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Agrisolar

Best Practice Guidelines

Version 2

SolarPower Europe

Foreword

The Agrisolar sector is expanding rapidly, and holds incredible potential. Since the publication of the first volume of SolarPower Europe's Agrisolar Best Practice Guidelines, the world has experienced multiple crises: from COVID-19, to Russia's invasion of Ukraine, provoking an unprecedented energy crisis. Meanwhile, the climate crisis and resulting biodiversity loss, are causing worldwide food insecurity, and an imminent water crisis. Consequently, European institutions and Member States are accelerating the deployment of green initiatives; industries, like solar, are encouraging the uptake of EU Green Deal objectives in all areas of the economy, including agriculture.

In order to tackle these issues, policymakers will play a vital role in developing the frameworks that drive the uptake of protective, dual-land use solar power. Agrisolar is a clear solution, which addresses and guarantees: decarbonisation; energy security; sustainable dual land-use; nature preservation; soil health; and food security. Agrisolar offers a complete solution with multiple economical, social, and environmental benefits. It effectively brings together two major sectors of our society and economy: agriculture and energy. Land is used for both agricultural production, and for photovoltaic (PV) power generation. With agriculture being particularly vulnerable to climate change, solar technologies can be seamlessly integrated into nature-positive solar sites, including dual land-use project types, like onshore floating PV and Agri-PV.

This guide aims to identify Agrisolar solutions for dual-land use, additional revenue schemes for the agriculture sector, and opportunities for greener rural development. These solutions are implemented through: sustainable equipment, local energy production, protection for workers, valorisation of waste, and restoration of degraded lands, requiring human intervention.

The goal of these Best Practice Guidelines is to draw on past experience, to offer an overview of existing business cases, trends, innovations, and best practices for implementation, in order to advise local and international actors on how to successfully implement Agrisolar technologies.

The report is aimed at solar and agricultural companies, investors, landowners, government departments, local authorities, industry associations, scientific research centres, consultancies, suppliers and, more generally, any party interested in Agrisolar. The minimum requirements, best practices, and recommendations presented in the guidelines, are drawn from the experience of the members of SolarPower Europe's Land Use and Permitting Workstream.

We thank all stakeholders who participated in this initiative, and in particular our partners from the agricultural sector who provided their expert input.

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Abbreviations

CAP	Common Agriculture Policy
DC	direct current
EPC	Engineering, procurement, construction
EU	European Union
GHG	greenhouse gas
GWp	Gigawatt peak
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
LCOE	levelized cost of energy
MWp	Megawatt peak
O&M	operation and maintenance
UUA	utilized Agricultural Area
SAC	sustainable agriculture concept

1 Introduction

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Today, the world faces an unprecedented crisis – human-induced global warming, which is rapidly affecting the Earth's climate. In March 2023, the Intergovernmental Panel on Climate Change (IPCC) published the final part of its 6th Assessment report; it concluded that greenhouse gas emissions due to human activities are warming the climate at an alarming rate: global surface temperature has risen by 1.1°C compared to the pre-industrial period. Under all emission scenarios, the IPCC estimates that global warming will reach 1.5°C by the early 2030s.

The recent IPCC report also highlights that the rise in global temperature impacts every region of the world, from rising sea levels or extreme weather events, to disappearing ice caps. The conclusion draws attention to adverse impacts on the environment, society, and economy. As stated in the report, "about half of the global population currently contends with severe water scarcity for at least one month per year...Climate change has also slowed improvements in agricultural productivity in middle and low latitudes..." (source)

The far-reaching and extreme climate effects have also recently impacted Europe. In 2022, Europe faced its hottest year on record resulting in severe droughts, low precipitation levels, and lower-than-average river flows. According to Copernicus data, the European continent has warmed faster than any other continent in the past decades (source). Similarly, last winter, which was recorded as abnormally dry and warm, is already affecting the natural water cycle in southern and western Europe. The drought impacts are already evident in France, Spain and Italy, raising widespread concern about the availability of water reserves, and the impact this has on agriculture (source).

In the meantime, rapid global population growth has to lead to an increase in the global demand for water, energy, and food production, impacting the accessibility of these goods. According to the United Nations' projections, the global population is expected to reach 8.6 billion in 2030, and 9.8 billion in 2050 (source). To meet the global demand in developing countries, agricultural production will have to double (source). In parallel, global energy consumption in different sectors, including the agricultural sector, will drastically increase. Approximately 3% of the world's total final energy consumption comes from the agriculture and forestry sectors, where around 73.3% of the total energy use is used for heating (source). In Europe, we have seen a 1% increase in energy consumption in the agriculture and forestry sectors, which accounted for 3% of the total energy used in Europe in 2020 (source).

In the past year, energy prices in Europe and beyond have skyrocketed, hitting a record high since 2008. As estimated by the International Energy Agency, 90% of the increase in energy prices was driven by high fossil fuel prices in 2022 (source) (source). This has impacted all energy-consuming sectors, including agriculture. High energy prices and the energy intensive sector can severely impact the economic stability of farms. In Europe alone, high energy prices have affected farmers and rural areas across the EU. The main impact in the agricultural sector is related to water access and energy use for the irrigation process.[1] Well-designed and efficient irrigation techniques require higher energy consumption, while an increase in energy prices can affect the viability of such irrigation systems (source).

1 "Irrigation is the controlled delivery of water for agriculture through artificial systems to meet water needs not met by rainfall for crop growth and development" (source).

As a response to this crisis, and to minimise the risk induced by global temperature rise, in 2019 the European Commission adopted its EU Green Deal package in line with the 1.5°C target of the Paris Agreement. This package unveiled a roadmap for Europe to become a climate-neutral continent by 2050. One of the objectives of the EU Green Deal is the 2030 target set out in the 'Fit for 55' package. The revised package proposes to target the EU's greenhouse gas (GHG) emissions reduction, and renewable energy deployment. The aim is to reduce GHG emissions by 55%, and increase the share of renewables in final energy mix to 45% by 2030 (42.5% binding target + 2.5% indicative). In March 2023, the EU provisionally adopted stricter legislation to accelerate the deployment of renewables, raising the EU's binding renewable energy target to 42.5% by 2030, with the ambition of reaching 45%.

In addition to the climate crisis, we are currently experiencing the world's worst energy crisis in 50 years. As a result of Russia's illegal invasion of Ukraine, the European Commission put forward the REPowerEU plan. Under the REPowerEU strategy, the Commission presented a plan to save and diversify the energy supply, produce clean energy, and end Europe's dependence on Russian fossil fuels.

The REPowerEU package included a first-of-its-kind EU Solar Strategy, increasing solar ambition in Europe by 43%, and uncovering several steps to speed up solar deployment. The unprecedented EU Solar Strategy provides the right framework to accelerate solar PV energy deployment in Europe, and sets out an EU solar target of 400 GWdc by 2025, 750 GWdc by 2030. Based on future energy deployment scenarios, Europe can surpass its set ambition, and reach the TW-level milestone by the end of the decade, five times the capacity installed today. For this reason, the solar sector is central European energy transition. Europe's ambitious objectives will require the mobilisation of all existing surfaces suitable for PV panels, and the development of new uses of spaces suitable for solar installations. Scaling up Agri-PV is an opportunity to accelerate the achievement of the EU's climate objectives, while making agriculture more resilient to climate challenges.

While the energy and climate crises place a burden on the agricultural sector, additional risks are inevitably arising. Globally, farmlands are being lost due to conversion to other land uses, or becoming less productive as a result of climate change (article). As estimated by the Joint Research Centre (JRC), in Europe, about 11% of agricultural land is under high risk of abandonment, with the largest share being arable land (source).

In parallel, global food insecurity has increased since 2016 (source). The increase in food commodity prices and the COVID-19 pandemic, have all impacted the global food market, and reduced the availability of food on a global level. Global food prices increased by over 60% in March 2022, in comparison to the previous year (source). Food insecurity has doubled in 2023 in comparison to the year 2020, with almost 345 million people at risk of not accessing sufficient food according to the World Food Organization (source). The Russian invasion of Ukraine had a significant impact on global food markets as Ukraine has seen a large decline in exports causing food prices to increase further.

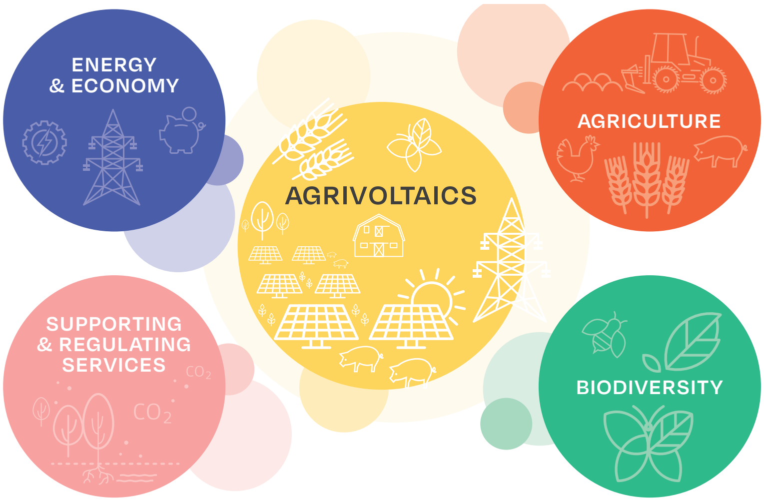
High food prices can impact the affordability to buy products, and threaten low-income and vulnerable groups globally. Food price volatility creates additional risks for farmers in Europe and beyond, as the average farm income in Europe remains below average. Farm household income has slightly increased in the last decade, however, it is still lower when compared to other professions (source).

The farmer population is decreasing across the EU, despite EU and Member State support. In 2020, there were 9.1 million farms in the EU, 37% less than in 2005 according to the European Commission.[2]

In Europe, farmlands account for approximately 50% of the EU's land surface, where agricultural area covers 39%, including arable lands, pastures and mosaic farms (source) (source). Soil health is inevitably linked to agricultural practices in the EU. Currently, there are a number of factors challenging soil health. For example, soil artificialisation, soil erosion, soil degradation, desertification, and reduction in organic matter as well as biodiversity loss are common factors impacting overall soil health and ecosystems in Europe.

2 Source.

FIGURE 1 CO-BENEFITS OF AGRIVOLTAICS



Vast areas of Europe face soil degradation at an accelerated pace induced by different land use activities. It has been estimated that 60-70% of Europe's soils are degraded while approximately 1 billion tonnes of soil are washed away by erosion annually. This causes a loss of around 1.25 billion euros per year in agricultural production (source). Combating the degradation of soil can offset GHG emissions, support healthy ecosystems, and ensure access to food among the growing population. Soil also plays a vital role in carbon sequestration. However, soil degradation leads to a loss of soil organic matter, and affects the soil's capacity to store carbon. Consequently, it is crucial to ensure sustainable land practices because it will help to preserve soil ecosystems, guarantee food security, and safeguard climate adaptation measures (source).

Land scarcity and expansion of different types of sectors put pressure on land resources and competition for land. Besides, additional pressure on land availability stems from an increase in global food production, which in turn is provoked by the growing population on a global scale. On top of that, human-induced activities and climate change pose high risks to the natural world. According to the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), at least one million animal and plant species are considered to be under threat of extinction. European policymakers' are also now prioritising environmental and biodiversity policies. With the EU Biodiversity Strategy 2030, the objective is to restore biodiversity by 2030 for the benefit of people, climate, and the planet. Healthy ecosystems are the foundation for human well-being, as they can provide food, fresh and clean water, and fuel (source). More than 90% of our food comes from terrestrial ecosystems, and provides humans with other services (source).

The development of renewable energies, particularly solar energy, on the one hand, and the maintenance of agricultural land use, on the other, could appear irreconcilable, leading to a conflict of use for the same land. However, there is a solution that makes it possible to maintain and enhance agricultural production, while producing photovoltaic energy: agrivoltaics (hereinafter referred as Agri-PV)[3] (defined in *Chapter 2: Sustainability*).

3 In this report, Agrisolar is used as a general term referring to a market sector, where sustainable agriculture practices are combined with energy generation. Agrivoltaics (Agri-PV) term is used to define a land-use concept that co-locates renewable energy generation with agriculture and nature conservation. In this report, an emphasis is put on agrivoltaics, including but not limited to socio-economic and environmental benefits, and EPC and O&M best practices.

In the past, Agri-PV has gained attraction worldwide due to its multifunctionality to co-locate energy generation, with providing multiple ecosystem services. This application brings a range of benefits, including land efficiency or land productivity, while maximising synergies between energy, food, and environmental security (see Figure 1).

PV panels offer a buffering effect to agricultural production facing extreme climatic events, and can provide favorable microclimatic conditions with the right design. Numerous studies have shown that shading by PV panels offers multiple additive and synergistic benefits, including reduced drought stress on plants, increased food and biomass production, and reduced heat stress or protect the plants against severe weather events. Ultimately, the synergies between the agricultural world and the photovoltaic sector, demonstrates the endless positive benefits of PV installations which do not harm agricultural activities.

The theoretical potential of Agri-PV is high: crop land accounts for almost one-third of the European territory (32%), where 28.2% is used as arable land, and 3.8% is used for permanent crops (source). An estimate shows that solar PV production could offset global energy demand if less than 1% of cropland were converted to Agri-PV systems (source).

In a recently published study conducted by the JRC, Agri-PV installed capacity on arable land and permanent grasslands and meadows in the EU, can reach the TW level. It is estimated that Agri-PV systems installed on 10% of the EU's Utilised Agricultural Area (UAA), could reach an installed capacity between 3.2 TW and 14.2 TW. Covering only 5% of the EU's UAA would lead to a total installed capacity of 1.5 TW to 7 TW (source). Such data highlights the potential of Agri-PV to contribute to decarbonisation targets, and secure renewable energy deployment.

Outside of the environmental benefits, Agri-PV offers multidimensional opportunities by facilitating sustainable development in agricultural areas. Agri-PV can be beneficial to rural economies, by creating jobs, generating community income, and tax revenues, and by providing diverse income revenues to farmers and landowners. Agri-PV can play a crucial role, especially in rural areas with high draughts and arid landscapes, which desperately need sustainable agriculture and energy production practices. Job creation and improving economic prosperity in rural areas, can in turn, reduce rural-to-urban migration or so-called rural depopulation.[4] In Europe, rural population decreased by an average of 0.1% yearly, while rural areas accounted for 45% of the EU's area in 2021 (source). Agri-PV can boost the socio-economic welfare of rural areas, which is the foundation for a sustainable and prosperous future.

