www.solarpowereurope.eu

Agrisolar

Best Practices Guidelines

Version 1.0

SolarPower Europe

Foreword

Agrisolar is a rapidly expanding sector with incredible potential. It brings together two major sectors of our society and economy: agriculture and energy. With the first edition of the SolarPower Europe Agrisolar Best Practices Guidelines, we take an exciting first step in joining forces with agricultural stakeholders, to better understand how the solar and agricultural sector can work more closely together, enhancing synergies to advance the energy and climate transition.

Enhancing the cooperation between the solar and agricultural world is essential for tackling one of the most important issues at the core of our modern livelihood, food production and electricity generation: access to land. Agrisolar enables us to move away from the traditional land-use competition towards a new paradigm based on synergies between agriculture and renewable energy. Moreover, Agrisolar can deliver a much-needed boost to sustainable rural development and can increase biodiversity protection.

We launched our workstream in April 2020 amid the largest health and economic crisis of the last hundred years. But 2020 was also the year of the European Green Deal, which sets the European Union on a path to achieve climate neutrality by 2050. With our work, we plan to leverage the EU's renewable energy ambition to achieve the nine objectives of the Common Agricultural Policy. Our ambition is to foster a more sustainable and qualitative agriculture, that is more respectful of its environment, and to cope with the increasing environmental hazards related to climate change. Furthermore, this will empower farmers to be at the heart of the European Green Deal and the post-COVID green recovery.

The goal of this guide is to draw on past experiences, to take stock of "what works" and "what doesn't", in order to advise local and international actors on successfully developing Agrisolar.

It is aimed at solar and agricultural companies, investors, landowners, government departments, local authorities, associations, federations, industry associations, scientific research centres, consultancies, suppliers and, more generally, any party interested in Agrisolar.

The minimum requirements, best practices and recommendations presented in this Guide are drawn from the experiences of the members of SolarPower Europe's Agrisolar Working Group. We thank all stakeholders who participated in this initiative, and in particular our partners from the agricultural sector who provided their expert input.

We are confident that this Guide will contribute significantly to the quality, performance, reliability, and sustainability of Agrisolar installations across the EU and the world.

EVA VANDEST
Head of Public Affairs,
Amarenco

Workstream Chair

WALBURGA HEMETSBERGER
Chief Executive Officer,
SolarPower Europe

Chair of the SolarPower Europe Agrisolar Workstream: Eva Vandest, Amarenco.

Coordinator of the SolarPower Europe Agrisolar Workstream and Project Manager: Miguel Herrero, SolarPower Europe.

Contact: info@solarpowereurope.org.

Contributors: Bas van Aken (TNO), Blandine Thuel (Acthuel), Eric Tonnaer (Vattenfall), Faustine Gaymard (Akuo), Felipe Canto Teixeira (Everoze), Guillaume Motillon (NCA environnment), Horacio Gonzalez Aleman (Farm Europe), Isabelle Decombeix (Enoe Energie), Jean-François Lerat (Sun'Agri), Katrin Aust (Bay Wa r.e.), Kay Cesar (TNO), Lucie Grenet (RES Group), Luisa Calleri (Elettricità Futura), Margot Varenterghem (CETIAC), Nelsie Berges (SER), Paul Elfassi (SER), Ragna Schmidt-Haupt (Everoze), Stephan Schindele (Bay Wa r.e.), Teresa Ojanguren Fernandez (Iberdrola), Xavier Daval (kiloWatt Sol).

Acknowledgements: SolarPower Europe would like to extend a special thanks to all members and agricultural stakeholders that contributed their knowledge and experience to this report. This would never have been possible without their continuous support.

Project Information: The SolarPower Europe Agrisolar Workstream officially started its work in April 2020. It operates through frequent exchanges and meetings. The Workstream reports reflect the experience and views of a considerable share of the European Agrisolar sector today. There was no external funding or sponsorship for this report.

Design: Onehemisphere AB, Sweden. contact@onehemisphere.se

Please cite as: SolarPower Europe (2021): Agrisolar Best Practices Guidelines Version 1.0.

Published: May 2021.

SolarPower Europe would like to thank the members of the Agrisolar Workstream that contributed to this report including:

SolarPower Europe's Sponsor Members:

Table of contents

List of tables

List of figures

List of abbreviations

Agri-PV	Agricultural Photovoltaics
CAP	Common Agricultural Policy
EPC	Engineering, procurement, construction
EU	European Union
FIT	Feed-in tariff
GHG	Greenhouse Gas
ha	Hectare
kW	Kilowatt
kWh	Kilowatt-hour
kW_p	Kilowatt-peak
LCOE	Levelised cost of electricity
MW	Megawatt
MWp	Megawatt-peak
OPV	Organic Photovoltaic
O&M	Operation and Maintenance
PV	Photovoltaic
SAC	Sustainable Agriculture Concept

List of case studies

1 Introduction

Climate change has exacerbated environmental issues in the European Union ("EU"), caused by the combination of increased greenhouse gas ("GHG") emissions, pollution, changes in land use, and declining biodiversity.

Agriculture is one of the most climate-dependent socio-economic sectors, with climate change affecting the sector in complex ways. Agriculture is particularly vulnerable to climate change because of the increasing variability of the timing and amount of precipitation, and the increase of extreme weather and climate events such as higher average temperatures or prolonged droughts.[1] Between 2007 and 2016, land temperatures in Europe were about 1.6°C warmer than in pre-industrial times.[2]

The agricultural sector is also a contributor to climate change[3] as global carbon, water, and nutrient cycles have been impacted by agricultural practices.[4] [5] Agriculture is the second largest contributor to GHG emissions in the EU, only behind the energy sector. While energy-related emissions have continuously declined over the last decades,[6] emissions from agriculture have remained almost constant at around 600 $MtCO_2e$ emitted per year.[7]

In addition to this, rural communities are facing specific socio-economic and development challenges. The income of EU farmers is still significantly lower than average incomes in many Member States,[8] while unemployment amongst young people in these areas is considerably high (18% unemployment in years 2015-2017).[9] These variations lead to poverty and rural exodus.

Another key challenge many EU countries currently face is the increasing pressure on Agricultural land availability, related to the development of new habitations and industrial sites, but also the deployment of on-shore renewable installations, such as ground mounted solar.

Through the European Green Deal, launched in December 2019, the EU is looking to simultaneously address the fight against climate change, and increased protection of our environmental resources. The EU's GHG emission reduction target will increase from the current 40% to at least 55% by 2030, with the objective of reaching climate neutrality by 2050 at the latest.[i] In June 2021, the European Commission will publish the so-called "Fit for 55' package" which will promote higher ambitions to deploy renewable energy, increasing the EU's 2030 renewable target from 32% to at least 38% of EU final energy demand. According to SolarPower Europe's modelling, a cost-effective trajectory to achieve climate neutrality will require reaching a 45% of renewable energy in EU final energy demand by 2030. As the most cost-efficient energy source in history, solar energy is primed to play a prominent role in delivering this.

In parallel, the European Union has the ambition to modernise its agricultural policy, in line with its climate ambition. To this end, the European Commission proposed a revision of the Common Agricultural Policy ("CAP"), which is currently under negotiation. In June 2020, the European Commission also launched the Farm to Fork and the Biodiversity Strategies to halt biodiversity loss in Europe and increase the

i The new EU GHG emission reduction target will be set in the European Climate Law, currently under negotiation between the European Council and the European Parliament.

sustainability of our food system. In this context, Agrisolar offers an innovative, efficient, and cost-effective solution to simultaneously promote sustainable agriculture and the clean energy transition.

Agrisolar refers to the integration of solar photovoltaic projects within an agricultural activity. For a project to qualify as an Agrisolar project, it should begin with a Sustainable Agriculture Concept (SAC, explained in Section 2.1). This SAC defines agronomical, environmental, and socioeconomic objectives and plans for the lifecycle performance assessment across all project dimensions.

Agrisolar offers a turnkey solution to reduce greenhouse gas emissions from the energy sector, deploy additional solar capacity, promote more sustainable agricultural practices, reduce the environmental impacts of agriculture, and drive rural development.

It includes a variety of business models, co-designed between the solar and the agricultural sectors such as Agrivoltaic (or Agri-PV) systems. But Agrisolar also includes the deployment of PV on the roof of agricultural buildings or for example, powering agricultural machinery with solar power.

Agrivoltaic systems (or Agri-PV) are Agrisolar solutions where a PV installation and a sustainable agricultural activity are co-located, and light management is performed. In other words, Agri-PV projects require optimisation between the quantity and quality of light that reaches crops and the PV cells.

The potential for Agrisolar in the EU is immense. **If solar were deployed on only 1% of Europe's arable land, its technical capacity would amount to over 900 GW, more than 6 times the current installed PV capacity in the EU.** In this regard, Agrisolar could be a central element to achieve the EU's climate and energy targets.

1.1. Rationale, aim, and scope

The dual approach between agriculture and solar PV can generate several positive synergies (defined in Section 2.2.). These include: increased land-use and resource efficiency, the preservation of agricultural land, reduced water consumption, improved crop yields, potential to increase soil carbon sequestration, the provision of ecosystem services, and contributions to the socio-economic welfare of rural communities.[10]

These synergies are maximised if the Agrisolar project follows environmentally sustainable guidelines. **However, the dual approach of developing an Agrisolar project has additional complexities compared to standard solar system.** This higher complexity **requires an important degree of foresight to maximize project quality** and ensure effective operation of the project both as an agricultural infrastructure and in its role as photovoltaic generation equipment.

The process to ensure high quality should begin at the planning and development stage of the project, following the SAC all the way through to the Engineering Procurement and Construction (EPC), and the Operations and Maintenance (O&M) stages.

The aim of this document is to **guide farmers, PV developers, regulators, and other stakeholders to develop high quality Agrisolar projects** in Europe and across the world. This Agrisolar Best Practice Guideline goes beyond the current environmental and social standards required by the European regulations and defines processes that will ensure Agrisolar projects are in line with the objectives of the European Green Deal.

