APPLICATION OF RENEWABLE ENERGY RESOURCES FOR FARMING

MODULE 2

INTELLECTUAL OUTPUT 1
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Summary

This module consists of the application of renewable energies for farming, focusing on photovoltaic energy, and the new modality called Agri-PV or agrisolar, as an innovative vision to create more sustainable agriculture in Europe with the help of solar and photovoltaic energy. This type of agriculture will bring impacts at social, environmental and economic levels.

Self-checking open questions

How can farmers support the new Sustainable Development Goals? Can I become more sustainable without losing money? Are renewable energies applicable in agriculture and farming? Where do I start? How does solar energy work? What is agrivoltaics or agrisolar? What is being implemented in Europe in order to obtain a more sustainable agriculture?

Objectives (Determination of the aims of chapters)

- Introducing renewable energies
- Linking renewable energy to agriculture and sustainability
- Defining agri-PV
- Describing technical application of renewable energies
- Explaining the fundamentals of the technical elements of solar energy

Introduction to Renewable Energy

European Energy Sector

Europe is consuming, and importing, increasing quantities of energy. EU countries are well aware of the advantages of coordinated action in this highly strategic field. This has led to common rules throughout Europe and a pooling of Europe's efforts to secure the energy that it needs at an affordable price, while generating the least possible pollution.

The EU overhauled its energy policy framework to help us move away from fossil fuels towards cleaner energy - and, more specifically, to deliver on the EU's Paris Agreement commitments for reducing greenhouse gas emissions.

The agreement on this new energy rulebook – called the Clean energy for all Europeans package – marked a significant step towards implementing the energy union strategy, published in 2015.

The new rules will bring considerable benefits for consumers, the environment, and for the economy. By coordinating these changes at EU level, the legislation also underlines EU leadership in tackling global warming and makes an important contribution to the EU's long-term strategy of achieving carbon neutrality (net-zero emissions) by 2050.

The EU has set an ambitious, binding target of 32% for renewable energy sources in the EU's energy mix by 2030. The revised Renewable Energy Directive (2018/2001/EU), which contains this commitment, entered into force in December 2018.

The world's largest importer

The European Union, the world's second largest economy, consumes one fifth of the world's energy, but has very few reserves of its own. Fortunately, here in Europe, our portfolio — known as the energy mix — is very diverse: from Austria's many dams, Poland's coal mines and France's nuclear power stations to the oil rigs of the North Sea and the gas fields of Denmark and the Netherlands, none of Europe's countries are alike, and that is not a disadvantage. Provided, of course, that those countries work together to make the most of their diversity.

Europe's energy dependence has an enormous impact on our economy. We buy our oil from the Organisation of Petroleum Exporting Countries (OPEC) and Russia, and our gas from Algeria, Norway and Russia. Europe's coffers are depleted to the tune of over €350 billion every year to pay for it. Energy costs are also constantly on the increase. That leaves us with no other option: EU countries have to be efficient, set ambitious goals and work together if they are to diversify their energy sources and supply channels.

Climate constraints

Leading experts have demonstrated what the exorbitant cost of climate change will be if the world does not succeed in reducing its greenhouse gas emissions. The energy sector is directly involved here as over 80 % of its output comes from fossil fuels, which emit carbon dioxide (CO_2), the main greenhouse gas, when they are burnt. In the future, therefore, the European energy sector will have to cut down on fossil fuels and make much more use of low-carbon energy sources.

Renewable energies as part of solution

Renewable energy is at the core of Europe's long-term energy strategy because it helps to reduce greenhouse gas emissions and reduces Europe's energy imports, making Europe more independent. This booming economic sector contributes to European technological leadership, providing EU countries and their regions with new 'green' jobs and high added-value exports.

The current EU objective is for 20 % of the energy consumed in the European Union in 2020 to come from renewable sources (and at least 27 % by 2030). Promotion of this objective throughout Europe has led to a spectacular increase in the production capacity of renewable energy sources. In 2011 over 100 gigawatts of solar panels were installed worldwide, 70 % of them in the EU. EU renewables production contributes to reducing fossil fuel imports equivalent to around €400 billion every year.

Europe's expanding renewable energy market has considerably reduced the cost of renewable technologies: the cost of solar panels has for instance fallen by 70 % over the last 7 years.

Renewable energy is also part of a growing 'green' technology sector which employs more and more people in Europe. In 2011, 1.2 million people had renewable-energy-related jobs. By 2020, the renewables and energy efficiency sector are expected to employ over 4 million people across the EU.

Main sources of renewable energy

Renewable energy resources are from sources of energy that replenish or renew themselves naturally. Renewable energy resources include the following:

- **Wind Energy**

The kinetic energy of the wind is converted into electricity by using wind turbines. Turbines can be located either on land or offshore. The amount of power generated varies with wind speed, which can make power supply difficult to predict over short time periods.

Wind energy as a renewable energy resource accounted for almost 13% of total primary energy production of renewable energy in EU-28 in 2015.

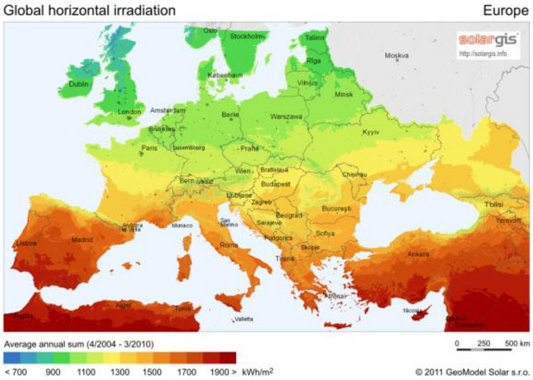
- **Solar Energy**

Solar energy is a renewable energy resource. Around 6% of total primary energy production of renewable energy in the EU-28 in 2015 was generated by this means. The most common example of electricity and heat generation from the sun are:

- Conversion of solar energy into electricity by using a photovoltaic cell
- Concentration of energy from the sun's rays to heat a receiver. This solar heat is transformed into mechanical energy by turbines and thus into electricity available for consumption
- Generation of heat energy through solar thermal technologies

The generation of electricity and heat by means of solar energy has the following main features:

- Solar energy is an infinite resource and freely available.
- Large areas of land are required to capture the sun’s energy with collectors.
- The generation depends on the level of insolation, which varies between different regions and weather conditions.
- Solar energy can be used in remote areas where the electricity power grid is not available.
- More and more everyday appliances can be operated with solar energy.



- **Hydropower**

In 2015, hydropower was Europe's largest renewable energy resource accounting for more than 14% of total primary energy production of renewable energy in the EU-28.

Hydropower is generated by first converting the potential energy stored in water into the kinetic energy of running water, which is then converted into electrical energy via turbines.

The main hydropower technologies are:

- Run-of-river hydropower plants - obtain energy for electricity production from river water.
- Reservoir hydropower plants – use water stored in a reservoir for electricity production.
- Pumped storage plants – here, water is pumped from a lower reservoir into an upper reservoir when electricity supply tops demand.

Where there is reservoir storage of water, hydropower can be generated when needed to meet rapid or unexpected fluctuations in demand. However, there are limited possibilities for sites and potentially high environmental impacts through land use and conversion.

- **Energy from Biomass**

Biomass - organic material of non-fossil origin, including organic waste - can be converted into bioenergy through combustion, either directly or via derived products. Around 64% of total primary energy production of renewable energy in the EU-28 in 2015 is generated this way.

Examples of derived products from waste streams include the conversion of waste oil into biodiesel, animal manure and organic household waste into biogas and plant or plant waste products into biofuel.

The following materials can be used in the generation of bioenergy:

- Wood and wood waste.
- The organic part of municipal solid waste.
- The organic part of industrial waste.

- Sewage.
- Manure.
- Crop plants and plant by-products of food production.

Along with the rain and snow, sunlight causes plants to grow. The organic matter that makes up those plants is known as biomass. Biomass can be used to produce electricity, transportation fuels, or chemicals. The use of biomass for any of these purposes is called biomass energy.

- Biomass, particularly woody biomass, can be directly combusted to generate heat and/or electricity.
- Biogas, primarily methane and carbon dioxide, is produced through the bacterial decomposition of organic matter like sewage, manure, organic household waste and plant crops.
- Biofuels are liquid fuels from a non-fossil biological origin and also represent a renewable energy resource. Biofuels can be divided into biogasoline and biodiesel depending on the material of origin used.

Since the organic plant matter has absorbed carbon dioxide as it grows, when it is finally burnt to generate bioenergy, it releases a comparable amount of carbon back into the atmosphere.

However, agricultural biofuel production is in potential competition with agricultural food production. According to the Helmholtz Centre for Environmental Research (UFZ), bioenergy crop production is rapidly increasing in the EU, and in 2011 used 13% of Europe's agricultural land. The land demand of bioenergy crops can be contentious and needs to be balanced in the context of an overall sustainable approach to land management.

- **Geothermal**

In 2015, geothermal energy contributed to around 3% of total primary production of renewable energy in the EU-28 countries.

Geothermal energy is present in the earth in the form of heat, and stored in rocks, trapped vapour, water or brines. This heat energy can be used directly for heating or to generate electricity.

A major advantage of geothermal energy lies in the reliability of its supply as well as its nearly unlimited availability. However, the technological system (pipe system) can require large amounts of space, and there are difficulties in maintaining the equipment which is mainly based deep under the earth's surface. Additionally, there can be adverse environmental impacts through the release of potentially harmful or hazardous substances as a side product of this kind of energy production.

According to the International Energy Agency (IEA) geothermal energy could account for around 3.5% of annual global electricity production and 3.9% of energy for heat (excluding ground source heat pumps) by 2050.

- **Tidal, Wave and Ocean Energy**

Tidal, wave and ocean energy currently make only a minor contribution to electricity production, both in the EU countries and worldwide. In 2015, this energy source contributed 0.02% of the total electricity generated from renewable energy sources in the EU-28.

Since the 1970s there have been a variety of technologies under development to exploit different sources of energy in the oceans, however, none of the different types of technologies are widely applied yet with France and UK being the only countries in the EU-28 which report primary energy production generated by this source in 2015.

Tidal, wave and ocean energy sources include:

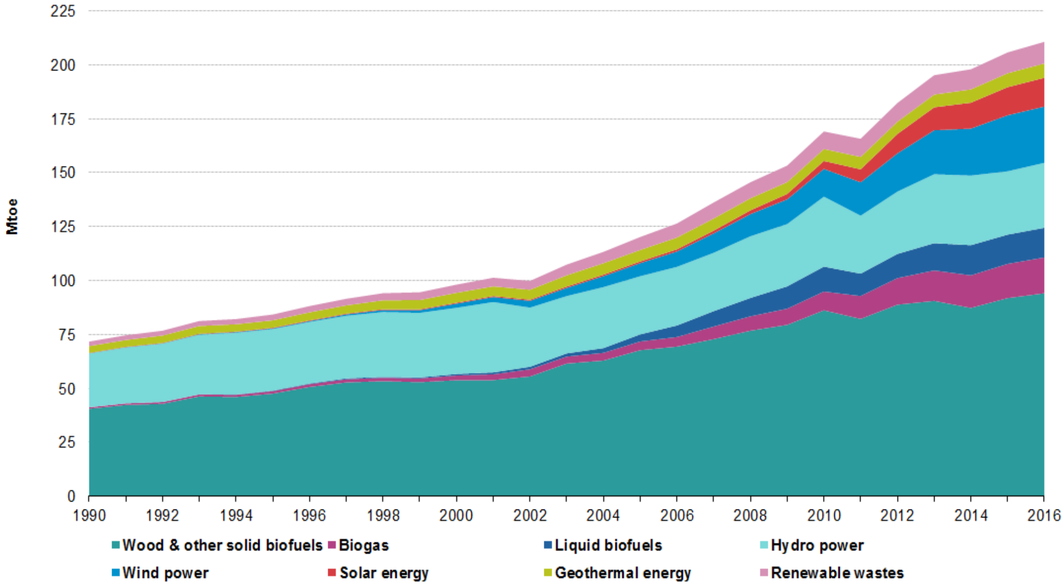
- Tidal energy: the potential energy in tides due to their rise and fall can be harnessed by building a barrage or other forms of construction across an estuary.
- Tidal (marine) currents: the kinetic energy associated with tidal currents can be harnessed using modular systems.
- Wave energy: the kinetic and potential energy associated with ocean waves can be harnessed by a range of technologies under development.
- Temperature gradients: the temperature gradient between the sea surface and deep water can be harnessed using different ocean thermal energy conversion (OTEC) processes.
- Salinity gradients: at the mouth of rivers, where freshwater mixes with saltwater, energy can be harnessed using the pressure-retarded reverse osmosis process and associated conversion technologies.

