Agrivoltaics – Photovoltaic greenhouse of the University of Patras

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EU Green Strategy

- In May 2022, the European Union presented the REPowerEU plan, which outlines the EU's strategy for a massive, rapid deployment of renewables to reduce the EU's dependence on Russia's fossil fuels.

- To achieve its solar energy targets, the EU is urging member states to address applications of solar energy and photovoltaics (PVs), not only on residential rooftops, but also on rural land.

Agrivoltaics (Agri-PVs)

- Agrivoltaics (Agrivoltaics/Agri-PVs) are one of the emerging "tools" in the energy sector.
- They have great potential, as they are related to the simultaneous production of agricultural products and environmentally friendly energy.
- Agri-PVs are a revolutionary approach, as they break away from traditional techniques of agriculture, dual use of land having the potential to be a sustainable solution globally, both in energy and food production.

Agrivoltaics (Agri-PVs)

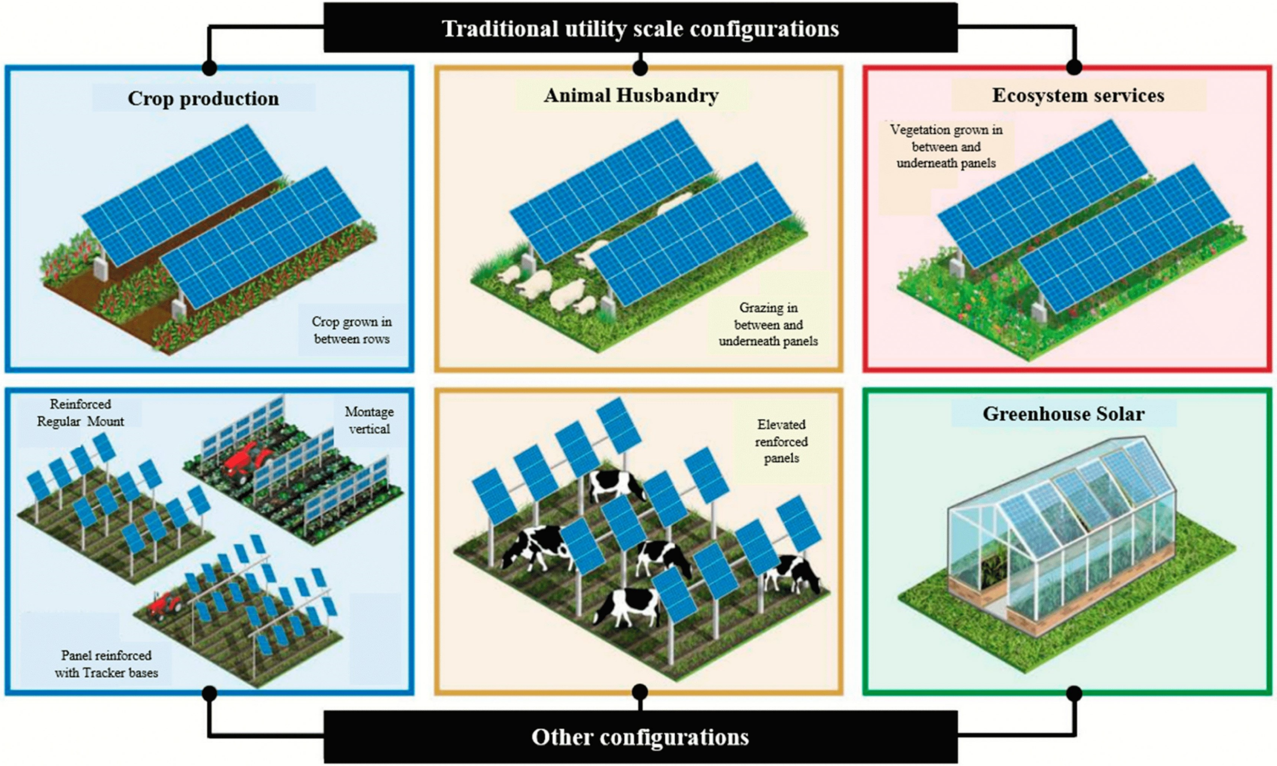
- Multiple uses of land can be effectively exploited through the implementation of Agri-PVs.
- Unlike conventional photovoltaic systems, where panels cover land and exclude agriculture, Agri-PVs applications are designed in a way that allows agricultural activities to remain the main land use.
- This approach combines renewable energy production with maintaining agricultural production, offering a sustainable solution for energy and agriculture.

Agrivoltaics (Agri-PVs)

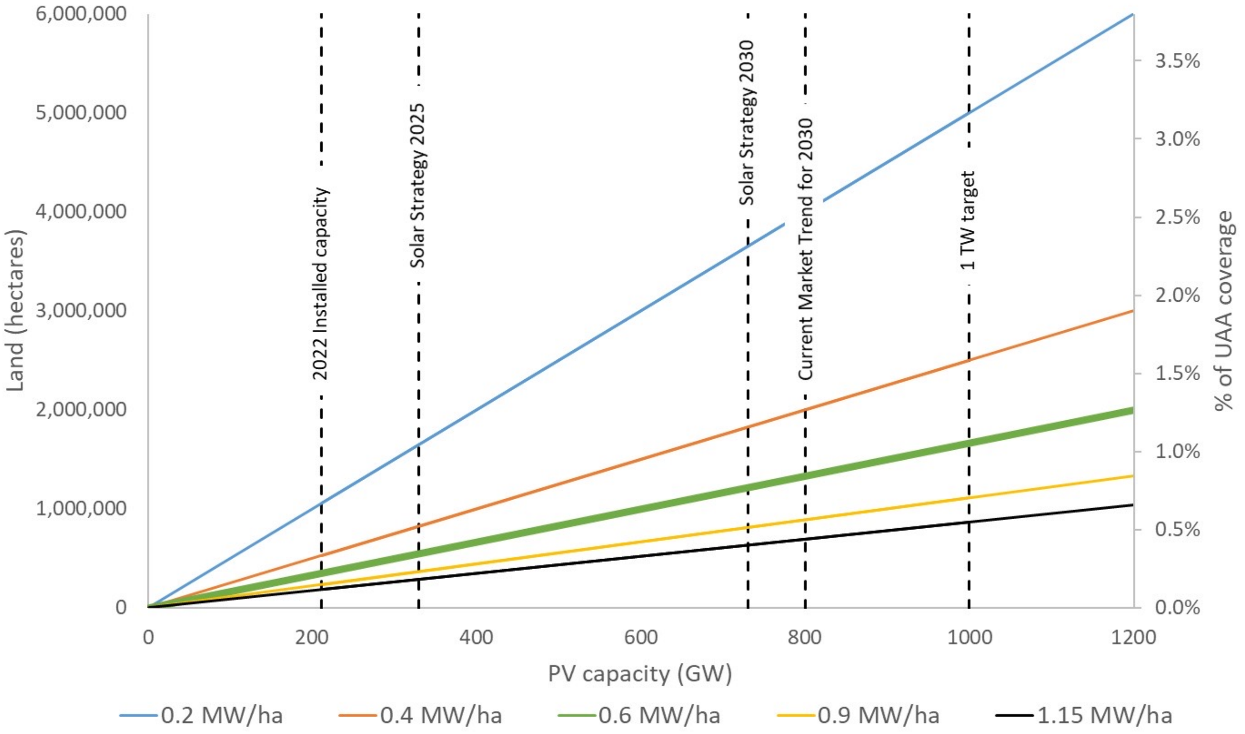
- Based on statistical data analysis, Agri-PVs have shown tremendous progress as they went from 5 MW in 2012 to 14 GW in 2021.
- According to the Joint Research Centre (JRC), installing Agri-PVs on just 1% of EU agricultural land will yield an installed capacity of 944 GW.
- This capacity alone might theoretically achieve the target for Agri-PVs by 2030.