This document provides Best Practices of the development of Agrisolar projects across the following market segments:

- Agri-PV systems (Chapter 3), including Controlled Environment Agriculture (Section 3.1) and Open field applications (Section 3.2), the EPC of Agri-PV systems (Section 3.3), and the O&M of Agri-PV systems (Section 3.4).
- PV on agricultural buildings (Chapter 4).

The document includes a discussion of trends and innovations in the field of Agrisolar (Chapter 5).

1.2. How to benefit from this document

The SolarPower Europe Best Practices Guideline **defines the key actions required of all parties involved in project development to maximize the sustainability of Agrisolar projects**, from an agronomical, ecological, and financial perspective.

1.3. Overview of applicable global standards and other relevant documents

- Australia: Australian Guide to Agrisolar for large-scale solar.
- Germany: Fraunhofer ISE (2021). Agrivoltaics: opportunities for agriculture and the energy transition. A guideline for Germany.
- Germany: DIN SPEC (Upcoming). DIN SPEC 91434 Agrivoltaic systems – Requirements for primary agricultural use.
- France: Artifex and Achtuel (2020). Agrivoltaism. Census of main applications (in French).
- France: ADEME (Upcoming) State of the art of photovoltaic systems in the agricultural sector, collection of feedback and production of a recommendation guide for public authorities.
- France: Plateforme Verte (Upcoming). Guide to good practice in agrivoltaics.
- France: AFNOR (Upcoming). Certification under the name "Vérifié Par". This will include the development of a "Positive Agrivoltaic Project" label ("Projet Agrivoltaïque Positif"), followed by the development of a certification process.
- France CRE (2017) Call for tenders for the construction and operation of innovative solar power plants (in French).
- Japan: Ministry of Agriculture Forestry and Fisheries Guidelines
- USA: Solar Massachusetts Renewable Target (SMART) Guideline Regarding the Definition of Agricultural Solar Tariff Generation Units.

Further international guidelines for improved ecological and social implementation relevant to Agrisolar:

- Germany: BNE (2020). Good planning guideline of BNE for improved biodiversity and social factors.
- United Kingdom: Lancaster University and University of York (2020) Solar Parks Impacts on Ecosystem Services (SPIES).
- EU-level: SolarPower Europe (2020). Engineering, Procurement & Construction Best Practice Guidelines Version 1.0.
- EU-level: SolarPower Europe (2020). O&M Best Practice Guidelines Version 4.0.
- EU-level: SolarPower Europe (2021). Solar Sustainability Best Practices Benchmark.

2 Sustainable agriculture and photovoltaics

© Wattmanufactur

The transition towards a more sustainable agricultural and food sector has been identified as one of the key priorities of the European Green Deal. Agrisolar can contribute to this ambition while simultaneously accelerating the EU's energy sector's decarbonisation.

2.1. Sustainable agriculture

The European Commission's proposal to modernise the CAP is closely linked with the ambition of 'greening' EU agricultural policy, adapting it to the changing socio-economic, energy, and climate challenges. In this light, the European Commission proposed that the CAP pillar focused on "rural development" seeks to achieve 9 specific objectives that "focus on the economic viability, the resilience and income of farms, on an enhanced environmental and climate performance, and on the strengthened socio-economic fabric of rural areas".[11]

The current use of land and water resources in the EU is not optimal. Around 80,000 hectares ("ha") of arable land were lost each year in the period between 2000 and 2017, as a result of land abandonment and the expansion of sealed areas.[12] To address this, in 2011

FIGURE 1 THE 9 CAP OBJECTIVES

SOURCE: European Commission.

the European Commission proposed to set a "net-zero land take" objective.[13] Agriculture, forestry, and fishing represent the lion's share of water consumption in the EU, accounting for approximately 40% of water resources in 2015.[14] Sustainable management of scarce water resources will be essential to maintaining agricultural practices in the EU.

Agriculture is one of the most climate-dependent socio-economic sectors, with climate change affecting the sector in complex ways. Agriculture is particularly vulnerable to climate change, due to the increased instability of the amount of precipitation and timing of precipitation and the recurrence of extreme climate and weather events (higher average temperatures and long droughts).[15] Between 2007 and 2016, land temperatures in Europe were about 1.6°C warmer than in pre-industrial times.[16] It is further affected by the ecological and environmental crisis endangering pollinating insects, increasing threat from pests on plants under stress and affecting bio-organisms that regenerate the productive ability of the soil.[17]

Rural populations are also decreasing across the EU. Between 2013 and 2017, approximately 500,000 people left rural areas in favour of larger urban centres.[18] Job prospects in rural areas are low. In many Member States, the income of EU farmers is still significantly lower than average[19] and young people unemployment is soaring with an average rate of 18%, between 2015-2017.[20]

2.2. Agrisolar and sustainable agriculture

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

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

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

Agrivoltaic systems, which co-locate a PV installation and a sustainable agricultural activity, can contribute to lowering the water needs of agriculture by shielding crops from heat and by reducing evapotranspiration.[21] The excess shading is especially beneficial for dry and water-limited areas, and for protecting against severe droughts in specific geographies.[22] One study indicated that, depending on the level of shading from PV panels, water savings could reach between 14-29%.[23] Plants with lower root density and a high net photosynthetic rate[ii] are ideal candidates to be cultivated within an Agri-PV system.[24]

2. Promote sustainable agricultural practices.

Agri-PV installations can for example deploy physical pest control measures, such as netting, and thereby reduce chemical pest control product[25] use and can contribute to food safety and biodiversity protection.

Recent research from the German energy market innovation association BNE[26] has shown that large-scale PV plants, when designed to be compatible with nature, deliver positive effects on biodiversity, compared to most conventional and monocultural uses.

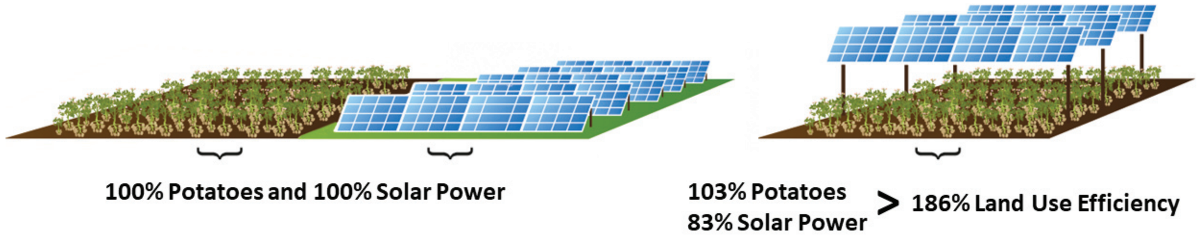
Agri-PV systems may also contribute to increased carbon capture,[27] which has been identified by the International Panel on Climate Change ("IPCC") as having a significant potential to abate GHG emissions.[28]

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

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

ii Defined by Encyclopedia Brittanica as "the rate of oxygen production either per unit mass (or area) of green plant tissues or per unit weight of total chlorophyll." https://www.britannica.com/science/photosynthesis/Basic-products-of-photosynthesis#ref60557

FIGURE 2 LAND-USE EFFICIENCY INCREASE FROM DEPLOYMENT OF AGRI-PV SYSTEM



SOURCE: Fraunhofer ISE.

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

The smart combination of solar and agricultural infrastructure can enable rural communities to become more competitive and sustainable.[29] The co-location of agriculture and PV enables the achievement of a higher land-use efficiency. Simulations indicate that Agrivoltaic systems may increase land use efficiency up to 60 to 70%, when compared to equivalent monosystems.[30] An experimental Agri-PV system with potatoes in Germany led to a 103% yield when compared to a control, while the PV systems generated 83% of the electricity that would have been generated on the similar plot of land, leading to an 86% increase in land use efficiency.[31]

While maintaining the agricultural use as the primary use of land, the dual use of land also serves to diversify farmer's incomes, protecting incomes and socio-economic development in rural communities even in the case of extreme drought.[32] An additional benefit includes reduced cost of insurance from potential crop failure.

Coupling shade-tolerant crops with Agri-PV systems increases the economic value of farms when compared to conventional agricultural practices.[33] Co-locating PV above crops helps to stabilise crop yields in some cases and may even increase the electrical yield of PV, thanks to the cooling effect of plants on PV panels.[34] The extra income benefits rural communities directly and improves rural infrastructure, value chains, and distributed electricity supply, which in turn can promote local farming.[35]

A study from 2017[36] shows that important benefits could be harvested for farmers, especially in the south of Europe. In the specific case of Spain, it shows that with normal conditions of deployment with 1.8 ha greenhouse (large-scale), the farm profitability would have a 9.89% increase, which would go up to 14,1% if investments are backed by state aids. Another study indicated that the deployment of Agrivoltaics can increase farm income by over 30%.[37]

Solar, as the most scalable and cost-effective clean energy technology, empowers farmers to be at the heart of the European Green Deal and the post-COVID green recovery. Solar creates more jobs per megawatt of power Installed than any other energy source.[38] Agrisolar business models can contribute to the creation of new citizen agricultural and renewable energy communities. Case studies analysed by the Joint Research Centre (JRC)[39] show that community energy projects exist in diverse forms across Europe including for example farm roofs equipped with solar panels, or windmills installed by rural communities on agricultural land.

2.3. The Sustainable Agriculture Concept

The sustainability of any solar project is linked to its socio-economic and environmental value. This section discusses which criteria can best evaluate the environmental and socio-economic value delivered by Agrisolar projects. Further information on how to maximise the sustainability of solar projects at large can be found in the Solar Sustainability Best Practices Benchmark.[40]

To ensure effective operation both as agricultural infrastructure and as photovoltaic generation equipment and to maximise the agro-ecological synergies identified in *Section 2.2. Agrisolar and sustainable agriculture* , Agrisolar project developers must go the extra-mile and define a Sustainable Agriculture Concept (SAC).

