

WOMEN GOING GREENER

2023-1-EL01-KA210-ADU-000164781



Reducing the environmental footprint
of Female Entrepreneurship

Module 6

Harvesting Solar Power



The European Commission support for the production of this publication does not constitute an endorsement of the contents which reflects the views only of the authors, and the Commission can not be held responsible for any use which may be made of the information contained therein

This document was developed by Energetska zadruga Elektropionir Beograd in the framework of the Project "WomEn Going Greener – Reducing the environmental footprint of Female Entrepreneurship".

This document reflects the views only of the authors, and the European Union cannot be held responsible for any use which may be made of the information contained therein.

Table of Contents

PHOTOVOLTAIC (PV) PANELS: HOW THEY WORK	4
Solar Energy and Earth	4
How Solar Panels Work	4
Types of Solar Panels	4
Materials for Solar Cells	5
Research on More Efficient Panels	5
Electricity Production from Solar Panels: From Direct Current to Alternating Current	6
Power Flow: From Battery to Inverter	6
Why Alternating Current?	6
Advantages of Solar Energy Production: Producer or Prosumer?.....	6
INTEGRATING SOLAR ENERGY INTO AGRICULTURE	8
Introduction	8
Agrivoltaics: solar and agriculture co-location	9
Benefits from agrivoltaics for farmers and entrepreneurs	11
CASE STUDIES OF SUCCESSFUL SOLAR-POWERED FARMS	12
Agrivoltaics in Serbia	12
Solar Harvest: Serbia’s first agrisolar power plant	13
Solar Power Plant Delta and Brankov solar	14
Agrivoltaics in Europe	15
Italy	15
Greece	18
Germany	19
Agrivoltaics in USA	21
Bibliography	22

PHOTOVOLTAIC (PV) PANELS: HOW THEY WORK

Solar Energy and Earth

The Sun is a continuous source of energy. The fusion reactions constantly occurring in the Sun generate vast amounts of energy, which is transmitted to the Earth in the form of electromagnetic radiation, primarily as visible light, infrared, and ultraviolet radiation. Approximately 1,366 watts per square meter of this energy reaches Earth's outer atmosphere (known as the solar constant). After passing through the atmosphere, around 1,000 watts per square meter reach the Earth's surface under optimal conditions. The radiation that reaches the Earth's surface is called **global solar radiation** and represents the sum of direct radiation (which creates shadows), diffuse radiation (weakened by passing through clouds), and reflected radiation (bounced off the Earth's surface).

How Solar Panels Work

Solar panels consist of photovoltaic (PV) cells, which are typically made from semiconductor materials such as silicon. These cells convert sunlight into electricity through the photovoltaic effect. The process works as follows:

1. **Photon Absorption:** When sunlight (photons) hits the solar panel, the energy is absorbed by the PV cells.
2. **Electron Excitation:** The energy from the photons excites the electrons in the semiconductor material, causing them to separate from their atoms.
3. **Creation of an Electric Field:** The structure of the PV cell contains built-in electric fields due to the layers of semiconductor materials (usually n-type and p-type silicon). This electric field forces the free electrons to move in a specific direction.
4. **Generating Current:** The movement of these electrons creates an electric current.

Types of Solar Panels

There are several types of solar panels, each with its own characteristics:

1. **Monocrystalline Solar Panels** (most commonly used):
 - **Material:** Made from a single continuous crystalline structure of silicon.
 - **Efficiency:** Typically 15-20%.

- **Characteristics:** They are more efficient and space-efficient compared to polycrystalline panels but are more expensive due to the more complex manufacturing process.
 - **Appearance:** Uniform dark color.
2. **Polycrystalline Solar Panels** (nearly phased out from the market):
- **Material:** Made from multiple silicon crystals that are melted together.
 - **Efficiency:** Typically 10-15%.
 - **Characteristics:** They are less efficient than monocrystalline panels but are more affordable and easier to manufacture.
 - **Appearance:** Bluish with a fragmented texture.
3. **Bifacial Solar Panels:**
- **Material:** Can be made from either monocrystalline or polycrystalline cells.
 - **Efficiency:** Typically 15-20%, but they can produce up to 30% more electricity by capturing light from both sides.
 - **Characteristics:** These panels are designed to absorb sunlight from both the front and back sides, making them more efficient in environments where light reflects off surfaces such as snow, water, sand, or artificial materials with higher reflection coefficients.

Materials for Solar Cells

- **Silicon:** The most common material used for solar cells. Both monocrystalline and polycrystalline panels are made from silicon.
- **Thin Films:** Include cadmium telluride (CdTe) and copper indium gallium selenide (CIGS). These materials are used in thin-film solar panels, which are lighter and more flexible but generally less efficient than silicon-based panels.

Research on More Efficient Panels

Researchers and companies around the world are working to increase the efficiency of solar panels. Some of the most significant developments include:

- **Perovskite Solar Cells:** This is a newer type of solar cell that promises higher efficiency and lower production costs. Companies like Oxford PV are leading the development of perovskite-based solar cells, with some prototypes achieving over 28% efficiency. These cells could be commercially available in the coming years.
- **Multi-Junction Solar Panels:** These cells stack multiple layers of different materials to capture a broader spectrum of sunlight, achieving efficiencies greater than 40%. They are currently used in space applications but could become available for terrestrial use as production costs decrease.

Electricity Production from Solar Panels: From Direct Current to Alternating Current

Solar panels produce **direct current (DC)**, which cannot be directly used in households. Most household appliances and power systems use **alternating current (AC)**, so conversion is necessary.

Power Flow: From Battery to Inverter

- **Direct Current from Panels:** When solar panels generate electricity, it is direct current (DC). This current can be directed to batteries for storage or sent directly to an inverter.
- **Batteries:** If the system uses batteries, they store the direct current, which can later be used when there is no sunlight, e.g., at night. From the batteries, the current again passes through an inverter before being used in the household.
- **Inverter:** This is a key component of any solar system. The inverter converts direct current from the panels or batteries into alternating current, which can be used in households or fed back into the power grid.