Goal and scope of the report

A dual land-use approach responds to renewable energy production needs, while simultaneously enhancing the value of agricultural production. Specifically, it facilitates climate adaptation measures and increases the agricultural sector's resilience towards climate crises, by providing optimal protection of crops in extreme weather conditions. Other benefits include an increase in land efficiency, an increase in water and other natural resource efficiencies, improved crop yields, soil health, and biodiversity enhancement. In parallel, Agri-PV can boost the local economy, and support rural development. To maximise these benefits, the Sustainable Agricultural Concept (SAC) needs to be followed. To ensure high quality Agri-PV projects, adequate planning, and project design need to be considered at an early stage, as well as throughout the project development and operation phase.

The aim of this report is, therefore, to review the existing Agrisolar Best Practice Guidelines, and provide updates on:

- The Sustainable Agriculture Concept and three-star benchmark system; these updates will include additional criteria included in the SAC;
- Existing Agri-PV projects in the EU; these updates will include data on crop yield, water and soil efficiency, biodiversity enhancement, and socio-economic benefits;
- Updates on innovation in Agri-PV; these updates will include an overview of new pilot projects and demonstrators, updates on new research projects, and innovation trends in the sector;
- Updates on the EPC and O&M best practices.

This document provides guidance for the deployment of sustainable Agri-PV practices for solar industry stakeholders; it also addresses wider stakeholder groups and serves as an informative tool for the Agrisolar sector.

4 The decrease in population size in rural areas due to out-migration (source)

2 Sustainability

Definition

In this report, Agrisolar is used as a general term to refer to a market sector where sustainable agriculture practices are combined with PV installations. Sustainable agricultural practices aim to improve environmental and socio-economic benefits for the farm, and its territory. Decarbonisation of the energy supply in the farm is already a good starting point, where other practices can be adopted to strengthen positive impacts such as agroecology, or local community engagement. The scope of Agrisolar includes, but is not limited to, the deployment of solar panels on barn roofs, or the use of solar electricity to power agricultural machinery.

Some other Agrisolar examples are:

- Integration of solar panels into irrigation systems: Some systems use floating solar panels or panels mounted on structures to generate energy, while supplying water to the crops. This solution enables a more efficient water usage by combining irrigation and solar energy production.
- Agricultural sheds with solar roofs: Agricultural sheds are often used to store equipment, rear livestock, or for crop protection. Thanks to the installation of solar panels on the roof of these structures, solar energy can be generated without losing agricultural land. The solar panels can be mounted on fixed supports or designed to track the sun's movement.

Agri-PV is defined as a land-use concept that co-locates PV installations and energy generation, with agriculture and nature conservation, which are dependent on sunlight.

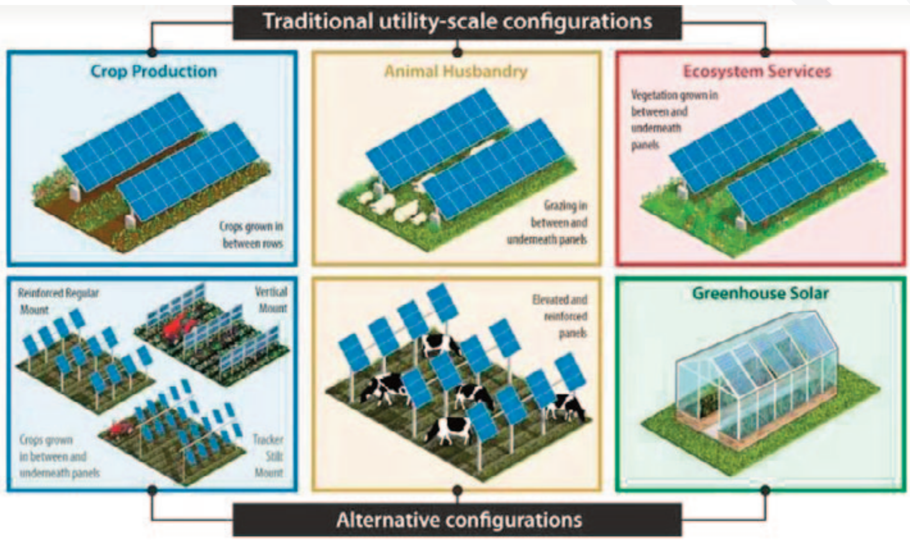
Agri-PV offers a wide-range of applications, adaptable to each production, site, and the local conditions (See Figure 2). Some of the most common applications can be seen in Table 1 on the followig page.

Agri-PV installations should guarantee that the agricultural activity is at least preserved, and at most improved. An approach of PV implementation on farmland in harmony with agriculture and nature conservation, needs to be at the core of Agri-PV development.

TABLE 1 COMMON AGRI-PV APPLICATION EXAMPLES

Combination of crops and solar farm	Another solution consists of cultivating intercropped crops, or offering grazing areas for animals between rows, and in some cases below solar panels. Preferred types of crops are those with leafy vegetables. These solutions allow an optimal land use, and an increase in land productivity.
Elevated solar panel systems, with or without dynamic systems	Solar panels are mounted on elevated structures above crops or animals. It allows crops to grow normally underneath, and to benefit from the partial shading provided by the panels. Solar panels benefit crops and animals, through climate change adaption, protection against adverse weather conditions, agronomic benefits, and/or improved animal welfare.
Solar - greenhouse	Systems that are equipped with solar panels to simultaneously produce agricultural goods, as well as energy. The solar panels provide shading to the crops, and protect against adverse weather conditions.
Aviaries with solar shading structures	Poultry farms often require covered structures to protect birds from adverse weather conditions and predators. In this context, solar shading structures are used as the roof of aviaries, and provide shading to the birds while generating electricity. The shading can be designed in order to allow an optimal natural light penetration to ensure animal welfare.

FIGURE 2 DIFFERENT AGRI-PV APPLICATIONS



SOURCE: Cleantechnica.

Sustainable EU Policies

European Common Agriculture Policy (CAP)

The CAP aims to create a cooperation between the agricultural sector, including European farmers, and the wider EU society. The main goal of the CAP is to support farmers, ensure continuous development of agricultural and rural sectors, while tackling climate change and guaranteeing sustainable management of natural resources. A new CAP reform was formally adopted in December 2021, and entered into force in January 2023. The revised CAP 2023-2027 is being built upon the concepts of greener, fairer, and more sustainable agricultural practices. The new CAP strategy sets out 10 specific objectives (Figure 2). In particular, the CAP focuses on greener and more sustainable agricultural activities, including but not limited to targets set towards eco-schemes, rural development, climate and biodiversity, and higher green ambitions. Eco-schemes will entail allocation of at least 25% of the budget for direct payments in support of climate- and environment-friendly farming practices such as organic farming, agro-ecology, carbon farming, etc.). 40% of the CAP budget will have to be utilised for climate objectives with 10% allocated to support biodiversity objectives (source).

CAP's 10 objectives are the groundwork of the EU CAP Strategic Plans – developed on a national level.

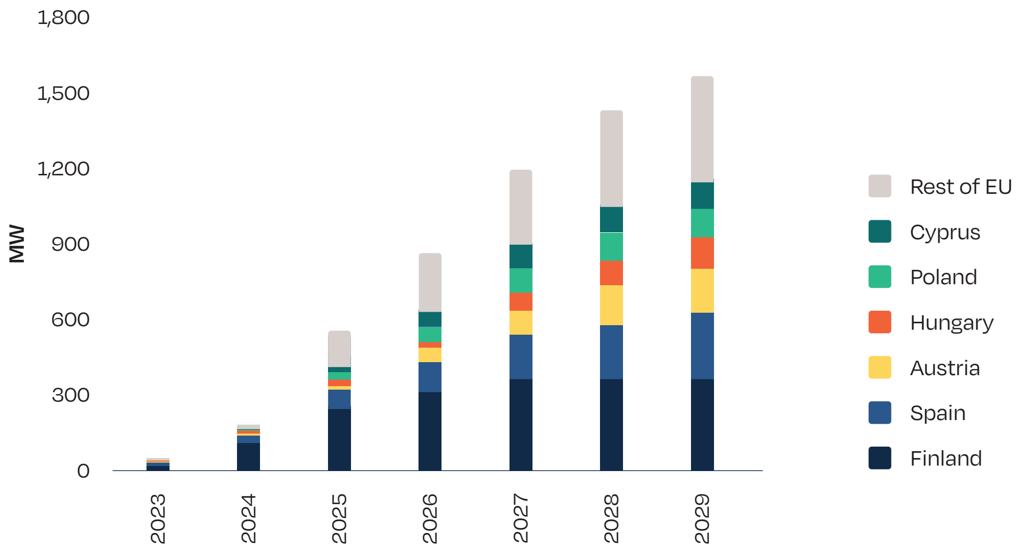
These plans are tailored to each Member State's needs and goals, while targeting EU-wide objectives. The CAP 2023-2027 is interlinked with other EU strategies and particularly, aims to achieve the objectives of both the Farm to Fork and Biodiversity strategies (source). As part of the CAP strategies, contributions towards climate change mitigation and sustainable energy deployment are included. In addition, Member States' National renewable energy targets for 2023 – 2027 are incorporated. An overview of the combined RES capacity targets reported in CAP plans is presented in Figure 3.

Currently, 14 Member States have incorporated solar PV under their CAP Strategic Plans. These countries are Austria, Belgium, Bulgaria, Cyprus, Czech Republic, France, Germany, Ireland, Italy, Luxembourg, Malta, the Netherlands, Spain and Slovenia (source). The Agri-PV term was integrated into four Member State Strategic Plans, in Germany, Italy, the Netherlands, and Slovenia. Both German and Italian CAP plans recognise the difference between PV and Agri-PV installations. The German CAP plan further promotes 'the installation of elevated PV systems that do not compromise the use

FIGURE 3 EU CAP OBJECTIVES

SOURCE: European Commission.

FIGURE 4 COMBINED RES ENERGY CAPACITY TARGETS IN EU CAP STRATEGIC PLANS, 2023-2029



SOURCE: JRC analysis based on (European Commission, 2022b)

of land for agricultural purposes' (source). Likewise, the Dutch CAP plan promotes Agri-PV, and specifically defines the necessity for PV modules to not interfere with agricultural activity. It also sets criteria for PV module distribution per hectare (source). The Slovenian CAP plan promotes Agri-PV without including further details (source).

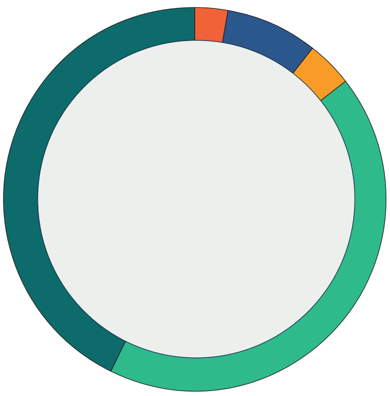
The EU should clarify the Agri-PV definition to ensure that Member States continue to disburse CAP direct payments to farmers who deploy Agri-PV systems on their land. Subsidies stemming from the CAP's second pillar aim to support agricultural activities, while promoting sustainable practices. As outlined in the recent JRC publication, this is precisely the objective of Agri-PV installations which collocate PV systems with sustainable agricultural activities. Therefore, CAP direct payments to the farmers continuing their agricultural activity and who do not receive subsidies through land leasing, should be maintained (source).

A long-term vision for the EU's rural areas – towards stronger, connected, resilient and prosperous rural areas by 2040.

In 2021, the European Commission revealed its plan on how to enhance rural development in Europe by 2040. The objective of the strategy is to assess the challenges and opportunities that rural areas face, as well as to put forward solutions that will enable more resilient, connected, prosperous and stronger rural regions (source).

Rural areas, in comparison to other regions, on average have older populations and will slowly decline in the coming decades. These areas have the lowest share of the population in age groups below 50 years. The unemployment rate among young people is also considerably higher in rural areas, reaching 13.4%. Nevertheless, rural areas in Europe are vital. They represent more than 30% of its population, and over 80% of its territory (see Figure 4). Rural areas are the 'bread and butter' of European society, as they support food production, manage natural resources, protect natural landscapes, and support recreation and tourism (source). The aging population combined with a lack of diverse employment opportunities, poor infrastructure and connectivity, creates not only an unattractive work environment and livelihood in rural areas but also poses a risk for the future of rural areas.

FIGURE 5 EU LAND COVER, 2018



SOURCE: EC-JRC.

Recently, climate change impacts have become more evident. Extreme weather and climate-related events like heatwaves, floods, and droughts affect many regions in Europe. Many parts of Europe reached their highest temperatures on record in the summer of 2022. As estimated by researchers at Graz University, Austria, 'Europe has been in drought since 2018' (source). Such extreme weather events are predicted to become more frequent, and more intense in the coming years (source). Some areas of Europe such as Italy, France and Spain are facing water supply challenges. Other sources claim that the summer of 2023 could be even drier than the previous one (source). Extreme weather impacts will affect not only cities and citizens, but will impact the agricultural sector. Today, countries like Spain and Italy are directly facing the consequences of droughts, something which is threatening their agricultural sectors (source).

The European Environment Agency (EEA) predicts that non-irrigated crops such as sugar beet, corn, and wheat will substantially reduce in southern Europe over the next 30 years. It is estimated that crops will decrease by 50% in 2050. As a result, farm income will also significantly decrease (with regional differences) by 2050 (sources).

Role of Agri-PV in sustainable agricultural development

Agri-PV has a key role to play not only in producing renewable energy, but also by supporting rural areas, and ensuring sustainable agricultural practices. Agri-PV offers several opportunities to minimise the environmental pressure, provide socio-economic benefits to farmers, and fight against climate change. Agri-PV provides solutions to minimise land scarcity issues driven by different competing sectors, and the growing global population. It also offers solutions to limit water scarcity issues; protect and increase crop growth; provide sustainable energy production; and support rural areas against severe weather conditions such as droughts and floods.

Environmental impacts

In a recent study conducted by *M. Wagner et al.*, environmental impacts of single-use agriculture and overhead Agri-PV systems were compared using Lifecycle Assessment (LCA).[5] The results illustrated the positive environmental benefits of Agri-PV systems installed on agricultural land. The results showcase the positive environmental impacts in fifteen out of sixteen impact categories, including land use, climate change, and eutrophication.[6] In addition, the results indicated that, under certain conditions, Agri-PV systems can contribute to renewable energy production without decreasing food production resources (article).

