Agrisolar Handbook

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SolarPower Europe

Foreword

As an MEP representing the heartland of Irish agriculture, as someone with a farming background, and as an MEP that has been heavily involved in formulating the EU policies driving the renewable energy revolution, agrisolar is an extremely exciting prospect.

Farmers are the custodians of the land, and whether we are talking about climate and energy, biodiversity, food security or economic competitiveness, we cannot achieve our objectives without the support of our farmers. This is why I am delighted to see the finalisation of this important SolarPower Europe report and I welcome its recommendations.

Agrisolar helps address two critical challenges: securing food production while accelerating the shift to renewable energy. By strategically placing solar panels above or between crops, agrisolar allows farmers to simultaneously cultivate food and harvest solar energy. This innovative approach optimises land use and creates new revenue streams for rural communities, all while contributing to our climate goals.

Agrisolar strengthens the vital relationship between agriculture and solar energy. The panels provide partial shade, helping to moderate temperatures, reduce water evaporation, and protect crops from extreme weather. Certain crops can thrive in these conditions, while the space beneath the panels can be used for livestock grazing or pollinator habitats, further enhancing biodiversity.

As we aim to meet an ambitious 90% reduction in emission by 2040 in the EU, agrisolar will be crucial for the acceleration of renewable energy deployment, while complementing and even enhancing agricultural productivity. It enables us to bring new opportunities to rural communities, boost acceptance of renewable technologies and the green transition more broadly and empower farmers to boost their incomes and better insulate themselves from energy price spikes.

To fully harness the potential of agrisolar, we must ensure farmers have the tools and incentives to participate. This includes simplifying grid connections, streamlining planning approvals, and putting payment schemes in place that encourage collaboration between agriculture and renewable energy – all of which are discussed in the report. By providing clear pathways and support, we can help farmers embrace this opportunity and contribute to a more sustainable future.

Agrisolar offers a clear and mutually beneficial way to combine agriculture and renewable energy. By empowering farmers, boosting rural economies, and advancing our shift to a zero-carbon electricity system, it can be a key driver of our progress towards Net Zero. I look forward to championing this opportunity and working alongside all stakeholders to ensure agrisolar fulfils its potential in the critical years ahead.

Seán Kelly

Member of European Parliament

Foreword

With the launch of the Agrisolar Handbook,

SolarPower Europe's Land Use and Permitting Workstream continues its work on the topic of agrisolar by providing insights into different economic models. The Agrisolar Best Practice Guidelines set out 2 pillars: i) an Agrisolar project adapted to each agricultural project in its particular context, and ii) additional revenues in support of the ecological transition.

This new Agrisolar Handbook proposes several archetypes for a successful, profitable project, where the value created must benefit the farmer, the solar stakeholders, investors and the local community, in particular through practices that are beneficial to the environment, the soil and biodiversity. This dual-use model of the soil should allow us to achieve the energy transition for the mitigation of carbon emissions, while providing additional services and income to farmers, supporting their adaptation to climate change.

Eva Vandest

Group Head of Public Affairs, Amarenco

Walburga Hemetsberger

Chief Executive Officer, SolarPower Europe

"This handbook provides good examples of multifunctional farming systems. Combining food and solar energy production in the same plot allows land managers to diversify and increase their viability and resilience. These solutions are welcomed developments in challenging times".

Ana Rocha

Director for the EU's agri- and forestry-related policies, European Landowners Organization (ELO)

"The production of energy in conjunction with agricultural production is an important condition for the expected transition of the European economy towards a carbon-neutral economy. It is also a contributory factor to the European Union's energy sovereignty. Through its research,agrisolar candeliver greatly in this process, by finding ways for solar PVproduction to go hand in hand with an increase in agricultural production, a reduction in the ecological footprint of the latter, and an improvement in farmers' incomes."

Yves Madre,

President, Farm Europe

Acknowledgement

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Table of contents

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Executive summary

The European agricultural industry is currently facing a complex set of challenges, ranging from rising costs, uncertainties around income, and access to land, to the impacts of climate change, water scarcity and other environmental challenges. These combined challenges shed a light on the need to develop innovative solutions to enhance the resilience and sustainability of agricultural sector in Europe.

The European Commission has made it a priority to strengthen the competitiveness, resilience, and sustainability of the agricultural sector. Building on the recommendations of the Strategic Dialogue, the Commission is expected to prepare a Vision for Agriculture and Food in the first 100 days of its new mandate, likely in the first quarter of 2025.

This handbook, therefore, comes at a pertinent time, highlighting the decade-long experience that the solar PV sector has developed on agrisolar, working hand-in-hand with the agricultural sector. **Agrisolar refers to projects that combine agricultural activities with solar photovoltaic (PV) electricity generation.** Different to traditional solar farms, agrisolar projects are seamlessly integrated into existing agricultural landscapes, allowing the dual use of land for both food production and energy generation.

This handbook serves as a resource for stakeholders interested in agrisolar, providing information on best practices, regulatory considerations, and case studies. By leveraging the potential of agrisolar, the agricultural sector can contribute to the transition to renewable energy, while enhancing its own sustainability and resilience.

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1. Agrisolar comes with multiple benefits and is a win-win-win for the farming sector, the energy sector and society at large.

Up to 60%[1]
crop yield increase (depending on crop type, season, regional climate and PV configuration

+20-30%
average water retention[2] for interrow and elevated PV systems

Up to +7°C[3]
increase of soil temperature in cold periods and

Up to -6°C[4]
decrease of soil temperature in warm periods

Up to 80%[5]
increase of soil carbon storage for solar grazing projects

Up to 60%[6]
increase in pollinators observed on one project

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[1]OMBREA (2022): The agrivoltaic demonstrator at Channay. ; SolarPower Europe (2023): Agrisolar Best Practice Guidelines version 2; Greg A. Barron-Gafford, et al (2022): Agrivoltaics provide mutual benefits across the food–energy–water nexus in drylands.
[2] Greg A. Barron-Gafford, et al (2022): Agrivoltaics provide mutual benefits across the food–energy–water nexus in drylands ; SolarPower Europe (2023): Agrisolar Best Practice Guidelines.
[3]SolarPower Europe (2023): Agrisolar Best Practice Guidelines version 2.
[4]SolarPower Europe (2023): Agrisolar Best Practice Guidelines version 2.
[5] Towner, E., Karas, T., Janski, J., Macknick, J. & Ravi, S. (2022): Managed sheep grazing can improve soil quality and carbon sequestration at solar photovoltaic sites
[6]SolarPower Europe (2023): Agrisolar Best Practice Guidelines version 2.

Agrisolar creates additional income for farmers, most often through land lease payment from the developers, and/or by directly providing agricultural infrastructure for farmers, and/or through reduction on energy bills. Such revenues contribute to the economic viability of the farm, and generates an income that helps farmers invest into transitional activities such as organic farming, agroforestry or electrification.

Agrisolar comes with agronomic benefits for farmers. While some systems require removing some productive land, they generally result in substantial increases in crop yield. They also in general support savings on water usage.