Why Alternating Current?

Alternating current (AC) is the standard in power systems for several advantages over direct current (DC):

- **More Efficient Transmission Over Long Distances:** Alternating current can be transmitted over long distances with fewer energy losses using transformers that can raise and lower voltage.
- **Simpler Distribution:** AC systems are designed to easily connect consumers to the grid, making them the standard for power distribution.
- **Safety and Standardization:** The use of AC is standardized in power grids and households worldwide, ensuring device compatibility and system safety.

Advantages of Solar Energy Production: Producer or Prosumer?

Prosumer (Producer + Consumer): When a solar power plant is connected directly to a household and the power grid, the plant owner becomes a prosumer. This means that they not only produce energy but also use part of that energy for their own needs. The

excess energy can be fed into the grid, for which the prosumer can receive financial compensation or credit for future energy consumption.

Advantages:

- Lower electricity bills, as the prosumer uses their own generated energy.
- Potential to earn or reduce costs by selling excess energy to the grid.
- Greater energy independence and stability.
- Decentralization of production systems and improvement of the distribution grid.

Disadvantages:

- **High Initial Costs:** Installing solar equipment, including panels, batteries, and inverters, requires a significant initial investment. Although the costs are recouped over time through savings on electricity bills, the upfront expenses can be a barrier for many owners.
- **Maintenance and Replacement:** While solar panels (25+ years) have a long lifespan, batteries and inverters (10-15 years) require regular maintenance and eventual replacement.
- **Dependence on Sunlight:** Prosumer systems rely on the amount of sunlight, so energy production can vary depending on the location, season, and weather conditions. Insufficient production may require additional power from the grid.
- **Regulatory Complications:** In some countries, there are complex regulations regarding grid connection, surplus energy sales, and compensation. This can lead to bureaucratic challenges for prosumers.

Pure Production Power Plant: Solar systems installed solely for energy production for the grid focus on generating the maximum amount of electricity, which is sold to distribution companies.

Advantages:

- Focus on maximizing production without the need for consumption management.
- Revenue generation exclusively from energy sales.
- Decentralization of production capacity.

Disadvantages:

- **High Installation and Maintenance Costs:** Building large solar power plants requires a significant investment in land, equipment, and infrastructure to connect to the grid. Regular maintenance and management can add to operational costs.

- **Impact on Land and Environment:** Large solar power plants require vast areas of land, which can lead to conflicts with the need for agricultural land or the preservation of natural habitats.

INTEGRATING SOLAR ENERGY INTO AGRICULTURE

Introduction

Sustainable agriculture and the production of healthy food are becoming imperative and one of the basic goals of the growing global population. According to the most recent United Nations estimates elaborated by Worldometer, the current world population is 8.2 billion. But that's not all: based on the United Nations projection the world's population is expected to increase from the current 8 billion to 9.7 billion in 2050 and could peak at nearly 10.4 billion in the mid-2080s. Given the ecological crisis we are certainly facing today, along with pollution and soil degradation, sustainable food production for a growing population will become a major challenge. In addition, land is a key resource for human activities under growing pressure.

The UN estimates that 20% of the Earth's total land area has been degraded only between 2000 and 2015. Also, it is important to note that land is necessary for a large number of human activities - therefore, land use becomes a challenging terrain for the confrontation of various stakeholders (different economic activities, urbanization, etc.). As one of the main priorities on a global level are to abandon fossil fuels and reduce carbon emissions, energy production from renewable sources and the green transition are becoming additional activities that put pressure on land use. Conflicts between agriculture and the expansion of RES that require large areas such as photovoltaic systems or energy crops arise. Therefore, a **key question arises: can food production and energy production from renewable sources be harmonized on the same land?**

The potential offered by solar energy is enormous - it is an inexhaustible free energy source. Theoretically, solar energy possesses the potential to adequately fulfil the energy demands of the entire world if technologies for its harvesting and supplying were readily available. However, there are many reasons why this potential has not been used to a sufficient extent. Despite the promising potential for solar photovoltaic technology to retrench global reliance on fossil fuels, large-scale PV development is experiencing complex challenges, including land use conflict and social resistance, which has previously been more commonly associated with large-scale wind farms. Growth in large-scale PV development can create land use disputes, especially in instances of competition between land for agriculture versus energy production. Social resistance is completely justified considering all the above: human needs are increasing due to the

growing population, and the unpolluted and non-degraded land is decreasing. Therefore, to overcome obstacles and make the best of both, it was necessary to explore new approaches such as "Agrivoltaics" (solar and agriculture co-location).

Agrivoltaics: solar and agriculture co-location

Agrivoltaics, the co-development of land for both agriculture and PV, is an innovative and increasingly popular approach to solar development. Most large, ground-mounted solar photovoltaic (PV) systems are installed on land used only for solar energy production. Such installations can threaten the local community, farmers and local food production. This was often the cause of social problems and disagreements: throughout Europe (especially in the southern Europe) and other parts of the world (e.g. USA, India) during the past decade, there have been several cases when local communities protested the projects of huge ground-mounted solar power plants. For the energy transition to be successful, it must be socially accepted, which is key to achieving a just transition. If the transition implies excluding the local community, and limiting local food production and food sovereignty, then we cannot talk about justice or sustainability.

But thanks to agrivoltaics systems (APV), it's possible to co-locate solar and agriculture on the same land, which could provide benefits to both competing industries. Co-location is defined as agricultural production, such as crop or livestock production or pollinator habitats, underneath solar panels or adjacent to solar panels. After they are installed, the solar panels leave about 90 percent of the free surface, on which food can be grown.