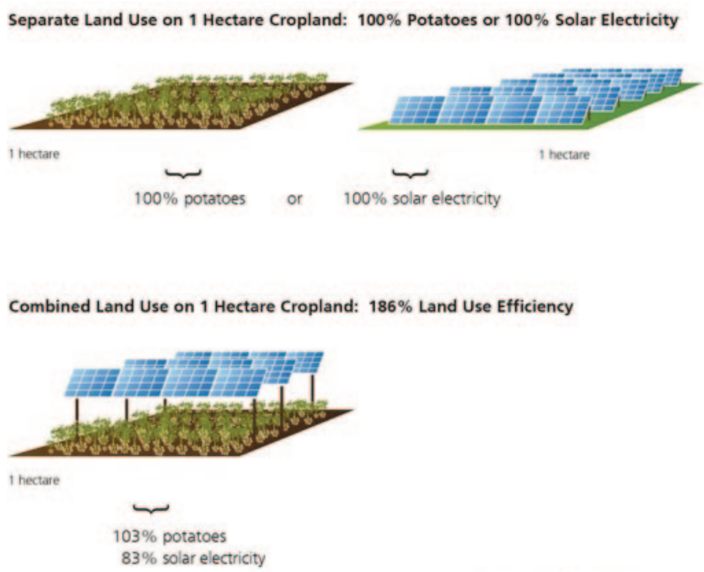
Land productivity

Various reports and studies have showcased the increase in land productivity, resulting from the co-sharing benefits of Agri-PV. According to a study conducted by *A. Sarr et al.*, Agri-PV systems can improve the land productivity by 35-73%, whereas other studies estimated the land productivity to increase by 60-70%. Figure 5 showcases the increase in land efficiency by 186% where PV installations are co-located with potato cultivation (source). Similarly, an increase of more than 30% in the economic value

5 A Life Cycle Assessment (LCA) is a methodology used to quantify potential environmental and energy impacts of a product, service, or a system through its entire life cycle.

6 Eutrophication: *the gradual increase in the concentration of phosphorus, nitrogen, and other plant nutrients in an aging aquatic ecosystem such as a lake* (source).

FIGURE 6 INCREASE IN LAND USE EFFICIENCY IN POTATO CULTIVATION WITH CO-LOCATION OF ENERGY PRODUCTION



of land has been estimated in a study conducted by Dinesh and Pearche (source). This increase in the economic value was achieved by reducing crop yield loss as a result of PV panels providing shading to selected crops (source).

It is estimated that converting 1% of available arable land in Europe to Agri-PV potato cultivation could enable the deployment of an additional 1,290 GWp. The absolute technical potential in MWp is even higher (source).

Water efficiency

Agriculture irrigation or watering accounts for 70% of total global freshwater usage (source). A rise in atmospheric temperature caused by global warming, and an increase in severe weather conditions will put additional stress on drought-prone regions. To adapt to these global challenges, water efficiency and sustainable water management will be essential. There is a high correlation between evapotranspiration,[7] and solar radiation. Therefore, reducing evapotranspiration will minimise the need for irrigation. Agri-PV can help to reduce water usage for irrigation by decreasing evapotranspiration through PV module shading (source). This will reduce crop water demands, and increase water use efficiency (source).

Some Agri-PV systems have proven to reduce energy use by improving a site's water use efficiency for irrigation purposes, for instance, by reducing evapotranspiration thanks to shading from PV panels (source). Moreover, improvements in microclimatic conditions, such as temperature and soil moisture, or water use efficiency for irrigation purposes, can positively impact crop cultivation in arid areas.

Similar studies have been conducted to assess soil moisture, the results showed an increase in soil moisture by 14.7% and 11.1%, in fixed and mobile installations respectively. More efficient water use can be achieved by maintaining higher soil moisture. A study conducted by Adeh et al., indicated that water use efficiency was estimated at 328% - an increase resulting from the use of Agri-PV panels (source). More specific results showcased the water use efficiency estimated at 157% for chili, 65% for tomatoes, and 12% for lettuce. Furthermore, a reduction of approximately 20% in the water demand for lettuce was estimated in another study (source).

7 Evapotranspiration: *loss of water from the soil both by evaporation from the soil surface and by transpiration from the leaves of the plants growing on it* (source).

Biodiversity enhancement

Agri-PV has significant potential to enhance biodiversity on solar sites. For instance, solar sites that establish solar pollinator habitats can benefit local biodiversity, and serve as an important conservation mechanism for endangered species (article). An increase in pollinator habitats can result in higher ecosystem restoration services such as crop pollination, and pest control in the vicinity of agricultural areas, which in turn can enhance crop yield for fruits like strawberries or blueberries (article). In addition, appropriately designed and managed solar sites placed on degraded or low-value agricultural land can restore degraded land and even provide significant biodiversity net gains. These benefits include but are not limited to improved soil health, greater diversity of local flora and fauna, and more generally – support restoration of ecosystems.

INFO BOX 1: CASE EXAMPLE – POLLINATOR ENHANCEMENT; 3BEE

Located in Sicily, Italy, ARCA – Francaviglia project spans across 5.2 hectares with a total capacity of 1 MW. The project is owned by Cubico Sustainable Investments, one of the world's largest privately-owned renewable energy companies. Willing to test potential actions to improve local biodiversity, Cubico engaged 3Bee to design an intervention on-site to restore biodiversity by introducing high-nectar plants within the site.

Two activities were performed: (i) implementation of a regeneration project based on high-nectar plants, and (ii) setting-up a monitoring protocol.

To determine the ideal selection of plants that would maximise nectar availability in the area, 3Bee employed Flora, an AI tool developed in collaboration with the European Space Agency, and leveraging Sentinel-II data. The most suitable set of plants were identified and introduced on approximately 1.6 hectares.

Monitoring protocol was put in place with the 2 following components:

- 4.0 Apiary (HiveTech): 3Bee established an apiary consisting of two hives to monitor honeybee populations and assess their response to the introduction of high-nectar plants. The apiary utilised advanced IoT (Internet of Things) sensors, to collect real-time data on hive health, productivity, and behaviour.
- Wild Pollinator Monitoring (Spectrum): In addition to honeybees, 3Bee deployed IoT sensors across the project site to monitor and track wild pollinator populations. These sensors captured data such as pollinator presence, abundance, and diversity, enabling us to evaluate the overall impact of the introduced plant species on local pollinators.

The preliminary findings indicate a significant improvement of approximately 10% in terms of local pollinator presence compared to the anticipated levels. These positive outcomes hold considerable potential for the surrounding agricultural area, as the increased pollinator activity will contribute to enhanced ecosystem services, such as improved pollination, benefiting local farms and their crop yields.

PV co-location with animal husbandry is another well-known concept, and has shown great results in land productivity and compatibility. Several studies have shown the increase in land efficiency by co-sharing livestock grazing with energy production (article).

Plastic reduction and circularity

Another benefit of Agri-PV systems is the reduction of existing crop protection systems. Different protection systems such as plastic tunnels and shade nets are commonly used to protect high-value permanent crops. Likewise, in warmer climatic regions like the Mediterranean area, protection systems can also be used for fields crops. Agri-PV can work as a protection system, and replace the use of plastic tunnels. The use of such plastic can potentially increase toxicity in the environment. Therefore, a reduction in plastic use thanks to Agri-PV systems can have a positive impact on the environment and circular economy.

Socio-economic

Socio-economic factors are key in supporting rural areas and their development. Agri-PV can play a role in contributing towards generating income, providing employment, and facilitating social support. Some of the socio-economic benefits of Agri-PV are listed below:

- Crop yield / food produce
- Avoiding losses and reducing some of the costs, for example, for irrigation
- Farmer income
- Energy generation as a means of additional revenue
- Renewable energy communities
- Electrification of the agricultural sector
- Job creation and providing new qualifications in the agriculture sector

Firstly, the Agri-PV installations protect crops by mitigating the impacts of adverse weather conditions, and therefore guarantee economic performance in a context of climate hazards.

Studies show that Agri-PV installations provide an opportunity to enhance economic performance, and can increase farmers' income (article). There are three main economic models for farmers to enhance the value of their farms.

Agri-PV business models:

1. Farmers can consume their own electricity production, and sell the surplus by injecting it into the grid (a solution adapted to agricultural areas that consume a lot of electricity).
2. The producer can sell all of their solar energy with a green energy price reviewed every quarter, and guaranteed for 20 years.

Agrisolar business model:

3. The most common solution is to rent a photovoltaic roof or an area (by renovating a roof or building a new co-financed building), in order to receive a monthly rent.

The income from the sale of electricity from the plants allows the owners and farmers to receive a guaranteed annual rent for the entire life of the Agri-PV plant. This allows them to diversify and stabilise their income, and thus contribute to the development of their activity. Agri-PV is not only an affordable and economically profitable technology for farmers to use; Agri-PV is also considered to be a safe investment (source).

In a context where the agricultural world is strongly subject to climatic hazards, it guarantees a farm's financial security. By contributing to the revitalisation of the agricultural world, Agri-PV also plays a social role in revitalising the region.

Agri-PV can also support rural development by creating additional jobs, generating additional revenues through energy production, and ensures overall economic stability. However, certain skills and knowledge are needed to further accelerate the deployment of Agri-PV. These are outlined in Table 2 on the following page.

Furthermore, trends and innovation in the Agri-PV sector have expanded in recent years. As a result of pilot projects and research facilities, Agri-PV can also support various agricultural trends such as agroforestry, permaculture, organic farming, and more (Please see *Section 5 Trends & Innovation*).

TABLE 2 SKILLS AND KNOWLEDGE NEEDED TO FURTHER ACCELERATE THE DEPLOYMENT OF AGRI-PV

Renewable Energy Engineering	Engineering is a key profession in the Agri-PV sector. From the design, to the installation and maintenance of Agri-PV solutions, the understanding of the PV technology, the system sizing, and electrical design or grid integration is essential.
Agricultural knowledge	A solid understanding of agricultural practices is also an essential component of an Agri-PV project. Knowledge on crop cultivation, irrigation, soil management, and livestock farming allow for optimised land use.
Project Management	Project Management: Effective project management skills are necessary to coordinate and oversee Agrisolar installations to ensure timely execution, resource allocation, stakeholder coordination, and adherence to quality standards and regulatory requirements.
Electrical Skills	Electricians or electrical engineers with expertise in solar PV installations are required to handle the electrical components of Agrisolar systems. Their expertise can be used to allow a proper wiring, connections, and commissioning of solar panels, inverters, and electrical systems.
Construction and Installation	Construction workers such as technicians or installers are needed to install the Agri-PV systems.
System Monitoring and Maintenance	Ongoing monitoring and maintenance are essential to ensure the optimal performance and longevity of Agrisolar systems. Technicians or maintenance specialists are responsible for regular inspections, cleaning of panels, troubleshooting, and repairing any technical issues.
Environmental and Land Use Planning	Professionals with expertise in environmental impact assessment and land use planning play a crucial role in evaluating the environmental and social implications of Agri-PV projects. These professionals can ensure sustainability and regulatory requirements are adhered to.
Research and Development	Researchers and scientists are essential when it comes to the development of new technologies beneficial to the Agrisolar sector. Moreover, studies, data analysis and innovative solutions contribute to more productivity, and a better integration of Agri-PV solutions into agricultural lands and operations.
Policy and Regulatory Experts	Professionals of the renewable energy policies, regulations, and incentives can provide guidance to better understand and navigate the policy landscape.

3-star benchmark for Agrisolar projects: System evolution

The above criteria allow us to advance an indicative framework to assess the quality of specific Agrisolar projects. This framework could take the form of a 3-star benchmark that could be used in advance of project development and throughout the project lifetime. However, the attempted proposal developed in these guidelines should not be considered a fully-fledged quality assurance framework or a standard. Instead, the guidelines are meant to inspire the development of robust regulatory frameworks for Agrisolar, as explained in Section 2.6 How to Support 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. The agroenergetic synergies, and its sustainability can be schematically represented, as seen in Figure 3.

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 lean 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. Notably, 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.

TABLE 3 AGRISOLAR CRITERIA

	MUST CRITERIA ★☆☆	**SHOULD CRITERIA** ★★☆	**COULD CRITERIA** ★★★
DIMENSION 1: Agriculture	• Has SAC 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, assessment of the use of equipment/machinery. • Fulfils the needs of agricultural activity and generates green electricity. • Selection of suitable crops: adaptation of crops that tolerate the partial shading caused by the solar panels to maximise agricultural productivity while allowing solar energy production.	• Demonstrate synergies between PV and agriculture. • Evaluation of light distribution and micro-climatic conditions. • Water management performed. • Demonstrate transition towards sustainable practices like reintroduction of trees and animals on the site, introducing regenerative agriculture (applicable guidelines such as FAO[8] guidelines on regenerative agriculture practices).	• Maximise synergies between PV and agriculture. • Demonstrate improvements on the resilience of agricultural activity. • Demonstrate a net saving of water consumption on the farm. • Change the agricultural model to a polyculture model (transition away from monoculture practices). • Favour agroecological practices (avoid chemicals, pesticide use, etc.), to enrich soil and restore biodiversity. • Implement efficient irrigation: install water-saving irrigation systems for agricultural crops to minimise water losses and optimise the use of water resources.

8 Food and Agriculture Organization of the United Nations.

TABLE 3 AGRISOLAR CRITERIA - *continued*

	MUST CRITERIA ★☆☆	SHOULD CRITERIA ★★☆	COULD CRITERIA ★★★
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.	• Set min. standards for soil preservation during construction and dismantling. • Efficient tech, degradability of structures. • Apply a lifecycle approach. • Transition towards sustainable agricultural practices by enhancing local flora and fauna. • Introduce net water savings in water consumption. • Reduce land disturbances. • Reduce soil pollution. • Create ecological corridors: provide habitats for native flora and fauna; e.g. incorporate areas of native vegetation, provide habitats for insect pollinators, birds and other species beneficial to the agricultural ecosystem.	• Provision of ecosystem services. • Apply environmental guidelines such as "BNE guide" to enhance biodiversity on the site. • Provide soil regeneration and carbon capture services; provide monitoring of the data. • Change micro climate conditions to adapt to climate change: as part of a biodiversity enhancement, use assisted migration methods to accelerate species migration processes. • Carry out afforestation or reforestation measures, particularly within or between land parcels to support biodiversity quality. • Increase tree cover on the site. • Increase land productivity. • Accommodate projects that can contribute to climate change adaptation.
DIMENSION 3: Socioeconomics	• Assessment of farm working conditions, including safety considerations.	• Analysis of lifetime financial savings from replacement of short-lived materials. • Impacts on the local supply chain are considered.	• Local action plan that integrates local communities and their views. • Establishment of/integration within the local agriculture and renewable energy community. • Accommodate local and energy-efficient distribution channels.
DIMENSION 4: LCA	• Performance monitoring of the system.	• Data collection on performance (Agricultural, Environmental, Energy, Socioeconomics).	• Provide detailed evaluation of performance of ecosystem and socioeconomic services. • Apply a definition of a set of indicators, methodology, and reporting of KPIs to the project.