Agrivoltaics (Agri-PVs)

Agrivoltaics (Agri-PVs)



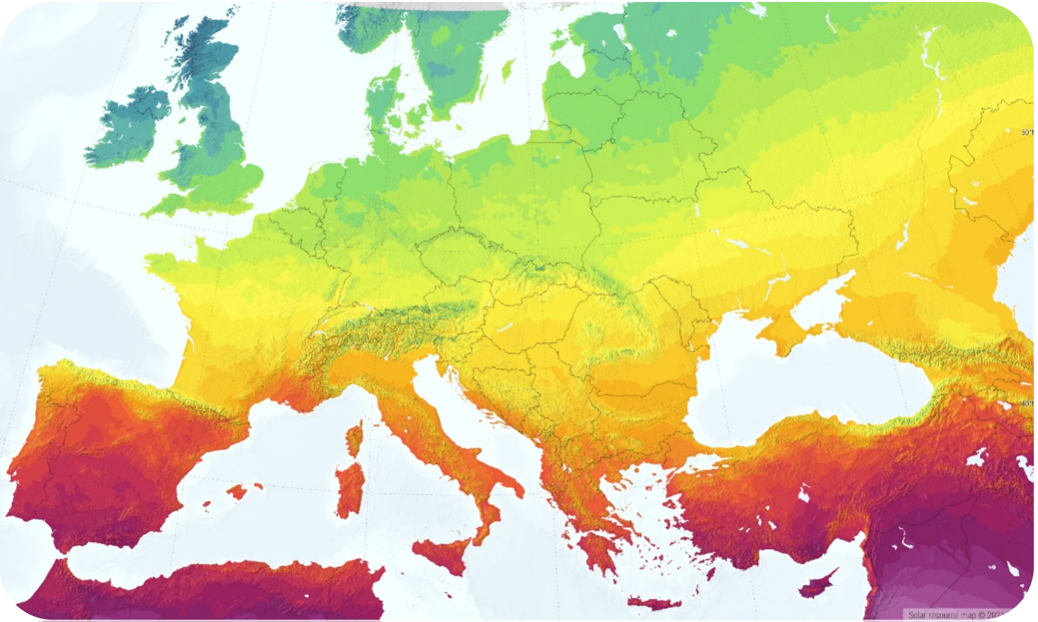
Land requirements and percentage of agricultural land used for Agri-PV systems to achieve the different EU photovoltaic installation targets.



Agrivoltaics (Agri-PVs)

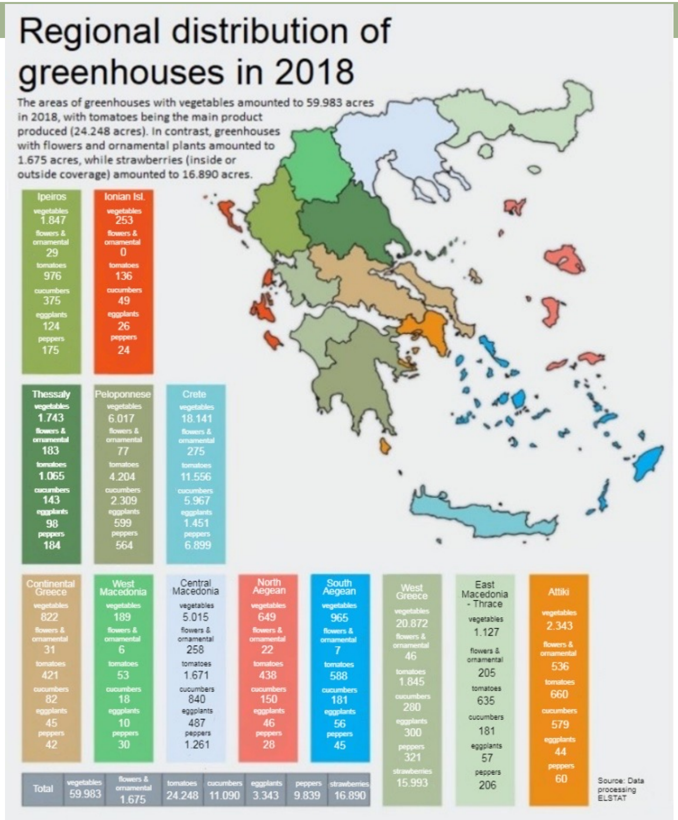
- Greece acquires an extremely favorable position on the world map in terms of climatic conditions (sunshine, temperature, etc.)
- Therefore, combined with its advanced know-how and technology there is the potential for substantial development of Agri-PVs.

Total Solar Radiation on the surface



Agrivoltaics (Agri-PVs)

- In the past two years, the agrivoltaics (Agri-PVs) concept is combined with greenhouses, as greenhouse crops are an intensive way of producing food with high production costs.
- In Greece the area covered by greenhouses reaches 60,000 acres (7th country in greenhouse crops in Europe), with 50% of production costs spent on energy consumption, with its prices gradually increasing.



Agrivoltaics (Agri-PVs)

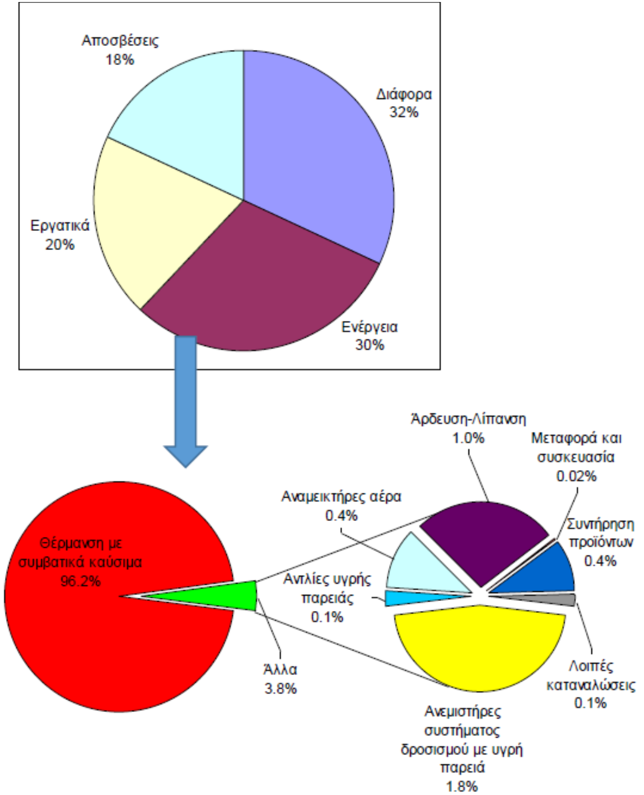
- The advantages presented through the innovation of Agrivoltaics are:
  - Triple benefit: Energy and food production, as well as water usage decrease
  - Increase of food production by up to 30%
  - Energy Savings up to 30%
  - Shading of plants and capture of harmful UV radiation
  - Lightweight construction combined with easy installation
  - Short depreciation
  - New high-paying jobs for young farmers and entrepreneurs
  - Protection of the environment, saving natural resources
  - Circular economy

Greenhouses

- Greenhouses are sophisticated constructions that require a combination of solar radiation, heating, ventilation, and cooling
- In the greenhouse, the microclimate is constantly changing and is controlled by a set of measures that interact with each other considering the balance of energy, water vapor, and CO_2.
- What technology really affects is the ability to control and modify the microclimate to increase productivity and use of energy, water, fertilizers and plant protection.

Greenhouses - inputs

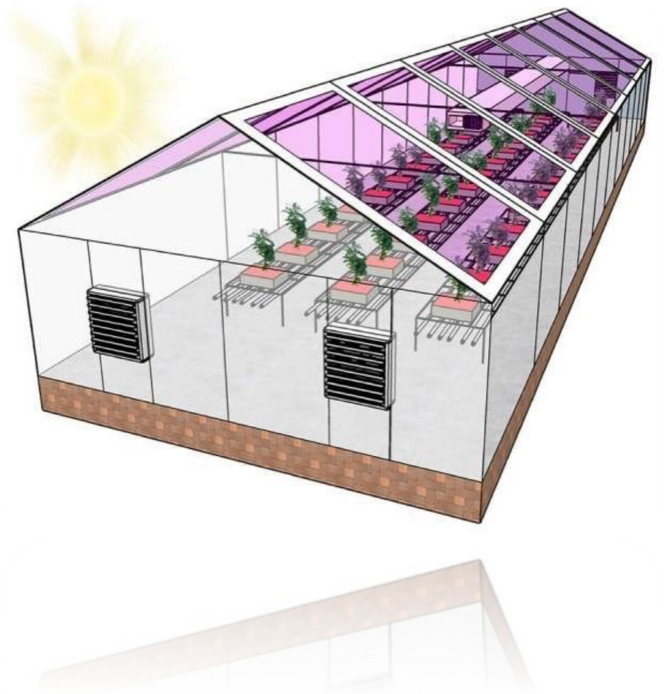
Challenges



	Greece	Turkey
Substrate, plant matter. & more	3%	18.2%
Fuels	**52%**	**32.2%**
Pesticides	**3.1%**	**7.8%**
Fertilizers	**15%**	**22.7%**
Water	1%	0.4%
Electrical energy	15.2%	17.4%
Labour	25%	15.9%

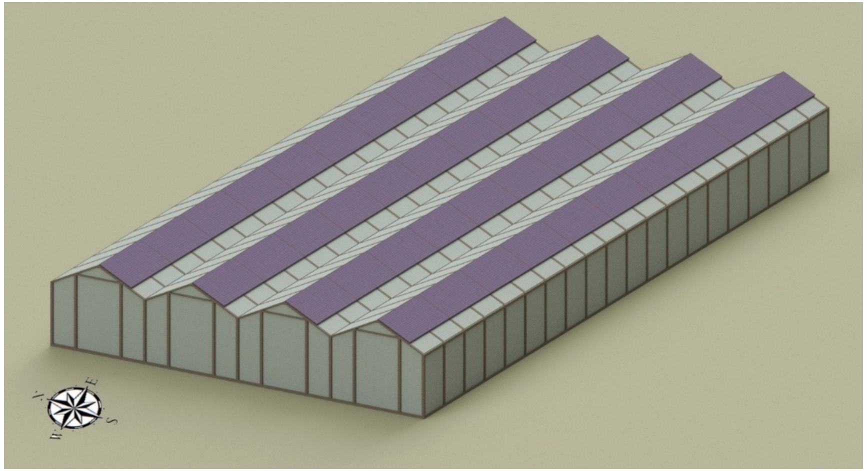
Energy autonomous greenhouses

Energy



Energy autonomous greenhouses

Energy



Photovoltaic greenhouse of the University of Patras

Semi-transparent photovoltaics integrated into the roof of the greenhouse of the University of Patras.