EU renewable energies evolution

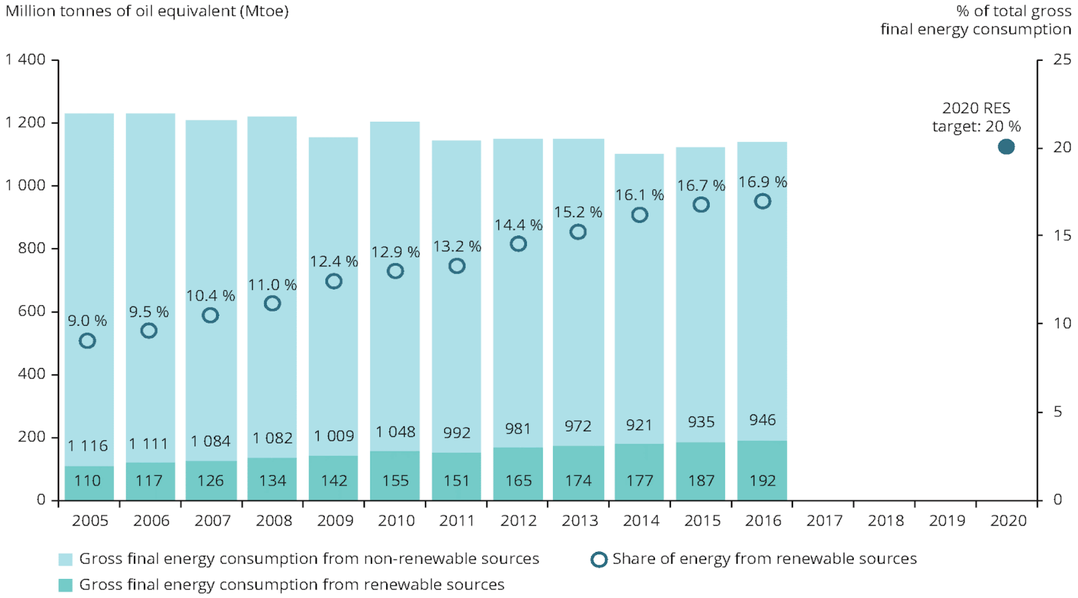
Renewable energy sources include wind power, solar power (thermal, photovoltaic and concentrated), hydro power, tidal power, geothermal energy, biofuels and the renewable part of waste.

The use of renewable energy has many potential benefits, including a reduction in greenhouse gas emissions, the diversification of energy supplies and a reduced dependency on fossil fuel markets (in particular, oil and gas). The growth of renewable energy sources may also have the potential to stimulate employment in the EU, through the creation of jobs in new 'green' technologies.

Renewable energy in the EU has grown strongly in recent years. More concretely, the share of energy from renewable sources in gross final energy consumption has almost doubled in the last few years, from around 8.5 % in 2004 up to 17.0 % in 2016.



This positive development has been prompted by the legally binding targets for increasing the share of energy from renewable sources enacted by Directive 2009/28/EC on the promotion of the use of energy from renewable sources. While the EU as a whole is on course to meet its 2020 targets, some Member States will need to make additional efforts to meet their obligations as regards the two main targets: the overall share of energy from renewable sources in the gross final energy consumption and the specific share of energy from renewable sources in transport.



Estimated effects of RES consumption

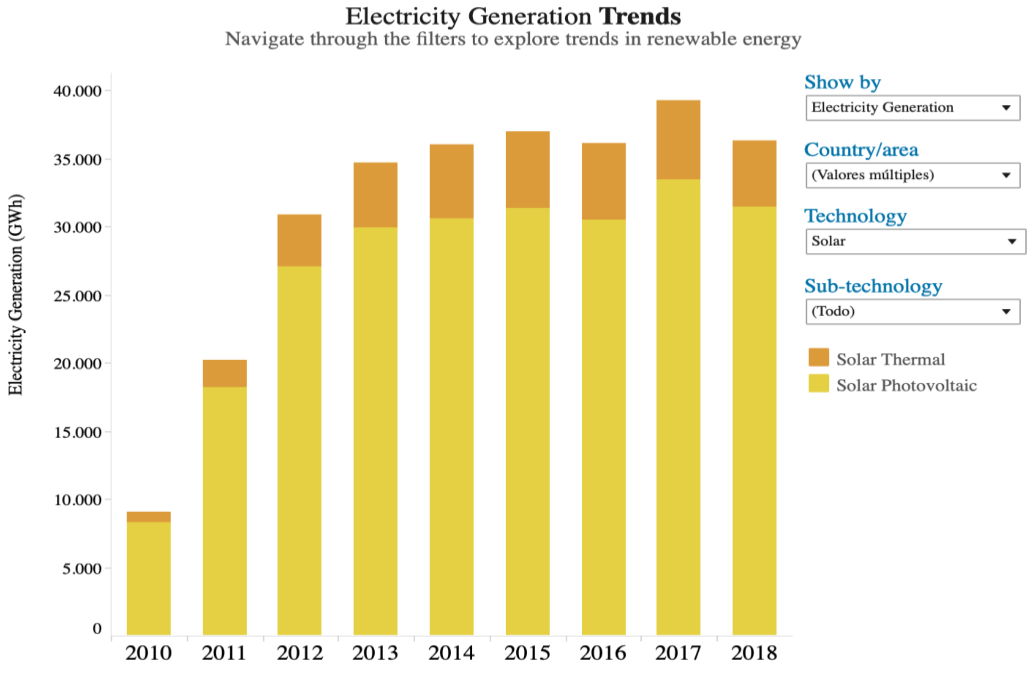
In 2015, the additional consumption of renewable energy, compared with the level of gross final RES consumption in 2005, allowed the EU to:

- Reduce total GHG emissions by 447 MtCO2 equivalent to 9% of the total EU GHG emissions.
- Cut its demand for fossil fuels by 135 Mtoe, or roughly 10% of the gross inland consumption of fossil fuels at the EU level.
- Reduce its primary consumption by 36 Mtoe, equivalent to a 2% reduction in primary energy consumption across the EU.

Photovoltaic solar energy

According to Eurostat sources, in 2008, solar energy was only 1% among the energy created in Europe by renewable energies. Due to its applicability in different settings, it has risen “from just 7.4 TWh in 2008 to 125.7 TWh in 2019” (Renewable energy statistics, 2020).

Solar power, as its name states, comes from the sun, converting the sunlight to electricity (European Commission, 2021). This type of renewable energy “is the cleanest and most abundant renewable energy source available” (Solar Energy Industries Association). and it can be used for generating electricity and heating, depending on the technology used. In this sense, there are three main ways to produce energy: photovoltaics, solar heating & cooling and concentrating solar power. Each method works in a different way, but the result is the creation of electricity or heating/cooling:



Show by: Electricity Generation
Country/area: (Valores múltiples)
Technology: Solar
Sub-technology: (Todo)

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- Photovoltaics (PV): uses solar cells assembled into solar panels to transform the sunlight to energy by photovoltaic effect. It is “installed on the ground, rooftops or floating on dams or lakes” (European Commission, 2021).
- Solar Heating & Cooling (SHC): collects thermal energy from the sun and provides hot water, space heating, cooling and pool heating (Solar Energy Association Industries).
- Concentrated solar power (CSP): uses mirrors for concentrating the sunlight. By doing so, it produces heat and steam that later generate electricity.

In the following lines, the document will focus on the application of these types of solar energy specifically for farming situations.

Components of photovoltaic installations

Photovoltaics' installations transform solar radiation through a collector field (PV or photovoltaic panel). This collector field is always equipped with batteries or other technologies, to transform radiation into energy generated by the panels.

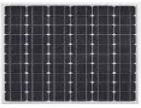
There exists different types of components that may vary depending on the type of installation, its usage and objectives. The most common components of a photovoltaic installation are:

- Photovoltaic panel
- Supporting structures for photovoltaic panels
- Regulator/Maximiser
- Batteries
- Power inverters

- **Photovoltaic panel**

In general, photovoltaic panels are formed by individual cells, known as solar cells. The solar cells are in charge of generating electricity. A combination of solar cells creates a solar panel and it is used to transform the solar energy into electricity (voltage). Usually, the minimum number of solar cells that form a solar panel is 36, but it can vary in size, depending upon the application purpose.

Lately, the most common type of photovoltaic panels is monocrystalline cells as it is more efficient and the price difference among polycrystalline has been reduced during recent years. Nonetheless, there are also other types that are being used, such as polycrystalline and amorphous thin-film solar panels. Hereafter, a short definition of these three PV cells:

Most common photovoltaic cells		
Monocrystalline silicon 	A cell made by just one crystal silicone, and provides between 14-21 % of efficiency. When the highest efficiency is used, the smallest surface is needed to get the same power. Nowadays, the ratio is around 225W/m^2.	
Polycrystalline silicon 	A type of cell that used to be cheaper than the monocrystalline silicon (nowadays the prices are more balanced), made by a number of different shades of blue crystals silicone, with efficiency between 12-18 % achieving a maximum surface power ratio of 175 W/m^2.	
Amorphous silicon 	Non-crystalline form of silicone also called thin film panels that are used as deposits on different surfaces, the flexible panel which can be used in curved or irregular surfaces. And they generate efficiency between 6-10 %.	
	CIS and CISG cells	Cells used in thin-film solar panels, made of copper, indium, selenide and gallium. Together with amorphous silicon, it is one of the three mainstream thin-film photovoltaic technologies (there is a third one called cadmium telluride). CIGS layers are flexible and normally use high-temperature deposition techniques, but in order to get the most out of its performance it is better to use them in cells deposited on glass. Albeit this type of cell outperforms polysilicon at the

		cell level, its module efficiency is lower due to less mature upscaling.

Supporting structures for photovoltaic panels

The photovoltaic module is supported and gets the necessary inclination to obtain the maximum efficiency by a structure. The structure is also responsible for fixing the PV modules against wind gusts, and supporting the wiring interconnection.

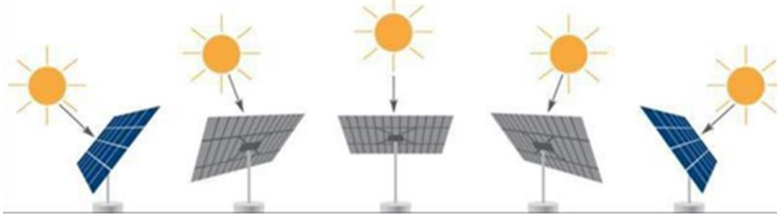
Made of anodized aluminium (easier to transport and weigh less), or galvanized steel.

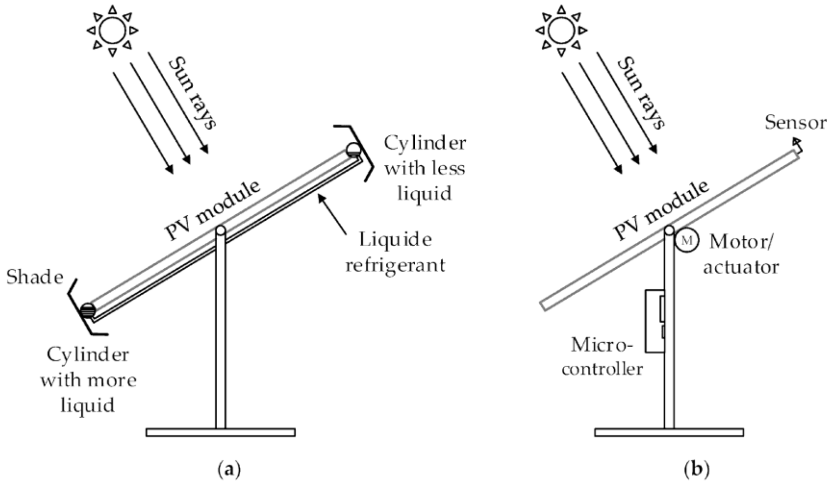
There are different types of structure that are supporting solar panel:

- Fixed structure: it is the type of structure that is anchored and secured in place. It can be coplanar and inclined.
    - Coplanar structure: situate in parallel with the installed panels surface to optimize their integration. It's recommended to leave a space ventilation of the panels between the surface and the structure.

    - Tilted structure: Type of structure that can change the inclination of the installation angle manually from two positions to achieve the ideal inclination for the installation.

- Sun tracking structure: it is the type of structure that can track one axis with the movement along one axis, or two axes to change the inclination of the panel. This type of structure is most efficient because it can reach up to 40% of the photovoltaic production efficiency.