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3 Best existing business cases

The sustainable agriculture concept provides a wide range of benefits not only to the environment, but also to the social and economic segment. Building on the existing knowledge, this chapter will focus on showcasing various existing Agrisolar projects across Europe. It will outline existing, operating Agrisolar PV projects, and include information on the design and concept of PV application, as well as providing insights into the development and implementation process. In addition, the chapter will build upon existing Agrisolar case examples that have monitored data on sustainability features. This chapter will include two existing case examples in Germany, and 6 case examples in France, Spain and Greece. It will provide observational data on the socio-economic, agricultural, and environmental benefits of these project sites.

CASE STUDY 1 AGRI-PV TRACKER SYSTEM IN BAVARIA, GERMANY (SCHLETTER)

CROP: GRAIN AND FOLLOWING REGULAR CROP ROTATION FOR STANDARD AGRICULTURAL LAND

One of the first Agri-PV Tracking Systems in Germany with 1,85MWp was developed in 2019 by the company DoppelErnte. Although this system is one of the first of its kind, it not only serves as a proof of concept, but has successfully delivered results for the owner when connected to the grid in 2020. The aim of the project was to keep the farming output as close to 100% by generating the lowest possible LCOE. Today, 90% of the land is still actively farmed, with a slightly lower agricultural yield in wet years, and the same yield as conventional farming in dry years. The symbiosis between PV generation and farming output resulted in an extension of the PV-Plant in 2021, initiated by the farmer, with O&M provided by the developer and local partners. Due to high acceptance from local authorities, and a well proven bankable concept which does not require subsidies, the permitting process was acquired within one year. With the upcoming regulatory changes, it may even be possible to achieve three-month approval periods for selected use cases.

An additional benefit of this PV tracker system is that there is no disruption to standard farming crop rotation processes. Consequently, existing machinery can be used without any modification. The distances between the trackers were designed to optimise yield for both farming and electricity output.

Bifacial module integration results in the best possible LCOE. The optimised row distance enables ideal sun exposure for the crops. For arid weather conditions, the PV-structure prevents soil dehydration. Irrigation will be analysed and optimised with soil moisture sensors and scientific support from Fraunhofer ISE.

© DoppelErnte.

CASE STUDY 2 STRAWBERRY PV GREENHOUSES IN EYRARGUES, BOUCHES DU RHONE, FRANCE (AMARENCO)
CROP: STRAWBERRIES

Connected to the grid in 2018, this project built 9 PV greenhouses to produce strawberries and other seasonal crops on 1.1 hectares of land with a production capacity of 2 MW. To optimise yield and production quality, the strawberry plants are renewed every two years. While Agri-PV strawberries have the same income as field plantings, Agri-PV strawberries can be harvested earlier, and over a longer period than other types of strawberries.

In a farm passed on from father to daughter, the various agricultural activities made it possible to increase the surface area, and balance the average income around 70K€/per ha. The shading of the greenhouses reduces water requirements by 20-30%, due to reduced evaporation and the Mistral wind drying out the soil. The products are sold locally in the region, and in Marseille via existing supply networks.

Focus on observations after 2 more years of activity:

Agricultural benefits:

- **Continuity of farming:** Successful transfer of the farm to a family member in 2023.
- **Breeding:** The outdoor includes laying hens, which deter parasites and pests, bringing a positive impact to organic farming, with less damage to the crops caused by insects.

Environmental benefits:

- **Water efficiency:** The shading of the greenhouses reduces the need for water by 20-30%. The site has a well with enough water available to ensure the agricultural production of vegetables, and the breeding of chickens throughout the year.
- **Climate resilience:** Existing cypress hedges protect the crops from the Mistral wind, and serve as a shade for poultry to cool off in hot periods, as well as a pantry with many larvae, seeds, plants etc. Farm birds also help to clear the hedges, which is essential in case of drought, and for fire prevention.

Socio-economic benefits:

- **Diversification of the activity (poultry and polyculture)**[9]: Strengthening resilience in the case of inflation where strawberry prices decreased in 2022.
- **Employment:** Created 1 full time employee + 2 seasonal workers for the harvest of strawberries in 4 to 5 greenhouses.
- **Market sale:** The products are sold in the region and in Marseille via existing supply networks.
- **Local acceptance:** No local acceptance problems.

9 The practice of growing several different crops or keeping several different types of animal on an area of land (source).

CASE STUDY 3 WINTER VEGETABLES GROWN IN PV GREENHOUSES IN TOULOUGES, PYRÉNÉES-ORIENTALES - FRANCE (AMARENCO) CROP: WINTER VEGETABLES; CELERY, FENNEL, SUCRINE, MINI-CHARD

Grid connected in 2017, the project deployed 21 PV Greenhouses over a surface of 2.1 hectares, with a generation capacity of 2 MW. The project included a year-long process to improve soil quality through the application of compost and the cultivation of a sorghum crop to aerate the soil. The farm is in transition this year, switching the entire site to a winter crop of sucrine, and a spring crop of courgettes. The objective of this transition is to anticipate the fall in organic prices, and to use Agri-PV to cushion the loss of income from arboriculture.[10] This transition also aims to maintain an average income around 50/60K€/per ha. In addition, apricot trees will be planted in all the inter-greenhouses.

The shading of the greenhouses reduces the need for water by 20-30% due to reduced evaporation, and the drying out of the soil by the Tramontane wind.[11] The possibility of recovering rainwater from the roof is being studied. The farm benefits from a trained and professional workforce all year long. The farmer uses their workforce depending on the markets and seasons, with a focus on arboriculture in later spring/summer and autumn, and another focus on horticulture[12] during spring.

The site is certified by Ecocert, and all the crops are organic. The very heavy frosts experienced at the end of winter 2022, did not impact the crops, providing an additional advantage. The farm's produce is sold locally.

Focus on observations after more than 2 years of activity:

Agricultural benefits:

- **Climate resilience:** Crops protected from a heavy frost experienced during winter 2022.
- **Bio-certification:** Organic crops certified Ecocert.

Environmental benefits:

- **Water efficiency:** Water savings about 20-30%.
- **Soil health:** Use of compost and the cultivation of a sorghum crop to aerate the soil.

Socio-economic benefits:

- **Economic stability:** Evolution of cultures to follow the market, and to maintain economic performance.
- **Job creation:** Retention of a skilled task force year-round, thanks to a continuous agricultural activity.
- **Market sale:** Local sale of the entire production.
- **Local acceptance:** No issue with neighbourhood and local opposition.

© Amarenco.

10 The study or practice of growing trees and shrubs (source).
11 A strong, dry, cold wind coming from the north-west (source).
12 The study or activity of growing garden plants (source).

CASE STUDY 4 INTRODUCING AGRICULTURE IN EXISTING SOLAR PLANTS ACROSS EUROPE (ENEL GREEN POWER) CROP: VARIETY OF CROPS

In January 2021, Enel Green Power launched 9 full-scale demonstration Agri-PV projects in three different countries, namely Greece, Spain and Italy. These demos will research the optimal conditions required to cultivate specific crops in existing ground mounted PV plants under various climate zones.

The demonstration tests carried out in Spain and in Greece, under different climate conditions and PV plant layouts (fixed or on trackers standard systems, equipped with mono- or bifacial modules), show very promising results. The species grown in the corridors between two modules' rows, compared with the ones in the control areas - free from modules - have an agricultural yield increase as follows:

- Spain: +40% forage; +20% thyme; +30% aloe; and +60% peppers. Water use reduction 15-20%.
- Greece: +15% oregano; +30% eggplants; +60% peppers. Strawberries: +18% in the yield production is recorded in the corridors; in addition, an increase of +14% is measured underneath the modules, reaching +36% using LED backlighting (full solar spectrum) during the daylight hours; water use reduction is measured at 15-20%.

Enel Green Power has adopted a holistic approach in the development of Agri-PV demonstration tests to foster a biodiversity-friendly agrozootechnical integration. Other sustainable agricultural practices were implemented in the demo sites, for example, the use of biodegradable mulching films. A network of sensors to measure agricultural parameters are installed to assess agriculture 4.0 (the pilot site for crops), as well as water reduction and fertilisation consumption. In addition, an increase was observed in local species that were previously in decline.

Agricultural benefits:

- Increase in crop yield: Increase in crop yield between 15-60% depending on the crop type.
- Soil health: Implementation of sensors to monitor the reduction of fertilisers.

Environmental benefits:

- Water efficiency: Reduced water use by 15-20% in both sites.
- Reduction in plastic use: Use of biodegradable mulching films.
- Biodiversity enhancement: Integration of pollinator habitats, protection of endangered species such as steppe birds and wild butterflies.

Socio-economic benefits:

- Job creation: Local community integration, with dedicated training sections for students, young people, and families.

© Enel Green Power.

INFO BOX 2: NEW DEMO PLAN IN ITALY; ENEL GREEN POWER

Enel Green Power has set up a new Agri-PV open lab in Italy, with vertical PV technology. The demo plant is 30kWp, equipped with bifacial modules, and the selected crops are lentils and saffron. This vertical Agri-PV plant is equipped with a water recovery system that reduces water usage, increasing the sustainability of the Agri-PV system. The results will be collected in 2023.

CASE STUDY 5 BELLEGARD ORCHARD IN OCCITANIA, FRANCE (AKUO)

CROP: APRICOTS

In 2015, Akuo launched the first Agri-PV project in mainland France, located in the Occitania Region (Gard). With an installed capacity of 2 MW generated through photovoltaic shading structures, the "Bellegarde" project combines power generation with the farming of organic apricots and beekeeping. Akuo's agricultural subsidiary, Agriterra, in partnership with the farmer Marc Portier conducted a previous agronomic analysis of the project. As a result, the crops and the technology were adapted to the characteristics of the territory. The shading structures bring several positive benefits for the crops. The crops are simultaneously protected from weather hazards, pests, and excessive sunlight, whereas apricots receive enough light to flourish and grow robustly.

In 2022, regions in France embraced exceptionally cold spells, impacting all agricultural yields. Nevertheless, the orchard in Occitania managed to produce yields, supplying around 8.5 tonnes/ha.

The irrigation water input was reduced by 50% compared to a conventional orchard farm. In addition, nest boxes for tits, bats, and birds of prey, were installed on the site two years ago, and the occupancy rate of the nests shows promising results.

Agricultural benefits:

- **Yield**: In 2022, the orchard farm produced around 8.5 tonnes of apricots/ha.
- **Climate resilience**: Panel shading allows the protection of crops from climate hazards and direct sunlight during heatwaves.

Environmental benefits:

- **Biodiversity enhancement**: Implementation of bird nests on the site.

Socio-economic benefits:

- **Farmer engagement**: Project was developed in partnership with a local farmer.

CASE STUDY 6 EXPERIMENTAL SITE ON GRAPEVINE, IN RIANS, FRANCE (OMBREA)
CROP: VINES

In response to climate change and extreme weather events, Ombrea is developing a climate regulation system in the form of controlled shade structures. The goal is to ensure favourable conditions for the proper development of the vines by adjusting shading. In 2019, Ombrea and SCP (Canal de Provence Company) partnered to combine their vision and expertise, setting up an experimental vineyard site in Rians, which is monitored by the French Institute of Vine and Wine (IFV).

Research of the site has shown positive results:

Climatic results:

- High temperature reduced in summer: 51% reduction in scorching hours (temperature reaching above 35°C) under dynamic shading;
- 66% reduction in temperature in periods with too much sunlight that can damage crops;
- Mitigation of heat waves that can lead to atmospheric water stress: 32% reduction;
- A systematically lower soil temperature under controlled shading.

Plant physiology result:

- A lower water constraint under shade compared to the non-shaded control areas;
- Vegetative growth: greater and longer sustained vegetative growth throughout the season.

Agronomic results:

- Yield and sugar content: need a further assessment to confirm the impact on yield and sugar under the shading system in comparison to regular vineyards.
- No organoleptic differences (smell and taste) observed in wines produced during the 2020 and 2021 vintages.

Dynamic shading treatment – vines.

Control Treatment – vines burnt.

CASE STUDY 7 EXPERIMENTAL SITE ON PEONIA, IN HYERES, FRANCE (OMBREA)

CROP: PEONIES

This experimental site assessed Peonies cv 'Sarah Bernhardt', which were put under a dynamic shadow protection system, compared to full sun exposure (e.g. control sites) in the same field conditions. Dynamic shading piloting was using Ombrea's technology during four full years. Air, soil temperature, photosynthetic active radiation, and humidity were recorded. Irrigation has been monitored and activated according to the needs of the crop. Yield and flower quality were also measured.

Climatic results:

- Soil temperature in winter was lower under the dynamic shading system;
- Soil temperature during warmer periods was systematically lower (up to 6 degrees);
- The period during which the peonies were under heat stress decreased by 34%;
- A decrease in excessive light, and thus potential photoinhibition was observed;
- Better fulfilment of chilling requirements during winter season was measured, from 20-38%.

Agronomic results:

- Measurements on peonies were in line with modification of pedoclimatic conditions.
- In control areas, plants were more exposed to climatic conditions, with a 27% increase of water needed during the summer, while leaf sunburn also increased in control treatment.
- Flower yield was improved under the dynamic shading system by up to 17%. This increase could be explained by better climatic conditions during the vegetative season which could lead to better carbon and nitrogen storage.

Peonies under dynamic shading structure.

Burnt leaves under control sites versus under dynamic shading.

The installation of Agri-PV systems requires unique EPC and O&M considerations, with implications on the design, installation, and operation of both the solar system, and the agricultural process.