Photovoltaic greenhouse of the University of Patras

- The photovoltaic greenhouse of the University of Patras is a greenhouse, in which semi-transparent photovoltaics were integrated into its roof for energy production.
- The photovoltaic panels designed by Brite Solar S.A. are not mounted on the greenhouse cover but are part of it.
- Considering the necessity of natural lighting for cultivation, but also the need for energy production that meets the energy needs of the greenhouse for functions such as heating, the semi-transparency of these PVs makes them ideal.
- They also have high permeability to solar radiation, with the percentage for Photosynthetically Active Radiation – PAR – amounting to 49%.

Photovoltaic greenhouse of the University of Patras

- The high degree of scattering of the incident light gives the advantage of avoiding the creation of strong shadows by possible skeletal elements under them.

The greenhouse

- The greenhouse of the University of Patras is a real-scale greenhouse, Multi-span type, with the axis of the greenhouse located in the direction East – West.
- It consists of 4 construction units with dimensions of 3.5 m wide and 16 m long.
- The gutter height is equal to 3.3 m, while the ridge height corresponds to 4.5 m.
- The frame of the greenhouse consists of steel elements of different shapes and diameters, which can affect the output of photovoltaics (bifacial) type, due to radiation reflectivity.

Equipment

- The greenhouse has an automated system of natural ventilation through openings (roof windows and side ones).
- To monitor the microclimate of the greenhouse and examine the effect of photovoltaic units on it, two ad-hoc data acquisition systems are installed, with the ability to record:
  - the internal temperature
  - the relative humidity
  - the global solar irradiance
  - the photosynthetically active radiation

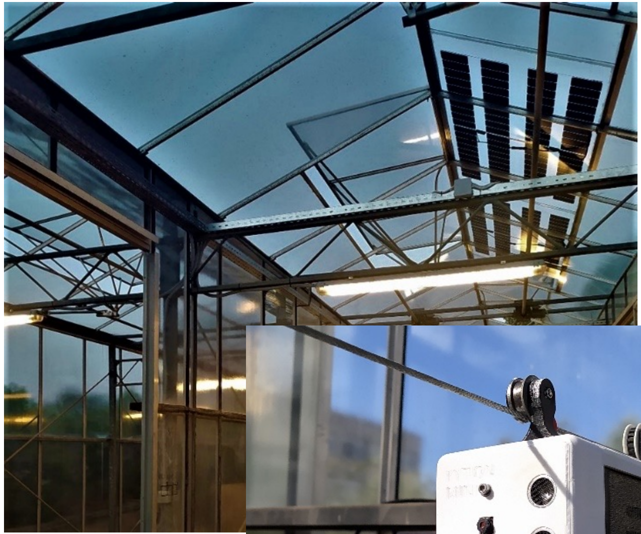
Equipment

- Inside the greenhouse there is also a robotic system - KYTION, based on the IoT (Internet of Things) which was designed in combination with:
  - an application for remote control of the greenhouse and data reception
  - temperature and relative humidity sensors,
  - Decision Support System – DSS,
  - RGB camera

Dionysios Bitas & Nikos-Kyriakos Papastavros

- For the recording of the external conditions, an automatic weather station is installed with the ability to record temperature, relative humidity, wind speed, precipitation, global solar irradiance, infrared radiation, and sky temperature.

Equipment

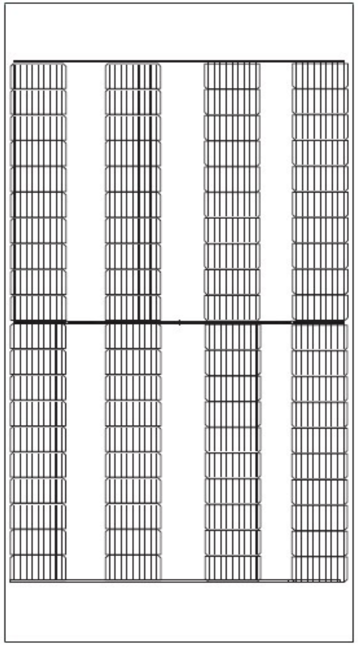


Cultivation

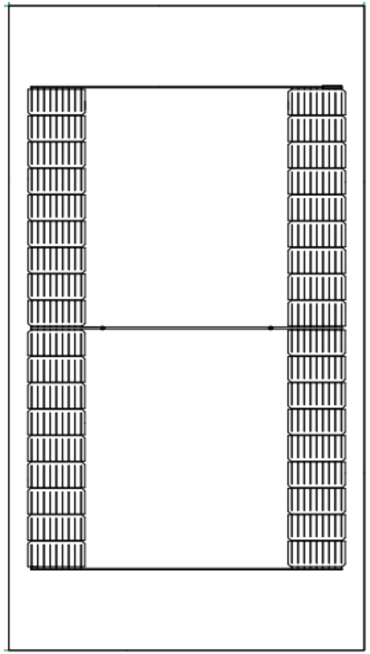
- A strawberry cultivation has been developed inside the greenhouse to draw conclusions about the effect of photovoltaics on the cultivation.

Semi-transparent Photovoltaics – Technical Characteristics

- The photovoltaics used are BSG-250/49 type (maximum power/transparency)
- They have special characteristics related to shading, permeability (in the range 400 to 700 nm), and maximum energy production (max power produced 250 W).
- An additional possible solution is the photovoltaic BSG-115/77 with lower maximum power, but greater transparency.
- One of the most important peculiarities of this photovoltaic system is that it is a bifacial type photovoltaic, with energy produced by the incident radiation, both from the external and the internal side.



BSG-250/49

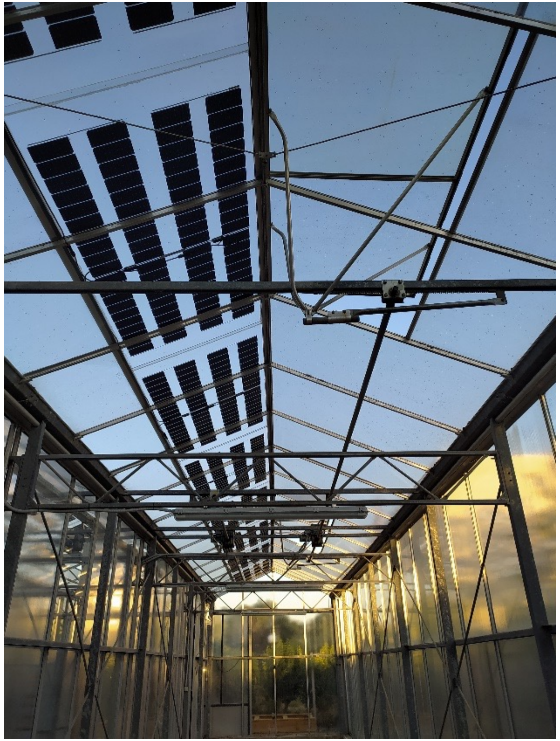


BSG-115/77

The semi-transparent photovoltaic panels

Photovoltaics from the outside

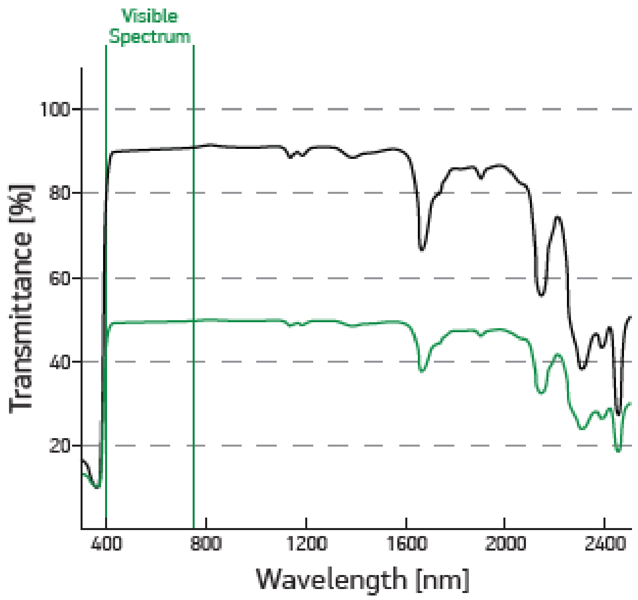
The semi-transparent photovoltaic panels



Photovoltaics from the inside

Semi-transparent Photovoltaics – Technical Characteristics

- The PV has dimensions of approximately 2.1 m long and 1 m wide and is 5.5 mm thick.
- It consists of two glass surfaces with solar cells lying between them. The number of cells is 80, with dimensions of 166x83 mm, creating an active surface of about 1.1 m^2. The solar cell type is monocrystalline silicon.
- The theoretical shading, they cause is about 51%, while the maximum permeability reaches 49% in the PAR spectrum.