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

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

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

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

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

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

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

2. An evaluation of the environmental impacts of the system.

As in standard solar photovoltaic projects, an effective assessment of the environmental impact of a given project is an essential element of Agrisolar projects.[41] Agrisolar projects must conform to the legal requirements in the project country and conform to international accepted standards such as the IFC Performance Standards and the Equator Principles.[42] In this regard, several authorisations may be required, including an Environmental Impact Assessment ("EIA").

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

iii In cases where an agricultural activity is pre-existing the deployment of an Agrisolar system.

iv Individual farmer, farmer cooperative, landowner, rural community, etc.

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

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

3. An assessment of the socioeconomic impacts of the project.

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

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

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

4. A lifecycle performance assessment

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

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

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

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

2.4. Towards a 3-Star Benchmark for Agrisolar projects

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 full-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 tend towards a two-star rating. Finally, an ideal project that fulfils additional best-in-class criteria ("Could criteria"), which maximise agroenergetic synergies or provide significant ecosystem services, will be awarded a full three-star rating.

FIGURE 3 3-STAR BENCHMARK FOR AGRISOLAR PROJECTS

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

TABLE 1 AGRISOLAR CRITERIA

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

2.5. Existing challenges for Agrisolar

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

Regulatory and administrative barriers

One of the main challenges for Agrisolar to develop across Europe is the low quality or absence of regulatory frameworks to support the development of Agrisolar projects. Many countries that have a significant potential to develop Agrisolar such as Spain, Portugal, or Italy currently lack a framework to develop Agrisolar. One exception is France, where the Tender Documentation Energy Regulation Commission provides a definition of Agrisolar systems.[V, 43] However, the French tendering framework is not as specific as the regime regulating the tendering of ground mounted solar plants.

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

Another very important barrier for the development of Agrisolar in Europe is the potential loss of CAP subsidies by farmers who deploy solar on their land. In Germany farmers saw their direct income support removed after they deployed an Agri-PV system designed to allow sheep to graze on site. This decision was revoked by the courts as a violation of EU law, arguing that the implementation of the CAP in Germany did not respect EU law.[44]

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

Technical barriers

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

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

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

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

Financial barriers

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

v “Installations that allow the coupling of photovoltaic production to a main agricultural production allowing a demonstrable synergy of operation”.

Other barriers

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

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

2.6. How to support Agrisolar

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

Farmers who deploy **Agrisolar** projects should continue to receive income support through **the CAP.**

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

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

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

Concretely, Agrisolar policy frameworks should focus on 6 areas.[45] Firstly, Agrisolar policy frameworks should establish targeted financial mechanisms depending on the size of projects. Furthermore, tax reductions or additional revenue streams should be provided for Agrisolar projects that provide important biodiversity and carbon capture services.

Secondly, complementing sound financing mechanisms, governments should create enabling frameworks to facilitate the development of Agrisolar projects. This enabling framework should address unjustified administrative barriers for projects,

vi Split incentives refer to any situation where the benefits of a transaction do not accrue to the actor who pays for the transaction. https://publications.jrc.ec.europa.eu/repository/bitstream/JRC101251/ldna28058enn.pdf support financing of projects, and provide technical support for farmers and rural communities who are looking to develop Agrisolar projects. An accelerated project permitting procedure should be allowed when presenting a sound and certified SAC.

> An accelerated project permitting procedure should be allowed when presenting a sound and certified **SAC.**

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

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

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

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

3

Agri-PV systems – EPC and O&M

© Bay Wa r.e.

There are a wide variety of approaches to Agri-PV systems. In this chapter we outline several archetypes of Agri-PV systems and describe useful case studies to illustrate them. The differences between these archetypes are not clear cut. In fact, the case studies described exist on a continuum of the different types of systems. However, an analytical distinction is helpful to establish broad categories of Agri-PV systems.

Following these descriptions, we outline key steps that should be followed to ensure Agri-PV projects are aligned with the requirements of a project SAC.

3.1. Controlled Environment Agriculture

Controlled Environment Agriculture ("CEA") is an approach to food production which aims to maximise agricultural production through the optimisation of natural resources such as water, energy, land, space, and light. CEA also provides protection necessary for agricultural practices. Severe and extreme weather events are becoming increasingly common across the EU. Hail, storms, drought, heavy rainfall, and heat waves can have a significant impact on agricultural activities. Higher temperatures and stronger rates of insolation can also have a negative impact on plant growth and quality.

However, traditional CEA systems used in agriculture do not last long and are easily damaged. The deployment of solar PV and resistant, long-lasting installations can replace short-lived protection systems. This also enables farmers to cut down on crop insurance costs.

Different Agrivoltaic CEA installations can be designed to fit different agricultural needs, by using different heights, row widths, panel tilts, panel orientation, and panel transparencies. These systems can provide additional shade for crops which may not tolerate high levels of sunlight.

3.1.1. Elevated PV with crops

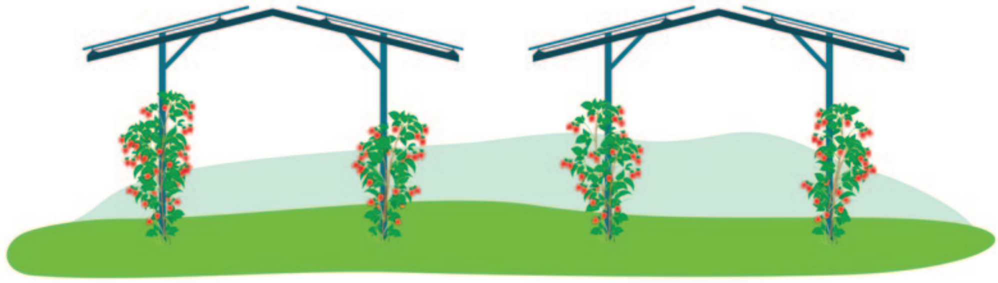
Solar panels can be deployed on elevated structures to provide shelter for horticulture, perennial crops, and special crops in addition to generating electricity.

Suitable crops

The deployment of elevated PV is particularly suitable for the cultivation of berries like raspberries, currants, blueberries, strawberries, and blackberries. Even a cultivation in soil is possible, for example for perennial raspberries. In the case of cultivation in a substrate, the rotation of crops plays a role in soil exhaustion.

Other perennial crops, such as fruit orchards and vines, are also suited for cultivation under elevated Agri-PV panels. These crops are grown for over 15 years and are usually replanted or grafted.

FIGURE 4 ILLUSTRATION OF ELEVATED PV WITH CROPS



SOURCE: BayWa r.e..

CASE STUDY 1 BELLEGARDE ORCHARD IN OCCITANIA, FRANCE (AKUO)

CROP: APRICOTS

In 2015, Akuo, launched the first Agri-PV project in mainland France, located in 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 PV structure was designed to fit the specificities of the land and farming needs. Apricots' variety was carefully selected to ensure its integration with the panels, thereby turning Agri-PV constraints into opportunities. Hence, yields improved significantly, standing now between 10 to 12 t/ha.

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. Furthermore, 70% of the water is saved compared to a classic apricot farm. Afterwards, cherries and grapes were also planted in the orchard, showcasing Akuo's expertise in managing projects which combine both an agricultural and energy component, and the harvesting abilities of Marc Portier.

CASE STUDY 2 ALBERS RASPBERRY FARM IN BABBERICH, THE NETHERLANDS (BAYWA R.E.)

CROP: RASPBERRIES

In 2020, BayWa r.e. developed their first "fruitvoltaic" system for raspberries which deployed 2.67 MWp on 3.3 hectares, protecting 31,000 raspberry plants in Babberich, the Netherlands.

The Babberich project is very beneficial and profitable for the farmer, both from a techno-economical and a techno-ecological point of view. Comprehensive testing throughout the pilot phase led to the creation of a tailored system that optimised crop protection. The project installed 10,250 modules, 41 inverters and two transformer stations, and the project achieves an efficiency of 0.8-0.9 MWp per ha. This is about 80% of a standard ground mounted installation and includes agricultural production on the same land area.

Before the project was developed, the system design was tested over four rows of raspberries planted in a pot, to ensure the best possible environment to maximize crop productivity, vegetative productivity, fruit quality, crop protection, to avoid post-harvest fruit rot development. This also optimised the plant's environment, such as the light transmission, photosynthesis, PAR (photosynthetically active radiation), temperature, and relative humidity measurements.

The installation allows the farmer to use less pesticides due to optimal rain protection and better ventilation. The farmer's well-being increased when harvesting, due to lower temperature and rain protection underneath the panels. An optimal light transmission could be achieved using transparent panels. The module efficiency is improved by the cooling effect from plants growth.

The project delivered increased crop yields by substituting the conventional wind protection elements with the Agri-PV system. No significant light intensity differences could be measured between the Agri-PV system and the previous plastic foil system, which is very important for photosynthesis. The system also provided more stable temperature conditions under the panels than under the plastic foils. The Agri-PV system also optimised the ground-cover ratio, the inter-row distance, the design of the PV component, and the panel tilt and orientation to ensure light availability was ideal. Overall, no differences in plant growth and leaf grade were observed, minimal amounts of fruits were aborted, and no diseases or pests were detected.

> "It is not before/after, it is the past and the future!"
>
> Piet Albers, owner of the Babberich raspberry farm, when asked whether he is satisfied with the before/after results of the test phase.

CASE STUDY 3 DYNAMIC ELEVATED PV TO PROTECT FRENCH WINE IN PIOLENC, FRANCE (SUN'AGRI)
CROP: GRENACHE NOIR VINES

In 2019, Sun'Agri deployed an experimental 84 kWp dynamic Agri-PV system over a Grenache Noir vineyard planted in 2001 in Piolenc, in south-eastern France. Agronomic monitoring carried out by the chamber of agriculture of Vaucluse and INRAE in the framework of the "Sun'Agri3" R&D programme has shown that the Agri-PV installation lowered the need for irrigation and increased the growth period for the grapes by two weeks – resulting in a 20% increase in grape weight, a 13% increase in content of anthocyanin, and a 15% increase in acidity.

These positive results are now being replicated on a larger scale in the Nidolères Estate. In 2018, 4.5 ha of new vineyard were planted close to Perpignan, in south-western France, with dynamic Agri-PV. Having saved water, time, and money, the first harvest of these 'Agri-PV grapes' is expected this year.