Depending on the type of farming and the agricultural operation of each Agri-PV site, Agri-PV systems need to be designed, installed, and operated in a way which allows the free and safe movement of farm machinery, farm workers, and livestock, while ensuring sufficient transmission of light and rainwater. For Agri-PV markets with existing Agri-PV technical guidelines or regulation, such as Germany, compliance and adjustments based on these requirements also need to be considered and implemented.

Traditionally the design, construction, and installation, of PV systems aims to maximise energy production. However, in Agri-PV systems the main target is the optimisation between energy production and agricultural production. To achieve this, the following parameters are of high importance:

EPC of Agri-PV systems

Structure height

The size and the height of Agri-PV systems should be adapted to the agricultural activity that will be carried out on the plot of land. Requirements related to Agri-PV structure height can be found in a few Agri-PV Technical Guidelines, where the definition of height, as well the requirement for minimum height of different Agri-PV systems are included.

There are different existing guidelines that establish certain criteria for Agri-PV structure height. These include:

1. The German 'DIN-SPEC 91434', which set out criteria for Agri-PV installations and their height parameters.
2. The Italian 'Agri-PV Technical Guidelines' document, which sets out a minimum criteria for Agri-PV structure's height.

Installing Agri-PV systems in the appropriate structure height is therefore crucial for allowing agricultural activity. However, the system height could also have an impact on energy production, when bifacial PV panels are installed, as well as on economic feasibility of such projects. The albedo[13], and returning light to the rear side of the panel could be affected by the ground type, coverage, and panel height.

When designing elevated-Agri-PV plants, the clearance profile must comply with occupational health and safety legislation. Critically, attention must be paid to ensure the PV system does not endanger workers or machinery.

Panel Tilt

The importance of tilt and azimuth[14] in Agri-PV installations is emphasised by a recent systematic review of Agri-PV research, which analysed 98 Agri-PV studies. The authors conclude:

13 The amount of the light hitting a surface that it reflects back (source).
14 East to south bearing (source).

"On one hand, the orientation and position of the PV array affect the extent of electricity generation; on the other, they influence plant growth rates through their control of the amount of crop-available irradiation. Therefore, in setting the tilt and azimuth angle in Agri-PV installations, crop-available irradiation should be carefully considered".[15]

The ideal panel tilt will depend on the agricultural activity, the module size, the typical weather conditions, and the windward side profiles of the project site. Dynamic systems which allow changing the panel tilt will add extra flexibility and bring benefits for both agricultural and electricity generation activities. A recent research project in Germany found that with the use of single-axis trackers, the electricity yields of Agri-PV systems increased by 22%-26%.[16]

In terms of agricultural activity, special attention should also be paid to the growth direction of crops.

Developers should ensure sufficient plant protection from weather events, and ensure that Agri-PV systems provide a homogeneous distribution of precipitated water to the crops under the modules. In this regard, draining water from the modules must be appropriately managed.

Row Distance

Row distance plays an important role in the shading and light transmission in Agri-PV systems, as well as the energy production and agricultural operations. As such, the inter-row distance should be adapted to the agricultural activity, and should be assessed on a case-by-case approach. Some national technical guidelines often prescribe an allowed ground coverage ratio, which can impact the row distance decision making. In all cases, the rows should also provide sufficient space for workers and agricultural machinery to safely carry out their duties.

For Agri-PV systems combined with light-sensitive crops, alignment and spacing between the module rows must be designed to optimise light availability and homogeneity, to avoid negatively affecting plant growth.

Ideally, the distance between rows should maximise the synergies between the PV system and the crop, created through shading and light homogenisation.

Water

Water is essential for practically any type of agricultural activity, therefore it is critical that Agri-PV installations do not interfere with the water needs of the agricultural operations. Generally, project developers should ensure an even distribution of precipitated water to the Agri-PV crop must be ensured. This can either be provided naturally, in which case an assessment of the crop water requirements, and of the typical climate conditions of the site should be carried out. In case local climate conditions do not meet the water requirements for the crop, an irrigation system should be deployed.

The positive impacts of Agri-PV systems on crops grown below may also have an impact on the design and installation of an Agri-PV site. Recent research found that Agri-PV can mitigate the effects of drought on plant-based food production, particularly in regions with pronounced droughts and heatwaves, such as Europe.[17] As such, when installing Agri-PV on shade-tolerant crops in dry-hot areas, higher ground coverage ratio can be deployed.

Soil

Draining water from the modules can lead to a drip edge, and associated dispersing of the soil. For all Agri-PV systems, crop-adapted rainwater collection systems, rainwater distributors, or similar devices can be used. Appropriate measures should be taken to restore the original soil structure during construction, and/or during the dismantling of the plant. The foundation of the Agri-PV system must minimise impacts on soil quality. Both when installing and dismantling the systems, there should be no negative consequence to the soil through compaction and land movement. In this regard, it is recommended to deploy the system when the ground is dry, using special tires and machinery, and/or moveable tracks. Agri-PV systems combined with crops should be deployed outside the growing season.

15 (source).
16 (source).
17 (source).

Foundations and Mounting Structures

Local construction standards must be respected, particularly with regards to the impacts of harsh weather conditions. To preserve agricultural land, the foundations of the Agri-PV system must be designed to ensure the system is fully removable.

Construction methods which provide secure foundations via removable fixtures in soil or soft ground should be used. In this regard, it is recommended to use a piling method, and to avoid the use of concrete or cementing whenever possible. Certain regions or soils require the use of solid and specific foundations. Animal husbandry projects should adapt the system foundations according to the types of animals on the project site. For example, cattle breeding will require deeper foundations than usual.

Light Distribution, PV Modules, and Installation Type

There are various techniques to achieve optimal crop growth and animal welfare, while maximising energy production in Agri-PV sites.

Installation Techniques

Different types of installation techniques are used, the most common (elevated, vertical, and between rows) are described in the Figure 6 below.

Choosing the appropriate installation technique should be made based on the type of agricultural operation, geographic location, and technical guidelines (where they exist).

FIGURE 7 DIFFERENT TYPES OF AGRI-PV INSTALLATIONS

Overview of farming technologies adoption and willingness to adopt globally.

SOURCE: Fraunhofer ISE.

PV Module Technology

Different PV module technologies can be used to optimise light transmission in Agri-PV sites. Some innovative technologies have been used for Agri-PV research, such as Concentrator Photovoltaic (CPV) modules, which use direct solar rays and diffuse solar rays separately for efficient use of the land. Direct irradiance is used for electricity production, while diffuse irradiance is used for photosynthesis of the crops. This technology is yet to be mass produced; therefore costs are still high. More commonly used types of PV module technologies in Agri-PV are semi-transparent and bifacial panels.

Semi-transparent

By adapting the transparency of the modules, Agri-PV systems can be adapted to optimise crop growth. Although more transparent panels have a lower energy yield, they guarantee an ideal, moderate amount of shade, and offer maximum protection for the crops. Furthermore, the lower energy yield can be partly compensated by the cooling effect of the plant growth which can impact panels' energy efficiency.

The panel transparency should be adapted to suit each crop, and create the best possible conditions for growth. This can be especially helpful for crops that cannot tolerate direct sunlight. The main limitation of this technology is that it is still premature for large-scale installations due to its lower efficiency.[18]

Bifacial:

The application of bifacial technology in Agri-PV installations offers advantages in different aspects, as it can produce electricity by simultaneously receiving direct sunlight and reflected light from the ground or plants. The efficiency of bifacial Agri-PV can reach up to 24%. As such bifacial panels can tackle the LCOE challenge of Agri-PV, while producing more energy in Agri-PV installations.[19]

O&M of Agri-PV Systems

Overall, existing electrotechnical and static regulations, as well as corresponding test requirements in the field of photovoltaic systems, should be respected in all Agri-PV projects.

Considerations related to O&M of Agri-PV sites involve additional elements and challenges, resulting from the elevation of PV panels, the limited access for O&M workers to the farm, and the requirement to consider the impact which any O&M related activity may have on food production.

General Maintenance of Agri-PV sites

Overall, the necessary maintenance work must be recorded by the installer of the plant in the operating manual and observed by the operator. The verified parameters of recorded data should be kept in a plant-specific operating protocol.

On the agriculture side, of things, crops and pasture should be carefully maintained to avoid fire hazards. During extreme weather events, like ice and icicle formation, as well as extreme wind and snow loads, for safety reasons, work should not be carried out under the plant. Sensible preparation, like rainwater distribution systems, can prevent the formation of icicles.

Fault Detection and Problem Fixing

In cases of reduction in energy production or problems in the PV systems, O&M workers may need to visit the Agri-PV site, enter the farm, and potentially interact with the farming operations. Therefore, clear coordination among farmers and O&M workers needs to be facilitated. Detecting and fixing faults in the Agri-PV sites (elevated or between rows of crops) may require additional measures such as climbing to reach the panels or working in close physical proximity to valuable crops. A PV monitoring system could be used for detecting faults or module mismatches in the PV system, therefore reducing interference with farming operations and preventing unnecessary entrance to the farm by O&M workers.

18 (source).
19 (source).

Health and Safety of Agri-PV Sites

Special care is required when maintaining Agri-PV systems, as people work on the site and as intensive agricultural use can take place, increasing the risk of damage and contamination. Farmers and workers should be well informed and, where possible, properly trained about any specific maintenance needs or risks associated with the PV systems.

Cleaning of Modules

Soiling and dust on the surface of PV modules can cause a significant decrease in PV power output. In Agri-PV sites, where PV panels are located above or adjacent to agricultural land, farming activity, such as the use of machinery, can generate large amounts of dust, leading to losses in energy yields.[20] The first research to analyse the impact of dust and soiling in Agri-PV plants, found an average daily soiling losses of 0.35% per day, and performance ratio decrease to values as low as 40% in summer months without precipitation or cleaning.[21]

As such, Agri-PV systems should be cleaned periodically. Agricultural soil cultivation, and the application of plant protection products can cause contamination. Therefore, a plant-specific, regular cleanliness check is recommended.

Furthermore, to minimise yield loss, the Agri-PV system and modules should be cleaned in case of heavy contamination. If a detergent is used then food, feed, and pharmaceutical legislation must be complied with. In general, cleaning procedures should only be initiated whenever strictly necessary, to avoid unnecessary loads or accidental damage to the PV system.

Cleaning may be more challenging in Agri-PV sites, due to the elevated panels. Trackers which allow an increased tilt angle that flips the panels could reduce this challenge, and make the cleaning of panels easier. The use of a hydrophilic coating on the PV panel surface could be helpful to maintain an optimal electrical output.

Similarly, certain agricultural activities and treatments can lead to chemical alteration of materials. Chemically, the most effective detergent will depend on the type of soil, and therefore on the crops and products applied to them.

Farming practices can generate occasional soiling, requiring rapid clean-up. It also be sometimes impossible to clean up without damaging farming activity. As farming activity is highly dependent on the weather; synchronisation with conventional preventive maintenance and cleaning schedules is unlikely. These operations must be carried out in "fire department" mode, such as curative maintenance, and is therefore less economical. Or the farmer will have to be a co-actor in the maintenance: for example, by rinsing the panels after certain operations.

Pasture Management

For relevant projects, an effective pasture management strategy must be followed which ensures grassland has sufficient time to regenerate. The division of the project site into several sections, in addition to a pasture rotation cycle is advised.

Electric safety

Safety must be considered very carefully when planning and designing any PV installation, and in particular Agri-PV. PV plants, like every electric installation, hold a certain risk potential such as the occurrence of fire and personal danger from electric shock. Safety of Agri-PV plants is in the core interest of the farmer, the developer, the installer, and maintenance teams, as well as insurance companies, policymakers and regulatory bodies. Moreover, incidents of fire and electric shocks could be detrimental to the growth and public acceptance of Agri-PV, especially in the early stages of the market, when dedicated binding standards and regulations are yet to be published or enforced. Therefore, the safety of Agri-PV plants needs to be investigated in detail.

Existing research shows that safety in Agri-PV installations is highly important for policymakers, farmers, and solar industry professionals. As an example, in a research study, risk, safety, and liability were mentioned as the main barriers for the development of Agri-PV in the US.[22] In the German DIN-

20 (source).
21 (source).
22 *'Integrating solar energy with agriculture: Industry perspectives on the market, community, and socio-political dimensions of Agrivoltaics'*, Energy Research & Social Science Magazine – Vol 75, May 2021

SPEC 91434,[23] it is mentioned that, "special care shall be taken when maintaining Agri-PV systems, as people work on the area and (intensive) agricultural use may take place, which increases the risk of damage and soiling ."[24] Safety considerations should be taken into account during the design, construction and operation of Agri-PV sites. The 2 main safety considerations in solar sites are electric shock and arcs. In Agri-PV sites there are several unique features which increase risks of electric shocks and electric arcs.

Key Safety considerations in Solar Systems

a. Electric Shock

Electric voltage is produced by solar panels from the moment they are exposed to sunlight. Since each panel produces around 40 volts (on average), a string of connected panels produces high voltage of about 400 volts to 1500 volts (depending on the type of solar inverter, and the lengths of the strings). This voltage is created by the mere exposure of the solar panels to the sun radiation. Turning off the solar inverter, or disconnecting the device from the grid, does turn off the current passing through the system circuit. However, it does not lower the voltage produced by the exposure of panels to the sun, called DC voltage). High voltage may pose a safety risk to the installer of the system, and people working in adjacent areas. To lower the DC voltage, a function that reduces the voltage on a panel level is needed.

b. Electric arcs (Fires)

An electric arc is created as a result of discontinuation of a conductor or connector. In a solar system consisting of many connection points and cables, an electric arc can be created if the cable is not connected as required, or is damaged. Electric arcs have several prominent features: strong light and very high heat. As such electric arcs are a common cause of ignition and fire in any electrical installation, especially a solar installation. Electric arcs can also 'electrify' the system including the construction, and endanger anyone who encounters it. The older the system, the greater the risk of arcing as a result of the ageing of the wiring, and the loosening of the connections.