Agrisolar reinforces farmers' environmental and nature restoration activities. The shade coming from agrisolar installations have a notably positive impact on pollinator population and soil quality under the panels.

2. Agrisolar uses land more efficiently

By collocating an agricultural activity with a solar PV project, agrisolar allows for multiple land-use, therefore increasing the efficient use of land. Agricultural activity is maintained, in some cases with a marginal reduction of useful surface, and/or in an increase in agricultural production.

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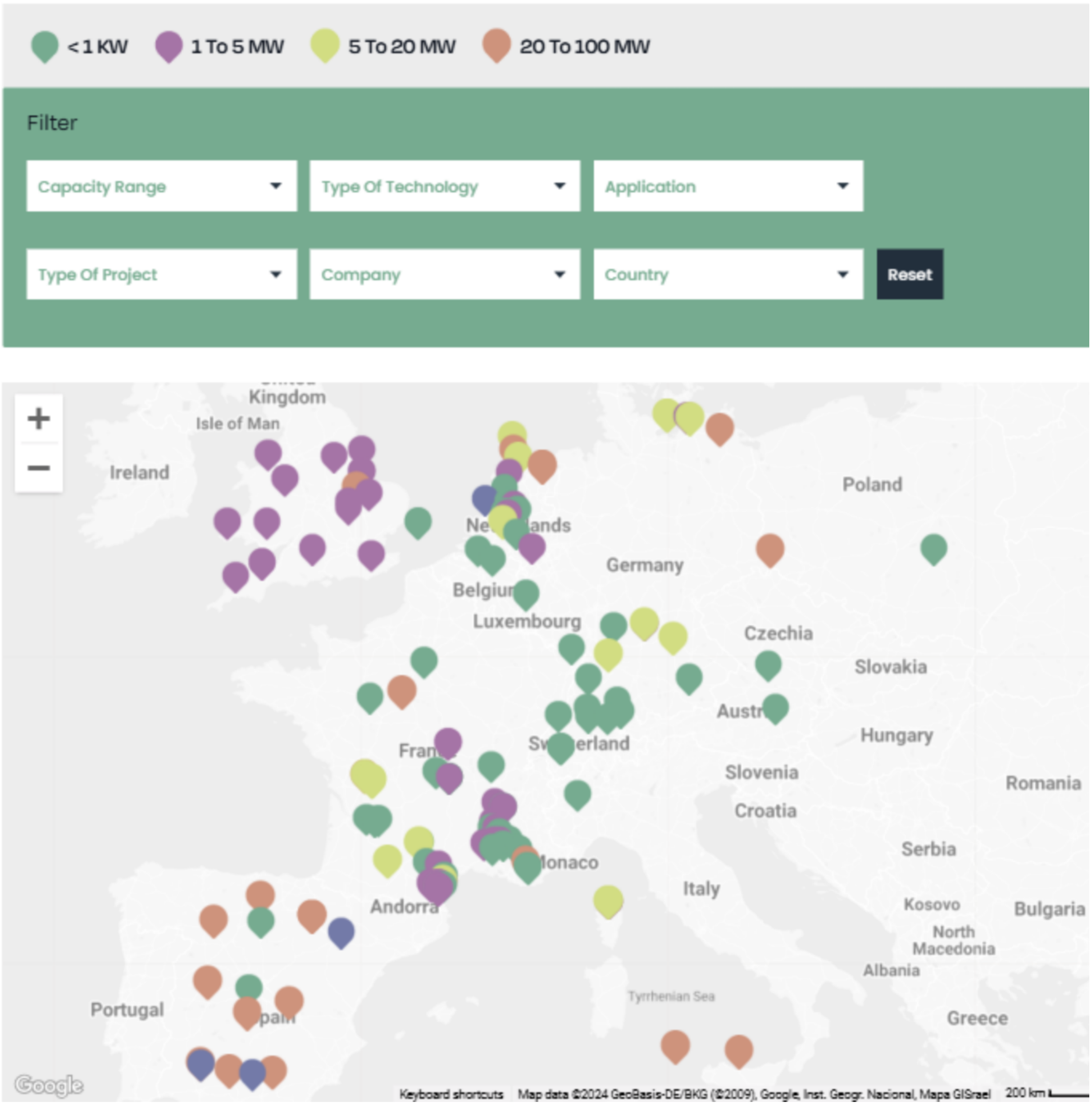
3. There are plenty of agrisolar projects across Europe already today, providing valuable experience and practices that can accelerate learning.

SolarPower Europe has created an online map of agrisolar projects listing the technologies and the characteristics (see below). The map highlights projects have been developed as demonstration or pilot projects across Europe. These projects not only provide valuable insights into the practicalities of integrating solar energy with agriculture, but also highlight the potential for increased farm income and energy self-sufficiency. However, due to a lack of comprehensive regulatory framework, agrisolar projects have been developed as pilot initiatives, preventing a full business model for agrisolar projects to materialise. Establishing clear guidelines and support mechanisms is essential for fostering the growth of agrisolar projects, and creating viable business modelS.



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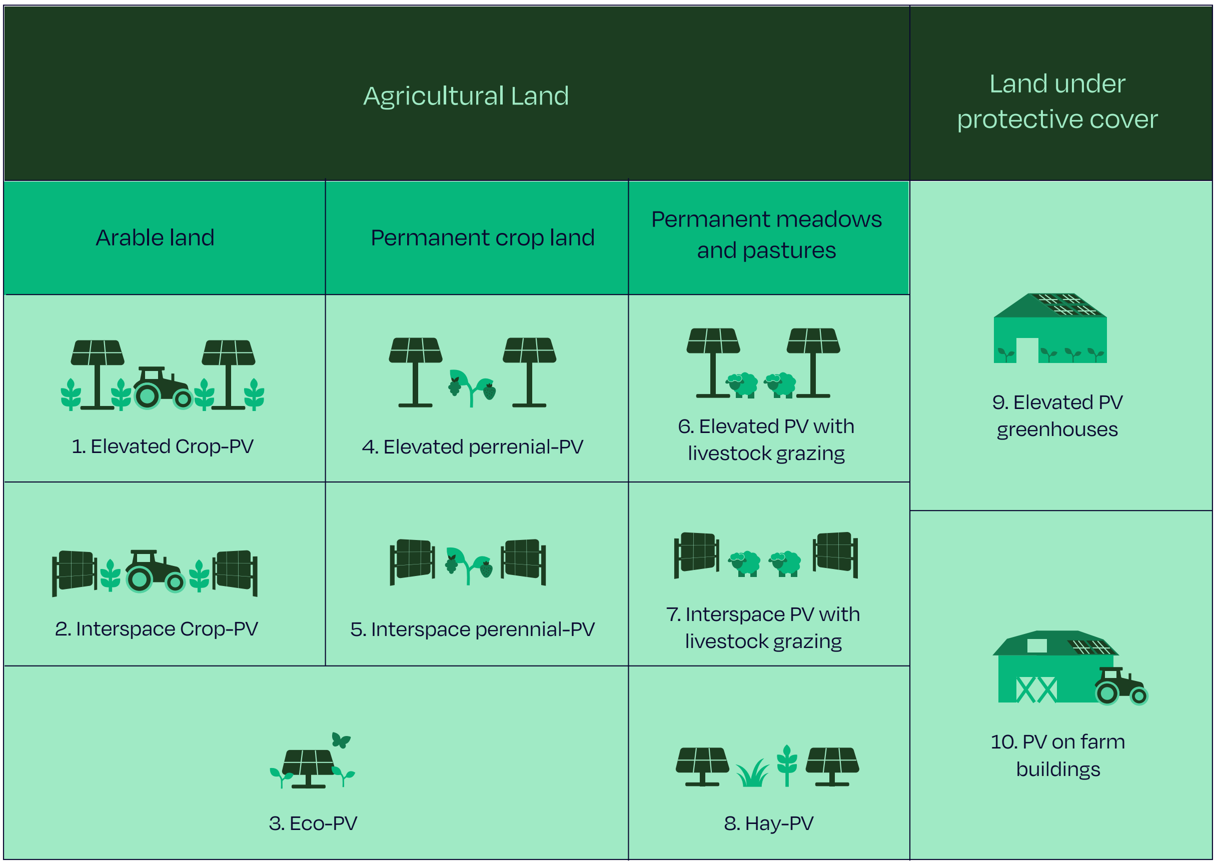
4. The exact business cases, agronomic implications and ecosystem services vary across different farming activities.