Regulators and Maximisers

- Regulators: electronic equipment that usually have an input voltage of 12, 24 or 48V, which controls and stabilizes the battery charge to get too low or too high, optimizing their battery life.
- Maximisers (Maximum Power Point Tracking – MPPT): they are new technologies controller charges equipment (power converters), used to analyze and compare photovoltaic panel flow energy with their internal algorithm and reach the best use of them, they can even reach an input voltage of 150cc.

Batteries

The battery is a recipient system that can store the energy from a source. Technology keeps innovating, and nowadays there are different types of batteries especially for the use in the renewable energy area, so then we can describe:

- Monobloc battery: it is an economical low maintenance battery that can reach as high as 400 cycles to 75 % of discharge. They are usually used in low demand in caravans, ships or weekend homes.
- GEL and AGM monobloc batteries: the type of batteries that during their operations don't emit gases, they are low self-discharge and can maintain charge for 6 months, so they lose less capacity during their lifetime due to their lower sulfating. Gel and AGM monobloc batteries are the perfect type of battery for the ships, caravans, and solar installations because they are lower.
- Semi-stationary monobloc batteries: Type of batteries that usually used in solar energy and high cycle application, they have two different models in these types of batteries: Flat plate or tube plate, with the only difference between both is that tube plate technology duplicate the flat plate technology's lifetime.
- CPZS batteries: 2V cells commercialized batteries that contain an opaque polypropylene that gives them the capacity to resist deep discharges and can reach a lifetime of 3000 cycles at 50 % of discharge.
- OPZS batteries: the most recommended batteries for photovoltaic solar installations, the electrolyte level that is visible though their wall helps with the low maintenance of those

batteries. They can lose half of their life time if they are not using appropriately in the recommended size, but normally they are prepared for deep discharges up to 3000 cycles at 50%.

- OPZV batteries: tube plate batteries with electrolyte in front of the form of gel. They are the kind of battery that can be installed in any position, with higher efficiency in their lifetime due to the low sulphate. OPZV are the recommended batteries where water is uncontrollable and for communications facilities. They have higher energy efficiency and are more expensive than OPZS batteries.
- Nickel-iron batteries: renewable batteries that can change every 7 or 8 years due to the electrolyte that they have which do not destroy them, so they are long lifetime batteries patented by William Edison in the 20th century to be used in electronics cars.
- Lithium-ion battery: these types of batteries have evolved a lot during recent years. Nowadays, they are highly used in photovoltaics, as they have increased their lifetime with a guarantee of 10 years approximately. It allows around 6000 cycles (number of charges) and they do not require maintenance. Moreover, they have a high storage capacity and low weight volume ratio.

Power inverter

The power inverters are equipment that are used to transform DC from the battery or directly from the photovoltaic panels, to a AC at grid voltage and frequency.

Two types of inverters can be found:

- Grid-tie inverter: these kinds of inverters need the signal of the grid to transform the energy generated at the same rate in the grid. They can range current power from 20-300W for inverters imbibed in the photovoltaic modules to medium and central inverters that can reach more than 100kW.
- Stand-alone inverters: these kinds of inverters just transform the energy into the preselected values, between these inverters. We can distinguish 3 different types:

    - Square wave inverters: inverters that can only be used to feed a television, computer or small electric devices, because they are less efficient than the others and not suitable for induction motors because of too many harmonics that they produce and that causing interference.
    - Modified sine wave inverters: those kinds of wave presented best price and quality to the feed lighting, television or, they have been modified to be closer to the sine.
    - Pure sine wave inverters: are the type of inverters that need complex technology, and they produce a pure sine wave.

Types of installations

There are three types of photovoltaic solar installation, depending on the use:

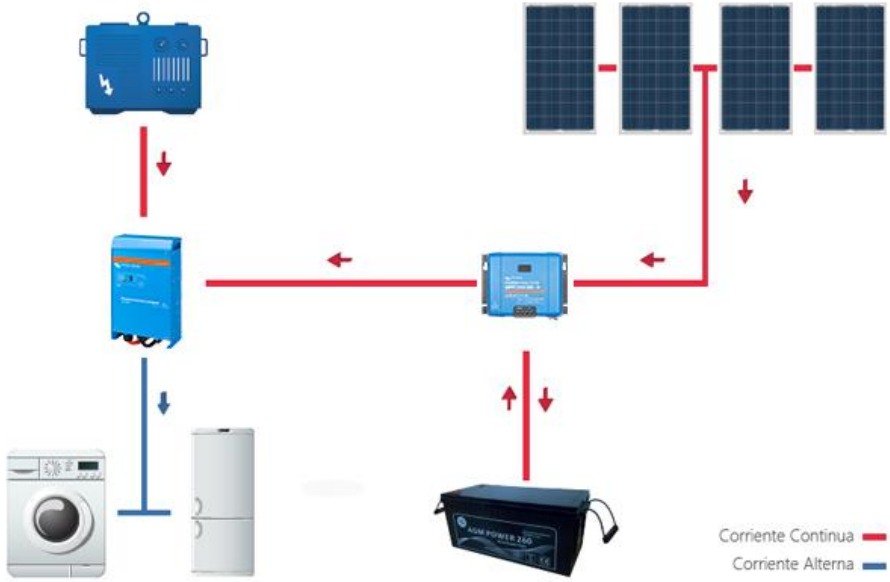
- **Off-Grid**

It is the type of electrification installation that is used for isolated houses, hotels, industries and rural areas. ´This installation takes place where the energy generated and stored is for different use. These kinds of installations are not connected to the network distribution. This installation is found in places where it is economically important to create a distribution network or where there is no access to the distribution network.

The components of this kind of installation are:

- Photovoltaic panel
- Regulator/ maximiser

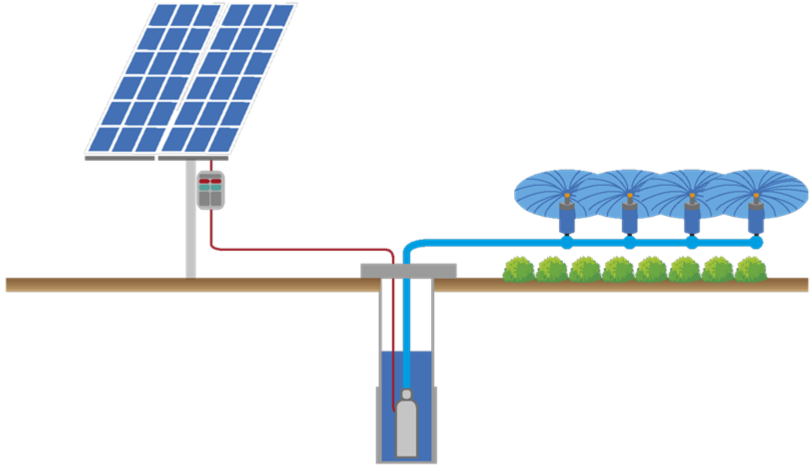
  - Battery bank
  - Inverter charger
  - Auxiliary generator



In this kind of installation, the regulator charges the battery with the energy generated by the panel or by direct current, and an inverter is needed to remove the energy stored in the battery by the regulator.

Off the grid is also used in installations that do not need a stored energy for their use, and works only where there is a photovoltaic production as: solar pump, solar irrigation, swimming pool, purifies or ventilation equipment.

  - Pumping and solar irrigation: a type of installation for irrigation systems which requires a controller to regulate the irrigation flow or pumping flow to a deposit depending on the existing radiation (some pumps include the controller). Currently, it is common to use frequency variators as solar pumps controllers.

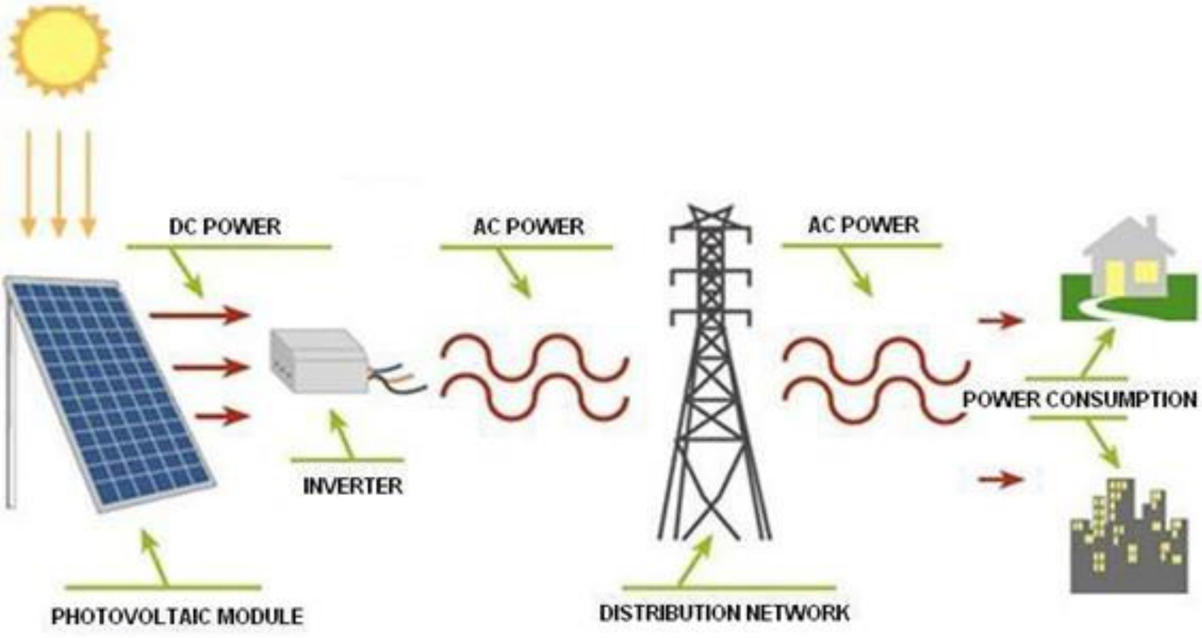


  - Solar purification of swimming pools: a type of installation where the photovoltaic solar panels transfer the energy generated directly to a pump controller to regulate the current.

- **Grid-tie installation**

Type of installation used for the electrical market that is the kind of photovoltaic installation that uses all the generated energy to the distribution network.

This type of installation only needs: photovoltaic panels solar and a Grid-tie inverter.

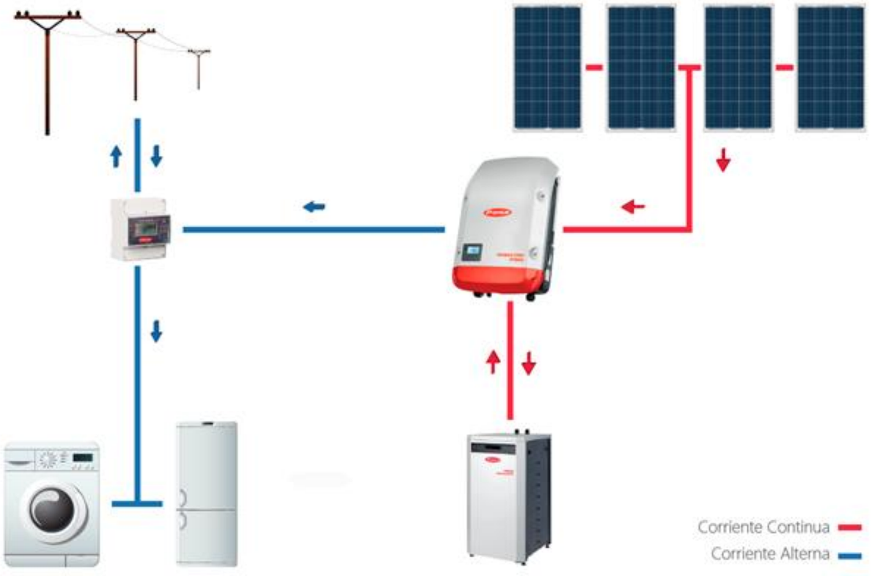


- **Photovoltaic self-consumption installation**

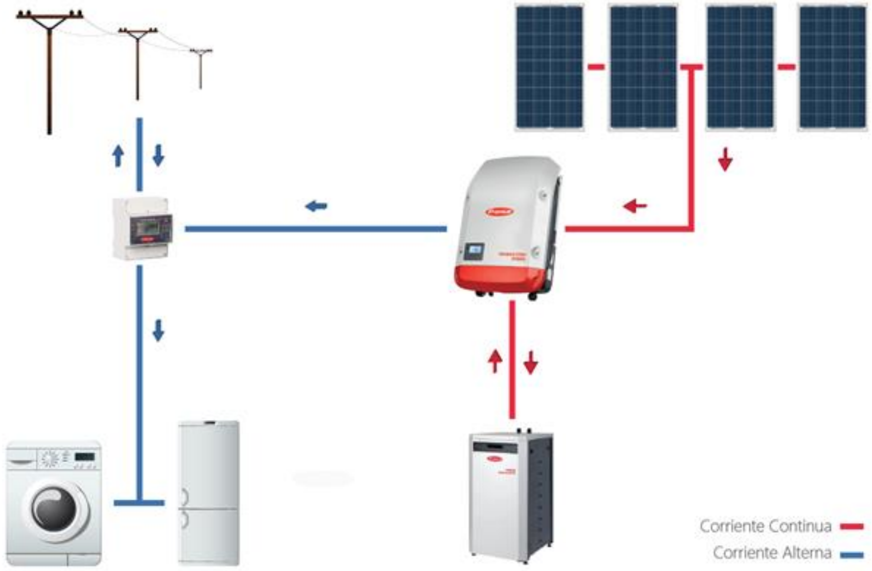
Photovoltaic self-consumption is the type of installation that mixes the Grid tie and the Off-grid installation system. Type of installation that consumes the necessary energy and discharges the surplus energy production to the grid.

