | **Model** | | **Name** | | |
| | | | | | |
| **Type:** - Module ☐ - String ☐ - Panel ☐ | **Technology** | | **Serial N°** | | |
| | | | | | |
| **Dimensions L x H** *(cm)* | Frame | | Active area | | |

| TEST CONDITIONS | | | | | |
|---|---|---|---|---|---|
| **START** | **Date** | **Time** | **END** | **Date** | **Time** |
| | | | | | |
| **Stand** | **MPPT N°** | **Temperature Channel** | **Tilt/Position** | | |
| | | | | | |

| DEGRADATION TEST | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **DATE** | $V_{MAX}$ *(V)* | $I_{MAX}$ *(A)* | $P_{MAX}$ *(W)* | $V_{OC}$ *(V)* | $I_{SC}$ *(A)* | *FF* | *G* *(W/m²)* | *T* *(°C)* |
| *Test Start* | | | | | | | | |
| *Test End* | | | | | | | | |
| **Delta (%)** | | | | | | | | |

| Annotations |
|---|
| |

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## DEGRADATION TEST

| START DATE | | TIME | |
|---|---|---|---|

*I-V Curve*

| $G$ $(W/m^2)$ | $T$ (°C) | $V_{MAX}$ (V) | $I_{MAX}$ (A) | $P_{MAX}$ (W) | $V_{OC}$ (V) | $I_{SC}$ (A) | FF |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

| END DATE | | TIME | |
|---|---|---|---|

*I-V Curve*

| $G$ $(W/m^2)$ | $T$ (°C) | $V_{MAX}$ (V) | $I_{MAX}$ (A) | $P_{MAX}$ (W) | $V_{OC}$ (V) | $I_{SC}$ (A) | FF |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

**START-END COMPARISON**

*I-V Curves Translated-Superimposed*

| $\Delta G$ $(W/m^2)$ | $\Delta T$ (°C) | $\Delta V_{MAX}$ (V) | $\Delta I_{MAX}$ (A) | $\Delta P_{MAX}$ (W) | $\Delta V_{OC}$ (V) | $\Delta I_{SC}$ (A) | $\Delta$FF |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

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# VISUAL INSPECTION AT TEST START

| DATE |
|---|
| |

| INSPECTION START TIME | INSPECTION END TIME |
|---|---|
| | |

| CAMERA MODEL |
|---|
| |

DEVICES AND SENSORS CLEANING

YES NO

## DEVICE ANOMALY DIAGRAM

| Report anomalies and attach corresponding photos (VIS and IR). |
|---|
| |

| ATTACHMENTS N. | |
|---|---|



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# VISUAL INSPECTION AT TEST END

| DATE |
|---|
| |

| INSPECTION START TIME | INSPECTION END TIME |
|---|---|
| | |

| CAMERA MODEL |
|---|
| |

DEVICES AND SENSORS CLEANING

YES    NO

## DEVICE ANOMALY DIAGRAM

| |
|---|
| Report anomalies and attach corresponding photos (VIS and IR). |

| | |
|---|---|
| ATTACHMENTS N. | |

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## 3.4 Annex 4: DR-03 PO-01: Attachments sheet

| ATTACHMENT N. | SHEET N. | DATE |
|---|---|---|
| | | |

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## 3.5 Annex 5: PO-02: Device cell mapping

### MAPPING FOR DEVICE CELL IDENTIFICATION

In order to correctly identify an active element of a PV module, normally consisting of cells connected in series and in parallel, the following rules must be followed:

- The modules are divided into two groups based on cell geometry.
  - **GROUP S**: modules of $P_{max}$ = 135 W, 105 W, 85 W (Square cells)
  - **GROUP R**: modules of $P_{max}$ = 120 W, 90 W (Rectangular cells)
- The device is considered to be placed horizontally resting on its longest side.
- The upper long side and the front face are identified by the location of the connection cables: the positive terminal is on the upper right side.
- The device is divided in a checkerboard pattern based on cell distribution and the following references are laid out:
  - **LETTERS** for the longer side, starting from A, from the negative terminal to the positive (i.e., from left to right)
  - **NUMBERS** for the shorter side, starting from 1, from top to bottom.

The highest maximum power device for each of the two groups (135 W and 120 W) is shown in the next page as an example.

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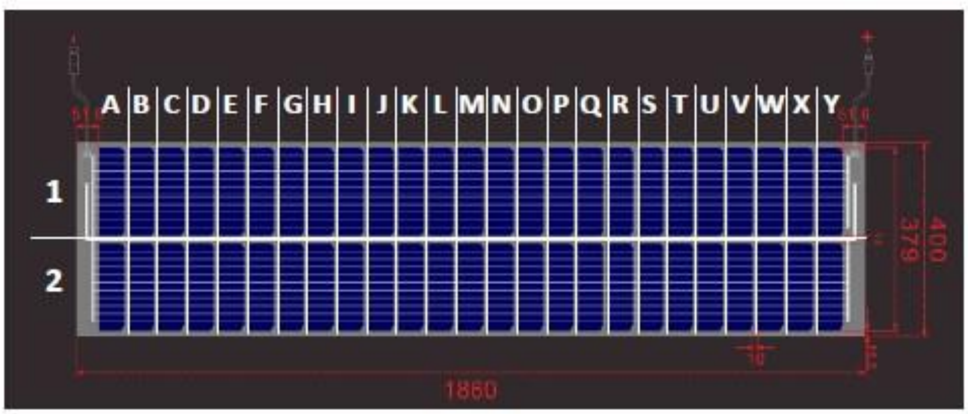
Group S modules:


Group R modules:

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## 3.6 Annex 6: PO-03: I-V curve shifting method

**SHIFT OF I-V CURVES TO STC**

**BLAESSER METHOD**

The shift of I-V curves to STC is useful to compare the electrical parameters of monitored PV modules over time, regardless of environmental conditions. From the devices' measured current-voltage characteristics, the different module parameters can be determined. If irradiance and thermal stability are sufficient, STC conditions can be determined. For the extrapolation of curves to STC, the Blaesser Method is used.