3.1.2. PV Greenhouses

Greenhouses dominate the CEA landscape. This technical solution protects the crops from external agents and weather hazards while improving the management of pests and disease. Greenhouses are completely integrated across Europe's agricultural landscapes. The extensive range and variety of structures, technical and technological characteristics makes greenhouses easily adaptable to the climatic and economic conditions of the environment where they are deployed. As a result, greenhouses have increased yields exponentially in a wide range of different territories.

Solar greenhouses that integrate solar panels into the structure can generate energy for injection into the grid, for consumption by the greenhouse itself, or for storage. Solar greenhouses have demonstrated their relevance in many European territories as they add-on an energy production to energy consumers, for air-conditioning systems, artificial lighting, cooling and heating systems, motor activation and solenoid valves, among other appliances.

Suitable crops

By adapting light distribution tools, Agri-PV Greenhouses are suitable for cultivating arugula, broccoli, Asian greens, chard, collard greens, kale, mustard greens, parsley, sorrel, spinach, scallions, kohlrabi, cabbage, hog peanut, alfalfa, taro, cassava, sweet potatoes, and squash. Herbs, such as mint, marjoram, basil, or parsley may also be grown. Furthermore, vanilla, curcuma, or ginger may be grown too.

However, further research is needed on shade-intolerant crops. Promising crops include cucumbers, pumpkins, cabbage, green peppers or some mushrooms which grow better under moderate light conditions.

This list of species is non-exhaustive and the future farmer should give specific attention to features of the greenhouse location, such as the soil structure, the local weather conditions, etc.

The choice of species farmed should be made by the future farmer, with knowledge of the specific features of the field and the planned cultures.

CASE STUDY 4 BARDZOUR PV GREENHOUSES (AKUO)
CROP: MARKET GARDENING IN PERMACULTURE, HORTICULTURE AND BEEKEPING

The Bardzour solar farm is the first of its generation to include lithium-ion battery storage with a capacity of 9 MWh, a world first for this level of power when it began operating in 2014. This project encompasses a mix of green technologies including Solar, storage, ground mounted panels & Agrinergie® photovoltaic greenhouses.

The Agrinergie® photovoltaic greenhouses combine greenhouses with a semi-photovoltaic cover. These anticyclonic greenhouses are financed by the electricity generation, allowing the management of the production with market gardening in permaculture, horticulture & beekeeping and ensures the continuity of agricultural production independent of weather conditions.

The crops are cultivated by inmates from a nearby prison who are trained to sustainable agriculture practices as part of the social reintegration strategy.

Moreover, the crops grown in the greenhouses require less chemicals, promoting organic farming. Finally, greenhouses foster a better management of the production cycles and better control of the yields. This agriculture production comes hand in hand with the power supply per year of an equivalent to 4,054 households and a reduction of 8,868 tons of CO_2 emitted.

CASE STUDY 5 STRAWBERRY PV GREENHOUSES IN EYRARGUES, BOUCHES DU RHONE, FRANCE (AMARENCO)
CROP: STRAWBERRIES

Grid connected in 2018, this project built 9 PV greenhouses to produce strawberries and other seasonal crops over 1.1 ha, with a generation capacity of 2 MW.

Large, young calibre strawberry plants were planted in 5 rows. To optimise the yield and quality of the production, the strawberry plants are renewed every two years.

While the Agri-PV strawberries have an identical revenue to open-field plantations, at around € 50,000 per ha, the Agri-PV strawberries can be collected earlier and over a longer period than other types of strawberries. The strawberries are sold directly in organic baskets in Marseille, with surplus sold to a local organic cooperative.

CASE STUDY 6 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 ha, 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.

For three years, every autumn, young fennel and celery plants were planted in the greenhouse. For the past two years with sucrine and this year a new mini-chard crop have also been cultivated. The site is certified by Ecocert and all the crops are organic.

The performance of the crops over the past three years has been extremely satisfactory and encouraging. Yields and income per ha are identical to those of the open field. To the farmer's great surprise, the very heavy frosts experienced at the end of winter, with temperatures going down to -7° on the site, did not impact the crops, which is an additional advantage.

The farm's produce is sold locally through an organic cooperative that collects and packages the production.

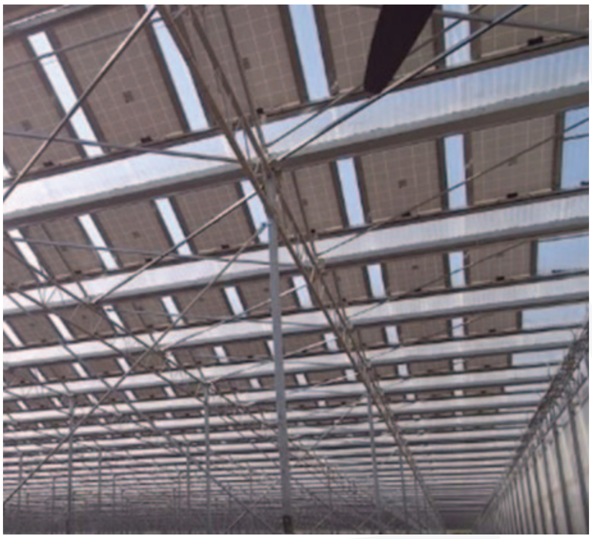
CASE STUDY 7 CITRUS FRUIT & AROMATIC HERBS PV GREENHOUSES IN LAMANON, BOUCHES-DU-RHÔNE (FRANCE) (ENOÉ). CROP: CITRUS FRUITS, AROMATIC HERBS, MUSHROOMS AND CHERRIES (EXPERIMENTATION)

Located in the South of France, this greenhouse was recently grid-connected (2021) and provides a work area of 2.9 ha for market gardening (citrus fruits, aromatic herbs, mushrooms, and cherries (experimentation). The greenhouse was built with an East-West orientation and included the deployment of a 3.04 MW solar system. This is a "Venlo" greenhouse with a 20 cm strip without modules on the south part of the roof (a). Light has been reduced on the north side of the greenhouse to optimize mushroom production by increasing panel density (b).

The first crops will be cultivated from May 2021. The farmer is committed to using the full potential of the project to experiment new production techniques, with a local approach. All the crops cultivated will be labeled organic and consumed locally, mainly by schools. The project will test cherries cultivation under PV Greenhouses, with about 5,000 m² of the project dedicated to agronomic reporting on this crop. The project is monitored by an agronomic partner who collects and analyses the data. The Lamanon Greenhouses will serve as a training centre for other farmers who wish to produce fruits and vegetables.

"Thanks to this high-performance tool, I'm going to produce citrus fruits in Provence. There is a very strong demand for those fruits which come from far away. We can't cultivate them outdoors. It's an agricultural project which respects the environment and allows the diversification of my business."

Denise Rodriguez



CASE STUDY 8 MARKET GARDENING DYNAMIC AGRI-PV GREENHOUSES IN GRANGES-SUR-LOT, LOT-ET-GARONNE, FRANCE (SUN'AGRI).
CROP: MAINLY TOMATOES, PEPPERS AND ZUCCHINIS. ALSO, AROMATIC HERBS, BEANS, AND CUCUMBERS.

This dynamic Agri-PV plastic greenhouse is a combination of an asymmetrical greenhouse with a dynamic Agri-PV system on the top. It consists of 9 chapels, each 6.4m-wide and 80m long for a total area of 5,000m^2. The design of the greenhouse maximizes the solar light input in the morning by having a larger east side. The orientation of the PV panels is managed by a software which uses agronomic indicators and adjusts their tilt according to the needs of the crop. The study of the crop growth started in 2019 as a comparison of a control zone without an Agri-PV system.

3.2. Open-field Agri-PV

Open-field Agri-PV systems, which include an agricultural activity in parallel to renewable energy generation, have already been in operation for many years. The practice of herding sheep, cows, or poultry in solar farms is well established. It is also possible to cultivate crops between the rows of solar panels and to design solar plants to maximise the provision of ecosystem services.

3.2.1. Ground mounted PV with animal husbandry

Carrying out animal husbandry within ground mounted solar plants is a very common approach. In this type of project, pasture and permanent grassland are allowed to grow between and below solar panels so that animals can graze on this pasture. The benefits of these systems include increased animal welfare from greater access to shade, as well as the use of land with low efficiency or with soil and climatic conditions more adapted for grassland.

Solar developers have allowed sheep herding to take place within solar parks for many years. In these cases, solar modules are elevated to a height of 1 meter. Sheep are particularly suited as they do not interfere with the structure of the standard ground mounted PV system and the low elevation of the solar modules. The developers were able to develop these systems without needing to adapt solar systems extensively in terms of spacing, inclination. This minimised reductions in the profitability of the photovoltaic project.

Other types of animal husbandry are being tested in ground mounted solar plants. However, these require solar systems to be adapted more extensively.

Suitable animals

- Sheep
- Pollinator/beekeeping
- Cattle
- Poultry
- Horses

CASE STUDY 9 LAND REGENERATION AND ANIMAL HUSBANDRY AGRI-PV PROJECT IN LAFITTE-VIGORDANE, HAUTE-GARONNE, FRANCE (RES GROUP).

The project, launched in 2020, was developed on a disused stone quarry and incorporates a floating and a land-based section. There was a demand from local authorities to regenerate the project site. A farmer was exploiting the land with field crops but observed very poor agricultural performance.

The farmer wished to transition towards sheep farming and RES SAS successfully supported this effort through the construction of a Agrisolar plant specifically designed to meet this need. The farmer currently herds 35 sheep on the site, with a view of increasing the flock to 70 sheep, who graze under solar panels installed at a 0.9 m height. The project includes an organic poultry farm around the lake with a poulterer, fences against predators, and trees to provide shade. In addition to this, beehives were installed under trees around melliferous flowerbeds.

The Agri-PV project included the planting of pasture, which will be re-seeded every 5 years. A control area was set-up to assess the growth of the grass under the solar panels, which will be reviewed by the regional agricultural chamber and the National Institute of origin and quality.