There are two types of self-consumption system:

- Direct self-consumption: Type of installation where the local charge consumes directly and instantly the energy generated by the installation, and discharges the surplus energy production at the grid.



- Self-consumption with accumulation: It is the type of installation where the batteries charging or discharging, is managed by additional equipment, and the surplus energy production is discharged in batteries till the time is more useful.



Calculations and design

This subchapter will capacitate the students to know the basis of a correct PV system sizing. It will include the calculation of energy needs, system losses, and dimension of each installation component. These concepts are very important for the optimal long-life operation of the equipment.

- **Calculation of the energy needs**

Daily energy consumption is needed when designing a photovoltaic system. That is why it is necessary to list all equipment and the daily number of operating hours in their use.

Table1. Power consumption of different equipment

Appliance	Power consumption (W)	Running hour/ days
Fridge class A+	80	10h
Led TV	70	3h
Washing machine	350	1.5h
Microwave	900	0.3h
Blender	200	0.25h
Computer	200	2h
Kitchen/ dining room lighting	26 x 6 units	3h
Room lighting	26	1h
Self-consumption	4	24h

Calculation of required power Ed (Wh), is obtained by multiplying the rated power P (w), by the operating hour (h) or the equipment.

$$\text{Ed (Wh)} = \pounds\ (\text{P (W)}.\ \text{h})$$

- **System losses**

The defined angle of inclination must be taken in account at calculating the energy generated by the panel.

Performance Ratios (PR), called system losses, is a 0.6 when there is a battery accumulation system installed, if it is a 0.8 and there is battery system accumulation, so it is a direct generation's system.

Performance ratios is calculated:

Loss orient	=	Losses due to the orientation (Value of the south orient is 0)
Loss dirt	=	is the losses by dirt, is a 5% of charges environments
Loss shade	=	is the shadows losses
Loss cable	=	estimated to be a 3%, is the wirings losses
Perf inv	=	estimated to be between 94-96%, it is the inverters performance, and it is obtained from the data-sheets technical
Perf reg	=	obtained from the data-sheets technical, its sum is calculated to be a 98% for a Maximiser; it is the Regulator/Maximiser performance
Perf bat	=	the battery's performance, calculated by the following formula:
Loss deter	=	the loss due to the panels deteriorated, defined by the panels technical sheet, and it is a 20% of the panels loss

- **Dimension of the Photovoltaics' Field**

Once we know the daily energy to supply and the losses energy system, the characteristics (type) of the panels to be installed, (Monocrystalline, Polycrystalline, amorphous) depending on the nominal peak power, we can now dimension the Photovoltaics' Field.

The official database available for each country or region, determine the irradiation area of the panels and also provide the radiation in the panels inclined surfaces which will be installed. In some of those databases, the total daily and monthly energy values are generated. By example, PVGIS (Photovoltaic geographical information system), by interring the requiring parameter, the PV production can be calculated by clicking on the monthly radiations tab, and select the location of the maps installation and click on "irradiation at the chosen angle: deg" on the right side, to define the angles installations of the panel.

The real energy that will be used is calculated by multiplying the efficiency of the system (performance ratio calculated with the EC.2) by this obtained irradiance (H(45)).

- For the daily PSH

1000W/m2 hypothetical solar irradiations amount of time known as Peak Sun Hours (PSH), commonly used on Photovoltaic's solar panel, is the equivalent number of the solar irradiations hours that are used daily, and it varies monthly according to the radiation area.

- For the monthly PSH

Therefore, the power to be installed (Pi) for the month (i), is obtained by dividing the energy required to supply the loads (Ed) by the monthly PSH.

Pi is divided between the selected panel Peak powers (Wp), to find the number of panels (np) to be installed.

- **Calculation of the regulator or maximiser MPPT**

The load current characterizes the Regulators and maximisers at the regulator output, and the output voltage at the batteries.

Depending on if it is a charging regulator or a maximiser MPPT, the load current is calculated by using a different method. The installed bank batteries are supposed to be the output regulator or maximiser voltage.

- **Regulator calculation**

Normally, it is recommended to select a regulator to resist to a simultaneous overloading on:

The regulator output current: This on supposed to be at least 25% higher than the load current under maximum consumption conditions, and its formula is:

Imax_cons = the maximum consumption load current, and it is calculated by dividing the maximum power demanded by the local load, by the voltage of the batteries (regulator output voltage).
Its formula is:

The regulator input current: calculated as the 25% to be higher than the short circuit generator's current.

Its formula is:

Isc = the panel's short circuit current
Npp = panels fitted in parallel's number of series

- **Calculation of the battery's performance**

One of the most important points in the Photovoltaic energy system, is the batteries performance that will define the current quality.

The capacity that the batteries need to supply the installation consumption can be calculated through the formula:

Cbat[Ah] = the batteries required capacity
N = autonomy days, it can be reached between 2-5 days depending on the needs and the used
Ed = daily energy that is needed for the house [Wh]
Vbat = the batteries bank voltage [V]
DODmax = the discharge maximum of the death battery, and it can be taken between (60-80) for the lead acid battery

- **Calculation of the inverter**

Once the battery capacity is known, we supposed to determine the capacity of the inverter that we need for the installation through that formula:

Pinv[W] = the power of the inverter that is need to be installed [W]
Peqsim = the simultaneously connected equipment [W]

Agri-PV

Introducing Agri-PV

The European Green Deal sets out a vision to achieve climate neutrality by 2050. This will require a deep transformation of Europe's society and economy; particularly of its energy and agri-food sectors.

The Clean Energy Package ("CEP"), adopted by the European Union in 2019, set out a framework to reduce greenhouse gas emissions by 40% by 2030, partly by reaching at least 32% renewable energy in the final energy demand. In 2020, the European Commission proposed the European Climate Law, which would set a legally- binding target of net zero greenhouse gas emissions by 2050, in addition to more ambitious 2030 targets.

Since 1962, the principal policy in the field of agriculture at the EU level is the Common Agricultural Policy ("CAP"). The CAP provided €58.82 billion in support for farmers in 2018 (European Commission, 2020) across its two pillars: the first pillar involves direct support for farmers, and the second pillar targets sustainable rural development. The European Commission proposed a revision of the CAP in 2018 for the 2021–2027 period, which is currently being negotiated. The revision aims to modernise and 'green' the EU's agricultural policy, adapting it to the changing agricultural, energy, and climate change context.

Within this framework, agricultural photovoltaics ("Agri- PV") offers an opportunity to simultaneously realise the European Green Deal, meet the EU's decarbonisation targets, and achieve the objectives of the CAP.

The principle behind Agri-PV is straightforward: the smart combination of agricultural infrastructure with a photovoltaic installation. This combination unlocks a variety of disruptive applications that capitalise on synergies between solar and agriculture. Agri-PV allows for solar to be combined with specific rural and agricultural activities, providing solutions to the needs of farmers and rural communities by driving investments and creating jobs in rural areas, supporting traditional and sustainable agricultural practices, or increasing the climate resilience of agricultural activities.

The EU has a key role to promote the multiple synergies between agriculture and solar electricity generation enabled by Agri-PV systems. Installed directly above crops, solar provides shade, protects crops against hail or frost, enables stable crop yields, and increases the electrical yield of PV panels (Barron – Gafford, 2019). Solar can be installed on agricultural hangars or on greenhouses and can support the development of modern infrastructure that improves the competitiveness of the agricultural sector. Utility-scale solar farms provide the perfect setting for sheep to graze (Kochendoerfer et al, 2019). Overall, there have already been a vast number of methods of integrating solar onto agricultural infrastructure, with innovations regularly appearing on the market. Public policies should boost the deployment of established Agri-PV systems, while simultaneously supporting innovative Agri-PV solutions.

It has been estimated that deploying Agri-PV on only 1% of global cropland could help meet total global energy demand (Adeh, Good, Calaf and Higgins, 2019). Since 2014, around 2,800 Agri-PV systems have been deployed worldwide, with a total capacity of about 2.9 GWp (Bay War.e.). The sector has seen significant growth in Japan, South Korea, and China, where regulatory frameworks and support schemes have already been in place for a number of years (Schindele et al, 2020).

The potential for Agri-PV in Europe is huge: the technical capacity, if Agri-PV were deployed on only 1% of the EU's arable land (European Commission, 2018), is over 700 GW. However, the development of Agri-PV in Europe is fragmented among EU Member States. The development of Agri-PV in Europe could establish the European solar industry as a global leader in this rapidly growing market segment.

For the EU to meet its potential and become a global leader in Agri-PV, a European framework to boost the growth of the sector is necessary in this briefing, we aim to highlight the synergies between Agri-PV and EU policies on sustainable rural development, the future of the agri-food sector, climate change adaptation, and the decarbonisation of islands. In addition to this, we provide concrete policy recommendations that can be taken on board by policy- and decisionmakers working on the topic of agriculture, energy, climate, and environment, at the EU, national, regional, and local level.

Enabling sustainable development in rural areas

In addition to the full implementation of the CEP, and specifically the Renewable Energy Directive (European Union, 2018) the European Union and its Member States should encourage the development of Agri-PV in Europe through at least four policy initiatives:

1. The revision of the CAP: Agri-PV can enable the achievement of the CAP's objectives. The second pillar of the CAP should promote the deployment of Agri-PV and Member States should include Agri-PV development plans in their CAP Strategic Plans.
2. The implementation of the Farm to Fork Strategy: Agri-PV can be at the core of a modern, sustainable, healthy, and equitable food system. The horizontal implementation of the Farm to Fork Strategy should integrate the various contributions of Agri-PV to increase sustainability, improve resilience, and boost innovation in the agri-food sector.
3. The revision of the EU Climate Change Adaptation Strategy: Agri-PV solutions contribute to the climate resilience of agricultural practices. The revised EU Climate Change Adaptation Strategy should provide targeted support for Agri-PV solutions that improve the resilience of agriculture to climate change.
4. The Clean Energy for EU Islands initiative: land-scarce regions are particularly suited for the deployment of Agri-PV. The EU islands should integrate plans to deploy Agri-PV to support food and energy security for their clean energy transition agendas.