This method was developed at the JRC Laboratories in Ispra (Italy) by physicist G.Blaesser. Its function is to determine the I-V characteristic at STC for modules or arrays placed outdoors. It is one of the most widely used methods.

This method is based on plotting the I-V curves under real conditions and involves a shift of the measured value of voltage and a ratio of the measured value of current. Each point on the I-V curve, with its measured values of current $I_1$ and voltage $V_1$, is shifted to a point of coordinates $I_2$ and $V_2$ according to the following expressions:

$$I_2 = I_1 \cdot \frac{G_{STC}}{G}$$

$$V_2 = V_1 + DV$$

$$\text{where } DV = D \cdot ln(G_{STC}/G) + B \cdot G + b \cdot (T_a - T_{STC})$$

- $G_{STC}$ and $G$ are the values of irradiance at STC (1000 W/m²) and measured (W/m²), respectively
- $D = V_t \cdot \#\ cells\ in\ series$ (V)
- $B$ is the coefficient related to the measured irradiance (V/W/m²)
- b is the coefficient of thermal tension (V/°C)
- $T_a$ is the ambient temperature
- $T_{STC}$ is the temperature at STC

The coefficients D, B and b lie within certain physical limits and are determined by minimizing the sum of the standard deviations of the calculated $V_{OC,STC}$ values.

Normally it is possible to measure the temperature of the module $T_m$, in which case DV is simplified and it is no longer necessary to determine B, but only D and b. DV, in this case, becomes:

$$DV = D \cdot ln(G_{STC}/G) + b \cdot (T_m - T_{STC})$$



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**PROCEDURE FOR DETERMINING D AND b**

Parameters D and b, required to shift the I-V curves to STC, vary depending on the PV module technology. To determine these parameters, a program was implemented in Matlab that requires the following input data:

1) the "significant data" files from a given period of measurements (preferably one year), which include only the stable I-V curves. This file contains the characteristic data of each measured I-V curve, namely:
   - maximum power ($P_{max}$)
   - maximum current ($I_{max}$)
   - maximum voltage ($V_{max}$)
   - short circuit current ($I_{SC}$)
   - open circuit voltage ($V_{OC}$)
   - Irradiance measured by the pyranometer
   - Irradiance measured by the reference cell
   - Module temperature
2) the value of irradiance and temperature considered at standard conditions (STC).

With this data, the program calculates D and b using only parameters relative to irradiance values greater than 400 W/m².

D and b are calculated by minimizing the standard deviation of the $V_{OC,STC}$ values, through the following formula:

$$V_{OC,STC} = V_{OC,meas} + D \cdot ln(G_{STC}/G) + b \cdot (T_m - T_{STC})$$

$$\frac{\sum_{i=1}^{N} \sqrt{\left(V_{OC,STC} - V_{OC,meas}\right)^2}}{N} = min$$

**PROCEDURE FOR SHIFTING THE I-V CURVES TO STC**

To shift the I-V curves to STC, a program was implemented in Matlab, which processes a set of curves selected based on the following criteria:

1) Date: the desired analysis period is defined
2) Time: between 11:30 a.m. and 1:30 p.m., so that the sun's rays are perpendicular to the panel's plane



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3) Global radiation: greater than 800 W/m²
4) I-V curve types: only stable curves are exported.

The necessary input is:

- the module spec $I_{SC}$ and $V_{OC}$
- the irradiance and temperature values considered at standard conditions (STC)
- The previously determined coefficients D and b.

The program then imports the I-V curves and shifts each point using the following equations:

$$I_2 = I_1 \cdot \frac{G_{STC}}{G}$$
$$V_2 = V_1 + DV$$

where $DV = D \cdot ln(G_{STC}/G) + b \cdot (T_a - T_{STC})$

- $G_{STC}$ and $G$ are the values of irradiance at STC (1000 W/m²) and measured (W/m²), respectively
- $D = V_t \cdot \#\ cells\ in\ series$ (V)
- b is the coefficient of thermal tension (V/°C)
- $T_a$ is the ambient temperature
- $T_{STC}$ is the temperature at STC

Concerning the significant points of the *i-th* curve ($I_{SC,STC,i}$ *and* $V_{OC,STC}$), the short circuit current ($I_{SC,STC,i} = I_{SC,i} \cdot G_{STC}/G$) shifts to a value for which the corresponding tension $V_{STC,i,0}$ is no longer zero, but it's equal to DV ($V_{STC,i,0} = V_{i,0} + DV = DV$). This is because, by correcting the curve, its shape slightly changes: in fact, the curve undergoes a horizontal translation but not a vertical one.
To find the short-circuit current value for which the voltage is zero, a function is needed that approximates the experimental curve given by the points of $V_{STC}$ and $I_{STC}$.
This function can be found via nonlinear regression, and it is a double exponential in the following form:

$$f(x) = a \cdot e^{b \cdot x} + c \cdot e^{d \cdot x}$$

where *a, b, c* and *d* are the parameters derived from the nonlinear regression analysis.
Having found the function's coefficients, the value of the short-circuit current $I_{SCSTC}$ is derived making x=0.
The program determines the coefficients of the double exponential through the ModelFun function, which requires initial guess values of a, b, c and d as input. Since these initial values greatly influence the final



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calculation, the program shows the trend of the double exponential and allows to correct the initial guess if it doesn't match the shifted I-V curve.

Having found the significant values of the shifted I-V curves, the maximum power and Fill Factor for each curve can be obtained.

The value of the maximum power at STC for the *i-th* curve is obtained by finding the maximum of all the power values resulting from the product between $I_{STC,i,m}$ and $V_{STC,i,m}$ with $m$ ranging from 1 to 256.

The Fill Factor for the i-th curve, on the other hand, is obtained from the ratio between the maximum power at STC ($P_{max,STC,i}$) and the product between $I_{SC,STC,i}$ and $V_{OC,STC,i}$.