The concept of a dual-use approach for both solar photovoltaic power as well as agricultural production was theoretically conceived by Goetzberger and Zastrow at the Fraunhofer Institute in Germany in 1981. They proposed to elevate the structure (by about 2 m) and the distance between rows (about 3 times the height of the modules) to achieve uniform radiation on the ground while at the same time allowing the movement of mechanized agricultural equipment. In 2004, Japanese engineer Akira Nagashima developed the first agrivoltaics system using a structure similar to a garden pergola. The first experimental pilot project, however, was installed in France, close to the southern city of Montpellier in the spring of 2010. This experimental farm led to the exploration of the potential of the open field agrivoltaics systems, giving rise to many scientific publications, from the effect of the rain distribution to the impact on microclimatic conditions together with growth, morphology, and yield in crops such as lettuce, cucumber and durum wheat.

Numerous empirical studies have investigated the technical viability of agrivoltaics systems, examining PV with plant cultivation, aquaponics, and livestock production. It has been demonstrated as a technically and economically practical use of agricultural land, capable of overcoming the dominant separation of food and energy production and increasing land productivity by 35–73%. The partial shade of solar panels reduces

the amount of direct sunlight reaching crops, changing the microclimate (cooler in the day, warmer at night) and increasing soil moisture levels. Researchers from the University of Arizona, led by Professor Greg Barron-Gafford in 2019, found that PV reduces the amount of incoming energy under the panels yielding cooler daytime air temperatures, averaging 1.2°C lower in the agrivoltaics system over the traditional setting. Also, they detected that soil moisture can be up to 15% higher under PV panels. There are both benefits and tradeoffs of co-locating agricultural crops with solar installations. In arid climates, for example, there might be higher yields with lower watering requirements; in extremely wet environments, panel spacing and other factors play an important role in managing on-site water distribution and eventual yields.

Different kinds of crops can be considered for cultivation in agrivoltaics systems, but priority is given to horticultural productions as alley cropping is more compatible with the geometrical constraints resulting from the supporting structure. The small size of mechanical engines used in vegetable production also motivated this choice. Among the major vegetable productions in Southern Europe and USA, lettuce was particularly adequate for these pioneer systems. Today, the most diverse types of fruits, vegetables, herbs, and medicinal and aromatic plants are grown in agrivoltaics farms around the world.

Foraging livestock can manage vegetation under solar arrays, which can be considered at the early phases of solar planning and installation by seeding appropriately and raising modules, wires, and electrical boxes. Livestock can reduce the maintenance costs of trimming beneath panels and reduce the need to use herbicide. A study conducted by Towner et al. (2022) shows that implementing managed sheep grazing significantly increased total carbon storage (10-80%) and available nutrients, and the magnitude of change correlated with the grazing frequency. Animals also benefit from the shade provided by solar panels. Sheep are the most common solar-grazing animals.

Agrovoltaics can also contribute to the protection of pollinators. The importance of pollinators is reflected in the fact that pollinators, both wild and domesticated such as honeybees, are responsible in whole or in part for the production of approximately 75% of the world's leading food crops (according to EU Pollinators Initiative). Many pollinator populations are threatened by land use change, intensive urbanization, intensive agricultural practices that include the use of large amounts of chemical agents (pesticides, herbicides, insecticides...), environmental pollution, invasive species, climate changes, etc. So how can agrosolar help protect pollinators? Under solar panels, pollinator habitats can be planted, and that has become a very successful practice, especially in the USA. Pollinator habitat under solar arrays can benefit farms by increasing local agricultural yield and can also host beekeeping operations. Solar beekeeping is the practice of placing honeybee hives on or near solar sites (pollinator-friendly solar farms = one more good practice of co-locating).

Benefits from agrivoltaics for farmers and entrepreneurs

What advantages can farmers and entrepreneurs have from agrosolar power plants? Such facilities provide both farmers and entrepreneurs with multiple benefits:

- **Protection of crops from adverse weather conditions** - solar panels act as protection against strong winds, hail, heavy rainfall, intense insolation, and high temperatures (especially in periods of severe heat waves). This has a positive effect on the reduction of losses, increases the yield in agricultural production, and increases overall productivity and business.
- **Creating additional income from electricity production:** farmers and entrepreneurs can not only produce energy for their own needs but can also sell the excess electricity produced. The advantage is that this is a relatively stable and predictable source of income, which reduces the financial risk of the business. If we rely solely on earning from agricultural products, we depend to a large extent on, for example, whether the year will be dry or whether there will be enough rain, but when we diversify our business and combine food and energy production, we create a more favorable and reliable environment.
- **Solar Land Lease:** lease of space above the crops to third parties who can invest in solar power plants. This is intended primarily for those farmers who do not want to directly invest in photovoltaic systems. They can rent their land to companies involved in the development of photovoltaic power plants. In this way, the farmer can earn additional income, without investing in solar equipment. The farmer continues to do what he knows best - which is food production, while the company or investor takes responsibility for the energy part of the business. In this way, the potential risk related to the energy market is assumed by the company.
- **Marketing benefits and contribution to sustainability:** through such collaborations and projects, farmers and entrepreneurs improve the image of the agriculture and energy sector, better position their products on the market, produce sustainable and green energy and contribute to decarbonization.
- **Reduction of labor costs and consumed energy:** those farmers who decide to use the produced electricity for their own needs, can reduce the consumption of electricity and thereby reduce business costs. Today, there is a wide range of different devices and machines on the market that are based on solar power and are used in the agriculture sector, such as solar tillers, solar milking machines, solar fencing systems, solar tractors, solar sprayers, solar insects and pest traps...

Agrivoltaics offers numerous advantages and potentials, but some limitations should be mentioned: some solar industry professionals see agrivoltaic projects as complex and require extra effort to actualize, including added layers of intricacy in system design and increased coordination with stakeholders. It is therefore clear that such projects require more time, planning, and financial investment.

CASE STUDIES OF SUCCESSFUL SOLAR-POWERED FARMS

In the following chapter, several different agrivoltaics projects from Serbia, Europe and USA will be presented, both commercial and pilot cooperative projects.