Semi-transparent Photovoltaics – Technical Characteristics

- Electrical characteristics:
  - Short-circuit current, I_{SC} equal to 11.47 A
  - Open circuit voltage, V_{OC} equal to 27.94 V
  - Current at maximum power point, I_{mpp} equal to 10.78 A
  - Voltage at maximum power point, V_{mpp} equal to 23.19 V
  - Maximum theoretical power output, P_{max} equal to 250 Wp (in STC)
- STC: Standard Testing Conditions are the standard control conditions of photovoltaics and are described by 1000 W*m-2 solar radiation and 25°C ambient temperature.

Installation of photovoltaic panels

The number of photovoltaics installed in the greenhouse is 12. 8 in the unit north of the greenhouse and 4 in the unit next to it.

The photovoltaics were placed on the south-sloping plane of the roof for maximum production, especially in winter when the sun is at its lowest point in the sky. Their installation was done by replacing the existing cover (glass), while an additional aluminum support was used.

The slope of the photovoltaics is at 24^{o}.

It is important that the photovoltaics that will be connected to each other are placed in positions that receive the same amount of radiation and therefore the same unit produces the same amount of energy.

Photovoltaic Panel Connection

- The photovoltaics have originally been connected in series forming 3 quads. In this case, the generated current of each quad is equal to the current produced by each unit:

$$\mathrm{I}_{quad} = \mathrm{I}_{PV,1} = \mathrm{I}_{PV,2} = \mathrm{I}_{PV,3} = \mathrm{I}_{PV,4}$$

- Respectively, the generated voltage of each quad is equal to the sum of the voltage given by each panel, ie:

$$\mathrm{V}_{quad} = \mathrm{V}_{PV,1} + \mathrm{V}_{PV,2} + \mathrm{V}_{PV,3} + \mathrm{V}_{PV,4}$$

- The 3 quads are then connected in parallel with the total current of the system being equal to the sum of the current produced by each quad and the voltage being equal to the voltage produced by each quad.

$$\mathrm{I}_{total} = \mathrm{I}_{quad,1} + \mathrm{I}_{quad,2} + \mathrm{I}_{quad,3}$$

$$\mathrm{V}_{total} = \mathrm{V}_{quad,1} = \mathrm{V}_{quad,2} = \mathrm{V}_{quad,3}$$

Photovoltaic Panel Connection

- With the final parallel connection, we can produce the highest current intensity necessary for the system, but at the same time the voltage is the maximum we are able to produce considering the specifications of the other elements of the system, such as the voltage inverter.
- At the same time, attention is required when connecting the panels to each other (in our case the creation of each quad). The connection is made between the positive and negative poles of each panel, with the result being a positive and a negative pole that will complete the circuit.

Photovoltaic System

- The photovoltaic system, apart from photovoltaics, requires several other devices, such as:
  - the charge controller
  - The battery
  - The voltage inverter
- The photovoltaic system is autonomous, the energy produced being stored during the day in the battery and feeding the greenhouse whenever necessary.
- However, as demand for power supply is constant, the system is also connected to the public electricity grid, which is used as a backup generator.

Photovoltaic System – Charge Controller

- The charge controller is responsible for charging the battery. It is designed to receive an open circuit voltage of 150 V from photovoltaics and supply the battery with up to 70 A current.

- This charge controller can connect to an external data source, as it records data on the power produced by photovoltaics, the generated current, the system voltage and the battery voltage.

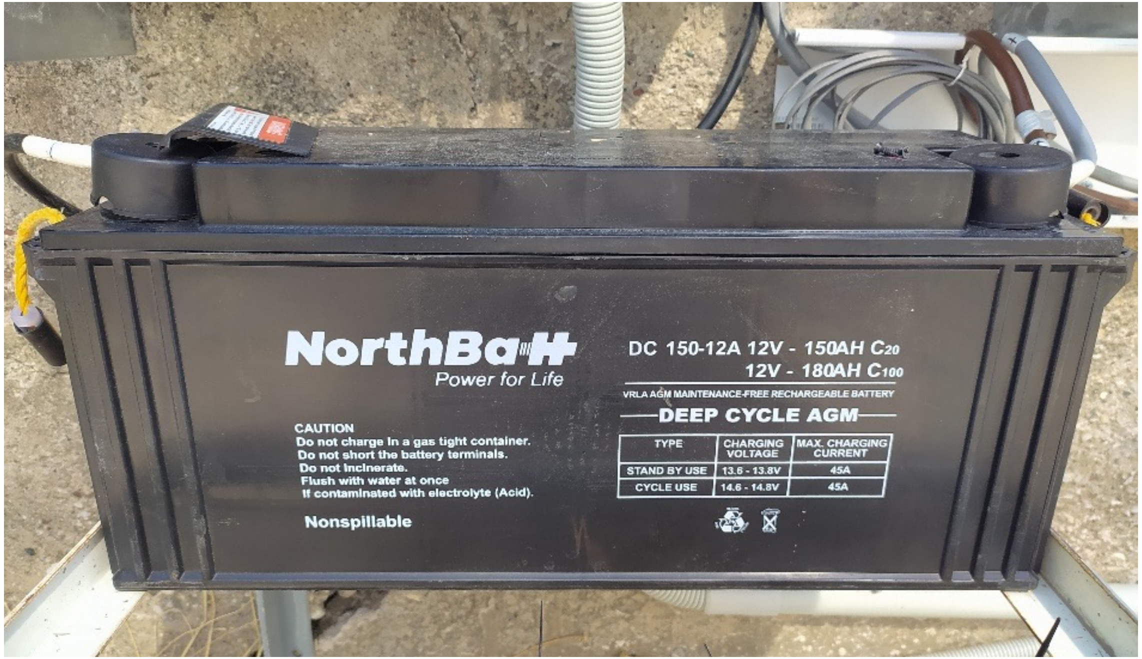
- In addition, charging the battery occurs through three states:
  - the bulk state, where the controller provides the maximum possible current to the battery when it is empty or almost empty, to quickly provide the system with the necessary energy,
  - the absorption state, where the regulator provides less current, as the battery is at safe levels for the system,
  - the float state, where the regulator does not supply or provides minimal current, as the battery is already full.

Photovoltaic System – Charge Controller

Photovoltaic System – Battery

- For the storage of the energy produced by photovoltaics, but also the energy coming from the grid if the photovoltaics cannot respond (case overcast sky), a 12V battery with a capacity of 150AH with a discharge rate of C20 or 180 AH with a discharge rate of C100 is used.
- Referring to a discharge rate of C20 or C100, we mean that the complete discharge of the battery occurs in a time of 20 or 100 hours, respectively.
- For the optimal battery selection, it is useful to evaluate capacity based on the smallest discharge rate. In our case, the C20.
- The battery contains more lead, heavier plates, and other special materials which enables it to provide more power and capacity for multiple charge cycles, but also to recover quickly from deep discharge cases, with these cases being frequent during the night or on days with full and long-term cloud cover.

Photovoltaic System – Battery



Photovoltaic System – Inverter

- It is important to know that the current generated by photovoltaics is direct (DC). However, most greenhouse devices consume alternating current (AC). It should also be noted that the voltage given by the battery is in the order of 12 V, while for most greenhouse operations 220 V is required.
- For the above two conversions, i.e. from DC to AC and from 12 V to 220 V, the inverter is responsible.
- The input voltage of the inverter system is between 10 and 17 V DC, while the corresponding output value is 230 V AC ± 5%. In addition, its output power (Output Power) is 900 W, while the maximum power (for a few minutes of operation) (Peak Watts) is 1600 W.
- The output power of the inverter, and by extension the inverter itself, is selected based on the total consumption of the greenhouse. Therefore, before choosing, it is important to study and measure all the power consumed by the different devices – functions of the greenhouse.