In conclusion, for each I-V curve considered and shifted, the following significant values will be obtained:

- $I_{SC,STC,i}$: short-circuit current at STC ($A$)
- $V_{OC,STC,i}$: open-circuit voltage at STC ($V$)
- $P_{max,STC,i}$: maximum power ($W$)
- $FF_i$: Fill Factor

The definitive significant parameters needed to compare the PV module against the initial operating conditions will be given by the average of the above values of each *i-th* curve shifted.



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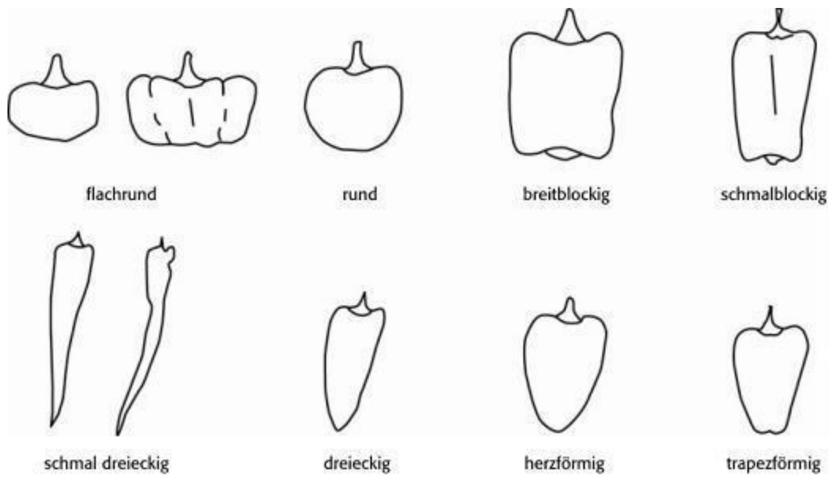
## 3.7 Annex 7: Evaluation of characteristics Fruit vegetables

Variety information

| | |
|---|---|
| **Kind of vegetable** | Tomato/Bell pepper/Chili pepper/Egg plant/Cucumber/ |
| **Name of variety** | |
| **Breeder** | |
| **Type** | Tomato: Cherry/Cocktail/Beef/Mini/Truss/...<br>Cucumber: Snack/Mini/Slicer/Asiatic/Long/...<br>Bell/chili pepper: Block/Pointed/Snack/Pepperoni/...<br>Egg plant: Normal/Mini/Snake/Segmented... |
| **Form** | <br><br>Round/flat/oval/pointed/fleshy/conically/slim/smooth...<br><br>2 = flat-round (flach-rund); 3=round (rund); wide-blocked |

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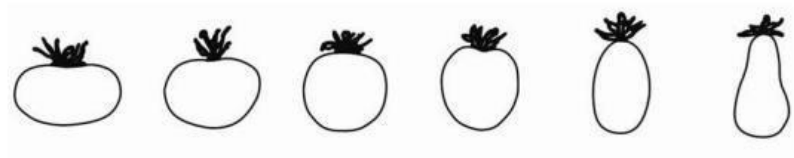
| | |
|---|---|
| | (breitblockig); narrow-blocked (schmalblockig); narrow-triangular (schmal dreieckig); triangular (dreieckig); heart-shaped (herzförmig);   trapezoidal (trapezförmig) 1= very flat round (sehr flach-rund); 2 = flat-round (flach-rund); 3=round (rund); 4=high-round (hoch-rund); 5= oval (oval); 6= pearshaped (birnenförmig) |
| **Fruit colour at ripe stage** | |
| **Fruit flesh colour** | |
| **Growth characteristics due tot he breeder** | Strong/open/generative/early fruit setting/long/early production/uniform fruits… |
| **Seed treatment** | Coating/Coating with fungicide/Coating bio/untreated |
| **Seed type** | Organic/conventionally/integrated |
| **Standard resistances** | Tomato: TSWV/ToBRFV/TYLCV/… |
| | Bell pepper: PMMoV/PVY/TMV/… Cucumber: CMV/CVYV/Ccu/… |
| **Taste** | Sweet/fruity/sour/aromatically/anstringent/bitter… |

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Growing parameters

| | |
|---|---|
| **Plants amount** | |
| **Stock density** | |
| **Substrate** | |
| **Location** | |
| **Sowing/planting date** | |
| **Harvest from.....** | |
| **Harvest until.....** | |
| **Plant protection treatments** | |
| **Irrigation method** | |
| **Temperature** | |
| **Cultivation treatments** | |

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Evaluation of Plants – Field (growth) parameters:

| | |
|---|---|
| **Date of evaluation/Nr.** | |
| **Growth vigour** | Very weak/weak/middle/good/very good |
| **Growth hight** | Very low/low/middle/high/very high |
| **Uniformity of whole stock** | Non uniform/relative uniform/very uniform=equally |
| **Uniformity of individual plant** | Non uniform/relative uniform/very uniform=equally |
| **Leaves mass** | Very few/few/middle/a lot/several |
| **Leaves colour** | Bright green/middle green/dark green/chlorotic/necrotic |
| **Inflorescence and flowers** | Amount and density of inflorescences and of really flowering items |
| **Amount of fruit stands** | |
| **Fruit setting and building** | Achievement of kind and variety specific size Very weak/weak/middle/strong/very strong |
| **Fruit ripeness** | Staining of the fruits, amount of stained fruits<br>Uniformity of staining of all fruits on the plant Uniformity of staining of whole stock |
| **Diseases and pest infestations** | Infestation place = roots/leaves/Fruit/tuber/…<br>infestation hight = measured from soil (substrate or bottom) to the infestation place<br>Infestation intensity = weak/middle/strong |
| **Root habitus** | weak/middle/strong |
| **Amount of side shoots (to remove)** | |
| **Amounts of spoiled fruits on the plant** | Amount and possible reason of the deterioration |
| **Vitality/total performance of the plant** | Coefficient leaves mass to fruit building = harmonically/imbalanced/… |
| **Occurrence of insects** | Kind, amount and location |