Unique characteristics of Agri-PV sites which may increase risk of Arcs and Electric Shock

- Agri-PV sites without fencing: While solar sites are generally fenced to prevent unauthorised entrance, and ensure that only trained solar professionals will enter the site, in Agri-PV sites this is not always the case; fencing may interfere with farming operations. In the few countries where there's a general fencing requirement for solar sites, such as Israel and Japan, this requirement is specifically removed for Agri-PV installation.
- Farmworkers, farm machinery, and livestock in physical proximity to the solar system: By definition, the dual-use of land for solar energy and food production, entails that the land will be used by both solar professionals and farmers. Farmers and farm workers may be less aware of the risks of solar systems. Further, there is a higher risk for damaged wiring and equipment than in normal PV systems. The presence of livestock also increases the risk of damaging the PV system, which then turns into a risk for farm operations, machinery, and workers.

Best practices & solutions to address Safety challenges in AgriPV

Existing Agri-PV Guidelines and Best Practices documents from various Agri-PV markets mainly focus on awareness, electrical safety, and cabling, to address and tackle safety challenges in Agri-PV:

a. Awareness

As a first step, all relevant stakeholders involved in the installation and operation of Agri-PV plants, must be aware of the relevant risks and safety considerations. Awareness can be found in several best practices and technical guidelines documents. Best practices include:

1. Ensure that all personnel are trained and educated, and know how to work and operate in an electrical facility. This will eliminate work accident risks, including farmers.

23 Agri-PV Technical Guidelines for the German Agri-PV market: DIN SPEC 91434 - 2021-05 - Beuth.de
24 (source).

2. Implement signs that signal and notify the power generation facility, and prevent any accidents caused by a third party:
    - Add safety signs such as electric shock warnings to electrical equipment such as power conditioners and connection boxes;
    - Add a safety sign that indicates buried cables.
3. Create awareness among farmers of the potential risks.
4. Ensure that EPC business operators are responsible for risk communication with farmers.

a. Module Level Power Electronics (MLPE) – Reducing System DC Voltage and mitigating arc risks

As previously stated, to be able to reduce the solar system voltage generated by the panels' exposure to sunlight, there is a need to reduce the voltage generated on the panel level (the DC voltage). This can be done by Module Level Power Electronics technology. MLPE devices are attached to one or more PV modules in a PV String. MLPE devices may include capabilities such as Connector Fault Sensing, and ability of lowering output voltage to a very low (and safe) voltage level.

Since DC voltage is generated whenever the panel/panel array is exposed to the sun, MLPE solution tackles the risks of arcs and electric shock by actively reducing the voltage generated by the panels and collectively reduces the voltage on the array to a safe level when needed, or triggered to. In addition, some advanced MLPE solutions are able to detect the potential for arc in advance and mitigate the risk with pre-emptive action. Given the above, it is recommended to apply Module Level Power Electronics in Agri-PV systems to reduce risk of electric shocks and fires. For more detailed guidelines, please see: 'Japanese Guidelines for the Construction and Installation of Agri-PV Systems' Link).

b. Protecting Cables from Damage and Exposure

Cables need to be protected, and not exposed to damage by livestock, farm workers, or farm machinery. This should be done by either burying the cables or installing them at an appropriate height. Below are a few examples of cabling related requirements, and guidelines found in Agri-PV Guidelines documents:

Good practice includes:

- Cables and cable tranches **should be installed at a safe depth**, to avoid any damage caused by ploughs and other agricultural machinery.
- **Minimising the number of cables in the ground** by directing them under module roofs, alongside the mounting structure. This approach also protects the cabling from direct rain or sun exposure, and increases the lifespan of the system.
- Additional elements include the installation of ram protections to cover cable trenches around the system structure posts.
- **If animal husbandry is being considered**, the height of cables and connectors should be properly defined to avoid animals damaging the systems and hurting themselves, either by touching or biting. For the same reason shelters are advised to use electric components such as string inverters or junction boxes. (SPE Agri-PV Guidelines Version 1.0).
- Many sites bury cabling, but on sites with above ground cabling, **sufficient marking and safety measures must be implemented** to ensure animal and human safety. **The depth of buried cabling should be deep enough to not disrupt agricultural activities**, such as tilling. **Cables should be buried to a minimum depth according to DIN VDE 0100-520 (VDE 0100-520)**, so that they are safe from the plough, and other agricultural machinery (German DIN-SPEC).
- **The cable wiring height** should be 2 metres or more, to avoid any contact by humans. It is desirable to take the same measures when installing a power generation system in an exposed location. Buried wiring, such as cables and ground wires, can be accidentally cut by farmers as they dig up the soil. Therefore, it is necessary to select a burial site that does not interfere with agricultural work (German DIN-SPEC).

c. Arc Fault Detectors

Arc-fault detectors reduce the risks of arcs, and resulting fire risks. It is recommended to use such technologies in Agri-PV installations.

5 Trends & Innovation

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As Agri-PV is at the crossroads of solar PV and agriculture, they have many challenges to address to ensure and accelerate their adoption and development. To address those challenges, science, research, and innovation are, and will remain, strong contributors to the Agri-PV sector for years to come. Researchers and innovators are key to improving the understanding of interactions between energy and agriculture systems, documenting and quantifying impacts and benefits to build more accurate business models, improving and scaling technology (hardware or software) and, developing test sites to show the realities of Agri-PV, and de-risk its adoption.

This chapter will reflect on ongoing research and innovation trends that promote Agri-PV. It will also highlight case studies that entail various innovative aspects such as technology installations, new agricultural applications, and other elements. It will be divided into sub-chapters and will include the following elements:

- Provide an overview of the public support granted by the EU institutions on the field;
- Give an overview, through examples, of the latest development trends in technology options, agriculture use cases;
- Showcase the dynamism, through examples, of the startup ecosystem active in Agrisolar, and the links with the Agritech sector.

In Europe, there are various public and private fundings aimed at supporting research and innovation across sectors. Some of the examples include public fundings such as Horizon Europe,[25] Recovery and Resilience Facility,[26] etc. Public funded research and innovation is key, and should be put forward to ensure advancements in Agri-PV. As part of Horizon Europe (HE), several Agri-PV-related research projects have been granted funding. The purpose of these public research fundings is to promote scientific excellence, and facilitate knowledge-sharing and developments in technology.

HE funded projects for Agri-PV

Currently, there are three HE funded projects that focus on research in Agri-PV:

- Symbiosyst
- REGACE
- PV4plants

This section will provide a brief description of these three HE projects, including the project context and objectives, results and learnings so far.

25 'A key funding programme for research and innovation, tackling climate change, helping to achieve UN Sustainable Development Goals and boost EU's competitiveness and growth.' (source).

26 'The Facility is a temporary recovery instrument. It allows the Commission to raise funds to help Member States implement reforms and investments that are in line with the EU's priorities, and that address the challenges identified in country-specific recommendations under the European Semester framework of economic and social policy coordination.' (source).

SYMBIOSYST

SYMBIOSYST project, kicked-off in early 2023, will introduce innovation by adapting standardised cost-effective solutions in terms of PV modules, mounting structures and O&M practices to the specific needs of various crops in different climates and landscapes. With this, the project aims to find solutions for cost-efficiency, while enabling aesthetically pleasing solutions that can be mass-manufactured and integrated within the landscape, and maintaining the primary goal of farming. The SYMBIOSYST project will fully exploit the synergy between land and crop, as well as open or closed Agri-PV systems. To this extent, the project will use Agri-PV to develop:

(i) The orchard of the future
(ii) A symbiotic integration of solar PV in open-field horticulture
(ii) Nearly zero energy greenhouses

The project's ambition is to create a fully integrated solution, from the design to the implementation phase, a symbiosis where PV and agriculture can have a mutually beneficial relationship, with positive ecological impacts on the landscape.

REGACE

The EU-funded REGACE Project develops and validates a disruptive radical innovative technology that will make Agri-PV a major contributor to the EU clean energy portfolio.

The REGACE solution will be highly competitive compared to other solutions, as it will fully address the desired destination impact of clean, affordable energy. The system demonstrated in this project will also be cost effective in areas with less sunshine. The core technology is a responsive tracking system mounted in the greenhouse driven by a PLC controller that changes the angle of the tracking system according to the plant's needs.

In addition to the economic impact, this will also lead to a significant positive effect on ecological-environmental sustainability, and reduced ecological footprint through its life-span maintenance and operation.

REGACE
Using Co2 for Green Energy

PV4PLANTS

PV4Plants boosts the energy-agricultural synergy of Agri-PV technologies to enhance growth conditions, and increase land use efficiency, crop yield, and renewable energy generation. This is achieved by optimising the light transmission of PV panels through cutting edge nanoparticles spraying on the PV glass surface. PV4Plants system is specifically designed to meet healthy harvesting, and to be adaptable to different climatic conditions and crop varieties that will be demonstrated in three highly replicable demonstration sites in Turkey, Spain, and Denmark.

Recyclability and reutilisation of components and materials both for the manufacturing and end-of-life of the PV4Plants system, are a central aspect of the project. The PV4Plants system will be certificated through the Environmental Product Declaration (EPD), compliance with ISO 14021, and the Sustainability Excellence Label by UNEF.

PV4Plants will boost its market penetration and uptake through:

- Innovative farmer engagement strategies to enhance their acceptance and trust of innovative Agri-PV systems;
- New financing schemes and business models to improve investment performance;
- The creation of a new mechanism designed to accelerate the uptake of Agri-PV systems in Europe, through a set of policy recommendations that will be developed together with public authorities.

Review of new pilot projects and demonstrators

Agri-PV is exponentially growing and maturing on a global scale. It is an innovative solution for both agriculture practices, and solar PV development. This chapter reviews its latest trends (see Table 1), providing an overview of the different use cases tested, replicated, and scaled to this day.

Grazing activities have shown the stronger adoption of Agri-PV, with crops and other related vegetal agriculture tested and replicated accordingly. However, their adoption and development at scale is still a work in progress. Technical feasibility is generally demonstrated and validated,and the scale-up now relies on the innovation needs of the market adoption such as cost competitiveness, adapted regulation, or customer buy-in.

See overview of innovative pilot projects and demonstrators in the following case studies.

TABLE 3 OVERVIEW OF DIFFERENT USE CASES TESTED, REPLICATED AND SCALED UP.

Maturity	Forestry and agroforestry		Grazing		Crops				Aquaculture
	Forestry	Agroforestry	Pasture intensification	Rotational grazing	Annual crops		Perennial crops		Open pond
					Cereals/ grain	Fresh market gardening	Orchards	Vineyards	
First of kind cases	X	X	X	X	X	X	X	X	X
Replicated cases			X	X	X	X	X	X	
Scaled			X	X					

CASE STUDY 8 DYNAMIC AGRI-PV SOLUTION INSOLAGRIN IN CONTHEY, SWITZERLAND (INSOLIGHT)
CROP: STRAWBERRIES AND RASPBERRIES

Swiss company Insolight has developed the dynamic Agri-PV solution Insolagrin: an adjustable transmission of sunlight and a static protection of the crops. Over the past 2 years, Insolight has teamed with Agroscope, Romande Energie, and CSEM to develop a pilot site in Conthey (Switzerland).

The demonstrator of the industrialised and commercially available Insolagrin solution was installed in 2022, using qualified components. Insolight's dynamic Agri-PV solution is based on three main elements:

1. Static semi-transparent panels provide physical protection to the crops while letting through the light.
2. A pilotable optical layer, made of a reflective agricultural screen that can be deployed to protect crops against heat waves, sunburns and night frost.
3. A light management software that controls the screen deployment based on crop-specific parameters, and on micro-climatic censoring.

Insolagrin is designed to give the right amount of sunlight to the crops, to convert excess light into electricity, and to provide an improved resilience against global warming and extreme climatic events. When the screen is deployed, it reflects light towards the bi-facial cells to boost power production by up to 30%: an increase of specific yield compared to a static system with the same transparency.

Agronomic trials are ongoing in Conthey with raspberry and strawberry crops to validate the solution, including piloting algorithm and parameters. First results collected over the 2021 and 2022 indicate:

1. Raspberry long-canes cultivated with Insolagrin had the same fruit yield and quality as those cultivated inside a multi-span plastic greenhouse.
2. Insolagrin enables a reduction of leaf temperature by up to 8°C on hot days, and an increase of ground temperature by up to 7°C on cold nights.

CASE STUDY 9 AGRI-PV OVERHEAD PILOT PROJECTS IN THE NETHERLANDS, GERMANY, AND AUSTRIA

In 2022, BayWa r.e. introduced four Agri-PV overhead model pilot projects across Europe, with one in Baden-Württemberg in the southwest of Germany, one in the state of Styria in Austria, and two in the centre of the Netherlands. By the end of 2022, this brings the total number of Agri-PV projects from BayWa r.e. in the European Union to 15.

In Germany, in the city of Oedheim, a 115 kWp "checkerboard" overhead model was applied on a raspberry test pilot. Thanks to interspacing clear panels with PV panels that, when combined, allow 70% light transmittance, the system design becomes "rainproof". In collaboration with the State Education Institute for Viticulture and Pomology Weinsberg (LVWO), the effects of this system design on the agriculture underneath will be monitored.

In Austria, near the city of Graz, in cooperation with their subsidiary ECOWind and the Haidegg research facility, BayWa r.e. completed a 340 kWp stone and pome fruit test pilot.

In the Netherlands, in cooperation with their subsidiary GroenLeven and with financial help from the Dutch government, BayWa r.e. built two Agri-PV test pilots in the communities of Enspijk and Randwijk. The Enspijk project, a 105 kWp cherry test pilot, was developed in tandem with Fruit Tech Campus, a local organisation bringing together business, education, and the government to innovate in agrotechnology. Randwijk, a 125 kWp pear pilot, was built in a similar collaboration with Wageningen University & Research.

In 2023, new pilots are in store which test the effects of "Rangevoltaic" Agri-PV systems, where sheep and cows can graze alongside with Agri-PV systems. Initial findings show that the capacity to reduce heat stress is promising, as well as findings that show direct ecological benefits from the introduced livestock.

CASE STUDY 10 EXPERIMENTAL AGROFORESTRY & AGRI-PV PILOT PROJECT IN CZECH REPUBLIC

CROP: FAST GROWING TREES, OTHER CROPS

Agroforestry Agri-PV experimental system is located on the grounds of VÚKOZ (Silva Tarouca Research Institute for Landscape and Ornamental Horticulture) in Průhonice near Prague, Czech Republic. It is an experimental workplace, where the effectiveness of the use of PV systems in agroforestry, and the mutual interaction between PV technology and the cultivation of crops and trees are investigated.