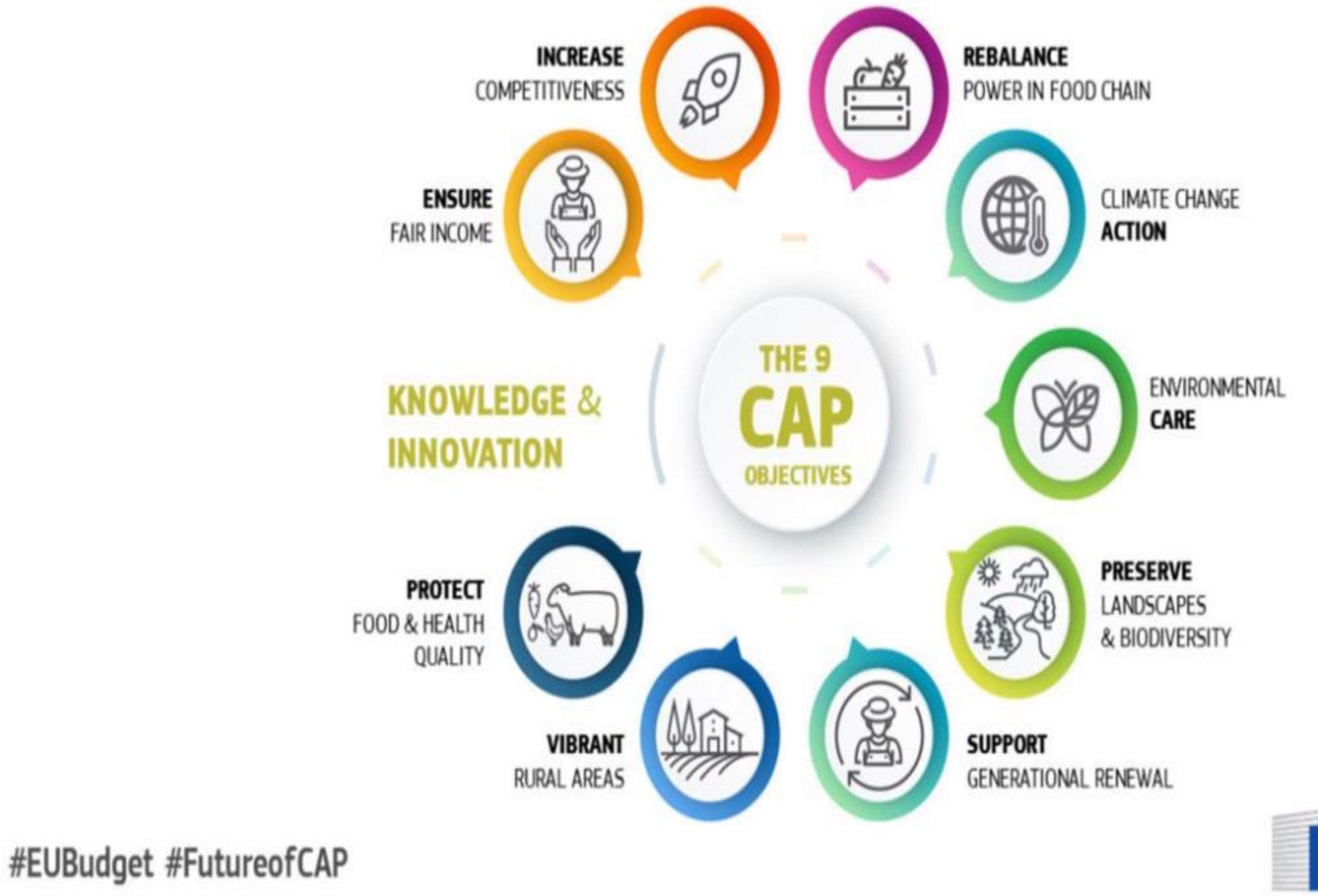
Agri-PV and the future of CAP objectives

One of the headline objectives of the European Green Deal is to ensure that the revised CAP fully reflects the EU's climate ambitions. This is to be achieved in part by ensuring at least 40% of the overall CAP budget contributes to climate action. In addition to this, the CAP includes funding and measures to support rural development, the "second pillar". In the 2014–2020 budget, the funding instrument for the second pillar, the European Agricultural Fund for Rural Development ("EAFRD"), had a budget of around €100 billion.

The Commission's CAP proposal aims to modernise the governance and the delivery of the second pillar by setting clear objectives and letting Member States come up with their own strategies for sustainable rural development. The Commission has proposed 9 specific objectives (see Figure 1) that "focus on the economic viability, the resilience and income of farms, on an enhanced environmental and climate performance, and on the strengthened socio-economic fabric of rural areas" (European Commission, 2018).EU Member States are currently preparing "CAP Strategic Plans" that will detail the interventions they will carry out to reach these objectives, which will be financed by EAFRD funds. These plans will be assessed by the European Commission and shall include concrete targets and will be subject to annual reporting by Member States.

In line with the objectives of the future CAP, EU Member States should integrate Agri-PV within their CAP Strategic Plans. Doing so will drive investments into rural communities, provide employment opportunities in rural areas, contribute to the resilience of agricultural practices, increase land-use efficiency, and improve water management, as well as enabling the achievement of the 9 CAP objectives.

How Agri-PV contributes to the CAP objectives?



The variety of applications addressed by Agri-PV leads to multiple benefits contributing to the CAP objectives outlined above.

1. **Solar investments for agriculture**
    - Objectives 1, 2, 7, 8

The income of EU farmers is still significantly lower than average incomes in many Member States (European Commission, 2018). The Agri-PV sector generates investments that support the competitiveness of the agricultural sector through farm and equipment modernisation. Both individual farmers and farmer cooperatives can benefit from the deployment of Agri-PV, which has been shown to increase farm incomes by over 30% (Dinesh and Pearce, 2016).

Different models exist depending on the ownership of the Agri-PV system. Agri-PV developers can act as “third- party investors'', in which they develop a project at no cost to the farmers. Developers receive remuneration from the sale of renewable electricity while farmers benefit from new agricultural infrastructure, such as new local storage space or durable crop protection systems, that increased farm productivity, or from a revenue complement in the form of rent paid on the use of their land.

Farmers can also invest and contract an Agri-PV developer to develop an Agri-PV system. Under this model, farmers must contribute to the CAPEX costs associated with the project. They then benefit from reduced energy bills if they self-consume the electricity and a stable revenue complement if they feed the energy into the grid.

2. Solar jobs for rural communities

- Objectives 6, 8

Unemployment in rural communities, specifically for young people, is an important challenge. Between 2015–2017, the average unemployment rate for young people in rural areas was 18% (European Commission, 2019). Furthermore, the rural population is decreasing across the EU. Between 2013– 2017, approximately 500,000 people left rural areas in favour of larger urban centres (European Commission, 2019). The solar industry stimulates the social and economic fabric of rural areas, generates new employment opportunities, and diversifies the economic structure of rural communities.

Solar creates more jobs per megawatt of power generated than any other energy source (Solar Power Europea, 2019). The development of Agri-PV projects supports jobs in the downstream activities of the PV sector, such as the installation, the engineering, or the operations and maintenance of the Agri-PV installations.

The modernisation of rural infrastructure and increased farm productivity makes rural communities more dynamic. When an Agri-PV installation replaces temporary infrastructure (e.g., a plastic greenhouse), it can contribute to stabilise employment opportunities and reduce worker seasonality.

3. Solar protecting crops

- Objectives 2, 3, 4, 9

Agriculture is particularly vulnerable to climate change. Higher temperatures, water scarcity, new pests, or extreme weather events endanger the resilience of our agri-food systems. In addition to this, the area cultivated within greenhouses is increasing in the EU, which has varied environmental impacts depending on the type of greenhouse used (EIP-Agri, 2019). Agri-PV addresses both challenges, by increasing the climate resilience of agriculture and improving greenhouse sustainability.

Deploying solar above crops delivers synergies that increase the climate resilience of agriculture. Dryland environments are particularly suited to Agri-PV installations, enabling synergies between the production of certain crops, water conservation, and renewable energy production, in addition to providing local ecosystem services (Barron-Gafford et al, 2019). Agri-PV installations also provide opportunities to deploy physical pest control measures, reducing the need to use chemical pest control products.

Agri-PV creates a business case to substitute plastic from low-cost greenhouses and to provide clean electricity for high-tech greenhouses. In the former situation, plastic is replaced by more durable materials, with added costs being offset by the generation of clean electricity. In the latter, the high-energy use from heating, cooling, and maintaining complex digital services can be met with self-produced electricity.

4. A more efficient use of land

- Objectives 4, 5, 6

Around 80,000 hectares of agricultural land was lost each year between 2000–2017 (European Environmental Agency, 2019). The loss of agricultural land is mainly attributed to land abandonment, and land sealing poses a risk to climate resilience. To address this, the European Commission proposed in 2011 to set a “net-zero land take” objective (European Commission, 2011). Agri-PV enables a dual- use of land, reducing land take and minimizing land competition between agriculture and renewable energy.

Agri-PV solutions above crops can improve productivity per hectare, while simultaneously reducing soil degradation and water usage. Productivity is increased by using dynamic tracking systems that can regulate the shade provided to crops (Valle et al, 2017).

5. Solar to improve water management

- Objectives 1, 2, 4, 5, 6

Agriculture, forestry, and fishing represent the lion's share of water consumption in the EU, accounting for approximately 40% of water resources in 2015 (European Commission, 2019). Sustainable management of scarce water resources will be essential to maintaining agricultural practices in the EU. Agri-PV contributes to lowering the water needs of agriculture by shielding crops from heat and by reducing evapotranspiration (Barnon-Gafford et al, 2019).

Soil under the shade of PV panels maintains soil moisture, providing ideal conditions for certain types of crops (Ibid). Water consumption can be further optimised with digitalised Agri-PV solutions that can track solar irradiation and better regulate the microclimatic conditions under the solar panels. Further, solar energy can be used to power the pumping of underground water for irrigation, replacing diesel generators.

Integrating Agri-PV in CAP Strategic Plans

The synergies between Agri-PV, the objectives of the future CAP, and the EU climate and energy targets must be harnessed. To this end, appropriate support mechanisms that stimulate private investments into the Agri-PV sector are needed. Reaching a sufficient level of investments will generate the necessary economies of scale to drive the competitiveness of the European Agri-PV sector.

A "European Agri-PV strategy" should be formalised within the future CAP. This strategy should boost the deployment of established Agri-PV systems, promote EU leadership in Agri-PV technological innovation, enhance the productivity of the agricultural sector and enable the deployment of renewable energy resources in rural areas. Designed in close collaboration with agricultural experts, an Agri-PV strategy should aim at enabling the clean energy transition in rural areas, drawing on the objectives of the CAP and of the Energy System Integration Strategy (European Commission, 2020).

At national level, solar investments should be prioritized within CAP Strategic Plans, as highlighted in the Farm to Fork Strategy. The European Commission should issue clear guidance to Member States on how their CAP Strategic Plans can maximise Agri-PV deployment, in line with their National Energy and Climate Plans.

Beyond this, Member States should include plans to develop Agri-PV regulatory frameworks as part of their CAP Strategic Plans. Several countries and sub- national regions around the world have already developed Agri-PV regulatory frameworks. These include Japan, South Korea, China, France, and Massachusetts (Schindele et al, 2020). Regulatory frameworks for Agri-PV are under development in the Netherlands, Switzerland, Austria, Germany, India, and California.

When designing regulatory frameworks to support the development of Agri-PV, policymakers should focus on 6 concrete actions:

1. Implement targeted financial mechanisms to support small, mid, and large scale Agri-PV through grants, Agri-PV Feed-in-Tariffs ("FiT"), and Agri-PV energy tenders, respectively.
2. Design an enabling framework for Agri-PV, ensure farmers deploying Agri-PV systems receive CAP subsidies and promote community-led Agri-PV.
3. Develop Agri-PV indexes that capture the agro-economic, environmental, and social externalities of Agri-PV systems.
4. Set clear and robust quality assessment criteria for Agri-PV projects and ensure independent and periodical assessment of project sustainability.

5. Ensure Agri-PV frameworks are policy coherent across energy, agriculture, environment, and climate policies, and that their development is a participatory process that involves all relevant stakeholders.
6. Prioritise public R&D funding towards research programmes supporting the energy transition in rural areas.

Sustainable agriculture and photovoltaics

Agrisolar can accelerate the transition to a sustainable agricultural system which contributes to the European Green Deal objectives, in particular those of the European Climate Law, the Renewable Energy Directive, the CAP, the Biodiversity Strategy, and the Farm to Fork Strategy. Specifically, Agrisolar can:

1. Contribute to a responsible use of natural resources such as land and water

Agrisolar projects are a responsible way to manage land and water. When designed and managed sustainably, they can improve productivity per ha, while simultaneously reducing soil degradation-, water usage or the use of single-use plastics.

Agrivoltaic systems, which co-locate a PV installation and a sustainable agricultural activity, can contribute to lowering the water needs of agriculture by shielding crops from heat and by reducing evapotranspiration (Barron-Gafford et al, 2019).The excess shading is especially beneficial for dry and water-limited areas, and for protecting against severe droughts in specific geographies (Dinesh et al., 2016).One study indicated that, depending on the level of shading from PV panels, water savings could reach between 14- 29% (Marrou et al., 2013). Plants with lower root density and a high net photosynthetic rate are ideal candidates to be cultivated within an Agri-PV system (Adeh et al., 2018).

2. Promote sustainable agricultural practices

Agri-PV installations can for example deploy physical pest control measures, such as netting, and thereby reduce chemical pest control product use (Solar Power Europe, 2020) and can contribute to food safety and biodiversity protection.

Recent research from the German energy market innovation association BNE (Bundesverband Neue Energiewirthschaft eV., 2019) has shown that large-scale PV plants, when designed to be compatible with nature, deliver positive effects on biodiversity, compared to most conventional and monocultural uses.

Agri-PV systems may also contribute to increased carbon capture (Barron-Gafford et al., 2019) which has been identified by the International Panel on Climate Change ("IPCC") as having a significant potential to abate GHG emissions (International Panel on Climate Change, 2020).