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Optically evaluation of fruits – Fruits evaluation:

| | |
|---|---|
| **Date of evaluation/Nr.** | |
| **harvest** | Kg per cultivation area |
| **Ø weight of individual fruit** | |
| **Ø diameter/length of the fruit** | |
| **Thickness of the fruit wall** | In the case of bell pepper |
| **Uniformity of the fruit size** | |
| **Uniformity of fruit form** | |
| **Fruit staining of individual fruit** | |
| **Course of fruit colouring** | For storage of not coloured fruits slow/medium/fast (if applicable) |
| **Amounts of brown spots** | |
| **Amounts of spoiled fruits** | |
| **Cause of nonmarketable fruits** | |
| **Colour of sepals** | bright/middle/dark/chlorotic/necrotic |
| **Adhesiveness of sepals** | easy/middle/strong |
| **Freshness of sepals** | very fresh/fresh/slightly dried/dried |
| **Fruit firmness** | Very firm/firm/soft/very soft |
| **Amounts of fruits with micro-cracks** | Amount and intensity of occurrence |
| **Brix** | |

Taste evaluation of fruits:

| | |
|---|---|
| **Sweetness** | Not sweet/slightly sweet/sweet/excessive sweet |
| **Sourness** | Not sour/slightly sour/sour/excessive sour |
| **Bitterness** | Non bitter/slightly bitter/bitter |
| **Aroma development** | Not present=none/slightly/middle/strong Foreign flavour |
| **Consistency** | Firm/soft/mealy/watery |

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## 3.8 Annex 8: Evaluation of characteristics of Pumpkin & Courgette

Variety information

| | |
|---|---|
| **Kind of vegetable** | Pumpkin & Courgette (*Cucurbita maxima* Duch., *C. moschata* Duch., *C. pepo* L.) |
| **Name of variety** | |
| **Breeder** | |
| **Type** | |
| **Fruit colour at ripe stage** | |
| **Fruit flesh colour** | |
| **Growth characteristics according to the breeder** | Strong/open/generative/early fruit setting/long/early production/uniform fruits… |
| **Seed treatment** | Coating/Coating with fungicide/Coating bio/untreated |
| **Seed type** | Organic/conventionally/integrated |
| **Standard resistances** | Px, CMV, ZYMV, WMV, PRSV |
| **Taste** | Sweet/fruity/sour/aromatically/anstringent/bitter… |

Growing parameters

| | |
|---|---|
| **Plants amount** | |
| **Stock density** | 1 plant per $m^2$; [Growing: 2-3 seeds should be placed not too close together c. 2-3 cm deep in a 7-10cm pot. Germination at 20-22°C, then 18°C.] |
| **Substrate** | |
| **Location** | |
| **Sowing date** | |
| **Date of emergence (in case of direct seeding)** | The date of the day on which approx. 50% of all plants have emerged is to be entered. |
| **Missing plants** | Before the first harvest, count the failed plants. If more plants fail later, the number of additional failures is recorded at the following harvest. |
| **Harvest from…..** | Harvesting of courgettes begins as soon as the first fruit reaches a marketable size, usually as early as 5 weeks after planting. Harvesting takes place 2-4 times a week, depending on the growth. The courgettes should have a length of 10-20 cm. The fruits should be cut with the stem.<br>Pumpkins are often harvested in one go in autumn before the first frost or before the stalks turn yellow and the skin has become hard. |

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| | |
|---|---|
| **Harvest until…..** | |
| **Plant protection treatments** | Disease and pest infestation is assessed once or several times, depending on the course of the disease. Infestation frequency, infestation intensity and date of the assessment shall be recorded. |
| **Irrigation method** | |
| **Temperature** | |
| **Cultivation treatments** | |

Evaluation of Plants – Field (growth) parameters:

| | |
|---|---|
| **Date of evaluation/Nr.** | |
| **Growth vigour** | At the time of the main harvest, the growth vigour is to be assessed: 1 = very weak; 3 = weak; 5 = medium; 7 = strong; 9 = very strong |
| **Uniformity of whole stock** | Non uniform/relative uniform/very uniform=equally |
| **Mass of leaves** | Very few/few/middle/a lot/several |
| **Colour of leaves** | Bright green/middle green/dark green/chlorotic/necrotic/variegated |
| **Leaf size** | 1 = very small; 3 = small; 5 = medium; 7 = large; 9 = very large |
| **Inflorescence and flowers** | Amount and density of inflorescences and of really flowering items |
| **Fruit setting and building** | Achievement of kind and variety specific size Very weak/weak/middle/strong/very strong |
| **Fruit ripeness** | Staining of the fruits, amount of stained fruits<br>Uniformity of staining of all fruits on the plant Uniformity of staining of whole stock |
| **Diseases and pest infestations** | Infestation place = roots/leaves/Fruit/tuber/…<br>infestation hight = measured from soil (substrate or bottom) to the infestation place<br>Infestation intensity = weak/middle/strong |
| **Root habitus** | weak/middle/strong |
| **Amounts of spoiled fruits on the plant** | Amount and possible reason of the deterioration |
| **Vitality/total performance of the plant** | Coefficient leaves mass to fruit building = harmonically/imbalanced/… |
| **Occurrence of insects** | Kind, amount and location |