Agrivoltaics in Serbia

Agrisolar is a relatively new concept in Serbia, but it has great potential. Serbia is traditionally an agricultural country, with a high share of agricultural land concerning the total area, and with traditionally represented agricultural production. About 48.7% of the territory of the Republic of Serbia is covered predominantly by agricultural land. Under intensive agricultural crops (arable fields, gardens, vineyards, orchards, etc.) is 37.1% of total agricultural land, while under grassy vegetation, which mostly consists of meadows and pastures is 11.6%. In addition, the potential of solar radiation in Serbia is about 30% higher than in Central Europe. According to the Department for Strategic Planning in the energy sector (Ministry of Mining and Energy of Serbia) total exploitable potential of solar energy is assessed up to approximately 0.64 Mtoe/year, and annually average value of radiation energy is from 1200 kWh/m²/year in the north-west to 1550 kWh/m²/year in the south-east, while in the central part it is about 1400 kWh/m²/ year. Also, the number of hours of solar radiation in the territory of Serbia is between 1500 and 2200 hours per year and there are about 270 sunny days on average.

In addition to the existence of natural potentials (agricultural production, agricultural land, and significant potential of solar energy), Serbia also made a strategic decision (following the strategic determination of the EU) to align the energy development with the EU member states, which means the decarbonization of the energy sector up to 2050 (net zero emissions by 2050). At the beginning of 2021, the Republic of Serbia introduced reforms of the national legal framework in the field of energy and climate change, as a starting point for the process of energy transition to climate-neutral development. With that, more complete harmonization with the regulations of the “Third Energy Package” of the EU energy legislation and certain provisions of the “Clean Energy for all Europeans” package was achieved. The Republic of Serbia adopted a new legislative package consisting of the Amendments of some already existing laws (Law on Energy, Law on Mining and Geological Research) and new Laws such as the Law on

Energy Efficiency and Rational Use of Energy, the Law on the Use of Renewable Energy Sources and the Law on Climate Change. At the end of 2023, the Integrated National Energy and Climate Plan was adopted by the Government of the Republic of Serbia, which plans to increase the share of renewable energy sources in electricity production to 45% in 2030.

All this creates opportunities for far more intensive development of agrivoltaics projects in Serbia, the expansion of which we can expect in the coming years.

Solar Harvest: Serbia's first agrisolar power plant

In February 2024, the Organic farm "Organella" became home to Serbia's first agrisolar power plant. Located in a rural area of Western Serbia and surrounded by natural landscapes, Organella produces organic fruit and vegetables, and from now on it will also generate green electricity on the same land where it grows its organic food. Under the solar panels, Organella farm will grow currants and rocket. The solar power plant has 48 photovoltaic panels, with a combined capacity of 17.5 kW. Placing solar panels above agricultural land brings a double benefit: under the solar panels that will generate electricity, there are plants which need shade in order to grow unhindered. The solar panels will provide them with the shade they need, while at the same time protecting them from hail. Moreover, evaporation from plants will cool the solar panels, increasing their efficiency and ensuring the maximum utilization of their capacity. During hot summer days, when air temperature exceeds 30 degrees Celsius, the efficiency of solar panels decreases, so they benefit when they get cooled with evaporation from plants that grow underneath. It is estimated that this agrisolar will reduce CO₂ emissions by 28 tons per year and that the annual energy yield will be 25.9MWh.

The Solar Harvest is the project of the Elektropionir energy cooperative (in cooperation with Organella Farm), and it is implemented as part of the Innovative and Just Green Transition initiative, aimed at ensuring energy security and reducing energy poverty, which is implemented by UNDP Serbia in partnership with the Ministry of Environmental Protection and the Ministry of Mining and Energy.



Photo: Installation of agrisolars on the Organela farm, Source: Elektropionir



Photo: Solar panels and currant seedlings at Organela farm, Source: Elektropionir

Solar Power Plant Delta and Brankov solar

In the northern part of Serbia (AP of Vojvodina) two new agrisolars projects are underway (planning documentation is currently being prepared): “Solar Power Plant Delta” and “Brankov solar”. Solar Power Plant Delta is located in the cadastral municipality of Banatska Topola, on agricultural land. Three agrisolars fields are envisaged on 157

hectares. The project includes a substation (110/35 kV), a link to a 110 kV power line and electrical and optical cables (180 hectares in total). According to the draft plan, the power plant will have an 88 MW connection point to the transmission system. The land below solar panels will be used for agricultural purposes, such as grazing for small livestock or growing crops that do not require extensive sunlight. The location for the second project, Brankov solar, is in the cadastral units of Mokrin and Kikinda. Solar panels and associated equipment would occupy 15 hectares.

Agrivoltaics in Europe

Currently, there are more than 200 agrisolar projects across Europe that exceed a combined capacity of 2.8 GW, including both pilot and commercial projects. These projects are mostly located across Switzerland, France, the Netherlands, Lithuania, Germany, Spain, Italy, Belgium, Austria, and the UK. In addition to common energy goals and the desire for decarbonization, the EU Member States made a clear decision to establish the Common Agricultural Policy (CAP), which also opened up significant space for the promotion and implementation of agrivoltaics projects. So far, 14 EU countries have incorporated solar PV under their Common Agriculture Policy (CAP) Strategic Plans. These countries are Austria, Belgium, Bulgaria, Cyprus, Czech Republic, France, Germany, Ireland, Italy, Luxembourg, Malta, Netherlands, Spain and Slovenia.

Italy

The number of agrivoltaics systems in Italy has grown over the years, to the point where they are now considered one of the key methods for achieving decarbonization goals. Also, it is important to highlight two documents: “Integrated National Energy and Climate Plan 2030” which foresees an increase in the share of energy produced from photovoltaic energy by 35 GW and 55% of electricity from RES by 2030 and “National Recovery and Resilience Plan” which aims to reduce energy costs in the agricultural sector and envisages the installation of at least 1.04 GW of agrivoltaics plants by June 2026, promoting hybrid agriculture-photovoltaic systems. It actually means that we can expect a real expansion of agrosolar systems in this country in the coming years.