Agrisolar projects can be divided into broad categories: **(1) Elevated Agri-PV** where panels are elevated above the crops or livestock thanks to the metal structures; **(2) Interrow Agri-PV** where panels are placed vertically allowing the agricultural activity to take place in between the 'rows' of PV modules; and **(3) solar PV placed on the artificial structures**, such as agricultural buildings, rooftops or greenhouses, where, depending on the type of structure, either traditional modules or flexible modules in films are used. Based on these broad categories, this handbook defines 10 archetypes, reflecting the Food and Agriculture Organisation of United Nations (FAO) agricultural land classification, and maps out solar PV configurations that can be applied to the relevant farming activities.



This handbook describes the different archetypes, incorporating the business cases, as well as agricultural and environmental considerations, and includes real-life examples and data on the added economic, social, or environmental value of agrisolar to farms across Europe. It also assesses different types of ownership structures, and how these structures can create added revenue and overall value for the farm and farmland.

The benefits for different agrisolar systems are summarised in Table 1.

TABLE 1 OVERVIEW OF DIFFERENT AGRISOLAR ARCHETYPES AND THE ASSOCIATED BENEFITS

Archetype/ Main components		Agricultural Land			Protective Cover	
		Elevated PV (all types of agricultural land)	Interrow PV (all types of agricultural land)	Eco-PV	Elevated solar greenhouses	PV on farm buildings
Business case	Revenue scheme	Land lease business model	Land lease business model	Land lease business model	Provision of infrastructure or for a lower cost Provision of sales of electricity for the farm (self-consumption)	Rent payment for roof Provision of new infrastructure Self-consumption or resale of electricity to the grid , supported by a tariff
	Ownership scheme	Higher cost for installation/ operation of projects due to elevated structure adapted to the agriculture practice	Cheaper costs for construction/ operation	Full ownership scheme applicable		
	Cost components			Supporting voluntary environmental objectives of the CAP (fallow land) Financing ecosystem services: (a) Integrated into Agri-PV project with agricultural activity, and porduction: or (b) GM PV system adapted to the regeneration of the soil and biodiversity	Modernisation and diversification of farm	Modernisation and diversification of farm
	Other economic factors	CAP subsidy should be maintained with the agricultural activity/ production Profitability harder to achieve	CAP subsidy should be maintained with the agricultural activity/ production			
	Economic scalability	Marginal operational projects in Europe (Innovative and experimental on arable land) - with expected growth due to climate change and impacts arising from rising temperates For tracker systems, arbitrage between electricity production and agricultural production from the owner of the control tool. Projects with these systems have to be determined for bacability			Economically not viable solution without subsidies	
Impact on agriculture		Marginal impact on land uptake (can vary based on national requirements and/or type of technology) Multiple services to agriculture: livestock well-being, protection from climate hazard events, adaptation to climate change, water savings, improve soil temperature and soil health Potential to improve yield and quality	Potential to maintain crop yield Potential to improve yield and quality Multiple services to agriculture: livestock well-being, adaptation to climate change, water savings	Fallow land regulations vary across MS and its impact on PV Change in agricultural practices to integrate ecosystem services	Maintenance of yield of crops due to protection of structures Possibility to cultivate new kind of crops thanks to microclimate conditions (e.g. crops like exotic fruits in South of France) Protection from frost and winds Longer period for harvesting	Better conditions ofr storing agricultural produce and machinery
Biodiversity/ Environment		Reduced evapotranspiration Reduced mean ground temperature Possibility to enhance local vegetation Improvements in water retention (an imporvement between 20-30% monitored in some operational projects) Possibility to increase animal abundance (better livelihood of bees observed in operational project)	Possibility to enhance local vegetation Possibility to increase animal abundance Improvements in water retention (an imporvement between 20-30% monitored in some operational projects) Increased carbon storage	Possibility to enhance local vegetation Possibility to increase animal abundance Improvements in water retention Increased carbon storage	Improvements in water retention Negligent impact on biodiversity (for existing greenhouses)	Negligent impact on biodiversity