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Optically evaluation of fruits – Fruits evaluation:

| **Date of evaluation/Nr.** | |
|---|---|
| **Grading** | The crop is divided into marketable and non-marketable goods according to quality standards. The marketable fruits are weighed and counted. The non-marketable fruits are recorded separately with the respective number of pieces as<br>- too large (courgette > 30 cm; patisson > 20 cm)<br>- other (rotten, diseased, malformed, discoloured)<br>For courgettes there are the following commercial classes: *Class Extra*, *Class I* and *Class II*.<br>They are graded either by length or by weight. For length grading, the minimum length is 7 cm (although harvesting for the market is only done from 10 cm onwards) and the maximum length is 35 cm. Other gradings (apply to classes *Extra* and *I*):<br>- 7 to 14 cm<br>14 to 21 cm<br>21 to 35 cm<br>For weight grading, the minimum weight is 50 g and the maximum weight is 450 g. Other gradings (apply to the *Extra* and *I* gradings):<br>- 50 to 100 g<br>- 100 to 225 g<br>- 225 to 450 g<br>These provisions do not apply to mini courgettes or fruit sold with flowers.<br>There are no regulations for pumpkins. |
| **Uniformity of fruit shape** | 1 = very diverse; 3 = diverse; 5 = medium; 7 = uniform; 9 = very uniform |
| **Uniformity of fruit size** | 1 = very diverse; 3 = diverse; 5 = medium; 7 = uniform; 9 = very uniform |
| **harvest** | Kg per cultivation area |
| **Ø weight of individual fruit** | The average weight of 5 fruits per replicate should be given. |
| **Ø diameter/length of the fruit** | The average weight of 5 fruits per replicate should be given. |
| **Fruit colour (Courgette)** | - green-fruited<br>1= very light green; 3 = light green; 5 = medium green; 7 = dark green; 9 = very dark green<br>- yellow-fruited<br>1 = very light yellow; 3 = light yellow; 5 = medium yellow; 7 = dark yellow; 9 = very dark yellow |
| **Uniformity of fruit colour** | 1 = very diverse; 3 = diverse; 5 = medium; 7 = uniform; 9 = very uniform |

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| | |
|---|---|
| **Fruit shape, size and colour inside and outside in pumpkins** | Description of the shape (e.g. round, oval, pear-shaped, rugby-shaped, elongated) and the colours inside and outside (e.g. light green, medium green, dark green, light orange, dark orange, yellow, red). If different varieties of the same species are in the trial, it is recommended to note:<br>1= very small; 3 = small; 5 = medium; 7 = large; 9 = very large |
| **Flesh to seed ratio** | 1 = flesh proportionally smaller than ovule; 2 = flesh proportionally approximately equal to ovule; 3 = flesh proportionally larger than ovule. |
| **Fruit firmness** | Very firm/firm/soft/very soft |
| **Shelf-life capacity** | 1 = very small; 3 = small; 5 = medium; 7 = good; 9 = very good |
| **Amounts of spoiled fruits** | |
| **Cause of nonmarketable fruits** | |
| **Colour of petals** | Yellow/orange/... |
| **Amounts of fruits with micro-cracks** | Amount and intensity of occurrence |

Taste evaluation of fruits:

| | |
|---|---|
| **Sweetness** | Not sweet/slightly sweet/sweet/excessive sweet |
| **Sourness** | Not sour/slightly sour/sour/excessive sour |
| **Bitterness** | Non bitter/slightly bitter/bitter |
| **Aroma development** | Not present=none/slightly/middle/strong Foreign flavour |
| **Consistency** | Firm/soft/mealy/watery |

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## 3.9 Annex 9: Evaluation of characteristics of Basil

Variety information

| | |
|---|---|
| **Kind of vegetable** | Basil |
| **Name of species** | |
| **Name of variety** | |
| **Breeder** | |
| **Type** | (frequently large-leaved Genovese type) (green or red leaves) |
| **Growth characteristics according to the breeder** | |
| **Seed treatment** | Coating/Coating with fungicide/Coating bio/untreated |
| **Seed type** | Organic/conventionally/integrated |
| **Standard resistances** | (if applicable) |
| **Taste** | Savory/sweet/mint, pepper, clove, anise and/or liquorice flavour |

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Growing parameters

| | |
|---|---|
| **Amount of plants** | |
| **Stock density 1** | 9er pots per $m^2$ (usually 30-35) |
| **Stock density 2** | Seeds per pot (usually 25-30) |
| **Substrate** | |
| **Location** | |
| **Sowing date** | |
| **Rising strength** | 10 - 14 days after sowing, determine the extent to which the plants have emerged fully or with gaps.<br>1 = absent or very slight; 3 = slight; 5 = medium; 7 = strong; 9 = very strong. |
| **Date of emergence** | The date of the day on which approx. 50% of all plants have emerged is to be entered. |
| **Structure of the plant** | Before harvesting, the structure of the plants in the pot is assessed. 1 = very loose; 3 = loose; 5 = medium; 7 = compact; 9 = very compact |
| **Number of plants per pot** | Before harvesting, count the number of plants per variation of 5 pots per replicate. |
| **Harvest** | Harvest in summer after 3-4 weeks, in winter 9-10 weeks. To determine the fresh mass yield, the plants are cut when they have reached a height of 12-15 cm. The cut is made 0.5 cm above the substrate. The total yield per pot is weighed. When harvesting, the plants of 10 pots per plot are to be taken. The weight of the sample is recorded. It must be taken into account that the crop is very sensitive to pressure. The leaves are plucked from the stems immediately after harvesting, and both fractions are weighed and freeze-dried. If available, take photocopies of the fresh leaves. If it is impossible to freeze-dry the samples, they should be dried at 30°C in a drying cabinet. (Only in the case of freeze-dried samples reliable analyses of the constituents are possible when sent to BOKU). |
| **Root habitus** | Weak/middle/strong |
| **Harvest date** | |
| **Plant protection treatments** | |
| **Irrigation method and amount supplied** | |
| **Temperature (range)** | |
| **Cultivation treatments** | |