3. Increase the EU's agriculture resilience to climate change and other shocks and stresses

Agrisolar solutions can be designed to address the negative effects of climate change on agriculture. Therefore, they can protect and shade agricultural activities from unexpected and extreme weather events such as hail, excessive solar radiation, and from pests and diseases.

4. Enable sustainable development in rural areas through higher yields and new business opportunities

The smart combination of solar and agricultural infrastructure can enable rural communities to become more competitive and sustainable (Solar Power Europe, 2020). The co-location of agriculture and PV enables the achievement of a higher land-use efficiency. Simulations indicate that Agrivoltaic systems may increase land use efficiency up to 60 to 70%, when compared to equivalent mono systems (Dupraz et al., 2011). An experimental Agri-PV system with potatoes in Germany led to a 103% yield when compared to a control, while the PV systems generated 83%

of the electricity that would have been generated on the similar plot of land, leading to an 86% increase in land use efficiency (Fraunhofer ISE, 2020).

While maintaining the agricultural use as the primary use of land, the dual use of land also serves to diversify farmer's incomes, protecting incomes and socio- economic development in rural communities even in the case of extreme drought (Santa et al., 2017). An additional benefit includes reduced cost of insurance from potential crop failure.

Coupling shade-tolerant crops with Agri-PV systems increases the economic value of farms when compared to conventional agricultural practices (Dinesh and Pearce, 2015). Co- locating PV above crops helps to stabilise crop yields in some cases and may even increase the electrical yield of PV, thanks to the cooling effect of plants on PV panels (Barron – Gafford et al., 2019). The extra income benefits rural communities directly and improves rural infrastructure, value chains, and distributed electricity supply, which in turn can promote local farming (Majumdar, 2018).

A study from 2017 (Carreño-Ortega, Á., Galdeano-Gómez., E., Pérez- Mesa, J.C., and del Carmen Galera-Quiles, M., 2017) shows that important benefits could be harvested for farmers, especially in the south of Europe. In the specific case of Spain, it shows that with normal conditions of deployment with 1.8 ha greenhouse (large-scale), the farm profitability would have a 9.89% increase, which would go up to 14,1% if investments are backed by state aid. Another study indicated that the deployment of Agrivoltaics can increase farm income by over 30% (Dinesh et al., 2016).

Solar, as the most scalable and cost-effective clean energy technology, empowers farmers to be at the heart of the European Green Deal and the post-COVID green recovery. Solar creates more jobs per megawatt of power installed than any other energy source (International Labour Office, 2011). Agrisolar business models can contribute to the creation of new citizen agricultural and renewable energy communities. Case studies analysed by the Joint Research Centre (Joint Research Centre, 2020) show that community energy projects exist in diverse forms across Europe including for example farm roofs equipped with solar panels, or windmills installed by rural communities on agricultural land.

The Sustainable Agriculture Concept

The sustainability of any solar project is linked to its socio-economic and environmental value. This section discusses which criteria can best evaluate the environmental and socio-economic value delivered by Agrisolar projects. Further information on how to maximise the sustainability of solar projects at large can be found in the Solar Sustainability Best Practices Benchmark (Solar Power Europe, 2021).

To ensure the effective operation, both as agricultural infrastructure and as photovoltaic generation equipment, and to maximise the agro-ecological synergies identified in the main section, Agrisolar and sustainable agriculture, Agrisolar project developers must go the extra-mile and define a Sustainable Agriculture Concept (SAC).

Overall, the SAC should ensure that the project does not conflict with the agricultural land-use and the viability (and in some cases, the continuity) of the agricultural activity. It should be developed in the initial stages of the project planning phase and include an assessment of the agronomical, environmental, and socio-economic impacts of the project. The SAC will be used to plan the agricultural activity, ensure the Agrisolar system is fully adapted to the agricultural activity, and that an appropriate lifetime monitoring of the system performance is prearranged.

The SAC should also seek to minimise negative environmental impacts and maximise potential environmental synergies. It will also ensure that the project will be economically viable for all parties, both from agricultural activity and the generation of electricity. The SAC implies a "tailor-made approach" to each project, adapting Agrisolar installations to farm size, location, soil topography, local climate conditions, impacts on biodiversity, and water management, in addition to the consideration of local rural communities.

The SAC should cover three general areas, including a definition of the agricultural activity that fits a specific type of Agrisolar system; the evaluation of the environmental impacts of the system; and the assessment of the socioeconomic impacts of the project. The SAC should include a plan for the monitoring of agricultural and photovoltaic performance of the system throughout its lifetime. The specific content of the SAC will vary depending on the specific project and Agrisolar solution. Below we advance several requirements that must be included in SACs, important elements that should be included in SACs and optional elements that could maximise agroenergetic synergies and the provision of sustainability of the Agrisolar system if included

1. A definition of the agricultural activity that fits a specific type of Agrisolar system

The SAC must include the general information of the agricultural activity and PV system associated with the Agrisolar system, an assessment of the needs of the agricultural stakeholders involved, information on the project land, and a technical plan of the Agrisolar installation. The SAC must also assess the equipment and machinery used to carry out the agricultural activity. The validity of the SAC must be confirmed by an independent third-party, to ensure the compatibility of the agricultural activity and a solar PV system.

In case of crop rotation, the SAC should include an evaluation of the expected crop rotation schedule. Particularly for Agri-PV systems combined with crop cultivation, the SAC should include an assessment of the light distribution and micro-climatic conditions required for crops to grow (such as temperatures, humidity, and wind). In the case of Agrisolar projects for animal husbandry, the SAC should consider the impact of the Agrisolar system on animal well-being.

Additional elements that could be considered include improvements on the resilience of the agricultural activity, in particular which types of crop protection systems could be deployed.

2. An evaluation of the environmental impacts of the system

As in standard solar photovoltaic projects, an effective assessment of the environmental impact of a given project is an essential element of Agrisolar projects (Solar Power Europe, 2020). Agrisolar projects must conform to the legal requirements in the project country and conform to internationally accepted standards such as the IFC Performance Standards and the Equator Principles (Ibid). In this regard, several authorisations may be required, including an Environmental Impact Assessment (EIA).

Given the agricultural dimension of Agrisolar projects, the SAC must also include an assessment of the expected impacts on soil erosion and expected soil silting, an assessment of water availability and the impact of the Agrisolar system on water efficiency.

The SAC should also plan for the residue free assembly and disassembly of the solar system, which should minimise the project's impact on the land.

Additional elements that could be considered are the impacts on carbon sequestration and the provision of local ecosystem services such as biodiversity.

3. An assessment of the socioeconomic impacts of the project

This must include a business plan for the project, an estimation of the economic efficiency of the project, and a calculation of the land-use efficiency. The SAC must also include an assessment of the working conditions on the farm, including any safety considerations linked to the deployment of electrical equipment.

An estimation of the expected financial lifetime savings from replacement of short-lived materials with a durable Agrisolar system should also be included.

The SAC could also include a local action plan that integrates the views and interests of local communities. The SAC could include a marketing plan for the agricultural products or a regional market analysis of the agricultural products that will be produced in the Agrisolar farm. In this regard, impacts on the effects of the project on local supply chains could also be considered.

4. A lifecycle performance assessment

Given the dual nature of Agrisolar systems, the SAC should include performance monitoring of both the agricultural and the photovoltaic performance of the system.

Agrisolar projects which demonstrate an improvement in performance, or which have gone beyond the actions initially planned in the SAC, could see their ratings increase. On the other hand, underperforming projects, or those which do not respect their SAC, could see their ratings decrease. In worst-case scenarios, where no significant agricultural activity or energy performance can be demonstrated, the status of the project as an Agrisolar project may be revoked.

Agrisolar projects should collect relevant agronomic, energetic, environmental, and socio-economic data which may be useful to further improve the quality of Agrisolar in the future.

The lifetime of the project could also be assessed, including a detailed assessment of the performance of the ecosystem and socioeconomic services provided by the project.

Towards a 3-star Benchmark for Agrisolar projects

In order to assess the quality of specific Agrisolar projects a framework could take the form of a 3-star benchmark that could be used in advance of project development and throughout the project lifetime.

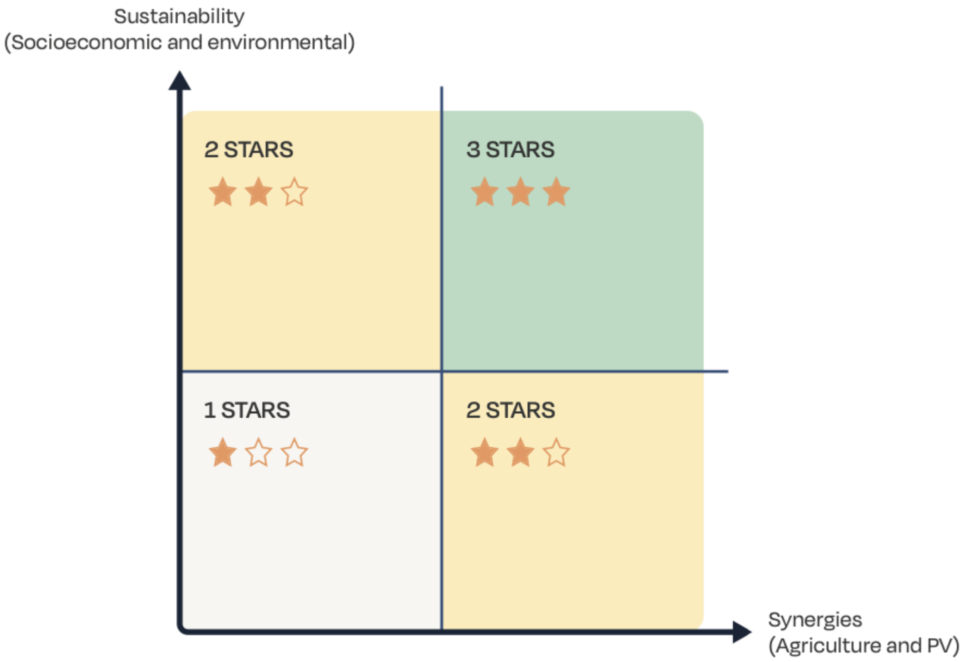
These guidelines are meant to inspire the development of robust regulatory frameworks for Agrisolar.

A 3-star benchmark captures how well a specific Agrisolar project is designed and operated in terms of the agroenergetic synergies it creates and its overall social and environmental sustainability agroenergetic synergies and its sustainability can be schematically represented as seen in Figure 12.

- **How to read the 3-star benchmark criteria**

An Agrisolar project which respects the essential criteria of the SAC ("Must criteria''), such as the preparation of the SAC itself, would qualify as an Agrisolar project with a one-star rating. If a project fulfils additional criteria ("Should criteria ''), such as demonstrating synergies between the PV system and the agricultural activity, or whether the project contributes to socially or environmentally sustainable practices, the project will tend towards a two-star rating. Finally, an ideal project that fulfils additional best-in-class criteria ("Could criteria ''), which maximise agroenergetic synergies or provide significant ecosystem services, will be awarded a full three-star rating.

It is important to bear in mind that, while fulfilling the "Must" criteria is a basic requirement to be considered Agrisolar, fulfilling "Should" and "Could" criteria remain optional. Not fulfilling one or more of these optional criteria would not preclude any system from achieving a higher quality rating. Importantly, the criteria identified in these guidelines are non-exhaustive and are meant only indicatively.


Sustainability
(Socioeconomic and environmental)
2 STARS
★★☆
3 STARS
★★★
1 STARS
★☆☆
2 STARS
★★☆
Synergies
(Agriculture and PV)

	MUST CRITERIA ★☆☆	SHOULD CRITERIA ★★☆	COULD CRITERIA ★★★
DIMENSION 1: Agriculture	• Has a SAC concept which includes general information of agricultural activity and PV system, assessment of needs of agricultural stakeholder, information on project land, technical plan of Agrisolar system, assess the use of equipment/machinery. • Fulfills need of agricultural activity and generates green electricity.	• Demonstrate synergies between PV and agriculture. • Evaluation of light distribution and micro-climatic conditions • Water management performed.	• Maximise synergies between PV and agriculture. • Improvements on the resilience of the agricultural activity.
DIMENSION 2: Environment	• Effective assessment of environmental impact of the project (standard Environmental Impact Assessment). • Assessment of impacts on soil erosion, soil silting, assessment of water availability.	• Min standards soil preservation during construction and dismantling • Efficient tech, degradability of structures. • Lifecycle approach • Transitioning biodiversity, more sustainable agricultural practices.	• Provision of ecosystem services. • Increased biodiversity measures "BNE guide" (no pesticide, local seeds). • Soil regeneration and carbon capture.
DIMENSION 3: Socioeconomics	• Business plan for the project • Assessment of farm working conditions, including safety considerations.	• Analysis of lifetime financial savings from replacement of short lived materials. • Impacts on local supply chain considered.	• Local action plan integrating views and interests of local communities. • Establishment of/Integration within local agriculture and renewable energy community.
DIMENSION 4: LCA	• Performance monitoring of the system.	• Data collection on performance (Agricultural, Environmental, Energy, Socio-economics).	• Detailed evaluation of performance of ecosystem and socioeconomic services provided.