Policy Recommendations

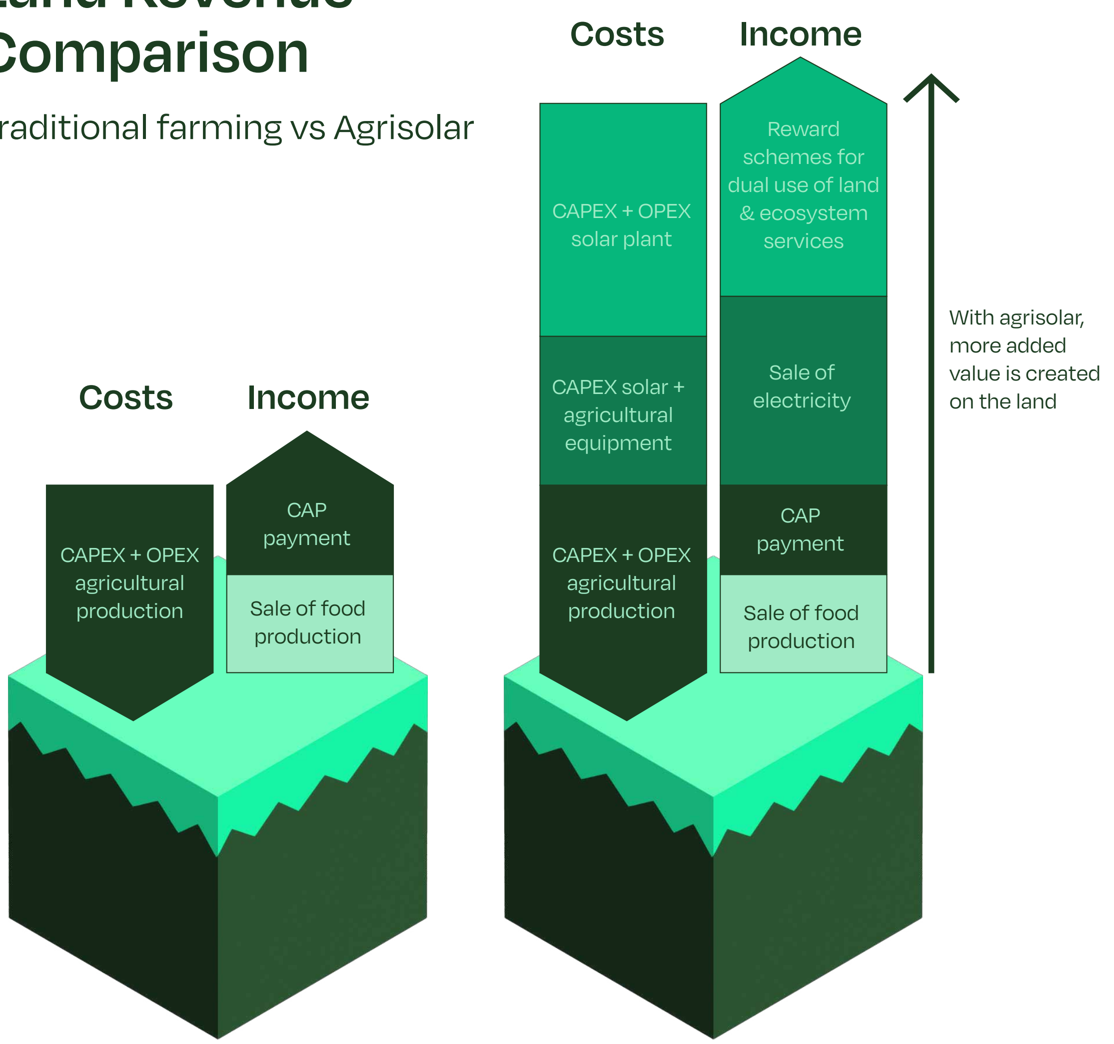
Further developing agrisolar will require creating an adapted framework at the nexus between agricultural and energy policies

Agrisolar is at the cross-roads of inter-disciplinary policy domains - agriculture, energy, and environmental policies - creating a more challenging setting. Supporting agrisolar growth requires taking targeted actions to develop a good policy framework and creating coherence between those three areas of policymaking.

Such frameworks should also create the right revenue streams to reward the added value of agrisolar projects and create sufficient incentives for farmers to benefit from these projects. The architecture of the different cost and revenue flows on land should recognise the value of agricultural activities, the value of energy production, and additional eco-system services such as environmental services or dual-use of land. A theoretical representation of the revenue flows before and after an agrisolar installation is available below.

Land Revenue Comparison

Traditional farming vs Agrisolar



With that logic in mind, SolarPower Europe urges policymakers to take the following actions:

1 Clarify that agrisolar has access to the Common Agricultural Policy (CAP)[7] direct payments.

Today, in many countries, farmers engaging in agrisolar activities lose access to the CAP schemes, due to the presence of a non-agricultural activity on agricultural land. The Common Agricultural Policy legislation, in fact, does allow for non-agricultural activities on agricultural land, but the problem lies in a national misinterpretation of the CAP. Therefore, it is critical to clarify the provisions of the Common Agricultural Policy by explicitly allowing for agrisolar projects on agricultural lands.

The revision of the next CAP Programme should provide a clear EU-wide definition of agrisolar to avoid misinterpretation of the term, which refers to a land use concept that locates PV installations and renewable energy generation together with agriculture production and nature conservation, while leaving sufficient flexibility to Member States to adapt the definition to their local context.

2 Develop relevant schemes to recognise the value of multiple land use.

Agrisolar increases the economic activity on the agricultural land, while retaining agricultural production. It also supports the growth of renewable energy sources, something which is included in the CAP's objectives.

Dedicated schemes, at the intersection between agricultural, environmental and energy policy, should reward such activities, providing a clear incentive for farmers to engage with them. Such schemes could be integrated through the eco-schemes foreseen in the CAP policy, by providing bonuses in the auction schemes, or by introducing other similar award-based mechanisms for agrisolar projects.

[7] The Common Agricultural Policy (CAP) is a support mechanism for European farmers and farms to ensure a stable supply of food, safeguards farmers' income, protects the environment and keeps rural areas vibrant.

Policy Recommendations

3 Recognise and integrate agrisolar into environmental requirements or support schemes on agricultural land, including by gathering data on agrisolar projects' environmental and nature benefits.

Agricultural land is subject to a number of schemes valuing carbon reduction on agricultural land, such as carbon farming, or the Nature Restoration Law. Agrisolar projects, when properly designed, can support nature restoration or biodiversity enhancement, by providing shade, increasing water retention, and providing overall benefits to the soil health.

It would therefore be critical to better integrate agrisolar plants into such schemes, monitored through specific indicators following, for example, carbon storage in the soil, water retention, biodiversity improvements, etc.

4 Improve permitting and grid connection procedures.

Agrisolar projects are still nascent in Europe. Permitting procedures, already challenging for solar power plants, are even more difficult for emerging solutions such as agrisolar. Complex bureaucratic processes can delay the implementation of agrisolar projects and increase costs.

The simplification of procedures, as well as the EU-wide harmonisation of rules, is needed to reduce entry barriers for farmers and developers, facilitating a more rapid deployment of agrisolar systems (Joint Research Centre of the European Commission, 2023). Guidance on specific agrisolar procedures could also be useful at the EU level.

5 Support further research and innovation in the agrisolar field.

Agrisolar includes a range of technologies, from proven design to more advanced technologies, which are often overlooked due to their higher cost. Supporting research and innovation is critical for the advancement of agrisolar (Joint Research Centre of the European Commission, 2023). A dedicated research programme should therefore be included in the Horizon Europe framework.

In addition, the biodiversity benefits that agrisolar can provide, should be based on scientific evidence: the European Commission's Joint Research Centre (JRC) should gather data on the environmental and biodiversity benefits of agrisolar plants.

1

Introduction

Extreme weather events and natural hazards are evident in all corners of the world. The changing climate is causing substantial damage and loss to nature, society, and economy. Europe faced record high temperatures in 2023, sparking the largest wildfires on record, and severely impacting the continent's nature reserves, while unprecedented flooding affected parts of Europe in the Autumn of 2024. As climate change negatively impacts nature and biodiversity, harming Europe's most precious wildlife and ecosystems, the agricultural sector is the first sector exposed to the climate emergency.

Increased challenges emerging from temperature anomalies, disrupted rainfall patterns, heatwaves, droughts, and storms, are all adversely affecting the farming sector. European agriculture is currently navigating a period of profound change and uncertainty, driven by a combination of political, economic, and agronomic challenges. Economically, farmers are facing rising operational costs, fluctuating commodity prices, and increasingly volatile global markets. The recent geopolitical tensions, including the Russian invasion of Ukraine, have exacerbated these challenges, disrupted supply chains and contributed to surging energy and input costs (European Commission, 2022a). Moreover, the demand for renewable energy is intensifying, pushing for new models of land use that can balance agricultural productivity with energy generation.