Furthermore, the project installed a garden for pedagogical purposes, to explain the various activities on the farm and to teach about how they contribute to sustainable development.

3.2.2. Ground mounted PV providing ecosystem services.

Ground mounted PV plants can be designed to provide valuable ecosystem services which support biodiversity protection, including for example the creation of habitats for local fauna, or creating corridors for wildlife to cross the project site.

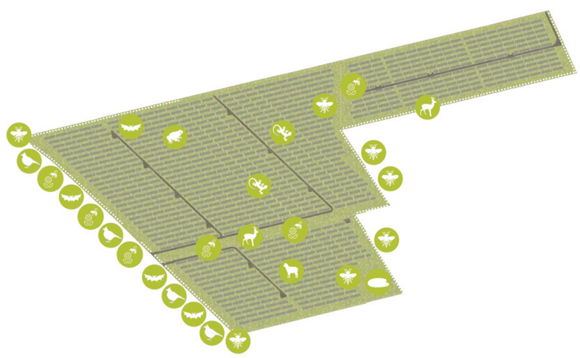
As noted in the SolarPower Europe Sustainability Best Practices Guidelines, to ensure PV projects provide ecosystem services, some methods to follow include: using best practice guidelines, using "Use of decision" frameworks and decision support tools (DSTs), and consulting local experts. Best practices have been defined by the German association BNE.[46] Several criteria are conducive to increase the biodiversity protection of solar parks such as planning sufficient spacing between module rows, limiting tractor movement, and including ponds for amphibians, bird and bat houses, and trees and hedges in the design of the solar park.[47] A useful DST is the Solar Park Impact on Ecosystem Services ("SPIES") decision-support tool,[48] which identifies natural capital and ecosystem service benefits from the application of specific design and management interventions in solar installations. Finally, it is good practice to consult with professional ecologists before carrying out specific interventions.

CASE STUDY 10 ECOLOGICAL CONCEPT AND BIODIVERSITY ON THE SOLAR FARM KLEIN RHEIDE, GERMANY (WATTMANUFACTUR).

The solar park in Klein Rheide forms a triad of i) clean energy production, ii) biodiversity and iii) extensive agriculture. A habitat was created by Wattmanufactur's subsidiary Osterhof - Ökologisches Flächenmanagement on the fallow land created by previous gravel extraction. The company created a habitat for 450 plants - including 17 on the Red List - as well as native wild animals, insects and amphibians.

The project includes a pond, which serves as a habitat for fish and other aquatic animals; sandpits and stone piles for lizards, and over 1,000m^2 of wetland biotopes as a habitat for amphibians. The project also includes secure corridors for the safe passage of wildlife, 5 wild beehives, 5 bat nests, 15 bird houses, and grazing areas for local shepherds.

The concept, design, EPC and O&M services offered by the developer were tailor made for the Agrisolar project, which is environmentally certified according to the EG-ÖkoVerordnung 834/2007.



3.3. EPC of Agri-PV systems

1. Definition of the Sustainable Agriculture Concept

As defined in Chapter 2 of these guidelines, Agrisolar projects must begin by defining a Sustainable Agriculture Concept.

2. Structure height

The size and height of Agri-PV protection systems should be adapted to the agricultural activity that will be carried out on the plot of land.

For systems with animal husbandry, it is essential to adapt the structure elevation to the selected breed. Generally, rustic breeds[vii] are picked because the animals are more robust and have low withers. The structure height should allow sufficient space for animals to safely walk under the panels. Furthermore, sufficient height should be provided to ensure adequate growth of grass and pastures.

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

3. Panel tilt

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. However they increase operation complexity and installation costs. For further information please see *Section 5.2 Fixed and dynamic Agri-PV*.

In terms of the agricultural activity, special attention should 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 shall be appropriately managed (See *7. Soil*).

vii Primary breeds with few genetic selections, normally more adaptable and robust.

4. Row distance

The inter-row distance should be adapted to the agricultural activity carried out on-site as defined in the SAC.

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 optimize light availability and homogeneity, to avoid negatively effecting plant growth.

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

5. Electrical safety

One of the key considerations in Agri-PV systems is preventing mechanical damage to the system cables caused by agricultural machinery.

Cables and cable tranches should be installed at a safe depth (of at least one metre) to avoid any damage caused by ploughs and other agricultural machinery. Good practice includes minimising the number of cables in the ground. Instead, cable ways should be directed under module roofs, alongside the mounting structure. In addition to protecting from mechanical damage, this protects the cabling from direct rain or sun exposure, increasing 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 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 for electric components such as string inverters or junction boxes.

6. Water

Water is essential for practically any type of agricultural activity. Particular attention should be paid to ensure that sufficient water is available on the project site to meet the needs of the agricultural activity defined in the SAC.

Generally, a homogeneous 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.

A rainwater recovery system can be installed under the solar panels, to increase water independence and reduce local water stress. This will be particularly useful for areas where a water inlet may be more difficult to install or if the agricultural activity requires a lot of water.

7. 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 (for more information see *8. Foundations and mounting structure*).

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.

8. Foundations and mounting structure

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 removeable fixture 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.

9. Panel transparency

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.

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. Glass-glass PV modules provide higher levels of light diffusion, whereas bifacial modules will maximise electricity yield. If bifacial modules are used the project should evaluate the albedo effect on the site.

10. Light distribution

Optimal crop growth and animal welfare will be maximised if adequate light availability and homogeneity is provided.

For light-sensitive crops, project developers should assess the light intensity - in some cases the degree of shading - and the light homogeneity. Peripheral effects caused by the various elements of the PV system which may provide shade must be examined.

Installing dynamic technologies that modulate the the light transmitted to the crops e has a significant potential to improve light availability, provision of shade, or protection from extreme weather events. These are discussed in *Section 5.2 Fixed and Dynamic Agri-PV*.

11. Additional protection systems

Fences are particularly important for Agri-PV systems combined with animal husbandry. Overall, fences should be adapted to the type of animal bred on site to avoid their escape and to protect them from potential predators.

Some animals may need very robust fences. In other cases, fences may need to be buried, to avoid animals escaping under a damaged fence or if space has been left between the ground and the fence.

It may also be important to design fences in a way that allows wildlife to uninterruptedly pass through the project site, for example to preserve a green belt. However, these measures to preserve wildlife may be at odds with the breeding of some types of animals as they may be small enough to escape through the holes or predators could easily enter the site.

Elevated PV systems can also be used as support to deploy nets, which can be installed between panel rows and around the Agri-PV system. This provides additional protection to both crops and animals against pests, disease, and predators. These can be complemented by planting trees and hedges in the project site.

In addition to shelter, Agri-PV projects with animal husbandry should install animal welfare equipment. For example, poultry projects should plan for the installation of dust baths. Cattle projects should plan the installation of scrapers, so that animals can scratch themselves instead of using the PV structures to do so.

3.4. Operation and Maintenance 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.

Additional elements to consider in the Operation and Maintenance ("O&M") of Agri-PV systems includes:

1. General maintenance of Agrisolar project sites

Overall, the necessary maintenance work must be recorded by the installer of the plant in the operating manual and observed by the operator. It is recommended to record the verified parameters in a plant-specific operating protocol.

Crops and pasture on site should be carefully maintained to avoid fire hazards.

For extreme weather events such as icing and icicle formation, as well as extreme wind and snow loads, for safety reasons, work should not be carried out under the plant. Rainwater distribution systems can prevent the formation of icicles.

2. Health and safety of project site

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 informed about any specific maintenance needs or risks associated with the PV systems.

3. Cleaning of modules

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 minimize loss of yield, 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.

The use of a hydrophilic coating on the PV panel surface could be helpful to maintain an optimal electrical output.

4. Pasture management

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

© Amarenco

4 PV on agricultural building

Buildings are typically the second most important expense of the farm. By acting as a third-party investor, the solar sector can provide farmers with solid buildings complying with building standards that integrate rooftop solar. This enables the set-up of business models which reduce and even eliminate the costs incurred by farmers in constructing agricultural buildings. In turn, farmers can concentrate and channel investments to develop their agricultural activity, their core business activity.

The design of the agricultural building will depend on the agricultural activity that has been defined in the SAC. A grain farmer will need large volumes, whereas a poultry farmer will need ventilation.

Agrisolar buildings can be used to:

- Provide storage and protection: against ageing, theft, bad weather, hazard mitigation, avoiding loss of fodder from too much water, less dependence on the weather.
- Increase animal welfare: high mortality rate in livestock without buildings.
- Provide shelter to aquaculture: protection of fish farming.
- Reduce the use of plastics and makeshifts buildings.
- Improve supply chains and encourage local production: by encouraging transforming workshop at the farm, direct sales, and short circuits.
- Better management of the space: by having all at one place, avoiding transportations and journeys, vehicle flows.
- Improve farm working conditions.

CASE STUDY 11 SOLAR HANGARS IN NOUVELLE AQUITAINE TO SUPPORT CATTLE FARMING (AMARENCO).

The project built two 800 m² buildings to provide storage space for the farmer to store the equipment and fodder needed to breed Limousin cows on a 230 ha farm. The hangars were built with a north-south orientation and included the deployment of a 284 kW rooftop solar system.

Amarenco's investment was instrumental to developing much needed infrastructure for the farmer, who now benefits from better working conditions, economic gains, and environmentally friendly agricultural practices. The building replaced the use of plastic sheeting and has contributed to reducing fodder waste. Furthermore, the building improved the comfort of the farmer who can now work under cover, protected from frost and bad weather.

"With 160 Limousin cows on my farm, I needed new sheds to store all my equipment and to store the fodder so that it would be protected from the weather. The earthworks began in mid-October 2019. By July 2020, my buildings were completed, and I could store my bales of straw. Now, thanks to the Amarenco buildings, I don't need to cover my buildings with tarpaulins anymore. There was good monitoring of the work site and the announced deadlines were met."

F. Tucholski

CASE STUDY 12 SOLAR HANGAR FOR HORSE BREEDING IN HAUTES-ALPES, FRANCE (ENOÉ).