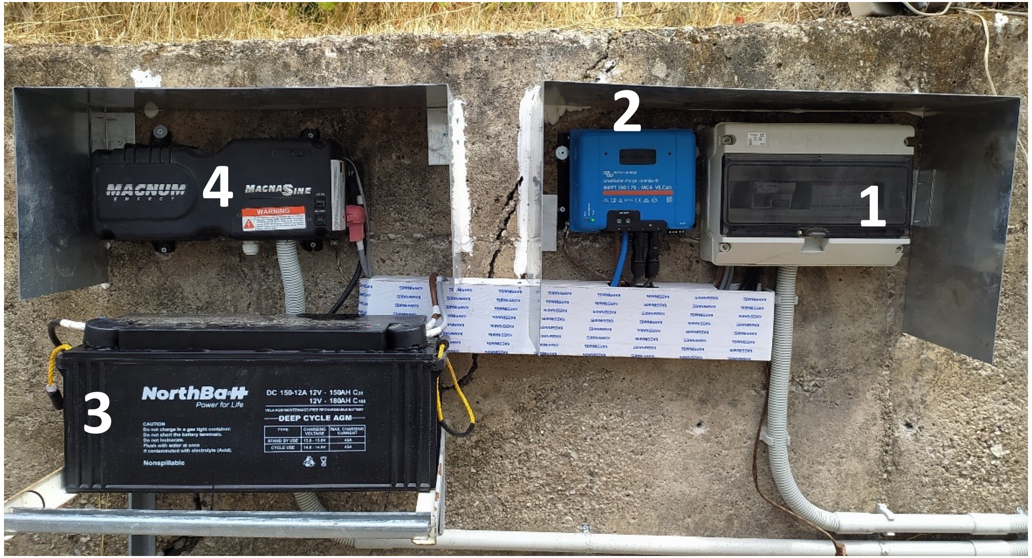
Photovoltaic System – Inverter

- Another factor to be considered is the existence or lack of an alternative energy source. If an alternative source exists an inverter is selected that can supply the system, either from photovoltaics or from the alternative source (e.g. fossil fuel combustion generator, PPG, etc.).
- In this system, a hybrid inverter has been selected which can supply the various elements, either through energy from photovoltaic panels or through the public electricity network.

Photovoltaic System

Current path in the system

1) Photovoltaic concentration (3 positive poles and 3 negative)
2) Charge controller
3) Battery
4) Inverter



Monitoring

- For system management, it is very important to be able to measure various elements, such as power consumed and produced, voltage and current before and after the inverter, etc.
- The measurements in the above system are made at two different points:
  - In the electrical panel of the greenhouse where is the endpoint of the system
  - On the charge controller

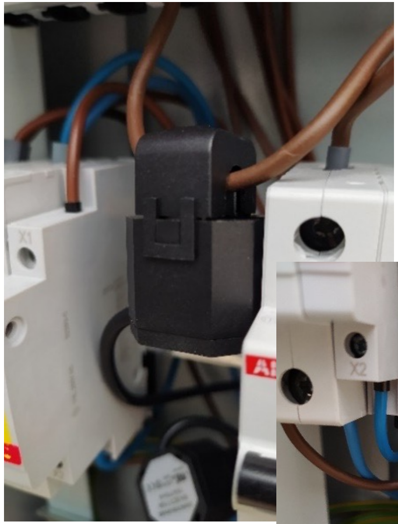
Monitoring

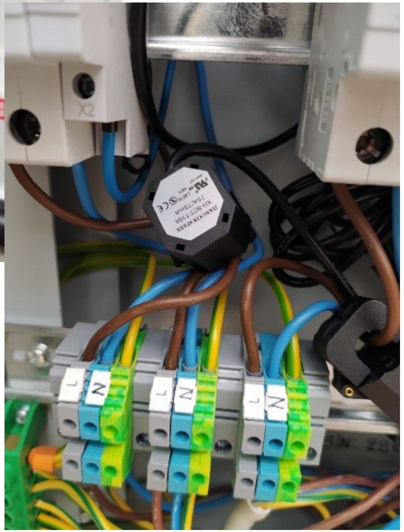
- The measurement system in the electrical panel consists of:
  - a wireless three-phase energy meter (DinRail 3-Phase Advanced) from Meazon S.A., which is used to measure and control one three-phase load or three single-phase ones,
  - three Split-Core AC adapters, capable of measuring up to 2400 A per phase
  - a Linux device (Janus Gateway) for retrieval, aggregation and transfer of data from the above devices to web analytics services via Ethernet.
- The data recorded relate to three different points:
  - Phase A: Supply from PPG
  - Phase B: Supply from inverter
  - Phase C: Total consumption

Monitoring

- In all three phases, data are recorded concerning active power, current, voltage, reactive power, frequency and power factor.
- Data is recorded with a time interval of 10 minutes, transferred over a ZigBee network to Janus Gateway and from there sent to the Cloud.
- The data is read and received through a specially designed page (dashboard) by the company.