Agronomically, Europe's agriculture is also contending with the impacts of climate change, including unpredictable weather patterns, soil degradation, and water scarcity. These factors threaten crop yields and the long-term viability of farming, making it critical for the sector to innovate in its approach to resource management and sustainability.

In this context of growing pressure on traditional farming practices, innovative solutions like agrisolar offer a promising path forward. Agrisolar refers to the integration of solar PV projects within an agricultural activity and can include examples such as solar PV modules placed on agricultural sheds or integrated into irrigation systems. Agrisolar encompasses the term Agri-PV, which refers to a multi-functional land-use configuration on the same agricultural land area where solar power generation is integrated into agricultural activity, offering techno-ecological synergies in agricultural activity, nature conservation, and facilitating the circular land economy by increasing land-use efficiency.

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Agrisolar can offer many benefits for the agricultural industry and rural communities:

- Agrisolar is **beneficial to rural economies**; it creates jobs, generates community income, and tax revenues, and provides energy security and diverse income revenues to farmers[8] and landowners.
- By generating their own renewable energy, **farmers can lower energy costs** and become less vulnerable to volatile energy prices, which have risen significantly due to global market disruptions.
- Agri-PV installations **protect crops** from severe weather events such as droughts, direct sunlight, floods and hail.
- Agri-PV solutions can also support sustainable farming methods such as regenerative agriculture by **improving water management**, i.e. reducing water usage for irrigation purposes due to lower evapotranspiration[9], and lower water needs of the crop due to lower temperature underneath the PV modules, reuse rainwater where rainwater collection systems are installed, and more.
- Additionally, incorporating vegetation into solar PV installations can enhance crop resilience to the physical risks of climate change such as increasing temperatures, floods, and extreme weather events. By creating a synergy between agriculture and solar PV systems, this approach also minimises land-use impact, addressing one of the main drivers of biodiversity loss.
- Agri-PV allows dual use of land for both agriculture and energy generation, maximising land efficiency and making better use of available resources without sacrificing food production.
- Agri-PV **introduces farmers to modern renewable energy technologies**, enabling access to precision farming toold, smart irrigation, and energy-efficient systems, which can further enhance productivity.

[8] There are different definitions of subjects providing agricultural activity (agricultural producer, manufacturer of agricultural products, agricultural enterprise, agricultural cooperatives, etc). For the simplification purposes, in this report a term farmer will be used to describe a person (or a group of persons) who provide agricultural activity on the land.

[9] Loss of water from the soil both by evaporation from the soil surface and by transpiration from the leaves of the plants growing on it. Britanica, The Editors of Encyclopaedia (2024): 'evapotranspiration'.

In their forthcoming report, BCG and BayWa r.e. show similar findings: Eco-PV and Agri-PV projects can accelerate the transformation of the farming sector toward regenerative agriculture. The impact of such PV projects extends beyond the renewable energy generation itself, but also supports regenerative farming practices, therefore benefiting the entire farm. By generating additional income, for example through land leasing and service contracts, deploying solar energy strengthens the farm's economic resilience and de-risks the P&L — particularly in the critical early years of transition to regenerative agriculture. While the exact financial impact will be specific to individual farms and projects, the preliminary findings of the report indicate that very substantial financial contributions are possible.

Given a volatile profitability profile and low overall profit levels of many conventional farms, a transition to regenerative agriculture combined with suitable PV projects can, dependent on PV project size and situation, lead to profit increases of more than 200% in the mid-term. Furthermore, Agri-PV in particular, promotes healthier soils, greater biodiversity, and enhanced resilience against abiotic stress, making it a tool to reduce risk for regenerative farm operations and its sustainable energy production.

In this handbook, different agrisolar solutions will be outlined and assessed to provide key information to the farming sector about how farmers and landowners can benefit from agrisolar projects on their farms. More specifically, this guide is developed as a communications tool for farmers and agricultural stakeholders, policymakers, and the solar industry, to showcase the different types of existing and emerging agrisolar business models, and how these business models can be applied for different types of agricultural activities.

The guide provides information about the economic aspects of business models, including but not limited to, revenues such as land lease, sales of energy that farmers can gain from agrisolar solutions, or other types of revenue diversification schemes. In addition, the handbook will focus on assessing how agrisolar solutions can contribute to ecological improvements, creating biodiversity net gains. This section will provide an outline of key indicators to assess biodiversity and other ecological parameters on agrisolar sites, and include key opportunities and risks related to the integration of these natural resources with solar energy production. The document will also put forward key policy recommendations to support the rollout of this technology and its relationship to biodiversity.

METHODOLOGY

As a basis for the report, different agrisolar archetypes are defined based on the Food and Agriculture Organization (FAO) land-use matrix and will be used throughout the report. FAO land matrix distinguishes these types of land areas relevant for agriculture (FAO, 2021) (Appendix):

- **Cropland - arable land**
- **Cropland – permanent crops**
- **Permanent meadows and pastures**
- **Land under protective cover**

Each archetype will provide an overview of the type of applicable agrisolar solutions for the specific land cover areas as seen in Table 2. Subsequently, under each of the archetypes, a description of key aspects such as technology, applicability to crops, and other aspects will be included. It will then provide an overview of the main business models, impacts on agriculture, and biodiversity benefits arising from these archetypes. Lastly, specific operational case studies will be highlighted to showcase real-life examples for different agrisolar archetypes.

To explore the linkages between agrisolar, biodiversity, and the surrounding policy environment, three main activities were undertaken. Firstly, desk research was conducted to study the ecological impacts of agrisolar, as well as the associated policy environment. Secondly, interviews with farming representatives were carried out to uncover obstacles, opportunities, policies, and recommendations for improvements related to agrisolar. Additional interviews with solar stakeholders were also conducted to gain insights about different types of agrisolar business models, as well as to collect operational case examples.

Lastly, a workshop was organised, bringing together solar developers and farming representatives to discuss the preliminary findings from the desk research and interviews, identify gaps, and gather additional information about relevant policy links for agrisolar.

2

Agrisolar Business Models

2.1 OWNERSHIP & BUSINESS MODEL SCHEMES

The combination of agriculture and solar PV provides a variety of different business models, and can be divided based on the ownership of the farmland, agricultural activity, solar PV systems, operational management, and other aspects. An overview of three different business models and relevant components can be seen in Table . Please note that these are simplified business models with components (third-party involvement, involvement of different agricultural stakeholders, etc.) that can vary on a case-by-case basis, and are not entirely representative of all case examples. Different challenges can also occur for different types of business models.