The first agrivoltaics plant of 1MW in Italy was built in 2011 (and one of the first in Europe) in Apulia (region also known by its Italian name Puglia, located in the southern peninsular section of the country). In recent years, this Italian entrepreneur and proud owner of the first agrosolar farm in this country has been working on the development of a new project of 8 MW, where he will implement a combination of the production of green energy and wine, i.e. growing grapes.

In the previous period, dozens of agrivoltaics projects were installed or approved for installation in Italy. In 2023, the construction of 13 agrivoltaics parks with a combined capacity of 593.7 MW has been approved, which will combine energy and agricultural

production. Twelve of these projects will be located in Puglia, while one will be installed in the neighboring region of Basilicata. These projects are expected to help achieve national renewable energy targets.

Regarding agrisolar project in Basilicata, in the municipality of Genzano di Lucania (province of Potenza), a 10 MW power plant is currently under construction. This plant is expected to be able to generate 6162 MWh of clean energy per year when it is fully operational. This project involves the use of structures with a height of 1.5 meters that will allow the cultivation of different types of crops, beekeeping and grazing of sheep.

In the following period, another new agrivoltaics farm is expected to start production: the Ramacca Plant, located in Ramacca, in the province of Catania. The plant, known as “Solare Ramacca fiume - Gornalunga”, will be located on an agricultural land of about 68 hectares and will have an installed rated power of 34 527 MWp. It will be equipped with an integrated storage system with an input power of 11.4 MW on solar tracking facilities. This plant is expected to produce a net amount of 72 500 MWh/year of electricity from renewable sources. In addition to the production of clean energy, the plant will have a significant impact on reducing CO₂ emissions into the atmosphere, with an estimated over 29 000 tons per year.

Among the already operational plants, there is that of the Renantis in Scicli, in Ragusa, of 9.7 MW of new solar capacity. The plant is estimated to produce about 20 GWh of renewable energy per year, equivalent to the needs of more than 5000 households. At the site, the cultivation of native crops and energy production will be combined. The crops have been selected in collaboration with the Department of Agriculture, Food and Environment of the University of Catania and include fruit trees, medicinal herbs, and a polyphyte lawn for sheep grazing, as well as bee breeding and honey production and other hive products. The agricultural activity will be managed by a local cooperative, which will bring significant benefits to the entire area, as well as creating new employment opportunities at the territorial level. This initiative not only promotes environmental sustainability and resource efficiency but also contributes to the economic and social development of the local community.

It is also worth mentioning the “Agrivoltaics Open Labs” initiative located in Salaparuta (Sicily). That is one kind of open-air innovation laboratory in which the integration between the production of solar energy, agriculture, and biodiversity protection is tested. Given that grape growing, and wine production are part of culture, history, and tradition in Sicily, the company that owns the vineyard decided to combine wine and energy production and invest in PV installation. In this way, in addition to wine, the company also produces energy, reducing costs and at the same time favoring sustainability (the so-called Agrivoltaics Wine).



Photo: Agrivoltaics Open Labs in Salaparuta (Sicily), Source: Enelgreenpower.com

Greece

Greece has some of the highest potential for renewable energy in Europe, with 50% more solar irradiation per square meter than Germany (which represents one of the leading countries in the field of agrisolar development). Southern regions of Greece receive more than 2000kWh/m² of global irradiation yearly, generating up to 1500kWh/kW of solar electricity. Other parts of the state also have significant solar potential. Over the past decade, the share of RES in total energy consumption has almost doubled, primarily as a result of wind and solar power generation. At the same time, Greece is phasing out coal and has decreased its greenhouse gas emissions by 43% since 2005. Favorable geographical position and climatic characteristics make this country very favorable for development and investment in agrivoltaic technologies. Therefore, we can expect their expansion in the future.

Regarding agrivoltaics projects in Greece, one interesting initiatives should be mentioned: In Ioannina (Northwestern Greece, region of Epirus) the first urban community agriphotovoltaic project is already being planned and a replication will follow in Skopje, North Macedonia (two 10-15 kW agriPV stations). It is an urban vegetable garden that will be combined with the production of green energy from photovoltaic panels. The pilot will be coordinated by the local energy community CommonEn and the design will follow participatory procedures with the involvement of citizens and local stakeholders. CommonEn was founded in 2021 and it was pioneered by Electra Energy (member of a REScoop.eu).

The second project that will be presented here is a project by Greek startup Brite Solar which is building a production line in Patras for transparent solar panels for agrivoltaic production. This facility in Patras will have an annual capacity of 150 MW in peak terms. Brite Solar aims to then boost it to 300 MW in future. This company has so far implemented several successful Open-field agrivoltaic projects across Europe such as:

- Open-field blueberry cultivation in Broekhuizen: one of the very first agrivoltaics projects in the Netherlands, initiated by a commercial blueberry grower.
- Open-field strawberry cultivation in Senden (Bavaria, Germany): initiated by a German grower of a variety of fruits (apples, pears, strawberries, various berries).
- Open-field apple pear and cultivation in Papendrecht (western Netherlands).
- Open-field pear cultivation in Randwijk (The Netherlands): situated on a research farm managed by Wageningen University & Research, this demonstration installation is part of the “Sunbiose” project that has received Dutch government support to facilitate the broader spread of agrivoltaics in the Dutch agricultural sector.