Monitoring





Split-Core AC adapters

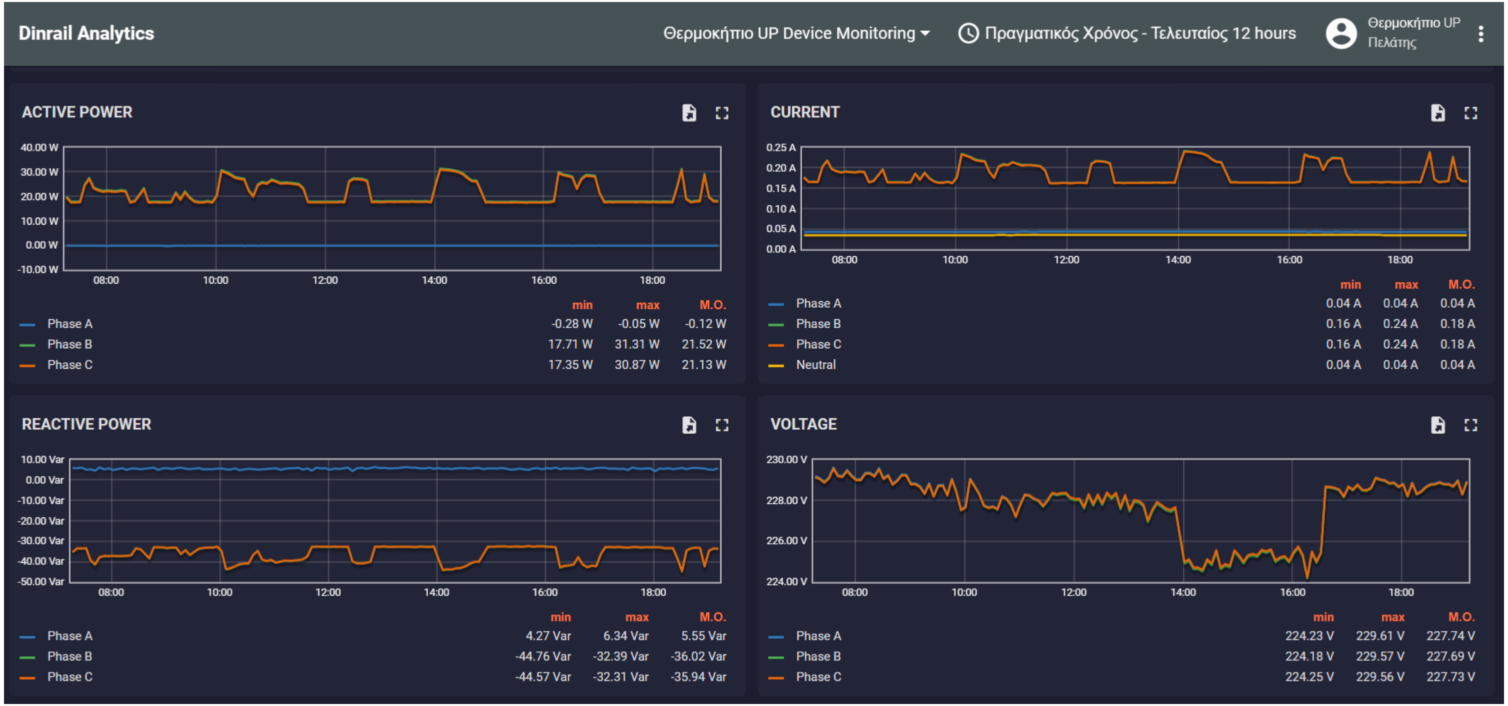
DinRail 3-Phase Advanced

Janus Gateway

Meters & Data

Meazon's dashboard

Meters & Data



Active power, current, reactive power and voltage time series

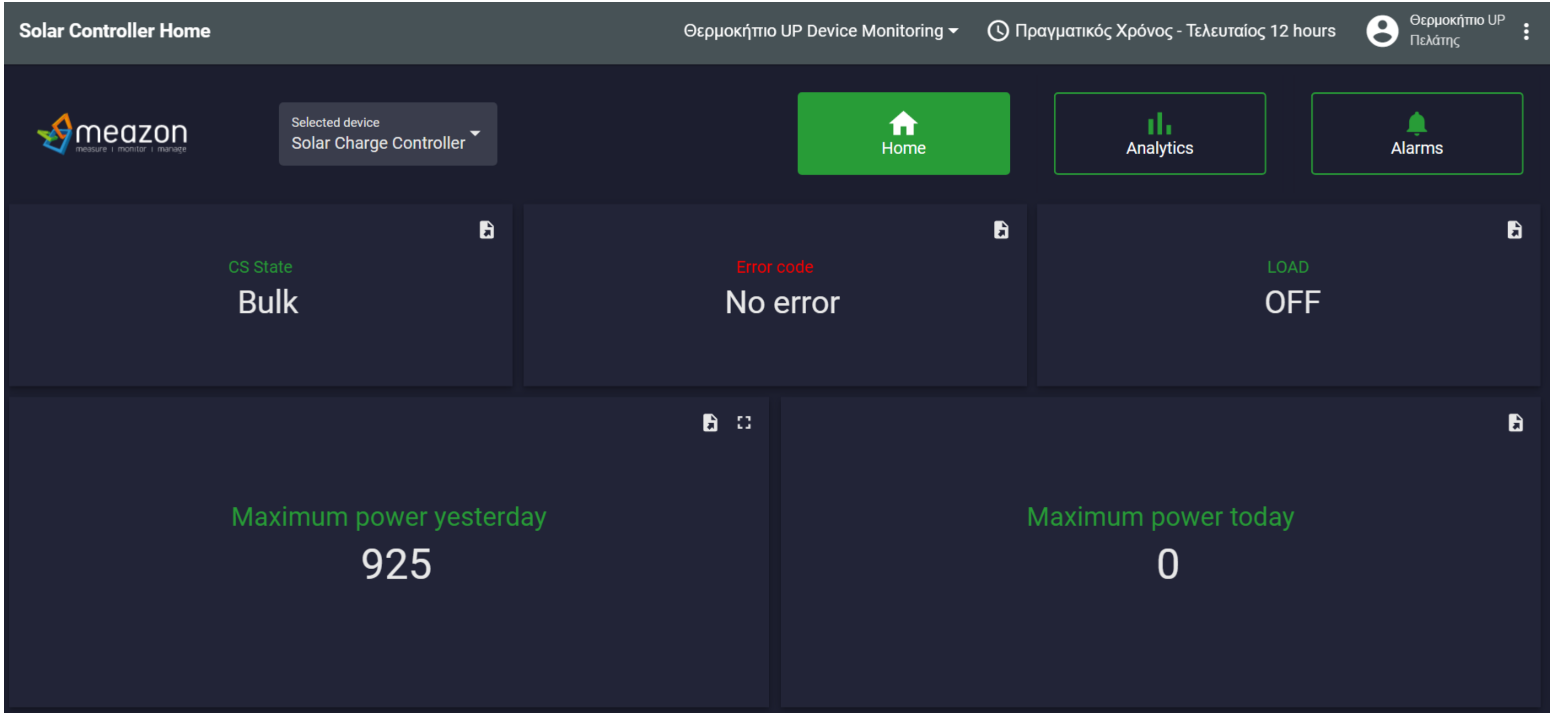
Monitoring

- The measurements taken by the charge controller are the battery voltage, the generated current (Current), the voltage of photovoltaics (PV Voltage), and the power produced (PV Power).
- The smart charge controller can record all these quantities and their real-time monitoring from any device via Bluetooth, with the help of an application from the company Victrom Energy.

Monitoring

- The charge controller also enables a USB connection to receive data instantly.
- The latter mode has been used in the system, through which the data recorded by the charger are transferred to Janus Gateway.
- From there, they are sent to the Cloud, where they are downloaded and read on Meazon's dashboard.

Meters & Data

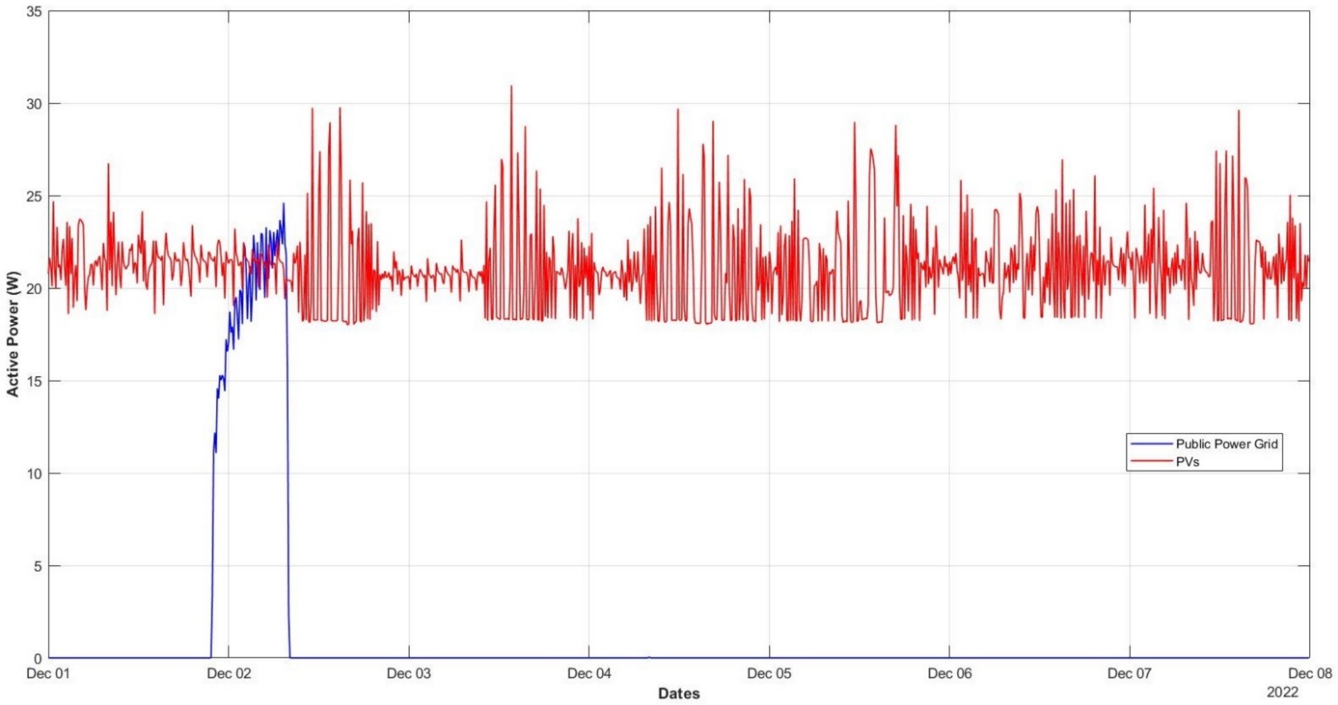


Meazon's dashboard for the charge controller

Meters & Data

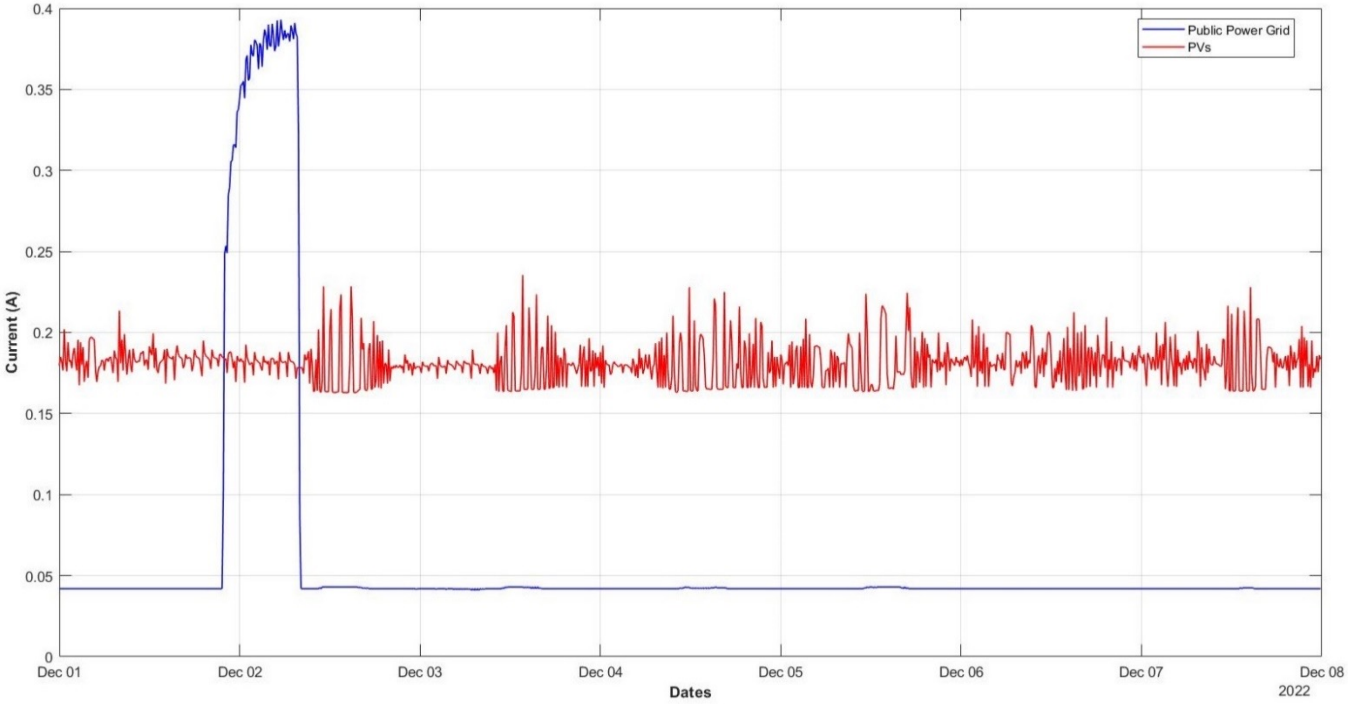
Time series of battery voltage, PV voltage, current and power output