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Evaluation of Plants – parameters:

| | |
|---|---|
| **Date of evaluation/Nr.** | |
| **Growth vigour** | Very weak/weak/middle/good/very good |
| **Growth hight** | Very low/low/middle/high/very high [or measurement of plant height] |
| **Uniformity of whole stock** | Non uniform/relative uniform/very uniform=equally |
| **Uniformity of individual plant / plants per pot** | Non uniform/relative uniform/very uniform=equally |
| **Leaves mass** | Very few/few/middle/a lot/several |
| **Leaves colour** | The colour of the leaves is assessed at harvest. 1 = very light green; 3 = light green; 5 = medium green; 7 = dark green; 9 = very dark green |
| **Anthocyanin colouration in redleaved varieties** | The intensity of the anthocyanin colouration is assessed before harvesting. 1 = absent or very low; 3 = low; 5 = medium; 7 = strong; 9 = very strong |
| **Leaf size** | Before harvesting, the leaf size is scored. 1 = very small; 3 = small; 5 = medium; 7 = large 9 = very large |
| **Leaf curvature** | Leaf curvature. At harvest, leaf curvature is scored. 1 = absent or very low; 3 = low; 5 = medium; 7 = strong; 9 = very strong |
| **Vitality/total performance of the plant** | harmonically/imbalanced/… |
| **Amounts of leaves with (brown) spots** | |
| **Diseases and pest infestations** | Disease and pest infestation is assessed once or several times, depending on the course of the disease. Infestation frequency, infestation intensity and, if applicable, quality and yield as well as the date of the survey shall be recorded.<br>Infestation place = roots/leaves/Fruit/tuber/…<br>infestation hight = measured from soil (substrate or bottom) to the infestation place<br>Infestation intensity = weak/middle/strong |
| **Occurrence of insects** | Kind, amount and location |

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Taste evaluation of leaves:

| | |
|---|---|
| **Sweetness** | Not sweet/slightly sweet/sweet/excessive sweet |
| **Savoriness** | Not savory/slightly savory/savory/excessive savory |
| **Aroma development** | Not present=none/slightly/middle/strong<br>detected flavour(s): mint, pepper, clove, anise and/or liquorice (others?) |
| **Consistency** | Firm/soft/mealy/watery/crispy |

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## 3.10 Annex 10: Evaluation of characteristics of Lettuce

| | |
|---|---|
| **Kind of vegetable** | Lettuce (*Lactuca sativa* L.) |
| **Name of species** | |
| **Name of variety** | |
| **Breeder** | |
| **Type** | e.g. iceberg, butter head, lollo |
| **Growth characteristics according to the breeder** | |
| **Seed treatment** | Coating/Coating with fungicide/Coating bio/untreated |
| **Seed type** | Organic/conventionally/integrated |
| **Standard resistances** | (if applicable) |
| **Taste** | Sweetish fresh; nutty mild; mild neutral; fresh, somewhat acidic |

Variety information

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Growing parameters

| | |
|---|---|
| **Amount of plants** | |
| **Stock density** | 8-11 plants per m$^2$ (Germination temperature 12-20°C ) |
| **Substrate** | |
| **Location** | |
| **Sowing/planting date** | |
| **Harvest** | Each lettuce is harvested once at the optimal time for it. The heads should have the weight, firmness and size typical of the particular crop.<br>For butter lettuce and iceberg lettuce, 300 g is the target in the greenhouse, for leaf lettuce (lollo type) 200-300 g. If these weights are not achievable due to previously occurring quality reductions, harvest should be earlier.<br>The leaves are separated from the stalk, and both fractions are weighed and freeze-dried. If possible, take photocopies of the fresh leaves. If it is impossible to freeze-dry the samples, they should be dried at 30°C in a drying cabinet. (Only in the case of freeze-dried samples reliable analyses of the constituents are possible when sent to BOKU). |
| **Closeness of the underside of the head** | Here, it is to be judged on 10 untrimmed heads harvested with all leaves per batch whether the leaves cover the underside of the head tightly and whether cavities are visible.<br>1= very open, 3 = open, 5 = medium, 7 = closed, 9 = very closed |
| **Sorting** | The harvested crop is sorted according to the quality standards and the marketable heads are recorded by weight and piece. The minimum weights of marketable heads under glass are 100 g for butter lettuce and 200 g for iceberg lettuce. The non-marketable produce is subdivided into bolting, rotted & diseased, and other ones and the respective number is recorded. |
| **Total value** | The total value takes into account all value-giving criteria for cultivation and marketing of the variety. 1 = very low, 3 = low, 5 = medium, 7 = high, 9 = very high |
| **Special features in the trial report** | Stability, stalk hardness, blisteriness, packaging possibility, suitability for marketing, with/without bracts for iceberg lettuce, cleaning effort |
| **Root habitus** | Weak/middle/strong |
| **Harvest date** | |
| **Plant protection treatments** | |
| **Irrigation method and amount supplied** | |
| **Temperature (range)** | |

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| | |
|---|---|
| **Cultivation treatments** | |

Evaluation of Plants – parameters:

| **Date of evaluation/Nr.** | |
|---|---|
| **harvest** | Kg per cultivation area |
| **Plant size** | Before harvesting, the plant size is rated: 1 = very small, 3 = small, 5 = medium, 7 = large, 9 = very large |
| **Head size** | For iceberg lettuce, the head size without bract is scored: 1 = very small, 3 = small, 5 = medium, 7 = large, 9 = very large. |
| **Head formation (except leaf lettuce)** | Head formation results from size and closedness of the head: 1 = absent or very low; 3 = low; 5 = medium; 7 = distinct; 9 = very distinct |
| **Head firmness (except leaf lettuce)** | The firmness of the head of the lettuce is assessed: 1 = very loose, 3 = loose, = 5 medium, 7 = firm, 9 = very firm. |
| **Leaves bulge (for leaf lettuce)** | leaf bulge is scored on fully grown leaves: 1 = absent or very slight, 3 = slight, 5 = medium, 7 = strong, 9 = very strong. |
| **Leaves curling (for leaf lettuce)** | leaf curling is scored on fully grown leaves: 1 = absent or very slight, 3 = slight, 5 = medium, 7 = strong, 9 = very strong. |
| **Number of missing positions** | Before harvesting, the missing positions are to be counted |
| **Colour** | For green-leaved varieties, the green colouring is scored: 1 = very light green, 3 = light green, 5 = medium green, 7 = dark green, 9 = very dark green. |
| **Anthocyanin colouration in brown- or red-leaved varieties** | For brown- or red-leaved varieties, the intensity of anthocyanin colouration is rated. 1 = absent or very low; 3 = low; 5 = medium; 7 = strong; 9 = very strong |