Germany

The use of renewable energy sources in Germany has a long tradition. Since 2000, the Renewable Energy Law (Erneuerbare Energien Gesetz – EEG) has set the legal framework for the energy transition in this country. Germany has set the goal of becoming greenhouse gas-neutral by 2045. Additionally, at least 80% of the electricity consumed in Germany will be generated from renewable energies by 2030. In recent years APV projects have gained popularity in this country, but they are still in a very early stage of development to be called “everyday practice”. In the 2021 novelty of the EEG, agrivoltaics entered the innovation rules as part of the so-called special solar facilities (together with floating photovoltaics and parking lot photovoltaics). Since then, their number has been growing and there are more and more interested farmers and entrepreneurs who are ready to invest. According to a recently published study by Wagner et al. (2024) „Factors influencing the willingness to use agrivoltaics: a quantitative study among German farmers“, 72.4% of German farmers are willing to use agrivoltaics. In 2024, there are a couple of dozen agrivoltaics farms in Germany, especially in southern part (Bavaria and Baden-Württemberg), where the number of facilities is higher compared to the rest of the country.

One of the interesting examples is the first agrivoltaics pilot on an apple orchard in Germany, located in Gelsdorf in Rhineland-Palatinate (West Germany). Its primary objective is to increase climate resilience in fruit growing while simultaneously harvesting green electricity. This project started in 2021, at Nachtwey organic fruit farm with installed capacity of 300 kWp. The produced solar power is, among other things, used for the electric tractor on-site and to operate the electric pump of the irrigation system, which replaces a diesel generator. The next example is the APV-pilot plant at the “Heggelbach” biodynamic farm community run by six families, located in the municipality Herdwangen-Schönach, Baden-Württemberg (Southwest Germany). This project started in 2016 with installed capacity of 194 kWp. The farm community cultivates around 180 hectares. The agricultural basis comprises grass-clover ley (27 ha), cereals (30 ha), vegetables (25 ha), ware potatoes (12 ha), and pasture for the herd of cows. The innovative solution increased the land use efficiency on the test area by more than 60%.

One of the current projects whose implementation is underway is the construction of an APV plant by the OEKOGENO. OEKOGENO is a cooperative based in Fribourg with 16 000 members, which has launched a Crowd-Investment campaign to built "Oekogeno Agri solar park" near town Ottweiler (Saarland, Southwest Germany). A 3.7 MWp agrivoltaics plant with bifacial modules will cover an area of 11ha. The open space, which remains as 12-meter-wide corridors between the modules, will be used twice: as a pasture for cattle of the Angus breed, which the owner of the land markets as organic meat, and as a cultivation area for hay.



Photo: The first agrivoltaics pilot on an apple orchard in Germany (Nachtwey organic fruit farm, Gelsdorf), Source: Baywa-re.de

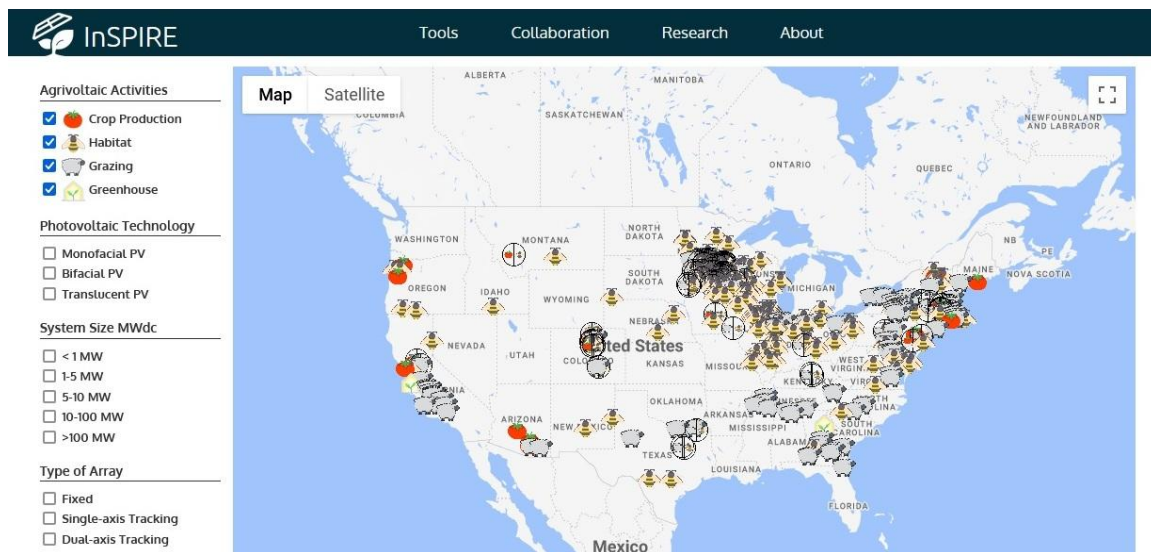


Photo: APV plant at the "Heggelbach" biodynamic farm community, Source: Baywa-re.de

Agrivoltaics in USA

In the United States, solar development is projected to grow substantially. By 2030, solar installation could reach 330 GW of installed capacity (to meet 14% of national demands), with 209 GW expected to be ground-mounted solar, which would require approximately 8000 km² of land, including agricultural land.

Agrivoltaics projects in the USA began to develop around 2011, however, their significant expansion began after 2016. By August 2024, the National Renewable Energy Laboratory has identified 571 agrivoltaics projects in the United States (with 10GW), of which crop production includes 35 projects (79MW, 360 Acres) and solar grazing includes 205 projects (7555 MW, 49 229 Acres). Sheep are the most common solar-grazing animals, but there are also several farms where cows, horses, llamas, and alpacas are represented. When we talk about growing food under solar panels in the USA, the following are most often grown on agrivoltaics farms: vegetables (cabbage, broccoli, kale, chard, peppers, parsley, tomatoes, lettuce, spinach, squash, basil, eggplant, celery, leeks, peas, cucumbers, string beans, zucchini, shallots, cauliflower, carrots, bush beans, yam, radish, etc); fruits (strawberry, blueberries, melon, watermelon, grapes), as well as medicinal and aromatic herbs. The number of agrosolar farms is growing year by year, due to the growing interest of American farmers, and all this is strongly supported by the U.S. Department of Energy which developed the “Farmer’s Guide to Going Solar” as a form of support for all new farmers who want to join this initiative. The most numerous agrivoltaics projects in USA are definitely “pollinator habitats” (418 sites with 4293 MW, which covers 23 784 Acres). States across the country are establishing standards that set fair, flexible, and science-based standards for what constitutes “beneficial to pollinators” in the managed landscape of a solar farm. Many states have adopted their own “Pollinator-Friendly Solar Scorecards”.