Graphical representations of data



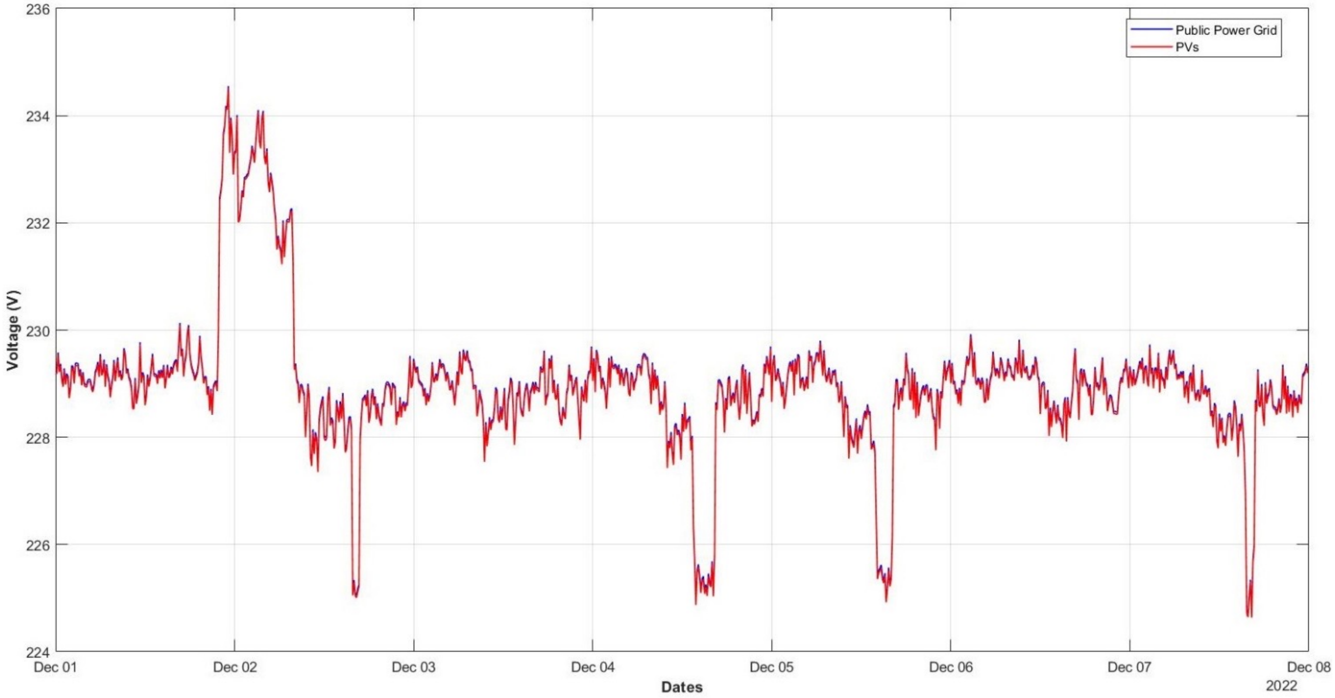
Active power (consumed) from PPG (Public Power Grid) and Photovoltaics (PVs)

Graphical representations of data



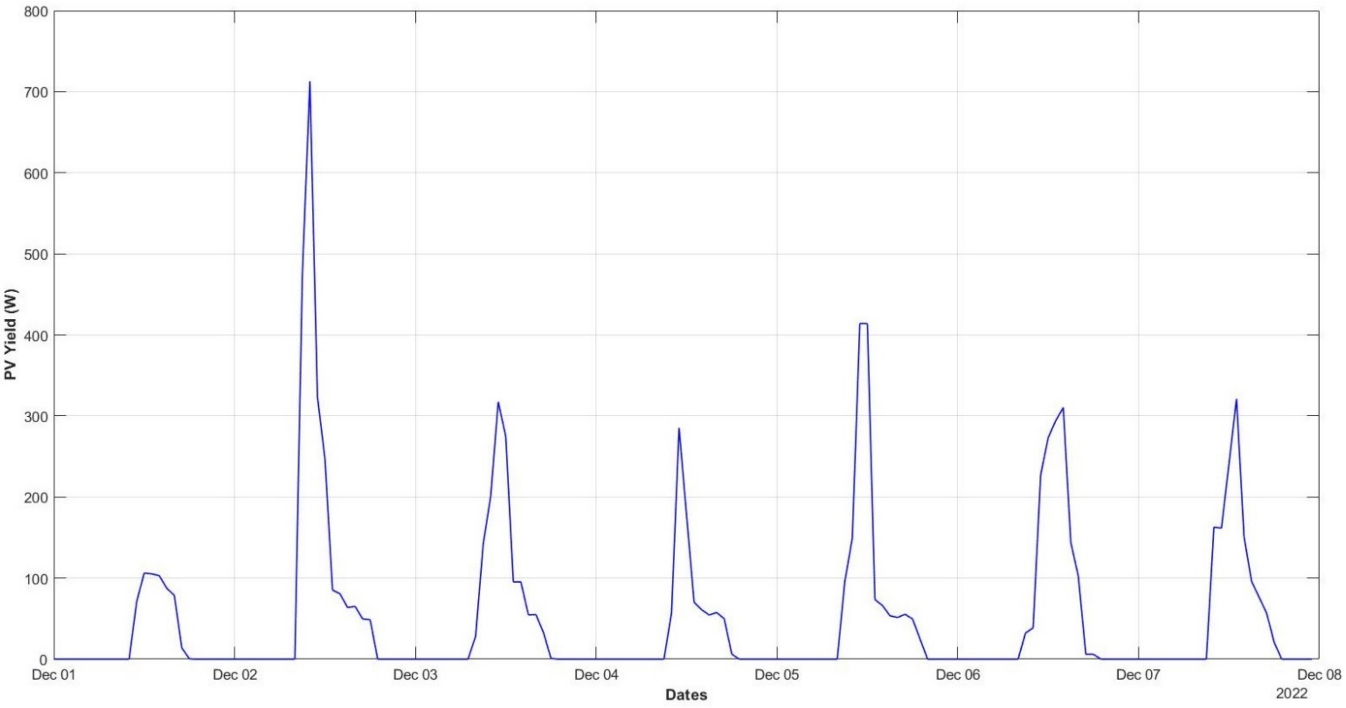
Alternating current (AC) produced by PPG (Public Power Grid) and Photovoltaics (PVs)