Existing challenges for Agrisolar

Regulatory, financial, and technical barriers currently curb the growth of the Agrisolar market across the EU.

- Regulatory and administrative barriers

One of the main challenges for Agrisolar to develop across Europe is the low quality or absence of regulatory frameworks to support the development of Agrisolar projects. Many countries that have a significant potential to develop Agrisolar such as Spain, Portugal, or Italy currently lack a framework to develop Agrisolar. One exception is France, where the Tender Documentation Energy Regulation Commission provides a definition of Agrisolar systems (CRE, 2017). However, the French tendering framework is not as specific as the regime regulating the tendering of ground mounted solar plants.

More specifically, existing tendering frameworks do not provide the right incentives to develop Agrisolar projects. Whereas several Agrisolar solutions have been a commercial success for several years, the innovative nature of some Agri-PV systems means that they are not always competitive when compared to traditional ground mounted solar systems. As most tendering schemes are awarded based on the price of energy, Agri-PV projects cannot yet compete in standard renewable energy tenders. The only exceptions here are innovation tenders in France and Germany. Consequently, this results in lower interest from potential investors and a lower provision of state aid to foster their development.

Another very important barrier for the development of Agrisolar in Europe is the potential loss of CAP subsidies by farmers who deploy solar on their land. In Germany farmers saw their direct income support removed after they deployed an Agri-PV system designed to allow sheep to graze on site. This decision was revoked by the courts as a violation of EU law, arguing that the implementation of the CAP in Germany did not respect EU law (Regensburg Administrative Court, judgment of November 15, 2018).

Agrisolar developers face difficulties in obtaining planning authorizations and other necessary permits. This is a result of a lack of knowledge and a lack of local permitting administrations who can evaluate files.

- Technical barriers

One important technical barrier is the availability of solar panels, modules, and structures that are appropriate for Agri-PV projects. Major module manufacturers do not yet market modules of a suitable size and efficiency for Agrivoltaic systems. The PV modules, for example, should be rather lightweight as they are often more elevated. The modules and structures also need to be designed in such a way that shadows cast on the ground are optimised for the crops. In this regard, transparent back sheets are particularly suited for Agri-PV systems as they offer the possibility to optimise the transparency of the PV panels that are most suitable for specific crops.

Electrical safety is a very important challenge too, as agricultural workers, agricultural machinery, and animals will be present on site. The structures of Agri- PV systems should also be designed to withstand potentially stronger wind impact.

The effect of dust spread by products, components, and fertilizers employed in agricultural activities to ensure crop production could impact the reliability and durability of PV module materials, in addition to impacting the power output of the system.

Accessibility can also be a challenge in developing Agrisolar projects. Access roads may not be well maintained, while communications may be impaired given lower quality internet access and phone network. Grid connections are another important technical barrier for Agrisolar projects. Rural areas may have lower existing grid capacity, which can increase connection costs and impair the business case of the project.

- Financial barriers

The innovative nature of many Agrisolar solutions results in a higher cost of capital when compared to traditional ground mounted solar. Furthermore, the higher risks associated with complex projects combining agricultural and energy investments have made financial investors and insurers reluctant to support the development of Agrisolar projects.

- Other barriers

One additional barrier for the development of Agrisolar projects is the difficulty in identifying land ownership. Farmers are not always owners of the land they farm, which may bring additional complexity, when entering mortgage and easement agreements. Furthermore, conflicts of interest may arise between landowners and farmers potentially creating a split incentives situation.

Furthermore, the lack of knowledge about the solar energy sector by agricultural partners can lead to additional hurdles. Agricultural partners may not be familiar with the typical project development timelines, the project lifetime, and technical aspects of integrating an agricultural activity with the generation of solar electricity. In some cases, the overcoming of low trust levels of rural stakeholders towards solar developers requires further efforts. Responding to reservations from agricultural stakeholders can be a key pillar for success.

How to support Agrisolar

Given the potential of Agrisolar to aid the transition to environmentally sustainable agricultural practices, to decarbonise the energy system, regulatory and political authorities (at EU, national, regional, and local level) should provide targeted support to overcome the barriers identified above. Doing so will accelerate the achievement of the objectives of the European Green Deal and strengthen the EU's leadership in future-proof technological innovation.

Agrisolar is a perfect fit for supporting the objectives of the European Green Deal, in particular those of the Fit-for-55 Package and the revision of the CAP. The revision of the Renewable Energy Directive ("REDII") should set ambitious targets to deploy renewable energy and strengthen the provisions on the permitting of renewable energy projects and access to land. In addition to this, the second pillar of the upcoming CAP should promote the deployment of Agrisolar projects. Specific types of Agrisolar projects have a significant potential to drive sustainable rural development and contribute to the achievement of the nine objectives of the future CAP. In this regard, farmers who deploy Agrisolar projects (which maintain the agricultural use of the land) should continue to receive income support from the CAP.

Overall, it will be essential to develop an EU-wide standard for Agrisolar, which provides a common framework and supports regulatory harmonisation across EU MS. An EU standard should nevertheless allow for sufficient flexibility to adapt to national and regional variations in agricultural practices, climatic conditions, soil qualities, or land costs, among many other factors.

EU Member States should also promote Agrisolar by developing regulatory and enabling frameworks for the development of Agrisolar projects. Overall, these frameworks should promote the development of Agrisolar projects as a strategy to address issues of access to agricultural land, and to promote sustainable agricultural practices and rural development.

Concretely, Agrisolar policy frameworks should focus on 6 areas (Solar Power Europe, 2020). Firstly, Agrisolar policy frameworks should establish targeted financial mechanisms depending on the size of projects. Furthermore, tax reductions or additional revenue streams should be provided for Agrisolar projects that provide important biodiversity and carbon capture services.

Secondly, complementing sound financing mechanisms, governments should create enabling frameworks to facilitate the development of Agrisolar projects. This enabling framework should address unjustified administrative barriers for projects, support financing of projects, and provide technical support for farmers and rural communities who are looking to develop Agrisolar projects. An accelerated project permitting procedure should be allowed when presenting a sound and certified SAC.

Fourthly, EU Member States should develop robust frameworks to evaluate the quality of Agrisolar projects, following the four dimensions of the SAC. Crucially, EU Member States should ensure such quality assurance frameworks are harmonised across jurisdictions to avoid unnecessary market barriers.

Fifthly, Agrisolar policy frameworks should ensure coherence across the agriculture, energy, environment, and climate change policy frameworks. These should be developed through a participatory process which considers the needs of rural stakeholders and the solar industry.

Lastly, Agrisolar frameworks should channel public and private R&D funding to research programmes focused on the identification of suitable crops for cultivation in combination with PV, the impacts of Agri-PV systems on yields and profitability, and on the demonstration of different PV concepts.

Thirdly, building on the framework advanced in these guidelines, governments should develop "Agrisolar indexes" that capture the agro-economic, environmental, and social externalities of Agri-PV systems. These indexes could be used to develop maps which capture the most suitable land for project development, considering grid access availability.

Technology

The way that power generation works is the same for agrivoltaics and ground-mounted photovoltaic systems. However, the requirements for the technical components and supports for the system are entirely different for agrivoltaics due to land cultivation: the height and alignment of the system, the mounting structure or foundation and, where applicable, the module design – everything should be adapted to cultivation with agricultural machines and the needs of the plants. Sophisticated light and water management are also import- ant to maximize yields.

To make the dual use of farmland for arable farming and power generation possible, the solar modules are typically installed at a height of three to five (in hop growing also more than seven) meters above the field. This makes it possible for large agricultural machines, such as combine harvesters, to work the land underneath the agrivoltaic system. To ensure that plants get sufficient light and precipitation, the spacing between the module rows is typically larger compared to conventional ground-mounted photovoltaic systems. That reduces the degree of surface coverage to about one third. In combination with the high supports, this approach ensures homogeneous light distribution and therefore uniform plant growth. When tracked modules are installed, light management can be specifically adapted to the development stage and needs of cultivated plants (B. Valle, T. Simonneau, F. Sourd, P. Pechier, P. Hamard, T. Frisson, M. Ryckewaert, and A. Christophe, Applied Energy 206 (2017).

Here the choice of the mounting structure, and in part also the solar modules, is generally quite different from ground- mounted photovoltaic systems. Various technologies and designs shall fulfil the site-specific requirements and farming conditions. Taking light management into account in planning the system is therefore recommended. In general, agrivoltaic systems should be state of the art and comply with the commonly accepted rules and standards.

Approaches for Agrivoltaics

Agrivoltaic systems, as in France and Japan, for example, are often mounted on tall supports. Here the clearance height describes the vertical unobstructed space between the ground and the lowest structural element. Various possibilities for the dual use of farmland are described in the following.

Systems with tall supports harbour great potential for synergy effects. However, they must allow for cultivation under the PV modules (figure 14).

The PV modules can also assume an important protective function against hail, rain, night frost and other extreme weather events. Figure 13 shows a research plant of the company BayWar.e. over an orchard. This plant in the Netherlands was built using modules with a larger cell spacing, which enhances the roofing and protective function while simultaneously providing more sunlight for the plants than other PV systems.

Synergy effects can also be realized with modules installed close to the ground. Next2Sun accomplishes this with bifacial modules that are installed vertically. While this type of system is more cost effective due to the low height of the mounting structure, the available light management options are also reduced. Systems installed close to the ground could how- ever provide a benefit by reducing the wind speed, which also affects evaporation.

Tubular PV modules installed horizontally on supports, implemented by the company TubeSolar AG, are another option. This innovative approach promises even light and water permeability over the surface area, which is important for uniform plant growth. The partner company Agratio GmbH combines these novel modules with low-cost support. Here the solar tubes are mounted on stays and suspended over the area under cultivation, resulting in half shade that is favourable for most agricultural applications.

Very narrow modules are installed over arable land in Japan under the name "solar sharing" in order to adjust the avail- ability of light. Here the agrivoltaic systems serve as an additional source of income and retirement provision for farmers. Many other technical solutions are conceivable, with various advantages and disadvantages.

Module Technologies

Fundamentally, all types of solar modules can be used in agrivoltaic systems. Modules with wafer-based silicon solar cells account for about 95 percent of the global PV market. The accepted composition calls for a glass pane on the front and a white covering film on the back. Opaque solar cells are serially connected at a distance of 2-3 mm and laminated between these two elements. A metal frame is used for mounting and stabilization.

In case of a transparent back covering (glass, foil), the spaces between the cells allows the light to largely pass through and reach the plants below. With conventional modules, the spaces between the cells make up four to five percent of the surface area. The spaces can be enlarged, and the module frames replaced by clamp mountings to increase light transmission. Modules with a greater ratio of transparent to total area can protect plants against environmental influences without reducing the availability of light to the same extent.

Bifacial modules can also use the ambient light incident on the reverse side for power generation. Depending on the radiation level incident on the reverse side, electricity yields can be increased by up to 25 percent (typically between 5 and 15 percent). Since the row-to-row distance tends to be larger and the supports tend to be taller in agrivoltaics, the amount of light available on the reverse side of the modules is particularly high. Therefore, bifacial modules are well suited for agrivoltaics. Bifacial glass-glass modules were used in the Heggelbach research project. Another advantage of modules with a double glass structure is the residual strength in case of glass breakage – benefitting occupational health and safety.

Thin film modules (CIS, CdTe, a-Si/µ-Si) can be realized on flexible substrates, making cylindrical bending possible. With an otherwise identical structure, their mass per unit area is approximately 500 g/m2 (grams per square meter) lower compared to modules with wafer-based silicon solar cells. The efficiency is somewhat lower, however. The cost per unit area for thin film modules is also slightly reduced.

This applies correspondingly for organic photovoltaics (OPV). Selective spectral adjustment of the active layers of OPV is also possible in principle, which means that part of the solar spectrum can be transmitted and used by crops growing underneath. However, OPV is still in the market launch phase. Low efficiency and durability are among the challenges.

In concentrator photovoltaics (CPV), the light is focused by lenses or mirrors onto small photoactive surfaces. CPV modules have to be implemented with solar tracking, except for very low concentrating systems. Diffuse light is largely transmitted. Only very few suppliers of OPV and CPV mod- ules currently exist for applications in agrivoltaics.