Map: Agrivoltaics installations located across the United States, Source: OpenEI.org

Bibliography

- Agrisolar Best Practice Guidelines, Version 2.0. (2023). SolarPower Europe.
- Ašonja, A., Vuković, V. (2018). The potentials of solar energy in the Republic of Serbia: current situation, possibilities and barriers. *Applied Engineering Letters*, 3, 90-97. <https://doi.org/10.18485/aeletters.2018.3.3.2>
- Barron-Gafford, G. A., Pavao-Zuckerman, M. A., Minor, R. L., Sutter, L. F., Barnett-Moreno, I., Blackett, D. T., Thompson, M., Dimond, K., Gerlak, A. K., Nabhan, G. P., & Macknick, J. E. (2019). Agrivoltaics provide mutual benefits across the food–energy–water nexus in drylands. *Nature Sustainability*, 2(9), 848–855. <https://doi.org/10.1038/s41893-019-0364-5>
- Coşgun, A., Sacid Endiz, M., Demir, H., & Özcan, M. (2024). Agrivoltaic systems for sustainable energy and agriculture integration in Turkey. *Heliyon*, 10(11), e32300–e32300. <https://doi.org/10.1016/j.heliyon.2024.e32300>
- Davis, R., Macknick, J. (2022). ASTRO: Facilitating Advancements in Low-Impact Solar Research, Deployment, and Dissemination. National Laboratory of the U.S. Department of Energy (NREL), Office of Energy Efficiency & Renewable Energy.
- Deteix, L., Salou, T., Drogué, S., & Loiseau, E. (2023). The importance of land in resource criticality assessment methods: A first step towards characterising supply risk. *Science of the Total Environment*, 880, <https://doi.org/10.1016/j.scitotenv.2023.163248>
- Draft of the New Spatial Plan of the Republic of Serbia, 2010-2035. Belgrade: Ministry of Construction, Transport and Infrastructure, Republic of Serbia.
- Dupraz, C., Marrou, H., Talbot, G., Dufour, L., Nogier, A., Ferard, Y. (2011). Combining solar photovoltaic panels and food crops for optimising land use: Towards new agrivoltaic schemes. *Renewable Energy*, 36, 10, 2725–2732, <https://doi.org/10.1016/j.renene.2011.03.005>.
- Energy Sector Development Strategy of the Republic of Serbia for the period by 2025 with projections by 2030 (2016). Belgrade, Republic of Serbia: Ministry of Mining and Energy, Department for strategic planning in energy sector.
- Goetzberger, A., Zastrow, A. (1981). On the Coexistence of Solar-Energy Conversion and Plant Cultivation. *Int. J. Sol. Energy*, 1, 55–69. <https://doi.org/10.1080/01425918208909875>
- Gvozdenac, D., Nakomčić-Smaragdakis, B., Gvozdenac Urošević, B. (2011). Tehnologije obnovljivih izvora energije. Fakultet tehničkih nauka.
- Hartmann, H.M., Gripoo, M., Heath, G. et al. (2016). Understanding Emerging Impacts and Requirements Related to Utility-scale Solar Development (Technical Report). US Department of Energy, Office of Scientific and Technical Information.
- Integrated National Energy and Climate plan of the Republic of Serbia for the period up to 2030 with projections up to 2050. Belgrade, Serbia: Ministry of Mining and Energy.
- Kabir, E., Kumar, P., Kumar, S., Adelodun, A. A., & Kim, K.H. (2018). Solar energy: Potential and future prospects. *Renewable and Sustainable Energy Reviews*, 82(1364-0321), 894–900. <https://doi.org/10.1016/j.rser.2017.09.094>
- Marrou, H., Guilioni, L., Dufour, L., Dupraz, C., Wery, J. (2013). Microclimate under Agrivoltaic Systems: Is Crop Growth Rate Affected in the Partial Shade of Solar Panels? *Agric. For. Meteorol.*, 177, 117–132. <https://doi.org/10.1016/j.agrformet.2013.04.012>