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| | |
|---|---|
| **Diseases and pest infestations** | Before planting, ensure that the soil is well sealed and well moist. If special cultivation measures are used, e.g. additional exposure, $CO_2$ fumigation or mulch materials, the type and duration of the measures carried out must be stated in the trial report. Plant protection as usual in practice.<br>Disease and pest infestation is assessed once or several times, depending on the course of the disease. Infestation frequency, infestation intensity and, if applicable, quality and yield as well as the date of the survey shall be recorded.<br>- Downey mildews of lettuce (*Bremia lactucae*): Yellow spots form on the upper side of the leaf, which later turn brown and dry out. A white spore lawn develops on the underside of the leaf.<br>- Botrytis (*Botrytis cinerea*, *Botrytis* spp. & *Sclerotinia* spp.): Grey mould infestation first causes rot on leaves, then on the base of the stem. This constricts and dies with brown discolouration. A grey fungal lawn forms on the infested parts of the plant.<br>- Sclerotinia rot (*Sclerotinia sclerotiorum* & *S. minor*, *Botrytis* spp. & *Sclerotinia* spp.): First outer leaves wilt, then the whole head. A white mycelium is formed on the rotting lettuce, in which black sclerotia later develop.<br>- Black rot (*Rhizoctonia solani*): Leaves lying on the ground are thin and black-brown in colour due to rot. Midrib and stalk remain long. At harvest, the uncleaned underside of the leaves is assessed. - Lettuce rot (general): If the pathogen cannot be determined or a mixed infection does not allow separate assessments, the rot is |
| | assessed as a whole. Initially, individual leaves rot, later the entire plant usually dies.<br>- Dry edge: The edges of the outer leaves turn brown and die. The dry edge is promoted by strong evaporation due to insufficient water supply, by too high salt concentration and too high night temperatures.<br>- Internal fire (calcium deficiency): The edges of the head-forming leaves turn brown and die off. For the assessment of the infestation, which can also be located inside the head, at least 5 marketable heads are to be cut at harvest. The assessment takes into account internal and external symptoms.<br>- Viral diseases: All viruses are recorded in a common assessment. In the case of mosaic viruses, the leaves show a light and dark green mosaic blotch. Plants infected early have crinkled leaves and do not form a head.<br>- Other occurring diseases and pests are to be mentioned in the trial report. This also applies to the occurrence of cold damage, sunburn and glassiness.<br>Infestation place = roots/leaves/…<br>infestation hight = measured from soil (substrate or bottom) to the infestation place<br>Infestation intensity = weak/middle/strong |


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| | |
|---|---|
| **Occurrence of insects** | Kind, amount and location<br>- Aphids: Different aphid species occur; there are also resistant varieties. |

Taste evaluation of leaves:

| | |
|---|---|
| **Taste** | Sweetish fresh; nutty mild; mild neutral; fresh, somewhat acidic |
| **Consistency** | Firm/soft/mealy/watery/crispy |

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## 3.11 Annex 11: Evaluation of characteristics of Melon Fruit

Variety information

| | |
|---|---|
| **Kind of vegetable** | - *Cucumis melo* L. (*C. melo cantalupensis*, European cantaloupe & Persian melon; *C. melo inodorus*, Argos melon, Banana melon, Canary melon, Casaba, Crenshaw melon, Gaya melon, Hami melon, Honeydew, Honeymoon melon, Kajari melon, Kolkhoznitsa melon, Japanese melons, Korean melon, Mirza melon, Oriental pickling melon, Pixie melon, Piel de Sapo, Sugar melon, Tiger melon; *C. melo reticulatus*, North American cantaloupe, Galia, Sharlyn melons; *C. melo agrestis*, Wilder melon cultivars; *C. melo conomon*, Conomon Melons, Pickling Melons, Korean Melon; Crossbred varieties, e.g. Crenshaw (Casaba × Persian), Crane (Japanese × N.A. cantaloupe).<br>- *Cucumis metuliferus* E. Mey, Horned melon<br>- *Citrullus lanatus* (Thunb.) Matsum. & Nakai, Watermelon<br>- *Benincasa hispida* (Thunb.) Cogn., Winter melon |
| **Name of variety** | |
| **Breeder** | |
| **Type** | |
| **Fruit colour at ripe stage** | |
| **Fruit flesh colour** | |
| **Growth characteristics according to the breeder** | Strong/open/generative/early fruit setting/long/early production/uniform fruits… |
| **Seed treatment** | Coating/Coating with fungicide/Coating bio/untreated |
| **Seed type** | Organic/conventionally/integrated |
| **Standard resistances** | e.g. resistances to fusarium, powdery mildew & viral diseases (if applicable) |
| **Taste** | Sweet/fruity/sour/aromatic/anstringent/bitter… |

Growing parameters

| | |
|---|---|
| **Plants amount** | |
| **Stock density** | 1 plant per m$^2$; [Growing: 1-2 seeds should be placed not too close together c. 2-3 cm deep in a 7-10cm pot. Germination at 25°C, temperature > 10 (12)°C.] |
| **Substrate** | |
| **Location** | |