TABLE 2 OVERVIEW OF DIFFERENT AGRISOLAR BUSINESS MODELS

<table>
<tr><th>Business Models</th><th>Energy producer owns and operates PV project (in agreement with farmer)</th><th>Farmer owns and operates the project</th><th colspan="2">Joint ownership</th></tr>
<tr><td>Management of costs and risks for PV</td><td rowspan="2">Energy producer</td><td rowspan="5">Farmer</td><td rowspan="5">Farmer</td><td rowspan="5">Energy producer</td></tr>
<tr><td>Revenue generation and benefits from PV</td></tr>
<tr><td>Revenue generation and benefits of the agricultural activity</td><td rowspan="2">Farmer</td></tr>
<tr><td>Management of costs and risks to the agricultural activity</td></tr>
<tr><td>Management of the PV system</td><td>Energy producer</td></tr>
<tr><td>Feasibility of business scheme</td><td>Commonly used</td><td>Applied on a case-by-case basis</td><td colspan="2">Innovative</td></tr>
<tr><td>Small-scale[10] [11] agrisolar projects</td><td>✓</td><td>✓</td><td colspan="2">✓</td></tr>
<tr><td>Medium[12] to large scale[13] agrisolar</td><td>✓</td><td></td><td colspan="2">✓</td></tr>
</table>

1. Energy producer owns and operates agri-PV project (in agreement with a farmer)

This type of business model is a commonly used scheme, and can be applied to all types of agrisolar archetypes. The objective is to produce renewable energy while maintaining and sustaining the agricultural activity. Some of the key characteristics include:

- All the risks and costs related to the energy production and to permit requirements, are managed by the energy producer.
- During 'development (up to 5 years) phase', PV projects involve high investments, risks and need for specialisation. In the 'construction phase', PV projects are considered 'derisked', with return on investment being lower but for a longer period of time. Solar projects, similar to real estate projects, are capitalistic and return in investments take longer to materialise. Solar players, by mastering this financial model, are offering that experience to the farmers. However, for small-scale projects, risks related to the financial aspects during the development phase can be lower.
- The energy producer receives revenues from the energy production through auctions, tenders or Power Purchase Agreements (PPAs), with different prices of electricity, length of contracts, rather fair stability and associated risks.
- Farmer who owns the land, rents it to the energy producer and performs agricultural activity, based on specific agreements with the energy producer. If the landowner and farmer are two distinct entities, the landowner rents the land, while the farmer performs the agricultural activity based on specific agreements with the energy producer which could include the use of land free of charge, and other benefits. Depending on the profitability of the agricultural activity, these benefits can include direct payments to the farmer. Agriculture activity can also be performed by a third-party.
- Costs and risks related to the farming activity are retained by the farmer. These risks can also be shared with the energy producer, and it will be based on specific agreements.
- This type of business scheme is universal and can be applied to all agrisolar archetypes.
- Applies to projects of any scale, but it is most common for medium to large-scale projects.

2. Farmer owns and operates the agrisolar project

This type of business model is rare today, but has great potential to develop in the future – especially for small-scale Agri-PV projects (below 1MWp). The objective is to improve farming activity, business, and produce renewable electricity (which can be used to support farming activity, used for self-consumption, or in some cases – sold to the grid). It applies on a case-by-case basis, given the high-investment requirements for the PV components. In most cases, this type of business model is feasible for medium to large agricultural stakeholders with investment capacity. Some of the key features of this type of business model include:

- Farmer manages all of the risks and costs as mentioned above.
- Farmer receives all the revenues and benefits of both activities (energy and agriculture production).
- Farmer manages and operates the energy production and agricultural activities.
    - This type of business scheme would mostly apply to small-scale projects (2-5 ha);
- It can be applied to all types of small-scale projects, and extend to all agrisolar archetypes.
- Often public incentives will be necessary to finance the project.

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[10] Note: small-scale projects are most often used for self-consumption and acquire faster permits. However, these types of projects can be more capex intensive.
[11] Small-scale agrisolar projects: below 1MW
[12] Medium-scale agrisolar project: range between 1–20MW
[13] Large-scale agrisolar projects: above 20MW

3. Joint venture between a farmer and an energy producer (hybrid)

This type of business model is innovative and not yet applied as a mainstream case. This type of model could be an interesting approach for both farming and solar stakeholders, while it also poses certain difficulties and uncertainties for solar developers. Some of the key characteristics of this type of a model include:

- The creation of a joint venture where the project is owned by the entity that takes on the debt with flexible/negotiated share ratios.
- Cost, risks and revenues, are shared according to specific agreements between the involved parties. However, investments and risks for this type of model are not always split equally between agricultural and energy stakeholders due to high capital required for PV installations.
- It is applicable to all types of archetypes.
- This type of business model can be applied to small-scale, medium, and large-scale PV projects.

For example, in Italy, this type of a business model is required by the government to access grants from the Recovery and Resilience Fund[14] for Agri-PV, and as a way to involve agricultural stakeholders into such projects. However, some economic challenges can arise in cases where both entities do not have equal ownership of the project. Likewise, additional challenges can appear when involving multiple partners in a joint venture.

4. An emerging business model for Eco-PV

A new type of business model is emerging, incentivising ecological services on the farmland. The objective is to produce renewable energy, while providing natural capital, ecosystem services and biodiversity improvement. In this type of a business model, PV is commonly owned by an energy producer, while the farmer manages the non-productive agricultural activity.

The main revenue stream for the farmer comes from land lease. However, as an emerging business model, some additional payments for ecosystem services provided might be applicable (for instance, carbon and biodiversity credits). Some of the main characteristics of this example include:

- Energy producer manages the risks, costs, and revenues of the energy production.
- Farmer is responsible for ecosystem service provisions.
- Applicable to Eco-PV.

2.2 REVENUE SCHEMES FOR AGRISOLAR BUSINESS CASES

As part of the business schemes, an important factor is also remuneration or revenue that the agrisolar project can bring. Depending on the type of business scheme, different revenue streams can be allocated to the farmer, landowner, energy producer, and any other stakeholders involved. Revenues can be paid through the project construction phase, operation of a solar project, or through additional services provided by the farmer. It is worth noting that revenue streams can also change depending on local regulations and local context. Furthermore, it is important to emphasise that the revenues gained from agricultural production and agricultural subsidies are mentioned, but will not be explicitly described in this section. Instead, the different revenue streams that the farmer and/or landowner can gain because of agrisolar projects will be assessed.

[14] The Recovery and Resilience Facility is the key instrument at the heart of NextGenerationEU to help the EU emerge stronger and more resilient from the current crisis.

Existing revenue streams a farmer receives during the operation of an agrisolar project

1. Revenues from sales of food production

A farmer continues to receive revenues from the sales of food production in combination with agrisolar projects.

2. Revenues from agricultural subsidies

A farmer continues receiving the financial support from agricultural subsidies (this might change depending on the national regulations for agrisolar). This also includes manure rights.

3. Revenue from ecosystem services

A farmer continues receiving revenue through carbon credits (or other applicable carbon market mechanisms). Monetisation of these services can be through other mechanisms like eco-schemes.