The project is located in an equestrian centre and apple farm in the South-East of France. The 800 m² building provides a space to sort apples and to protect the riding arena. The building, with an East-West orientation, includes a rooftop solar system with a capacity of 183 kWp.

The Regina Horse Breeding produces purebred Arabians for endurance. Its activities are mainly outside, the solar hangar is extending the centre's activities for additional months and providing a comfortable work area for horses and trainers.

"We are located at 1,100 meters above sea level. Before this project we had to take 4 months-off, but now we work all year in good conditions. What a wealth of convenience!"

Maryline Planas

4.1. EPC of agricultural buildings with PV

The EPC of an agricultural building with PV means meeting the needs and wants of farmers, and means integrating the building within its local setting, as well as ensuring sufficient ventilation.

4.1.1. Building design

The building should be designed in accordance with the farmer's needs and the requirements set by the agricultural activity as defined in the SAC. Important design elements to consider include the building size, shape, and height; the slope and pitch of the roof; and the building orientation (East-West, or North-South).

Important elements to pay attention to: plan sufficient access space for agricultural machinery and adapt the layout of the building to the farmer's needs, which may include the installation of a stall, a feeding corridor, or storage space.

4.1.2. Construction standards

Agricultural buildings should conform to existing local, regional, or national regulations in terms of structural integrity. Insurers may also impose specific building standards and restrict activities which may have too high an impact on the solar panels. The building should also be properly integrated within the local landscape and historical architectural traditions.

Meeting these strict construction standards may increase the costs of a building when compared to non-compliant buildings.

4.1.3. Ventilation

When agricultural buildings are used to shelter animals, they should be designed to provide sufficient ventilation for the animals. Animal breeding can saturate the air quickly. Furthermore, appropriate ventilation allows for a better control of infectious agents such as mastitis, lameness, or bronchopneumonia, among other things.

Important criteria to consider when designing agricultural buildings, include the number of animals that will be housed in the building, the area per animal available, the volume of air available, expected temperature, humidity, and the openings of the buildings.

Caption to image. © SPE

We have identified several trends and innovations that will contribute to further integrating agricultural practices and photovoltaics, improve the quality of Agri-PV systems, optimise synergies between agriculture and PV and improve levels of environmental and socio-economic sustainability.

5.1. New agricultural practices for Agri-PV

Several novel approaches to combine agricultural activities with Agri-PV systems identified above are emerging. Across the various types of Agri-PV systems identified above. These include introducing animal husbandry, such as poultry, under elevated PV panels and growing crops between and below ground mounted PV systems. Some projects also aim to study the introduction of agricultural practices in existing PV plants (Case study 13). Another very interesting innovation is the vertical deployment of bifacial solar panels. Concepts for these systems are currently being developed, with some projects currently under construction or gathering performance data. Future editions of the Agrisolar Best Practices Guidelines will incorporate these new concepts and updated best practices in *Chapter 3. Agri-PV systems – EPC and O&M*.

CASE STUDY 13 INTRODUCING AGRICULTURE IN EXISTING SOLAR PLANTS ACROSS EUROPE (ENEL GREEN POWER)

In January 2021, Enel Green Power[viii] launched nine full-scale demonstration Agrivoltaic projects in three different countries: Greece (two demos), Spain (five demos) and Italy (two demos). The demos will research the optimal conditions required to cultivate specific crops in existing ground mounted PV plants, without altering the layout of solar modules. The locations chosen for the demo tests enable testing a broad variety of crops, in various climatic areas, and PV plant layouts.

The results of the project will help define strategies to integrate agro-zootechnical activities within PV plants. The testing sites, each implemented on an area of 2-3 ha, will evaluate how various crops can be cultivated between and underneath the panels, according to the specific microclimates or shading. The demo sites include a variety of PV plant designs, including some which are equipped with trackers or fixed structures, some using mono or bifacial panels.

The first preliminary results should be available at the end of 2021 and the demonstration phase will be completed in December 2022. The collected data will be compiled in an Atlas, defining the suitable agricultural practices depending on the solar technology, local climatic conditions; and the social, economic, and environmental context.

The PV plants with specific cultivations are:

- Greece
  - Pezouliotika PV plant, located in Thrace: cultivation of aromatic herbs, flowers and mixes of plants capable of attracting pollinating species.
  - Kourtesi PV plant, located in Ilia region: cultivation of medicinal herbs, cardoon and safflower.
- Spain
  - Totana PV plant, located in Murcia region: cultivation of artichokes, broccoli, peppers, pitaya (a tropical fruit rich in iron and vitamin E), medicinal and aromatic herbs.
  - Valdecaballeros PV plant, located in Extremadura region: cultivation of medicinal and aromatic herbs.
  - Augusto PV plant, located in Extremadura region: cultivation of forage crops, broccoli, eggplants, cauliflower.
  - Las Corchas PV plant located in Andalusia: cultivation of lavender and flowers to attract pollinators.
- Italy
  - Bastardo PV plant, located in Umbria: cultivation of different species of herbs and forage crops, cucurbits and combinations of plants that attract pollinators.
  - Montalto di Castro PV plant, located in Latium: cultivation of legumes, asparagus and saffron.

SOURCE: BayWa r.e..

viii Enel Green Power is the company of Enel Group focused on the development and management of renewable energy generation.

5.2. Fixed and dynamic Agri-PV

One promising trend in the field of Agri-PV is the use of dynamic technologies. In fixed Agri-PV systems, the design of the system is determined and optimized before installation. Photovoltaic modules are then integrated at definitive orientation. This includes the Elevated Agri-PV systems, CEA, and open-field Agri-PV systems.

Dynamic Agrivoltaic systems can adapt to agricultural needs by changing the module orientation or through modulation of the light transmitted to the crops. Dynamic systems can provide additional opportunities to optimise the sun and shade of the underlying crops, or to protect the crops from inclement weather. Dynamic technologies can be deployed on Controlled Environment Agriculture and Open-field Agri-PV systems and can be combined to accommodate the needs of a wide variety of crops and geographies. Given the technical complexity of their use and the need for additional data to optimise panel tilt, they are often integrated into experimental devices.

We can distinguish four types of dynamic systems : Single-axis (Case study 3 and case study 8), Dual-axis, retractable systems, and dynamic light transmission systems (Case study 16).

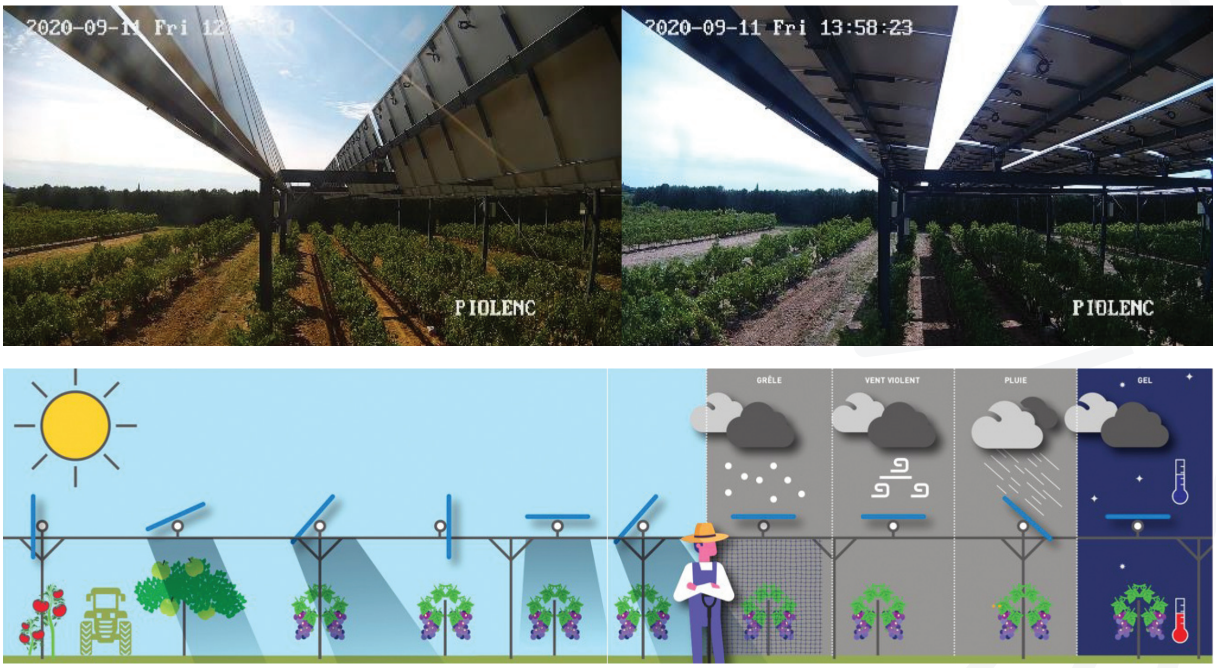
Photovoltaic systems that are oriented on a single axis can tilt their modules very strongly (see picture below). The panels can be oriented parallel to the rays of sun or to precipitation. Conversely, panels may be oriented in parallel to the sun to provide shade or shelter for the crops cultivated underneath.

The dynamic orientation results in complex trade-offs, balancing agricultural and energy production. It requires intelligent piloting of the shade and light alternations in accordance with the needs of the plants. These may include: preventing the risk of burning leaves and fruits, since such risk is higher in the event of rapid alternation in strong sunlight.

Dual-axis trackers enable finer shading variations and therefore more homogeneous shading over time but tend to be more complex and expensive. Retractable systems install solar panels on rails, which allows them to move horizontally to provide shade or light to the crops underneath.

No single type of dynamic Agri-PV system is superior. The impact will be different depending on the time of year, latitude, type of crop in place, climatic year, and many other factors. The advantages and disadvantages of each technology and each technology's ability to provide a concrete solution for a given culture in a given context needs to be further explored, because the available feedback is still limited and cannot be generalized.

Dynamic structures may be more sensitive to wind effects. Special care should be taken during the design phase to ensure that structures can properly resist static and dynamic loads caused by wind. In case of heavy winds, a strategy to manage panel tilting should be put in place.