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| | |
|---|---|
| **Sowing date** | |
| **Date of emergence (in case of direct seeding)** | The date of the day on which approx. 50% of all plants have emerged is to be entered. |
| **Missing plants** | Before the first harvest, count the failed plants. If more plants fail later, the number of additional failures is recorded at the following harvest. |
| **Harvest from…..** | Unfortunately, trying to judge internal quality traits based on external changes can be subjective, inconsistent, and tedious. Ripeness judgement of the cantalupensis group may be made by assessing the development of a musky odour. In most cases, when cantaloupes and muskmelons are ripe, they detach themselves from the vine, leaving a dish-shaped scar on the fruit where the stem was attached. The green-fleshed honeydews don't slip from the vine or develop a strong aroma, so ripeness is a bit more difficult to detect. When ripe, the colour of the rind should be a creamy yellow rather than green, and the rind will become smooth and waxy rather than dusky. If you press on the bottom of a ripe honeydew (the opposite end from where it's attached to the vine), it should feel slightly soft or at least a little springy.<br>Like honeydews, watermelons don't have a scent or slip from the vine when they're ripe, but they do provide several clues that tell you they're ready to eat. Look for the small leaf and stem-like curl that occur near where the melon is attached to the vine. When watermelons are ripe, this leaf and tendril will turn brown and dry. In many cases, the part of the watermelon that's resting on the ground will also turn yellow. |
| **Harvest until…..** | |
| **Plant protection treatments** | Disease and pest infestation is assessed once or several times, depending on the course of the disease. Infestation frequency, infestation intensity and date of the assessment shall be recorded. |
| **Irrigation method** | |
| **Temperature** | |
| **Cultivation treatments** | |

Evaluation of Plants – Field (growth) parameters:

| | |
|---|---|
| **Date of evaluation/Nr.** | |
| **Growth vigour** | At the time of the main harvest, the growth vigour is to be assessed: 1 = very weak; 3 = weak; 5 = medium; 7 = strong; 9 = very strong |
| **Uniformity of whole stock** | Non uniform/relative uniform/very uniform=equally |

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| | |
|---|---|
| **Mass of leaves** | Very few/few/middle/a lot/several |
| **Colour of leaves** | Bright green/middle green/dark green/chlorotic/necrotic/variegated |
| **Leaf size** | 1 = very small; 3 = small; 5 = medium; 7 = large; 9 = very large |
| **Inflorescence and flowers** | Amount and density of inflorescences and of really flowering items |
| **Fruit setting and building** | Achievement of kind and variety specific size Very weak/weak/middle/strong/very strong |
| **Fruit ripeness** | Staining of the fruits, amount of stained fruits<br>Uniformity of staining of all fruits on the plant Uniformity of staining of whole stock |
| **Diseases and pest infestations** | Infestation place = roots/leaves/Fruit/tuber/…<br>infestation hight = measured from soil (substrate or bottom) to the infestation place<br>Infestation intensity = weak/middle/strong |
| **Root habitus** | weak/middle/strong |
| **Amounts of spoiled fruits on the plant** | Amount and possible reason of the deterioration |
| **Vitality/total performance of the plant** | Coefficient leaves mass to fruit building = harmonically/imbalanced/… |
| **Occurrence of insects** | Kind, amount and location |

Optically evaluation of fruits – Fruits evaluation:

| **Date of evaluation/Nr.** | |
|---|---|
| **Grading** | The crop is divided into marketable and non-marketable goods according to quality standards. The marketable fruits are weighed and counted. The non-marketable fruits are recorded separately with the respective number of pieces.<br>Basic requirements of marketable fruit:<br>- Mature;<br>- Similar varietal characteristics;<br>- Fairly well formed;<br>- Not overripe;<br>- Free from: diseases, decay, sunscald;<br>- Without serious scars or excessive scuffing, stem end smooth,<br>- Fruit firm without signs of bruising, free from damage by any means. |
| **Uniformity of fruit shape** | 1 = very diverse; 3 = diverse; 5 = medium; 7 = uniform; 9 = very uniform |

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| | |
|---|---|
| **Uniformity of fruit size** | 1 = very diverse; 3 = diverse; 5 = medium; 7 = uniform; 9 = very uniform |
| **harvest** | Kg per cultivation area |
| **Ø weight of individual fruit** | The average weight of 5 fruits per replicate should be given. |
| **Ø diameter/length of the fruit** | The average weight of 5 fruits per replicate should be given. |
| **Fruit colour** | typical of variety (e.g. pale green to cream coloured) |
| **Fruit flesh colour** | typical of variety (browning is undesirable) |
| **Uniformity of fruit colour** | 1 = very diverse; 3 = diverse; 5 = medium; 7 = uniform; 9 = very uniform |
| **Fruit shape** | Description of the shape (e.g. round, oval, pear-shaped, rugby-shaped, elongated) |
| **Flesh to seed ratio** | 1 = flesh proportionally smaller than ovule; 2 = flesh proportionally approximately equal to ovule; 3 = flesh proportionally larger than ovule. |
| **Fruit firmness** | Very firm/firm/soft/very soft;<br>firmness may be measured with a penetrometer (loss of firmness starts from the fruit centre and progresses outwards, hence may be measured at three meaningful positions in the cut fruit) |
| **Shelf-life capacity** | 1 = very small; 3 = small; 5 = medium; 7 = good; 9 = very good |
| **Amounts of spoiled fruits** | |
| **Cause of nonmarketable fruits** | |

Taste evaluation of fruits:

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|---|---|
| **Sweetness** | Not sweet/slightly sweet/sweet/excessive sweet |
| **Sourness** | Not sour/slightly sour/sour/excessive sour |
| **Juiciness** | Not juicy/slightly juicy/juicy/excessive juicy |
| **Bitterness** | Non bitter/slightly bitter/bitter |
| **Aroma development** | Not present=none/slightly/middle/strong Foreign<br>flavour |
| **Consistency** | Firm/soft/mealy/watery |
| **Sugars or soluble solids content (SSC)** | Sugar content is the parameter that is applied most widely in quality assessment and expressed as °Brix. Varieties are differentiated based on their °Brix. The lowest acceptable °Brix in melons is 8-10 °Brix depending on cv. |

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| **Titratable acidity (if applicable)** | Titratable acidity measures the organic acid content of the fruits citric, ascorbic, malic, and succinic acid levels. As fruits ripen, the acidity decreases, but some acidity is required to ensure the fruits meet consumer taste preferences. Sugars and acidity, in tandem, are necessary to produce the flavour consumers like most. |