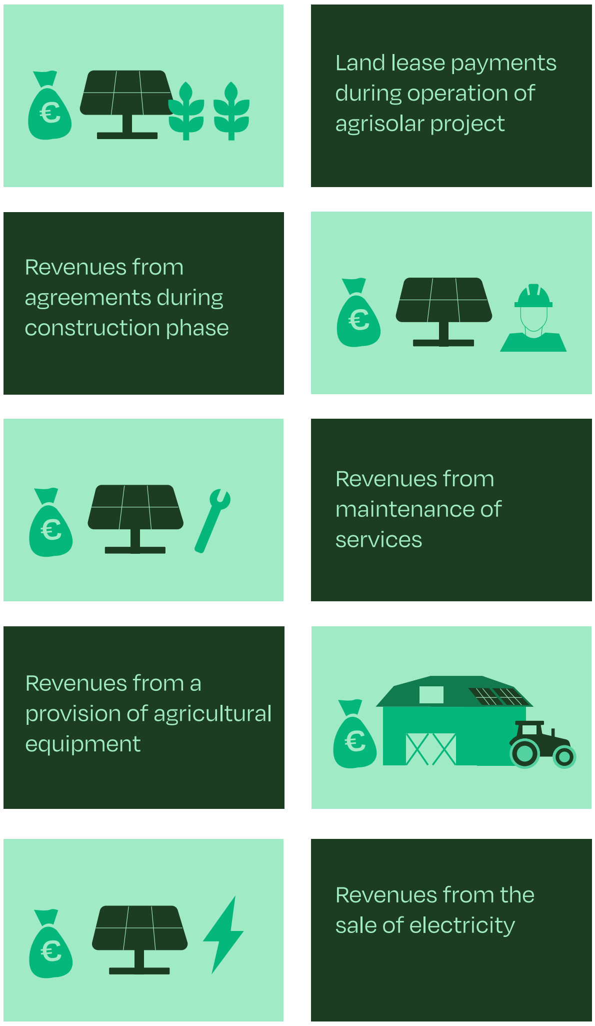
Additional revenue streams a farmer and/or landowner receives during the operation of an agrisolar project

4. Revenues from land lease agreements during operation phase:

- Land lease payments are a common type of revenue scheme usually paid through specific agreements between energy producers and farmers, and/or landowner during the lifecycle of the agrisolar pvroject.
- Land lease can be paid out per kWh, MWp, or through a fixed price paid out annually or in a single payment. Land lease payments are typically paid as amount per hectare per year. The creation of performance remuneration schemes has been ideated by some developers, and are an innovative way of involving farmers in the Agri-PV project and allows them to successfully comply with stricter regulations.
- In some instances, when the farmer is a tenant farmer, land lease incomes are paid for a farmer, and landowner. The type of financial distribution amongst the two stakeholders can change depending on the local context.
- In some cases, the farmer who is a tenant farmer can access and manage the land free of charge.

Revenue streams

Additional revenue streams a farmer and/or landowner can recieve through an agrisolar project



5. Revenues from agreements during construction phase:

- Some remuneration can be paid during the solar installations' construction, where farmers can be compensated for the loss of agricultural activity. This can be paid out in a single payment for a fixed price signed under an agreement.

6. Revenues from maintenance services:

- Farmer can be hired as a service provider for inspection, module cleaning, greenkeeping (e.g. grass cutting), or vegetation management, and remunerated for services provided.

7. Revenues from a provision of agricultural equipment:

- These types of revenues are not common case examples. However, in some instances where a farmer is a tenant farmer and has no incentive to invest in new infrastructure, energy producers can contribute with additional benefits by providing a farmer with new infrastructure. There are different types of infrastructure which can be provided and will depend on the case-by-case basis. The most common infrastructure provided by energy producers are irrigation systems. Other examples include greenhouses, water storage facilities, crop storage facilities, digitalisation, and others. However, these additional benefits can vary depending on the agricultural component and its profitability.

For projects where the infrastructure cost is high (e.g. high-end agriculture products or solar PV greenhouses), a rent payment formula is not a common and feasible business case. However, as mentioned above, farmers can be provided with new infrastructure at low cost, or fully covered by energy producers and applied on a case-specific basis.

8. Revenues from maintenance of agricultural equipment:

- Farmers can also benefit from additional maintenance services of agricultural equipment, for instance, asbestos removal.

9. Revenues from the sale of electricity:

- Farmers can also be involved in a project as investors. However, this type of revenue acquisition is rare due to high investment rates. Similarly, local participants can be involved in crowd funding.
- Farmers who own the solar PV project and use the electricity for self-consumption (powering agricultural machineries, etc), can also benefit from reduced energy bills.

10. Revenues from the land sold or transferred:

- In instances where the farmer is not a landowner, selling the land or a portion of the land can be an additional revenue stream for the landowner. In these circumstances, farmers continue agricultural activity on the land, despite the change in land ownership.
- Often farmland is excluded from inheritance tax. Hence, if the farmland remains farmland in an Agri-PV project, in contrast to a conventional, monofunctional solar park, no tax payment is necessary if the ownership of land is transferred due to inheritance.

In general, an increase in revenue streams stemming from agrisolar projects can bring not only monetary value to the farmer, but also provide economic stability and improve the farm's resilience. Securing the economic stability and income of the farm can in turn provide a farmer with better access to bank loans and debt to finance agricultural components, thereby accelerating the transition to sustainable and regenerative agriculture. Some examples can be seen in the United States (US), where the Federal Office of Energy Efficiency & Renewable Energy offers a "Farmer's Guide to Going Solar" (Office of Energy Efficiency and Renewable Energy, 2024).

3

Agrisolar Archetypes

This section will provide an overview of different types of agrisolar archetypes based on land cover classification. Furthermore, it will provide an overview of biodiversity benefits relevant for different archetypes. Lastly, it will also assess the business models relevant for each archetype, and what impact each can have on agriculture. A section on environmental benefits and operational case examples is also included.

TABLE 3 TYPES OF AGRISOLAR BUSINESS MODELS CLASSIFIED PER TYPE OF LAND COVER AREA

Agricultural Land			Land under protective cover
Arable land	Permanent crop land	Permanent meadows and pastures	
1. Elevated Crop-PV	4. Elevated perrenial-PV	6. Elevated PV with livestock grazing	9. Elevated PV greenhouses
2. Interspace Crop-PV	5. Interspace perennial-PV	7. Interspace PV with livestock grazing	10. PV on farm buildings
3. Eco-PV		8. Hay-PV	

Agrisolar provides different solutions tailored to different agricultural activities and farmer needs. Different agrisolar configurations can be described as follows:

Interspace PV

PV systems where the farming activity takes place between the rows of PV modules.

Elevated PV

Elevated PV systems where the farming activity takes place underneath the PV modules.

Specific requirements for interspace and elevated configurations can vary across Member States, and will differentiate between regulatory specifications. Some examples include:

- In Germany, DIN SPEC standard defines a minimum criterion for elevated Agri-PV with a minimum height of PV modules at 2.10m, and for vertically oriented PV modules, 0.8m.
- In Italy, requirements for advanced Agri-PV solutions set a minimum criterion of 2.10m for elevated Agri-PV, and a minimum of 1.30m in width for interspace Agri-PV with animal husbandry.

Elevated PV Greenhouse

A closed PV system where PV modules are placed on the roof of the greenhouses.