- Marrou, H., Wery, J., Dufour, L., Dupraz, C. (2013). Productivity and radiation use efficiency of lettuces grown in the partial shade of photovoltaic panels. *European Journal of Agronomy*, 44, 54-66. <https://doi.org/10.1016/j.eja.2012.08.003>
- Naushad, M., Sagar, A. (2023). Solar energy in Agriculture. *Just Agriculture: multidisciplinary e-newsletter*, 23, 12, e-ISSN: 2582-8223.
- Pascaris, A. S., Schelly, C., Burnham, L., & Pearce, J. M. (2021). Integrating solar energy with agriculture: Industry perspectives on the market, community, and socio-political dimensions of agrivoltaics. *Energy Research & Social Science*, 75, <https://doi.org/10.1016/j.erss.2021.102023>
- Pringle, A., Handler, R., Pearce, J. (2017). Aquavoltaics: Synergies for dual use of water area for solar photovoltaic electricity generation and aquaculture. *Renewable and Sustainable Energy Reviews*, 80, 572-584. <https://doi.org/10.1016/j.rser.2017.05.191>
- Pump, C., Trommdorff, M., Beckman, V., Bretzel, T. (2024). Agrivoltaics in Germany – Status Quo and Future Developments. *AgriVoltaics World Conference 2023, Legal Framework & Public Policies*, <https://doi.org/10.52825/agripv.2i.1005>
- Saxena, N.N., Kumar, P. (2021). A Review on Application of Solar Energy in Agriculture Sector. *International Journal of Innovative Research in Engineering & Management (IJREAM)*, 8, 6. <https://doi.org/10.55524/ijirem.2021.8.6.23>
- Sekiyama, T. Akira Nagashima Sunlight Power Generation System. Patent No. 2005-277038, 6 October 2005.
- Sovacool, B. (2009). Exploring and Contextualizing Public Opposition to Renewable Electricity in the United States. *Sustainability*, 1, 3, 702–721. <https://doi.org/10.3390/su1030702>
- Tariq, G. H., Ashraf, M., & Hasnain, U. S. (2021). Solar Technology in Agriculture. *IntechOpen*. <https://www.intechopen.com/chapters/77058>
- Toledo, C., Scognamiglio, A. (2021). Agrivoltaic Systems Design and Assessment: A Critical Review, and a Descriptive Model towards a Sustainable Landscape Vision (Three-Dimensional Agrivoltaic Patterns). *Sustainability*, 13(12), 6871. <https://doi.org/10.3390/su13126871>
- Towner, E., Karas, T., Janski, J., Macknick, J. & Ravi, S. (2022). Managed sheep grazing can improve soil quality and carbon sequestration at solar photovoltaic sites [Conference presentation]. *AGU Fall Meeting 2021*, New Orleans, LA, United States. <https://doi.org/10.1002/essoar.10510141.1>
- Wagner, J., Buhner, C., Golz, S., Trommsdorff, M., Jurkenbeck, K. (2024). Factors influencing the willingness to use agrivoltaics: A quantitative study among German farmers. *Applied Energy*, 361, 122934, <https://doi.org/10.1016/j.apenergy.2024.122934>
- Wüstenhagen, R., Wolsink, M., Bürer, M. (2007). Social acceptance of renewable energy innovation: An introduction to the concept, *Energy Policy*, 35, 5, 2683–2691. <https://doi.org/10.1016/j.enpol.2006.12.001>.

Websites:

- Associazione Italiana Agrivoltaico Sostenibile, available at <https://www.associazioneitalianagrivoltaicosostenibile.com/>
- Balkan Green Energy News, Brite Solar to complete agrisolar panel plant in Greece by end-2024, available at <https://balkangreenenergynews.com/brite-solar-to-complete-agrisolar-panel-plant-in-greece-by-end-2024/>

- Balkan Green Energy News, Solar Harvest: Serbia's first agrisolar power plant, available at <https://balkangreenenergynews.com/solar-harvest-serbias-first-agrisolar-power-plant/>
- BayWa-re, Agrivoltaics in Germany, available at <https://www.baywa-re.de/en/solar/system-applications/agri-pv#our-expertise>
- Brite Solar, Open-Field Agrivoltaics, available at <https://www.britesolar.com/argipv>
- CommonEn Energy Community of Epirus, available at <https://www.commonen.gr/en/#erga>
- DW, Energy democracy takes off in Greece, available at <https://www.dw.com/en/greece-renewable-energy-gets-a-democratic-retrofit-in-democracys-birthplace/a-68238698>
- Electra Energy.coop, Community Solar Garden, available at <https://electraenergy.coop/en/communitysolargarden-en/>
- Energypress Greek energy news portal: Community Agrivoltaics: A new application of social and climate justice, available at <https://energypress.eu/community-agrivoltaics-a-new-application-of-social-and-climate-justice/>
- Enel Green Power, Agrivoltaics - a valuable ally in the energy transition (author Stefano Amaducci, PhD), available at <https://www.enelgreenpower.com/learning-hub/contributors/agrivoltaics-ally-energy-transition>
- Enel Green Power, In Sicilia l'energia rinnovabile si fa come il buon vino, available at <https://www.enelgreenpower.com/it/media/news/2024/03/agrivoltaico-salaparuta>
- Elektropionir, Elektrana solarna berba, available at <https://elektropionir.rs/elektrana-solarna-berba/>
- European Commission, Common agricultural policy, available at https://agriculture.ec.europa.eu/common-agricultural-policy_en
- Farmer's Guide to Going Solar, U.S. Department of Energy, available at <https://www.energy.gov/eere/solar/farmers-guide-going-solar>
- Fresh Energy, The Center for Pollinators in Energy, available at <https://fresh-energy.org/beeslovesolar>
- Infobuildenergia, Agrivoltaico e sostenibilità: in Puglia si fa la storia e si crea comunità, available at <https://www.infobuildenergia.it/approfondimenti/fotovoltaico-agricoltura-agrivoltaico-progetti/>
- Infobuildenergia, Impianti agrivoltaici, come sfruttare l'energia solare per migliorare l'agricoltura, available at <https://www.infobuildenergia.it/approfondimenti/impianti-agrivoltaici-energia-solare-agricoltura-esempi/>
- MERCOM Clean energy insights, available at <https://www.mercomindia.com/italy-greenlights-agrivoltaic-projects>
- Ministero dell'Ambiente e della Sicurezza Energetica, available at <https://va.mite.gov.it/it-IT/Oggetti/Info/9788>
- NREL Transform in Energy, Solar Market Research & Analysis, Agrivoltaics, available at <https://www.nrel.gov/solar/market-research-analysis/agrivoltaics.html>
- OEKOGENO, available at <https://oekogeno.de/>
- Open EI: Open energy information, data and resources, available at https://openei.org/wiki/InSPIRE/Agrivoltaics_Map
- Oxford PV, Perovskite solar cell achieves 28% efficiency, OPE Journal, available at <https://ope-journal.com/news/oxford-pv-perovskite-solar-cell-achieves-28-efficiency>
- PV Magazine, available at <https://www.pv-magazine.com/>

- REScoop.eu, April Success story: Combining negative energy bills and positive energy futures in Greece, available at <https://www.rescoop.eu/news-and-events/stories/april-success-story-combining-negative-energy-bills-and-positive-energy-futures-in-greece>
- Solar Power Europe: Agrisolar Europe, available at <https://agrisolareurope.org/insights/>
- United Nations: Our growing population: available at <https://www.un.org/en/global-issues/population>
- Worldmeter:World Population Clock, available at <https://www.worldometers.info/world-population/>