The system consists of a total of 24 modules divided into three chains of 8 modules each. The total installed power of the system is 6.72 kWp. The modules are installed on rotating structures (half upright, vertical; half inclined) in rows of trees. Vertical and tilt PV systems consist of three different technologies: PERC, bifacial PERC, and CIGS, all installed at SolarEdge Technology.

The research will focus on assessing land humidity and temperature around the PV system, in comparison to the site without PV modules.

CASE STUDY 11 100 KWP TREE GREENHOUSE - REPRODUCTION OF A CANOPY WITH SEMI-TRANSPARENT MODULES AND GRADUAL SHADING, IN AILLAS, GIRONDE, SOUTHWEST OF FRANCE (AMARENCO)
CROP: TROPICAL TREES

Amarenco is designing, over a surface of 1000m², an Agri-PV tree greenhouse of 100 kWp in Aquitaine, planned to be operational in 2024.

This Agri-PV project was initiated by the site operator according to their own agricultural project and plans, which included an unheated greenhouse covered with opaque and semi-transparent photovoltaic modules.

In this innovative project, the photovoltaic covering allows for:

1. A bioclimatic concept with sunshine and shadow all year long, and enabling an agroforestry concept with stratification of crops, depending on their needs for light or shade.
2. A "canopy like" structure providing shadow and replicating glade conditions. The greenhouse has been dimensioned – 5 metres high - with a long-term vision to be able to host taller trees such as avocado and papaya trees. It is also designed to ensure and maintain optimal climatic and pedoclimatic conditions, which are crucial for the success of those cultures. Several factors were taken into account such as polycarbonate fronts, vegetation density and stratification, hygrometry management, and water storage.

The greenhouse will be managed in partnership with research entities, and equipped with measurement tools. Expectation in terms of microclimate benefits is to reach up to 5.5°C temperature increase with respect to control sites.

Working with tree coverage, this innovative Agri-PV project is expected to contribute to soil health and structuration due to their fine roots that increase soil biological activity, soil fauna, and water storage.

© Amarenco.

CASE STUDY 12 LOVENJOEL / TRANSFARM EXPERIMENTAL AGRI-PV SITE (KU LEUVEN)
CROP: WHEAT AND OTHER FIELD VEGETABLES

© KU leuven.

The Lovenjoel KU Leuven pilot site is located on the premises of TRANSfarm. TRANSfarm is a University of Leuven research facility that aims to facilitate scientific research on a pilot scale in the broad domain of the sustainable circular bioeconomy and translational biomedical research. This research is supported by the European Union's Horizon 2020 research and innovation programme HyPErFarm.

The structure is made up of a straightforward elevated design, reaching a height of 5m spanning 13m per section. To limit the size of the steel structure, panels are placed in a pitched roof shape of 12°. In this setup, ground coverage ratio can be adjusted annually or seasonally to fine-tune shading to the relevant crops at that time (450-1500 kWp/ha), independent of the machines. Particularly in a crop rotation where different crops are grown each year, an annual adjustment of the ground cover ratio is desirable.

In this experimental field, we are comparing various crops with the standard growing conditions in conventional agricultural settings to determine the synergies achieved. Centrally, a rotation with wheat, is combined with other field vegetables. The project focuses on the crops' manageability and benefits for PV performance. For this, extensive monitoring of environmental parameters and module conditions is put in place. Results are expected in Q3 of 2023.

CASE STUDY 13 : HyPErFarm AGRI-PV DEMONSTRATION FACILITY IN STRAßKIRCHEN, BAVARIA (FRAUNHOFER ISE) CROP: POTATOS, WHEAT, BARLEY AND CABBAGE

© Krinner Carport GmbH

At this innovative Agri-PV research facility located in Bavaria, a multidisciplinary team of researchers examines not only the viability of Agri-PV systems on arable land, but also closely monitors the microclimate alterations and impacts on crops with a network of sensors. Other elements being assessed include: the application of residues-based biochar to substitute fertiliser and on-site battery storage to maximise self-consumption of the generated electricity. During the four-year project period from 2020 to 2024, the impact of the Agri-PV system will be evaluated, particularly in relation to crop growth and health of typical crops for that region, namely potatoes, wheat, barley, and cabbage. The 302 kWp Agri-PV facility was installed by Krinner Carport GmbH in Straßkirchen, Bavaria, in 2022. Krinner Carport GmbH demonstrated with their innovative earth screw substructure, and a mounting structure supported by cables, that new Agri-PV systems can be built with substantial reductions in material consumption. Moreover, during the construction process, there was a focus on minimising the impact on soil. The HyPErFarm project receives funding from the European Union's Horizon 2020 research and innovation programme.

CASE STUDY 14 DYNAMIC AGRI-PV ON FRUIT FARMING IN AUVERGNE-RHÔNE-ALPES, FRANCE (SUN'AGRI & SEFRA)

Sun'Agri, as a service provider, supports farmers in the development of their project to protect their crops from climate change. Once the farmer has defined production targets, and identified what protection they want, Sun'Agri develops, builds, and pilots the Agri-PV project for a third-party investor who will be the electricity producer.

Sun'Agri's dynamic Agri-PV technology consists of:

- A network of sensors to collect weather data (temperature, humidity, solar distribution, wind) and agroclimatic data (evapotranspiration, leaf wetness, leaf temperature)
- Artificial intelligence to pilot the microclimate (simulation of agronomic and climate conditions, and weather forecast)
- A physical structure composed of bifacial photovoltaic panels rotated by trackers, and protective nets to shield the plant from hail

Sun'Agri and the SEFRA, an experimental fruit farm in the French region of Auvergne-Rhône-Alpes, partnered to conduct experiments using this dynamic Agri-PV technology on fruit farming, heavily impacted by climate change. The Etoile-sur-Rhône project emerged with the need to protect crops from climate change and weather hazards, optimise production and production quality, and establish techno-economic references in fruit farming. Two sites were built as part of the Etoile-sur-Rhône project:

- An experimental site of 100 kW was built in 2021 on existing peach trees;
- And a demonstrator of 1.9 MW was built in 2022 with trees (apricot, nectarine, cherry) planted after the construction of the Agri-PV structure.

The SEFRA monitors the agronomic performances in terms of quality and quantity (fruiting rate, yields), tree growth, phenological stages of the different varieties, development of diseases, pests and auxiliaries, and water and fertiliser consumption.

The first results have shown that the Agri-PV structure significantly reduced the impact of a frost episode on peach trees, with only 9% loss of flowers under the shutters against 35% in the control area.

© Sun'agri & Sefra.

CASE STUDY 15 VERTICAL BIFACIAL AGRI-PV SOLUTION IN AUVERGNE REGION, FRANCE (ENGIE)
CROP: VARIOUS CROPS, OR ANIMAL HUSBANDRY

Camelia is a flexible vertical bifacial Agri-PV solution deployed by Engie, compatible with various farming activities, from cows to cereal and cabbage crops. A mounting system conceived and engineered by Engie R&I (CRIGEN & Laborelec), and Engie Green France and external partners in 2021, Camelia's first 90 kWp pilot project is situated on a 1-hectare plot of grassland belonging to France's leading state research institute in agronomy, INRAe.[27] Construction was completed in May 2023.

This project consists of 9 north-south rows of vertically mounted bifacial PV modules. Each row is approximately 3m high, and is composed of two lines of modules in landscape orientation. Inter-row distances of 12 and 18m were selected, with INRAe to adapt to the agricultural practices and allow the operation of existing farming machinery. Research is carried out on:

- New microclimates caused by the partial wind-shielding, and shading on the prairie ecosystem (e.g. humidity and vegetation growth);
- Biodiversity;
- Behaviour and well-being of the cows.

These investigations will continue over at least the next 3 years, during which, a variety of grazing strategies will be tested. Laborelec has installed an advanced monitoring system to obtain a granular perspective of the electrical generation, albedos, and the novel daily and seasonal power profiles.

The electricity generated on this Camelia pilot project will be used by the local milk and cheese producer.

27 Institut National de la Recherche Agronomique et Environnementale.

CASE STUDY 16 SYMBIZON PROJECT: ECOLOGICAL STRIP FARMING COMBINED WITH BI-FACIAL PV MODULES: ALMERE, THE NETHERLANDS (VATTENFALL)

Symbizon is the first project where single-axis trackers are combined with ecological strip farming. The project is newly developed, commissioned in the first quarter of 2023 with, a size of 0.7 MWp. The pilot project's main aim is to assess the crop growth and bifacial modules' yield.

Within the project, developers check the exact benefit of bifacial panels (testing rows with and without bifacial modules). Furthermore, the project is trying to optimise the tracking algorithm, to optimise the symbiosis between agriculture and electricity production. For this project, Vattenfall works in cooperation with Research Institute TNO, AERES University, ERF/HEMUS (strip farming expert), and RVB (governmental landowner). The project also focuses on crop growth. Below the pilot project, there will be a reference field without modules, to check exactly how shade influences crop growth. An assessment of two different row widths - 9 and 15m pole to pole - will be investigated.

A wide variety of crops will be sowed. As with strip farming every 6m holds a different type of crop, to increase the biodiversity. During the project, different crop growth and yields will be assessed to find a crop cycle that grows well, has a good business case for the farmer, and has enough demand in the market to allow for a large-scale roll-out.

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CASE STUDY 17 WINESOLAR AND THE CONVIVE PROGRAMME, TOLEDO, SPAIN (IBERDROLA)
CROP: VINES

In Spain, Iberdrola is developing several initiatives related to Agri-PV, with two flagship projects in this field: Winesolar and the Convive Programme. Iberdrola launched – through its PERSEO International Startup Programme – a challenge to find solutions to combine PV plants with agricultural and livestock uses. A consortium formed by Viñedos del Rio Tajo (Grupo Emperador), ESGEO, and PV Hardware won this challenge with their project Winesolar. A 41 kWp pilot project has been built in a high-performance winery owned by Viñedos del Rio Tajo in Toledo (Spain). In this area vineyards are already suffering the effects of climate change.

Vineyards are intensively monitored; the censors record data relating to:

- Solar radiation
- Soil humidity
- Wind conditions
- The thickness of the vine trunk, among others.

The project's aim is to protect vineyards by generating shade thanks to an intelligent tracker. Three trackers have been installed throughout every four rows of vineyards. An artificial intelligence algorithm is being developed to control these trackers to adapt them to the physiological needs of the vineyards, as well as to optimise photovoltaic production.

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INFO BOX 3: CONVIVE PROGRAMME, IBERDROLA

The Convive Programme was created with the aim of being a continuous improvement programme, that integrates all the initiatives and alliances for the coexistence between renewables, and their contribution to socio-economic development, and biodiversity conservation.

This programme integrates specific actions for each project and its location, as well as global actions. There are three main areas of action:

1. **Socio-economic development:** Initiatives that enable the projects' contribution to economic and social development at the local and national level;
2. **Protecting and enhancing biodiversity:** Actions that contribute to the integration of facilities into the territory and landscape, by improving their contribution to biodiversity;
3. **Learning from the experts:** Improving the impact of renewables, and the social acceptance of the energy transition through third party partnerships.

Some examples include:

- Integration activities in projects: grazing, horticulture, beekeeping, etc.;
- Commitment to local employment, relying on local suppliers at different stages of the projects;
- Installation of energy communities, and support to municipalities for the definition and implementation of development plans;
- Research and innovation into new technologies (e.g. Agri- PV).

INFO BOX 4: ECOVOLTAIC CASE STUDY, SOLTEC

Soltec has a strong commitment to sustainability, and thus is integrating a new standard called Ecovoltaics. Under this approach, Soltec creates PV plants with the minimum environmental impact, and the greatest social benefit. A concept based on the fulfilment of 50 actions for biodiversity enhancement, socio-economic excellence, circular economy and carbon off-setting, in order for solar PV plants to meet the 17 UN Sustainable Development Goals. The company is currently constructing the first 100% Ecovoltaic PV pilot plant in the South-East of Spain. This project will implement Agri-PV activities as one of the core foundations of Ecovoltaics.

Support systems and tracking system innovation

CASE STUDY 18 INNOVATIVE AGRI-PV TRACKING SYSTEM: SHARING THE SUN (SOLTEC)

In parallel, Soltec launched a portfolio of tools and functionalities in Soltec's PV trackers products' catalogue to optimise crops, livestock, and energy generation activities. Soltec developed an algorithm for PV trackers called **Sharing the Sun** prevents the crops to cast shade into the panels, while keeping an acceptable energy yield. This algorithm is accompanied by a set of **special modes** for the operator in cases where the agro-machinery is working on the field, or when harvesting activities are necessary in between the rows of solar panels.

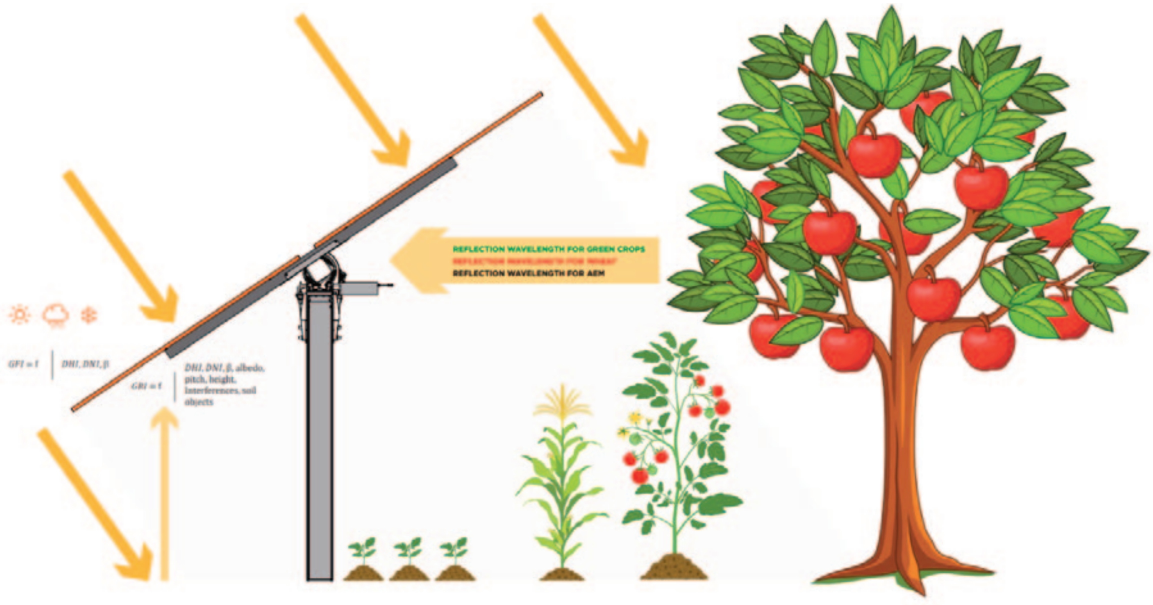
Tracking innovations covers:

- Irrigation systems;
- Livestock monitoring;
- Data acquisition modules;
- Improved algorithms.