Mounting Structure and Foundation

- **Design of the Mounting Structure**

The type of mounting structure must be adapted to the specific agricultural application and its respective needs. Examples include planning the system height and the distances between the steel supports. Here it is important to take into account the headlands, clearance height and working width of agricultural machines. The research plant in Heggelbach was designed so that even large harvesters can drive underneath. The distance between the ground and the bottom of the structure measures five meters. Aside from the possible synergy effects, the benefits of a large clearance height include easy vehicle access to the land and more homogeneous light distribution underneath the system. On the other hand, the investment costs for the mounting structure are generally lower for lower clearance heights, because less steel is required and the static demands are correspondingly reduced.

The row spacing, alignment, and height of the agrivoltaic system are of crucial importance since they help determine the light availability. These parameters should always be adapted to meet the needs of the crops grown underneath the agrivoltaic system. The row spacing for the research plant in Heggelbach, for example, is 9.5 meters with a module row width of 3.4 meters. Higher or lower values are possible depending on the shade tolerance of the cultivated plants. Yet, much larger row spacing does increase the land requirement and thus the system costs in relation to the electricity yield.

- **One and two-Axis Tracking**

There are systems, for instance in France, that work with 1 or 2-axis tracking, meaning that the solar modules follow the sun using a tracking mechanism. With single-axis photovoltaic tracking, the modules follow the sun horizontally according to the sun's angle of incidence (elevation) or vertically according to the sun's orbit (azimuth). Two-axis trackers do both and therefore maximize the energy yield. However, two-axis systems with large module tables can create an umbra underneath the modules, while other parts of the field receive no shade at all. Tracking of the PV modules was considered uneconomical for sites in Germany during preliminary investigations for the system in Heggelbach. Notwithstanding the higher acquisition and maintenance costs, tracking can however optimize the energy yields and light management for plant cultivation (B. Valle, T. Simonneau, F. Sourd, P. Pechier, P. Hamard, T. Frisson, M. Ryckewaert, and A. Christophe, Applied Energy 206 (2017) (Section 5.4 Light Management). Through flat roofing, two-axis tracking systems have the potential to protect the plants against hail or extreme sun while shade can be reduced during the growth phase.

- **Anchoring and Foundations**

The anchoring or foundation ensures the statics and stability of the agrivoltaic system. Proof of fulfilling these safety requirements must be provided when building a system. For agrivoltaic systems, permanent concrete foundations are not recommended in order to preserve valuable farmland. Alternatives include piled foundations or special anchoring with Spinnanker anchors. Since no concrete is used, the system can be disassembled without leaving any trace.

Mobile agrivoltaic concepts make it possible to assemble the system, disassemble it again, and install it in another location without the use of larger machines. A possible benefit: A building permit may not be required since this is not a structural alteration. Therefore, mobile agrivoltaics allows for flexible adaptation to agricultural farming, including spontaneous deployment in crisis regions.

Light Management

Shade on farmland varies according to the sun's daily course and changing position over the course of the year. Homogeneous light is desirable for healthy plant growth, uniform ripening and maximizing synergy effects. This can be achieved in various ways:

1. A southern orientation (0°) was not chosen in Heggelbach. Based on simulations and measurements, a southwest or south-east orientation, respectively with a 45° deviation from south, is most suitable. A power generation reduction of about five percent was included in the calculations. The actual alignment may deviate due to local conditions.
2. Another option is to retain the southern orientation and use narrower PV modules, as with solar sharing in Japan.
3. Homogenous lighting can also be obtained with an east-west alignment of the modules. Shade movement over the course of the day is maximized with this orientation. To avoid a shadow under the fixed modules that are entirely impervious to light, the width of the module rows should be considerably less than the height of the system. As a rule of thumb, the clearance height should be at least 1.5 times the width of the module rows. This factor should be at least 2 for tracked modules. Trans- parent modules on the other hand reduce the factor in both cases, depending on the degree of light transmission (see Section 5.3.2 Tracking).
4. Two-axis tracking of the PV modules is another option for selective light management and higher electricity yields. As already described in Section 4.3.2, however, this is associated with higher investment and maintenance costs. Systems with large module tables and two-axis tracking tend to be unsuitable for growing cultivated plants because of the umbra behind the modules. Other parts of the field are in turn permanently exposed to full sunlight.

In Heggelbach, the spacing between the rows of PV modules with an inclination of 20° was increased by around 60 percent compared to conventional ground-mounted photovoltaic systems, making around 69 percent of the total solar radiation available to the plants.

Water Management

Rainwater running off the eaves of the modules can cause soil erosion by washing away the soil.

To avoid negative consequences for plant growth in at-risk locations and applications, various water management approaches can be considered in the system design: Similar to light management, narrow or tubular PV modules can prevent the accumulation of larger amounts of water under the module edge. If the modules are intended to provide structural protection for the crops, on the other hand, tracking the PV modules (Y. Elamri, B. Cheviron, A. Mange, C. Dejean, F. Liron, and G. Belaud, Hydrol. Earth Syst. Sci.22.2, 2018) to distribute precipitation coming off the eaves or channelling the rainwater are better options. In the latter case, sufficient water must be provided through irrigation. Collecting and storing rainwater can help to conserve groundwater resources, especially in arid regions, or make agriculture possible in the first place.

Size of the PV System

The average size of installed agrivoltaic systems varies considerably from country to country. Aside from economic viability, decentralization and social aspects, the key criteria to be considered include the impact on the landscape and thus the social acceptance. Smaller systems with 30 to 120 kWp are found in Japan, for example. On the other hand, power plants of several hundred MWp have already been built in China.

Table 3. Overview of approval steps for agrivoltaics

PROCESS STEPS	INSTITUTION	COMMENTS
Building permit	Municipality	Zoning map and development plan
Required expert opinions	Certified expert	Environmental, soil, and glare protection report. Wind load testing.
Recording of the easements	Notary	Right of way and ownership structure, for example
Insurance	Insurance company	A study conducted in cooperation with the Gothaer Versicherung insurance company showed that the amount insured for an agrivoltaic system should not be significantly more costly than for a comparable, conventional solar installation

What path Germany is going to take remains open and will likely be viewed differently depending on the region. Smaller systems, typically installed over special crops, accommodate the regions of southern Germany which are characterized by smaller land parcels and higher aesthetic sensitivity. In regions of northern and eastern Germany with large areas of land, on the other hand, bigger agrivoltaic systems may make sense for the large agricultural farms, in order to economically compensate for the lower annual solar radiation through economies of scale.

The land requirement for agrivoltaic systems is typically 20-40 percent higher compared to ground mounted photovoltaic systems with the same nominal output. Currently an agrivoltaic system has a capacity of 500 to 800 kWp per hectare, while a conventional PV system has a capacity of 600 to 1100 kWp per hectare depending on the design. Using bifacial modules can increase the electricity yield: In the first year of operation, the output of the research plant in Heggelbach was 1284 kWh per kWp of capacity, while a conventional solar installation at that site only produces 1209 kWh per kWp.

Approval, Installation and Operation

- **Approval Process for Agrivoltaic Systems**

Some specifics must be considered in the approval process for the construction of an agrivoltaic system. The required documentation should be prepared in close coordination with the technology partners. An overview of the required permits, expert opinions and documents is provided in table 3.

In the research plant in Heggelbach, the arable land under the agrivoltaic system was identified as a special use area. Thus, the claim to agricultural land subsidies was permanently lost, even though arable farming continues. Furthermore, agrivoltaic technology is neither supported through the ordinance on tenders for ground-mounted photovoltaics nor through the EEG feed-in tariff.

There is no certification system for agrivoltaic systems in Germany to date. Fraunhofer ISE is currently working with project partners to prepare a DIN specification that defines quality standards which serve as criteria for tenders, funding eligibility or simplified planning processes.

This includes the definition of agrivoltaic indexes and corresponding test procedures, which can be applied by certifiers such as the VDE (Association for Electrical, Electronic & Information Technologies) or the TÜV.

- **Installation of an Agrivoltaic System, Using Heggelbach as Example**

An agrivoltaic system should be adapted to the respective local conditions and cultivation methods. Project planning and land use planning are usually handled by a specialist firm. These tasks were assumed by BayWar.e. for the research plant in Heggelbach.

The technical partners are responsible for all the planning and the processes related to the construction, installation and operation of the system. This includes:

- Finding partners to purchase the excess electricity and for feeding it into the grid material procurement and logistics planning
- Construction of site setup and soil protection
- System setup
- Concept for connection, lightning protection, and monitoring
- Grid-connection
- Technical maintenance and removal

The first hearing on the development plan for the research plant by the Herdwangen-Schönach municipal council took place on 13 October 2015, and the building application was submitted only six months later on 6 April 2016. Fraunhofer ISE obtained approval for the grid connection from Netze BW on 24 July 2015. The building permit was issued on 3 May 2016. However, construction approval was tied to a review of the statistics by an independent test engineering office. A soil report was also prepared to calculate and document the actual holding force of the foundation.

The results of this expert report and feedback from the test engineer were incorporated in the revision of the agrivoltaic mounting structure.

Contracts for the installation of the agrivoltaic system were awarded to various companies in accordance with the procurement ordinance, and the construction sequence was coordinated in detail and in close consultation with the Hofgemeinschaft Heggelbach. The power electronics and wiring of the agrivoltaic system were installed so the research plant could be quickly connected to the grid upon completion. Statics calculations were performed and the agrivoltaic system was adapted accordingly. Among other things, an Alpinanker anchor had to be installed for the foundation of the agrivoltaic system in addition to the Spinnanker anchors.

According to the original schedule, the start of construction was planned for July of 2016. However, preliminary work could not be completed on time due to various building law delays, so the start of construction was delayed until August of 2016. Nevertheless, the system was successfully completed in time for the opening ceremonies on 18 September 2016.

- **Agrivoltaics in Operation**

The solar modules are always not fully accessible due to the crop cultivation and the height of the support structure. Maintenance and repairs should therefore be carried out when fields are fallow. Safety comes first and not all maintenance vehicles are suitable for use on fields. An applicable maintenance and repair concept is to be developed in the future, establishing maintenance intervals and the scope of maintenance work as well as calculating possible costs.

Test questions

1. What type of criteria can best evaluate the environmental and socio-economic value delivered by Agrisolar projects? Justify your answer.

2. Define the three most common types of solar cell panels.

3. What structures are not fixed? Coplanar; sun tracking and inclined.

4. What type of PV installations exist? Justify your answer.

5. What is a MPPT? Justify your answer.

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Annex

Glossary

CPzS: Tubular lead plate vibration resistant battery with liquid electrolyte and opaque container.

EU-28: abbreviation of European Union which consists a group of 28 countries - from 1st of July 2013 to 31st of January 2020 - (Belgium, Bulgaria, Czech Republic, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Croatia, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Malta, Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, Sweden, United Kingdom) that operates as an economic and political block.

OPzV: Tubular lead plate stationary battery with solid electrolyte in gel form.

List of abbreviations

AC: Alternative current

AGM: Absorbent glass mat

Agri-PV: Agricultural Photovoltaics

a-Si: Amorphous silicon

CAP: Common Agricultural Policy

CapEx: Capital expenditures

CC: Constant Current

CdTe: Cadmium Telluride

CEP: Clean Energy Deal

CIS: Copper, Indium and Selenium

CISG: Copper, Indium, Gallium and Selenide

CO2: Carbon Dioxide

CPV: Concentrator photovoltaics

CSP: Concentrated solar power

DC: Direct current

EAFRD: European Agricultural Fund for Rural Development

ED: Energy division

EEG: in German stands for Erneuerbare-Energien-Gesetz, meaning Renewable Energy Sources Act

EIA: Environmental Impact Assessment

EU: European Union

FiT: Feed-in-Tariffs

GHG: Greenhouse gases

GWP: Global Warming Potential

IEA: International Energy Agency

IPCC: International Panel on Climate Change

KW: Kilowatt

MPPT: Maximum Power Point Tracking

MtCO2: Metric tons of carbon dioxide equivalent

Mtoe: Mega tonnes of oil equivalent

OPEC: Organisation of Petroleum Exporting Countries

OPV: Organic photovoltaics

OPzS: It stands for O = Ortsfest (stationary) Pz = PanZerplatte (tubular plate) S = Flüssig (flooded); a flooded type of tubular-plate, lead acid, deep cycle batteries

OTEC: Ocean Thermal Energy Conversion

PR: Performance Ratio

PSH: Peak Sun Hours

PV: Photovoltaic(s)

R&D: Research and development

RES: Renewable Energy Source(s)

SAC: Sustainable Agriculture Concept

SHC: Solar heating and cooling

TWh: Terawatt-hour

UK: United Kingdom

V: Volt

W/m2: Watt per square metre

W: Watts

WP: Watt peak