SOURCE: Sun'Agri.

5.2.1. SWOT analysis of Fixed and Dynamic Agri-PV

TABLE 2 SWOT ANALYSIS OF FIXED AND DYNAMIC AGRI-PV

SWOT ANALYSIS OF FIXED AGRI-PV SYSTEMS	
STRENGTHS	**WEAKNESSES**
• Agricultural structure at zero or lower cost for the farmer. • Protection against climate hazards in a context of climate change, allowing a regular agricultural production. • Installations generally located in former agricultural areas, alowing for continuity with agricultural projects. • Versatility of systems available that can be adapted to the need of the farmer (structure design, high, distance row, panel disposal, etc.) • Water management. • Larger project areas, linked to the type of agriculture activity. • Good economic profitability.	• Lower light sharing could cause lower yields most of the time, or a delay in harvest dates. This can be compensated in the long term by better protection of the structure against climate hazards. • Limited PV cover ratio < 50%.[49] • Partial understanding of crop varieties compatible in specific geographical locations (territory, soil, agricultural methods, etc.).
OPPORTUNITES	**THREATS**
• Choice of crops adapted to the climate conditions under the PV panels, decisive for obtaining good agronomic results. • Differentiated management of green spaces or material use for light diffusion limits the variability, in yield or quality, within the plots.	• Alibi projects, with no significant agricultural project. • No consideration of agroecological needs related to specific designs of PV systems.
SWOT ANALYSIS OF DYNAMIC AGRI-PV SYSTEMS	
STRENGTHS	**WEAKNESSES**
• Dynamic control of panel orientation enables the provision of specific services to crops while considering their needs, depending on the phenological stages. • Potential additional agronomic benefits, including higher degree of crop growth optimisation. • Shading can be reduced to a minimum by minimising photovoltaic coverage rate. • Optimised protection against climate hazards in the context of climate change. Soil protection and water management.	• Expense and time for developing the algorithms in charge of the intelligent control of these systems. Must continuously be adapted to the pedoclimatic contexts and to the varieties of crops considered. • At its early stage: a few generalizable agronomic returns, (data for 2019 and 2020) mainly with dry and hot summers, not necessarily representative. • For the vines, mechanization challenges to the right of the posts of the structure. • LCOE is presently higher and not stabilized, than other PV systems on agricultural land. • Requires additional effort or cost during design to ensure resilience to wind effects.
OPPORTUNITES	**THREATS**
• Agronomic interest in high value-added productions per ha. • Increased synergies between the PV structure with agricultural tools, such as anti-hail and anti-insect nets, by using them in accordance with the dynamic strategy. • Improved potential to adapt agricultural activities to climate change. • Balanced governance between the need to have an independent and neutral actor to manage the panels, the need to involve the farmer, and the production of electricity. • Agronomic monitoring by independent organizations to monitor agronomic results and adapt, if necessary, the management of panels.	• Possible downward spirals in controlling the panels which could, depending on the phenological stages, promote solar monitoring (maximization of PV production) to the detriment of the crop in place.

5.3. New Generation of PV modules and systems

The use of specialised technologies such as more transparent panels or modules that can filter out the light spectrum needed by PV and needed by the crops beneath are still in a research and development phase.

- Semi-transparent solar cells are showing significant promise to reduce energy needs in greenhouses.[50]

CASE STUDY 14 SEMI-TRANSPARENT ORGANIC PHOTOVOLTAICS DEPLOYED IN AND ABOVE GREENHOUSES IN NANTES, FRANCE (ARMOR). CROP: TOMATOES

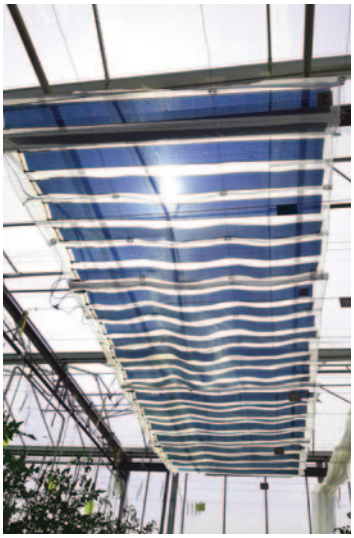
Within the framework of a partnership with Eiffage Energie Systèmes, and Groupe Olivier, ASCA® Organic PV ("OPV") films from ARMOR have been deployed on greenhouses located near Nantes, France. Semi-transparent, ultra-light weight, and low light sensitive OPV modules were deployed on the inside and on the outside of a greenhouse. The OPV modules diffuse light, have a reliable 20-year lifetime, and are industrially produced. The combination between light diffusion, shading, and electricity generation offers great potential for agricultural photovoltaic applications..

The surface of the installed demonstrators (pictured above) covers 43 m²:

- Horizontal shades. The OPV films are integrated in a shading fabric and installed in both existing plastic and glass greenhouse (left-side image);
- Vertical shade installed inside a glass greenhouse (centre image);
- Modules directly stuck to the vertical outer face of the greenhouse (right-side image).

After more than a year of monitoring the experiment proved OPV's ability to harvest as much energy in a glass greenhouse as in a plastic greenhouse where the light is totally diffused. It has also shown that it can easily be incorporated in a deployable and retractable system with no specific reinforcement of the existing structure. It could therefore respond to the variability of season or weather conditions.

ASCA® OPV films reaches 30% transparency and can be produced in different colors. It offers the advantage of letting part of the solar spectrum pass through, thereby enabling photosynthesis to take place. Further experiments are needed on wider surfaces and in relation to different crops to assess impact on plant growth.


CASE STUDY 15 SPECIAL PV MODULES ALLOWING DYNAMIC LIGHT TRANSMISSION IN ALMERIA, SPAIN (INSOLIGHT). CROP: LETTUCE.

European company Insolight[51] has developed PV modules which offer an innovative approach to dynamic Agri-PV. These modules combine high electricity output (20% efficiency) and adjustable light transmission (20% - 70%) to ensure a continuous optimization between crop photosynthesis and electricity generation.

This is achieved by an optical micro-tracking system which selectively concentrates direct sunlight onto solar cell arrays or transmits light through the module.

The Insolight solution can be deployed in Controlled Environment Agriculture Agri-PV systems, to replace fixed protective structures on crops, such as plastic tunnels on berries, enabling agrivoltaic deployments without land-take.

Insolight's demonstrator deployed in Almeria (Spain) in which Iceberg lettuce was cultivated. Results showed a 20% increase in biomass versus the control condition, lowered air temperature and relative humidity, and protected the crop from a heat wave.

CASE STUDY 16 PEAR ORCHARD WITH SEMI-TRANSPARENT MODULES (KU LEUVEN) CROP: PEAR.

This very recent project explores the feasibility of semi-transparent modules in line with pear production. The semi-transparent modules (with a 13.3 kWp capacity) were chosen to maximise the protection against hail while minimising the light reduction for the pears. The 40% transparent modules with diffuse backsheets are elevated by 4.6 metres, consistent with the agricultural machinery, using wooden columns as mounting structures. The diffuse backsheets improve the light distribution and light penetration within the orchard, to mitigate pear yield losses. Currently, the special modules with a power of 185Wp cost about €1/Wp for this small pilot project, but significant cost reductions are to be expected by economies of scale.

6 Conclusion

To deliver the European Green Deal and reach climate neutrality by 2050 we must accelerate both the decarbonisation of our energy system and the transition to sustainable agriculture. To achieve the former, the EU and its Member states must significantly accelerate the deployment of additional renewable energy capacity. For the latter to happen, EU Member States and institutions must ensure the future CAP is in line with the objectives of the European Green Deal.

Now is the time to deliver on these objectives through Agrisolar, a successful cross-sectoral collaboration between the agricultural and solar PV sectors. Through Agrisolar both sectors foster sustainable rural development, optimise agricultural yields, increase revenues for farmers, deliver on the 9 objectives of the CAP, and generate clean electricity. When appropriately designed, built, operated, and maintained, Agrisolar projects contribute to the EU's climate and sustainable agriculture ambitions. The case studies featured in these guidelines (*Chapter 3. Agri-PV systems – EPC & O&M* and Chapter *4. PV on agricultural building*) showcase successful examples of this cross-sectoral approach contributing to the objectives of the European Green Deal.

We understand Agrisolar as intimately linked to sustainable agricultural practices. Agrisolar projects can reduce the use of single-use plastics (such as Case studies 2 and 11), can create spaces for wild flora and fauna to thrive (as in Case study 10), and can minimise the water needs of crops (for example in Case study 1). Some projects contribute to regenerating degraded land, making it into agricultural land (such as Case study 9), while other projects look to re-introduce agriculture into existing solar plants (Case study 13). Agrisolar design offers a chance to preserve Europe's unique gastronomy (Case study 3) and enables the preservation of endemic fruit and vegetables species which are threatened by global warming.

Furthermore, Agrisolar can generate socio-economic benefits for rural communities. Some projects have a direct impact on the well-being of agricultural workers (such as Case studies 11 and 12) and projects can create job opportunities for local prison inmates (Case study 4). Many projects are directly integrated into local agricultural value chains, providing fruits and vegetables for local schools (Case study 7), or selling produce through local agricultural cooperatives (Case studies 5 and 6).

Finally, innovations developed by the solar sector will further increase the possibilities of integrating solar into sustainable agricultural activities. Some companies are looking into ways of integrating sustainable agriculture into existing solar parks (Case study 13). Furthermore, technical innovations such as the use of dynamic technologies (as in Case studies 3, 8, and 16) or the development of semi-transparent PV modules (Case studies 14, 15, and 16) will be key trends to follow in the coming years.

Every Agrisolar project is unique as it must be adapted to the local agronomical, environmental, and socioeconomic conditions of the project site, and adapted to the needs of farmers and other relevant stakeholders. The most important element to ensure that Agrisolar projects perform effectively as agricultural and photovoltaic projects is to begin by clearly defining a Sustainable Agriculture Concept (as explained in Section *2.3. The Sustainable Agriculture Concept*). Defining a Sustainable Agriculture Concept means assessing how to improve the sustainability of the agricultural practices carried out on site, assessing whether the project can provide local ecosystem services, assessing how it can be best integrated within the local social and economic setting, all while generating clean electricity.