These system innovations are planned to be tested in a number of projects in Spain and France during 2023 and 2024.

Innovation in albedo-enhancing materials

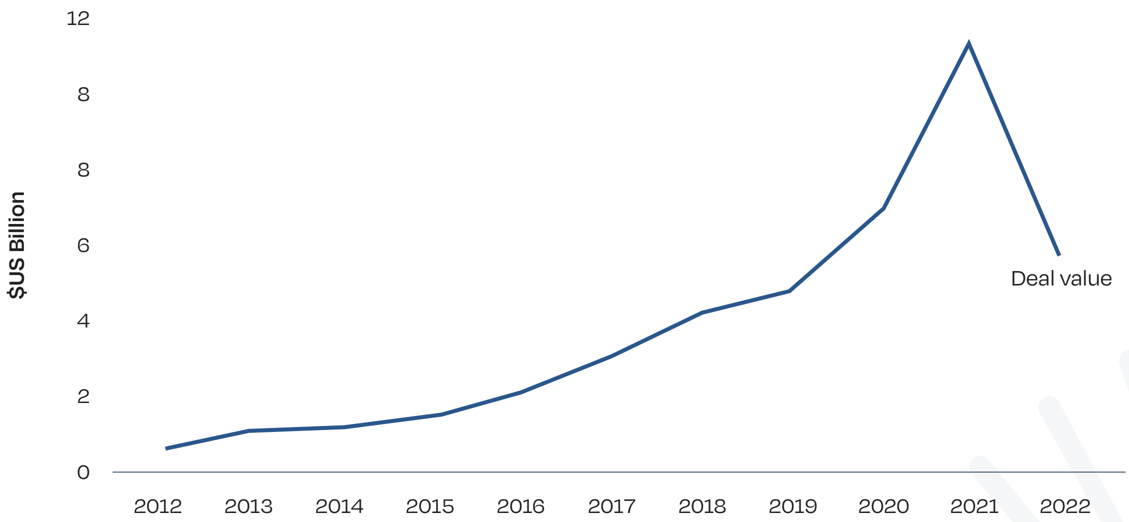
Additionally, in vineyards in the Jumilla wine region, located in the South-East of Spain, Soltec installed a pilot project that uses **albedo-enhancing materials** in a bifacial PV plant. After several months, data collected shows an increase of irradiance on the rear-side of the PV panels, that allow for obtaining a boost of 2.6% in energy yield. Soltec also tested a **bifacial panel's optimisation algorithm**, that allowed for obtaining a gain of 0.3% in energy yield. This algorithm utilises the optimal solar tracker position in a bifacial PV plant, considering the total amount of front and rear radiation. With these positive results, it is possible to extrapolate this experience into Agri-PV, considering that growing crops in the same field of a bifacial PV system has a negligible impact on the energy yield.



Agritech innovation

Beyond the natural moves by solar developers into Agri-PV activities as detailed previously, the innovation trends are also framed by new applications and use cases coming from, or enabled by the startup ecosystem. Likewise, a trend in Agritech solutions has also been growing in Europe and beyond. The extended activity in Agritech has been booming over the past years as shown by the venture capital activity in the field (See Figure 7). The development of Agritech shows how innovative solutions are being brought to the agricultural sector. This shows a trend in agriculture to become more technical and more innovative, with technologies adopted at a faster pace, which can also be seen in other sectors.

FIGURE 8 OVERVIEW OF INVESTMENTS IN AGRITECH BETWEEN PERIODS 2012 AND 2022

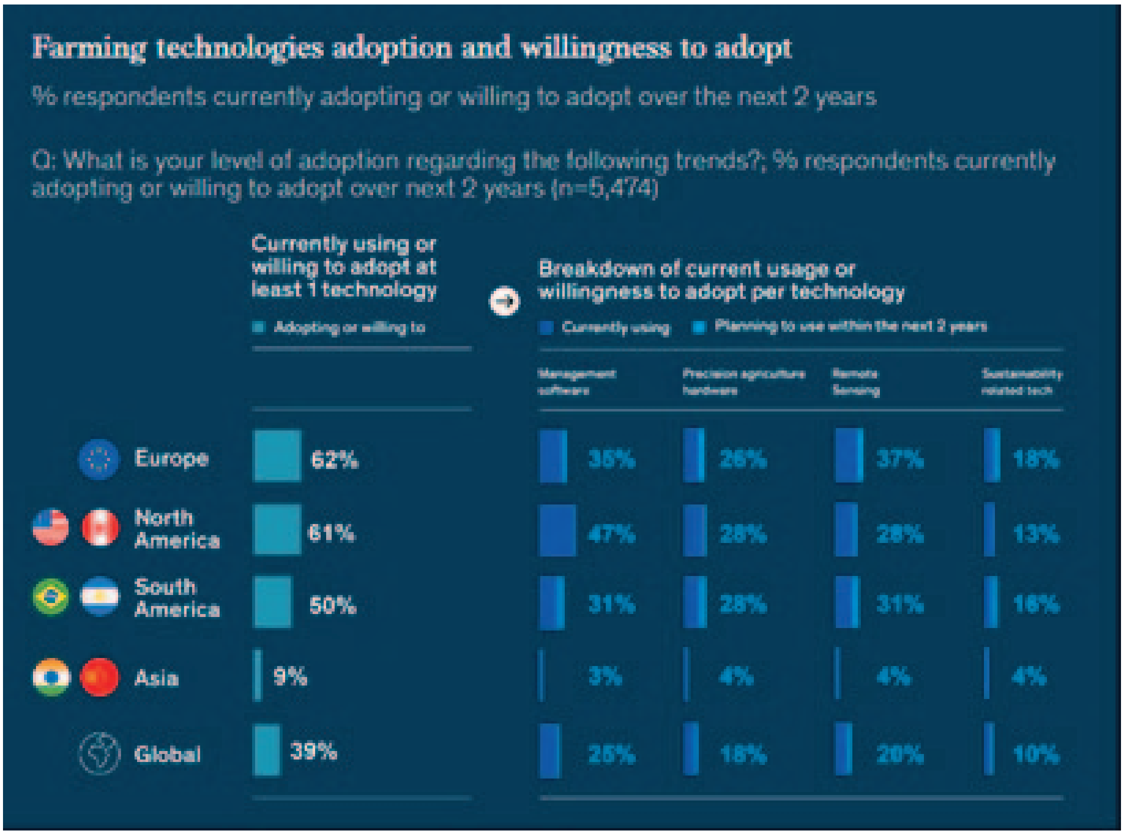


SOURCE: PitchBook.

Agritech and Agri-PV could be two sides of the same coins, as Agri-PV and Agritech create synergies. On the one hand, Agri-PV brings structures, communications, power, data, and new capabilities to traditional agricultural areas. Those elements are key enablers for the main technology types of agritech, data acquisition, and censoring and hardware innovation.

On the other side, Agritech is creating a dynamic of technology adoption in agriculture that could break barriers for the expansion of Agri-PV use cases and projects. As shown by McKynsey & Company (Figure 8), European and North-American farmers will be more prone to consider technology adoption over the coming years.

FIGURE 9 OVERVIEW OF FARMING TECHNOLOGIES ADOPTION AND WILLINGNESS TO ADOPT GLOBALLY.



SOURCE: McKinsey & Company, Global Farmer Insight 2022.

CASE EXAMPLE SMART SENSORS FOR POLLINATORS (3BEE)

The rapid decline of biodiversity worldwide is a grave concern. Addressing this pressing issue, 3Bee Technology emerged as a pioneer by developing a suite of technologies dedicated to designing and monitoring biodiversity on land. 3Bee's approach hinges upon 3 cutting-edge technologies:

- **Flora**, an innovative solution developed with the European Space Agency, that employs satellite imagery to observe and quantify site suitability for pollinators, ensuring their natural habitats are preserved and nurtured.
- **Spectrum**, an IoT sensor, which perpetually listens to the environment, detecting the presence of pollinators, thereby providing a comprehensive assessment of their populations.
- **HiveTech**, an IoT sensor specially devised for beehives that provides insights into hive health status and honey production. Indirectly, this provides an overall image of the site's environmental status, and the health of the ecosystem.

The benefits of the service are the following:

- It facilitates access to clear, quantitative data, to gauge performance in terms of pollinators' biodiversity, creating transparency.
- This data can further guide the design of site operations, and planning mitigation actions to enhance biodiversity, ensuring the preservation and growth of various species.
- It also provides data that allows for clear communication to stakeholders, and aids in comprehensive ESG reporting, mitigating the risk of greenwashing.

Today 3Bee has more than 5,000 censors installed, and over 2.5 million hectares of land. When it comes to PV plants, 3Bee's technology and services have been seamlessly embedded into over five Agri-PV plants across Europe, helping the integration of agriculture, beekeeping, and biodiversity with renewable energy production.

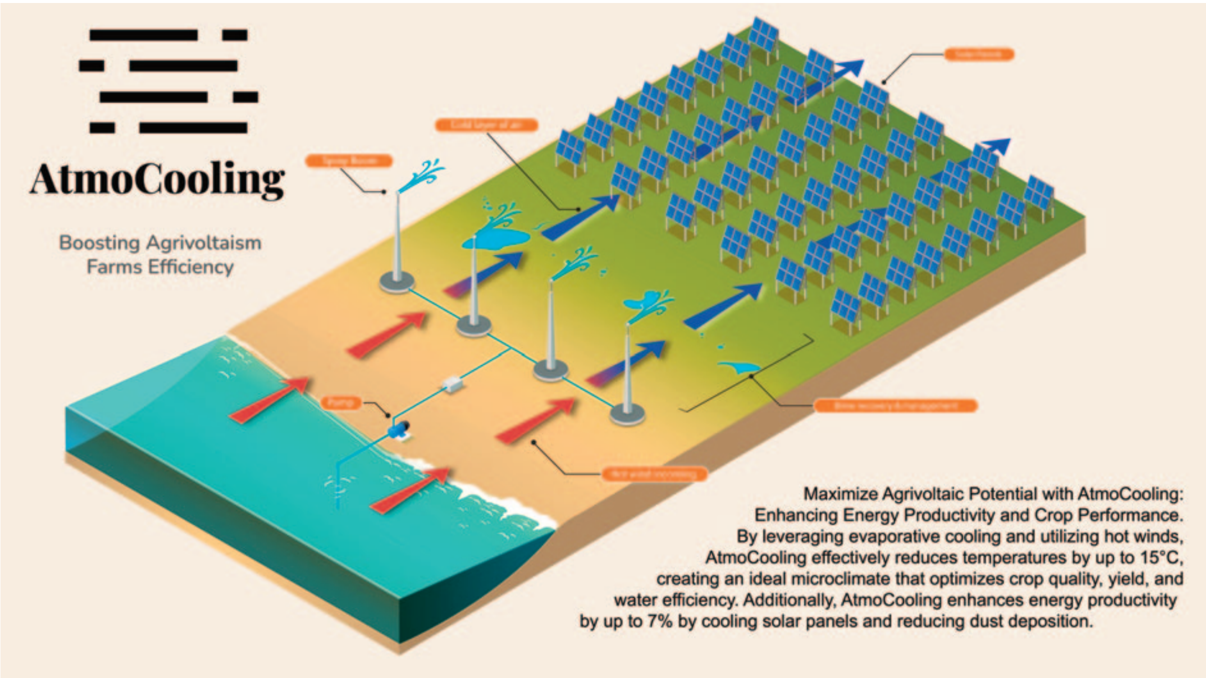
(i) (ii) (iii)

CASE EXAMPLE ATMOCOOLING - BOOSTING AGRIVOLTAIC FARMS' EFFICIENCY

Using abundant water resources such as seawater or certain rivers, AtmoCooling generates a layer of cool air close to the ground through evaporation.

This cool microclimate zone becomes more productive for growing staple crops, providing pasture lands for livestock, or boosting solar farm efficiency.

Atmocooling collects and analyses incoming weather data in order to dynamically operate its system to control liquid and solid drifts within limited distances, and optimise its cooling efficiency.



CASE EXAMPLE IN ALICANTE, SPAIN

Energy bills represents up to 50% of farmers' production costs in Europe, a cost that has increased 12 times over the last decade. Using solar energy for irrigation can represent the best alternative to reduce these energy costs. Solaqua technology leads a new generation of PV systems for irrigation that:

- Can work isolated from the grid, without needing back-up, and preventing water hammers and early degradation of the pumping system;
- Allow for up to 70% of energy cost reduction (energy term + fixed term), for all types of irrigation systems;
- Provide energy-as-a-service, eliminating the up-front costs for the farmer, and guaranteeing the energy supply;
- Guarantee maximum quality of the installation by applying advanced quality assurance procedures;
- Ready-to-implement projects: no risk for the farmer;
- 360° approach: Solaqua manages the development, EPC, financing, O&M and performance surveillance of the system.

Power: 360 kW

Performance results:

- 5 years of operation
- +99% availability
- 79% of savings

CASE EXAMPLE ANIMOB MAFRA

Animob is a pre-seed Agritech startup providing service in the utility vegetation management sectors, with a practical solution for land management, valorisation of local production, and mitigation of the effects of climate change.

Animob is developing a digital "Matchmaking" platform to connect livestock farmers with landowners, integrated with a regenerative land management service through animal mobility. It is a digitally organised grazing service, which outlines necessary governance rules, to connect landowners with animal producers on the online platform ("Online Match"), and subsequently manage livestock and land ("Onsite Match") in a regenerative way. This ensures commercial, legal, safety, logistics, and animal welfare conditions. Their service to owners and farmers allows owners to reduce the environmental impact and risk associated with vegetation management operations (controlling biofuels and unwanted species; and improving the chemical, physical, and biological characteristics of the soil). Animob's service allows farmers to access new areas and food for their livestock, which will be reflected in lower farm costs, and improved meat quality. Together, all stakeholders contribute to the carbon capture in the soil, combatting desertification, and preventing biodiversity loss.

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