Graphical representations of data



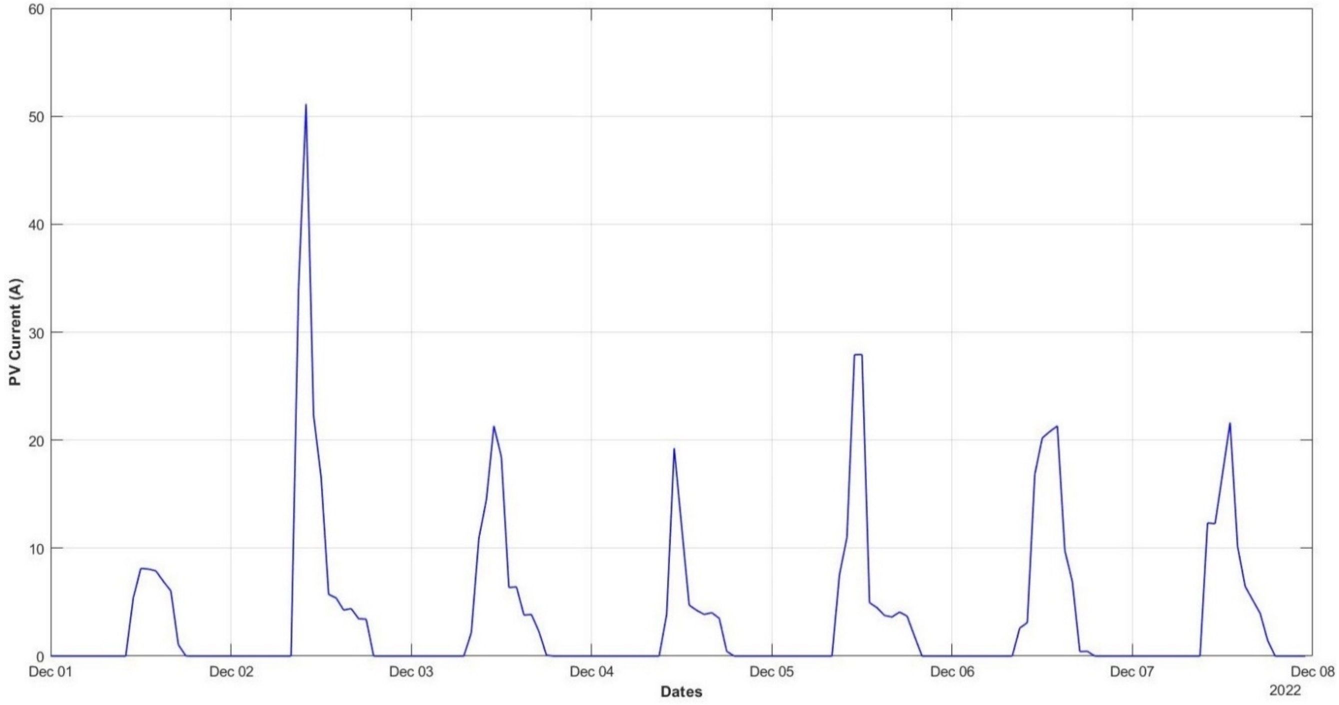
Voltage from PPG (Public Power Grid) and Photovoltaics (PVs)

Graphical representations of data



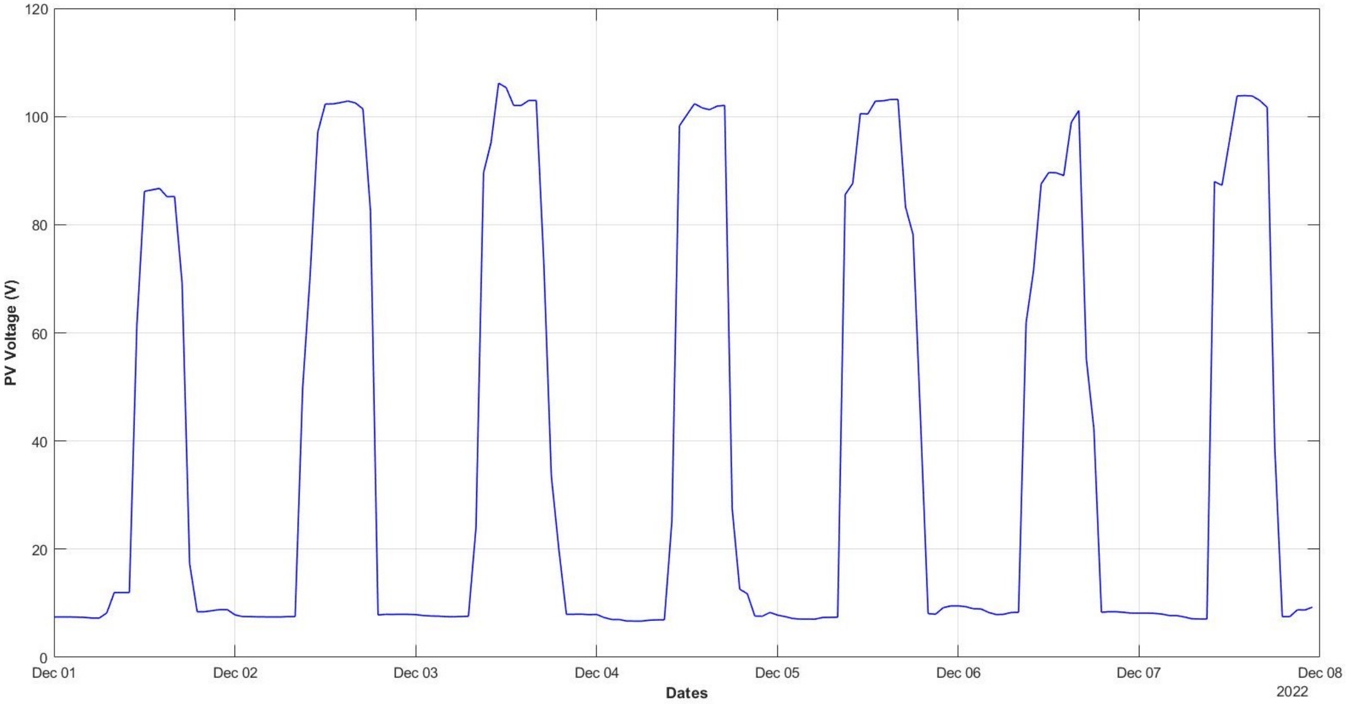
Power produced by photovoltaics

Graphical representations of data



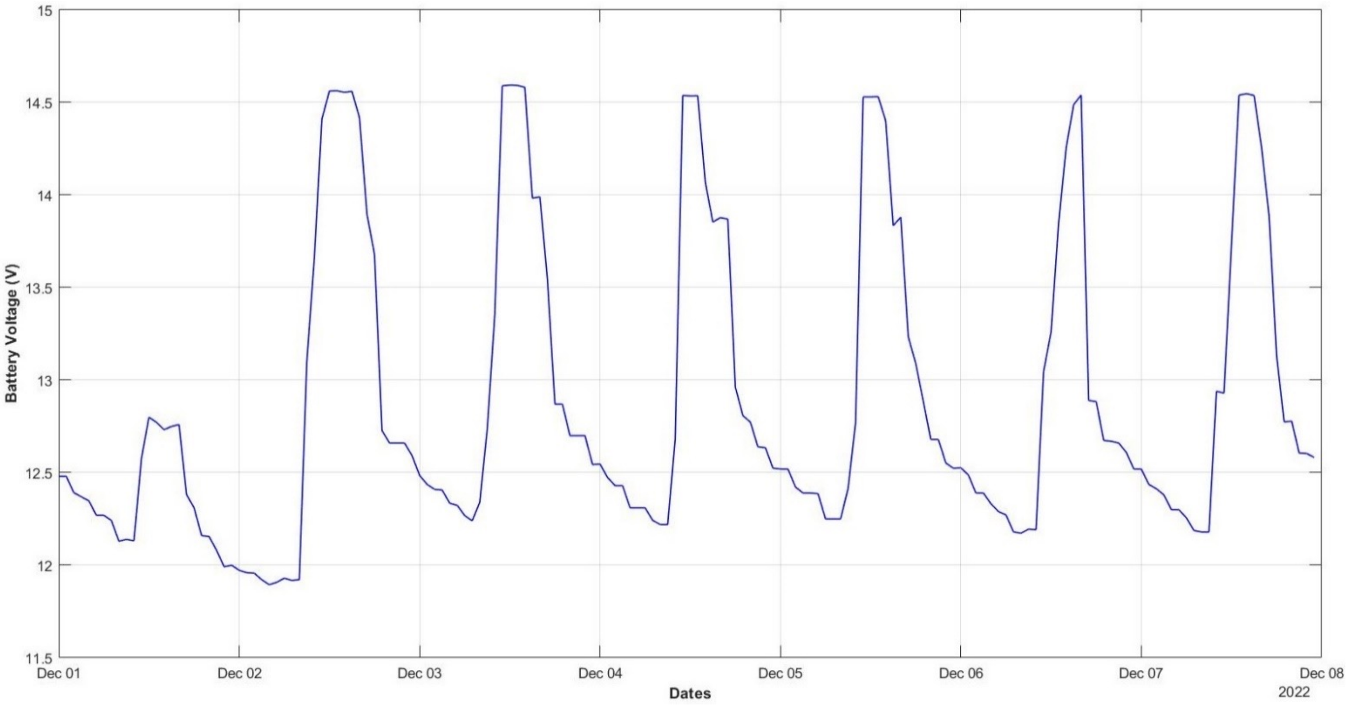
Generated electricity (DC) from photovoltaics

Graphical representations of data



Photovoltaic System Voltage

Graphical representations of data



Photovoltaic System Battery Voltage


THANK YOU