Following best practices throughout all 19 areas identified in these guidelines will ensure Agrisolar projects deliver tangible benefits, as planned in the Sustainable Agriculture Concept. Agri-PV projects should ensure panel height, tilt, and module inter-row distance is adapted to the agricultural activity. As agricultural projects, Agri-PV projects should furthermore ensure sufficient water is available on site, should ensure that the soil quality is protected, and that the project minimises any impact of the foundations on the project land. Throughout their lifetime, owners, operators, and other parties of an Agri-PV project should ensure the agricultural production and the cleanliness of PV modules are maintained, all while protecting the health and safety of the workers. Agrisolar projects which deploy PV on agricultural buildings should also follow certain best practices, to ensure that the building design fits local landscape requirements and complies with construction standards.

We must also increase the collaboration between the agricultural, food, rural, environmental, and solar sectors. These guidelines are an example of how fruitful collaboration can be. This collaboration should be replicated institutionally to deliver successful policy coherence between agricultural, energy, climate, environmental, and socio-economic policies.

Such a collaborative approach should support the development of an EU-level harmonised standard for Agrisolar. Such frameworks should be sufficiently harmonised to stimulate the growth of an EU Agrisolar sector which is sustainable, while providing flexibility to adapt to various specificities of rural settings and climatic conditions. The indicative framework described in Section *2.4 Towards a 3 Star Benchmark for Agrisolar projects*, is a first step in this regard. Furthermore, it can be used as a basis for Member States to develop policy coherent quality assurance and enabling frameworks for Agrisolar.

Lastly, policy makers are needed to develop sound Agrisolar frameworks, unleashing the benefits of Agrisolar business models. Agrisolar still faces many regulatory and administrative barriers, which must be removed. Above all, farmers who develop Agrisolar projects on their land should not lose their CAP subsidies. Furthermore, enabling frameworks should provide accelerated permitting procedures for projects who develop a high quality and certified SAC. Targeted financial and technical support, in the form of grants and FiTs, should be provided to farmers and communities who develop smaller projects. For larger Agrisolar projects, targeted tendering schemes that value the provision of agricultural, environmental, and socio-economic benefits provide necessary incentives. Finally, there more to learn about this market segment. Public and private R&D funding must be channelled to advance our understanding of crops, PV system designs, and business models which can maximise the benefits of Agrisolar.

Through Agrisolar, we have the opportunity to enhance the attractiveness of rural territories, while promoting sustainable agricultural practices, regenerating depleted land, and generating clean electricity among many other advantages. As shown by these guidelines, the solar and agricultural sectors have already begun working together to ensure the quality, performance, reliability, and sustainability of Agrisolar projects is of the highest level. Future editions will seek to improve on our recommendations, to promote a highly sustainable Agrisolar sector in the EU and across the world.

References

1. European Environmental Agency (2019) – Climate change adaptation in the agriculture sector in Europe.
2. European Commission (2018) – Evaluation of the EU Strategy on adaptation to climate change.
3. IAASTD (2008) – Agriculture at a Crossroads: International Assessment of Agricultural Knowledge, Science and Technology for Development – ISBN 978-1-59726-550-8(2008).
4. Bondeau et al. (2007) – Modelling the role of agriculture for the 20th century global terrestrial carbon balance – Global Change Biol 13, 679–706.
5. Johnson et al. (2014) – Global agriculture and carbon trade-offs – Proc. Natl. Acad. Sci. USA 111, 12342–12347.
6. European Environment Agency (2020) – Annual European Union greenhouse gas inventory 1990–2018 and inventory report 2020.
7. European Environment Agency (2020) – Trends and drivers of EU greenhouse gas emissions.
8. European Commission (2018) – CAP specific objective: Ensuring viable farm income.
9. European Commission (2019) – CAP specific objective: Jobs and growth in rural areas.
10. Riaz et al. (2020) – Module Technology for Agrivoltaics: Vertical Bifacial vs. Tilted Monofacial Farms.
11. European Commission (2018). Proposal for a Regulation establishing rules on support for strategic plans to be drawn up by Member States under the Common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing Regulation (EU) No 1305/2013 of the European Parliament and of the Council and Regulation (EU) No 1307/2013 of the European Parliament and of the Council. COM(2018) 392 final. Available at: https://eur-lex.europa.eu/resource.html?uri=cellar:aa85fa9a-65a0-11e8-ab9c-01aa75ed71a1.0003.02/DOC_1&format=PDF
12. European Environmental Agency (2019) – Climate change adaptation in the agriculture sector in Europe.
13. European Commission (2011) – Roadmap to a Resource Efficient Europe.
14. European Commission (2019) – Evaluation of the Impact of the CAP on Water.
15. European Environmental Agency (2019) – Climate change adaptation in the agriculture sector in Europe.
16. European Commission (2018) – Evaluation of the EU Strategy on adaptation to climate change.
17. IPCC Special Report: Special Report on Climate Change and Land (2019): Chapter 5 on food security.
18. European Commission (2019) – CAP specific objective: Structural change and generational renewal.
19. European Commission (2018) – CAP specific objective: Ensuring viable farm income.
20. European Commission (2019) – CAP specific objective: Jobs and growth in rural areas.
21. Barron-Gafford et al. (2019) – Agrivoltaics provide mutual benefits across the food-energy-water nexus in drylands.
22. Dinesh et al. (2016) – The potential of agrivoltaic systems.
23. Marrou et al. (2013) – How Does a Shelter of Solar Panels Influence Water Flows in a Soil-crop System? – European Journal of Agronomy. 2013; 50, 38–51.
24. Adeh et al. (2018) – Remarkable agrivoltaic influence on soil moisture, micrometeorology and water-use efficiency – PLoS ONE, 13(11), e0203256.
25. Solar Power Europe (2020) – AGRI-PV: How solar enables the clean energy transition in rural areas.
26. Bundesverband Neue Energiewirtschaft e. V. (2019) – Solar parks – profits for biodiversity.
27. Barron-Gafford et al. (2019) – Agrivoltaics provide mutual benefits across the food-energy-water nexus in drylands.
28. International Panel on Climate Change (2020) – Climate Change and Land.
29. Solar Power Europe (2020) – AGRI-PV: How solar enables the clean energy transition in rural areas.
30. Dupraz et al. (2011) – Combining solar photovoltaic panels and food crops for optimising land use: Towards new agrivoltaic schemes – Renewable Energy, 2011; 36(10), 2725-2732.

31. Fraunhofer ISE (2020) – Agrivoltaics: opportunities for agriculture and the energy transition. A guideline for Germany

32. Santra et al. (2017) – Agri-voltaics or Solar farming: The Concept of Integrating Solar PV Based Electricity Generation and Crop Production in a Single Land use System – International Journal of Renewable Energy Research 7(2): 694-699

33. Dinesh and Pearce (2015) – The potential of agrivoltaic systems.

34. Barron-Gafford et al. (2019) – Agrivoltaics provide mutual benefits across the food-energy-water nexus in drylands.

35. Majumdar (2018) – Dual use of agricultural land: Introducing 'agrivoltaics' in Phoenix Metropolitan Statistical Area, USA – Landscape and Urban Planning, 170, 150–168

36. Carreño-Ortega, Á., Galdeano-Gómez, E., Pérez-Mesa, J. C., & del Carmen Galera-Quiles, M. (2017) Implicaciones políticas y medioambientales de los sistemas fotovoltaicos en la agricultura en el sureste de España:¿ Pueden los invernaderos reducir el efecto invernadero?.

37. Dinesh et al. (2016) – The potential of Agrivoltaic systems.

38. Solar Power Europe (2019) – Solar Factsheets – Employment and job creation.

39. Joint Research Centre (2020) Energy communities: an overview of energy and social innovation. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/energy-communities-overview-energy-and-social-innovation

40. SolarPower Europe (2021). Solar Sustainability Best Practices Benchmark.

41. SolarPower Europe (2020) – Engineering, Procurement & Construction Best Practices Guidelines Version 1.0.

42. Ibid.

43. CRE (2017) - Appel d'offres portant sur la réalisation et l'exploitation d'Installations de production d'électricité innovantes à partir de l'énergie solaire. https://www.cre.fr/Documents/Appels-d-offres/appel-d-offres-portant-sur-la-realisation-et-l-exploitation-d-installations-de-production-d-electricite-innovantes-a-partir-de-l-energie-solaire

44. Regensburg Administrative Court, judgment of November 15, 2018 - RO 5 K 17.1331.

45. Solar Power Europe (2020) – AGRI-PV: How solar enables the clean energy transition in rural areas.

46. BNE (2019). Solarparks - Gewinne für die Biodiversität. https://www.bne-online.de/fileadmin/bne/Dokumente/20191119_bne_Studie_Solarparks_Gewinne_fuer_die_Biodiversitaet_online.pdf

47. Bundesverband Neue Energiewirtschaft e. V. (2020) – Gute Planung von PV-Freilandanlagen.

48. SPIES (2021). Solar park impacts on ecosystem services. https://www.lancaster.ac.uk/spies/

49. Marrou, H. (2012), « Produire des aliments ou de l'énergie : faut-il vraiment choisir ? Evaluation agronomique de la productivité de systèmes agrivoltaïques »

50. Ravishankar et al. (2021) – Balancing crop production and energy harvesting in organic solar-powered greenhouses.

51. Insolight (2021). THEIA: Translucency & High Efficiency in Agrivoltaics. https://insolight.ch/agrivoltaics-insolight/

www.solarpowereurope.eu

SolarPower Europe

SolarPower Europe - Leading the Energy Transition
Rond-Point Robert Schuman 3, 1040 Brussels, Belgium
T +32 2 709 55 20 / F +32 2 725 32 50
info@solarpowereurope.org / **www.solarpowereurope.org**