PV on farm buildings

Consists of PV modules placed on the roofs of agricultural buildings such as barns and agricultural sheds.

Eco-PV

Nature-inclusive solar PV that can be developed on agricultural land (either productive or non-productive), and provides ecosystem services.

Under CAP regulation as well as the Nature Restoration law, these PV solutions should:

- Support voluntary environmental objectives of the CAP on set-aside fallow land (art.13 of Reg 2021/2115, spec. regarding GAEC 8).
- Be adapted to provide resource-efficient land, and be eligible to access CAP Eco-schemes (art. 31 of Reg 2021/2115).
- Assist the implementation of the Nature Restoration Law, specifically in accordance with art.10 and art. 11 aimed to:
    1. Improve pollinator diversity and reverse the decline of pollinator populations by 2030;
    2. Enhance biodiversity in agricultural ecosystems;
    3. Provide access to voluntary markets through proven positive impact on ecosystems (e.g. soil carbon storage, etc).

What is not considered Eco-PV

- Vegetation management that is required by public authorities and for solar production purposes;
- Any type of environmental compensation measures that are aimed to compensate for the construction of solar installations, or the solar installation's impact on its surrounding landscape.

[15] DIN Specification: a document that specifies requirements for products, services and/or processes.

[16] Advanced Agri-PV systems are defined as:
- Where agricultural activity >70% of the area
- Ground Coverage Ratio (GCR) <40%
- Continual agricultural activity with at least 60% yield
- 2.1m height (crop) of 1.3m (animal husbandry)
- Monitoring with regards to water saving and agricultural activity continuity.

An important element to consider when developing Eco-PV parks, is the possibility of maintaining agricultural land after the lifetime of solar PV parks. The aim of the Eco-PV parks is to help farmers transition to more ecologically- friendly farming practices and/or to meet the European or national agro-environmental objectives. In a long-term perspective, agricultural land should remain agricultural land, even after the decommissioning of solar PV installations.

3.1 FARMING ON ARABLE LAND

Typically, arable land is defined as: 1) land under temporary crops; 2) temporary meadows (for mowing or pasture); 3) land under market and kitchen gardens; or 4) land temporarily fallow (< 5 years). In Europe, arable land represents around 62.3% of total agricultural land use. Arable land is ploughed or tilled regularly, usually under a system of crop rotation.

Standard agricultural activities on arable land are predominantly industrial[17] (energy crops, tobacco, oilseed, fiber crops), and non-industrial crops (cereals, root crops, fresh vegetables, strawberries, flowers, fallow land, etc.).

PV systems can be designed to fit farming activity that takes place on arable land and undergoes crop rotation without impacting or altering the farming processes. These types of PV solutions are known as Crop-PV. This chapter will provide an overview of the following three archetypes:

- **Elevated Crop-PV**
- **Interspace Crop-PV**
- **Eco-PV**

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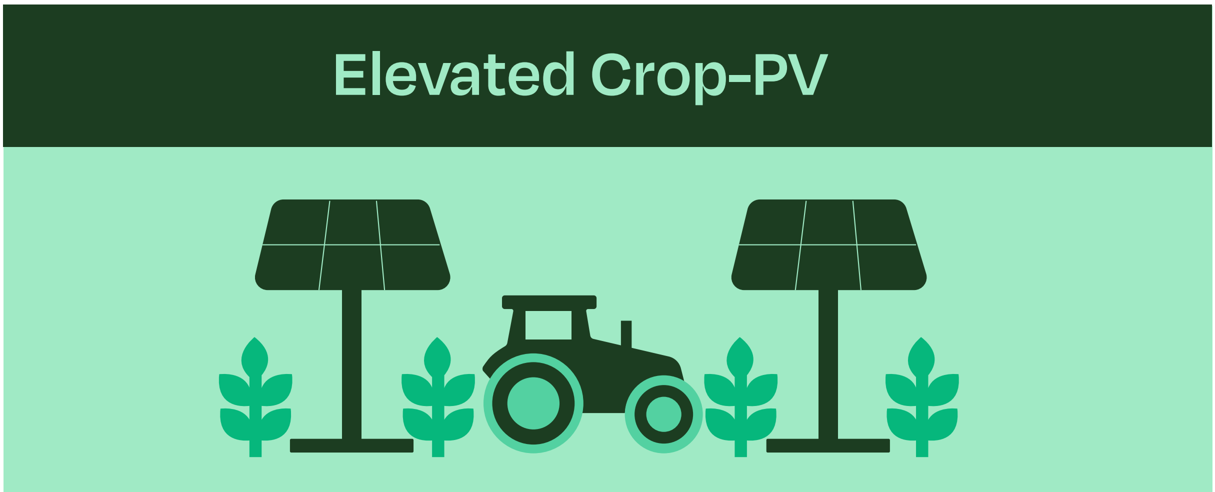
Industrial crops are crops which are normally not sold directly for consumption, because they need to be industrially processed prior to the final use. European Commission (2023): Eurostat Glossary: 'industrial crops'.

ARCHETYPE 1: ELEVATED CROP-PV



Elevated Crop-PV refers to PV systems installed above crops grown on arable land. These types of systems are adjusted to the specific requirements of agricultural machinery for sowing, spraying, and harvesting throughout the season. Likewise, these solutions are well adapted to fit with the regular crop rotation by using fixed-tilt systems, or by adjusting tracking systems or developing mobile PV solutions. These configurations will depend on the type of crop, and light needs.

Business case

Elevated Crop-PV is not a commonly applied business model, and covers only a marginal installed capacity of Agri-PV projects in Europe. This is due to economic constraints: Elevated Crop-PV systems naturally require higher investment needs due to an increase in expenses for materials with an average increase in costs between 20 to 60%. Subsequently, the more complex the Agri-PV structures, the higher the costs for an Agri-PV system. Whether PV modules are installed on a rooftop, ground-mounted or an Agri-PV project, should not have an impact on the cost. The difference of cost will depend on the infrastructure supporting the panels. The higher the structure is, the higher the cost, and even more so when the structure includes trackers or other technology.

The most common business scheme applied for Elevated Crop-PV can be either: a) where the energy producer owns and operates the project (in agreement with a farmer); or b) where farmer has a full ownership of the project. Currently, these types of projects are small-scale projects with a potential to scale up. A common remuneration scheme provided for these solutions include land lease payments and/or provision of the installation.

Impact on agriculture

The number of operational Elevated Crop-PV projects in Europe is marginal; therefore accessible data on the effects on crops and land from these projects is small. However, there is growing evidence that these projects not only take up a small amount of land (up to 25%), but can also provide protection for the crops from climate hazards and potentially increase crop yield.

Environmental benefits

Elevated solar panel installations enhance water retention capabilities, reduce evapotranspiration rates, and mitigate increases in mean ground temperature. These measures collectively benefit crop productivity, while conserving water resources. Biodiversity strips can be sown, and alternative ecological farming practices can be applied, such as a reduction in pesticide use.

Case Example 1

Lovenjoel /TRANSfarm experimental Agri-PV site (KU Leuven); Lovenjoel, Belgium

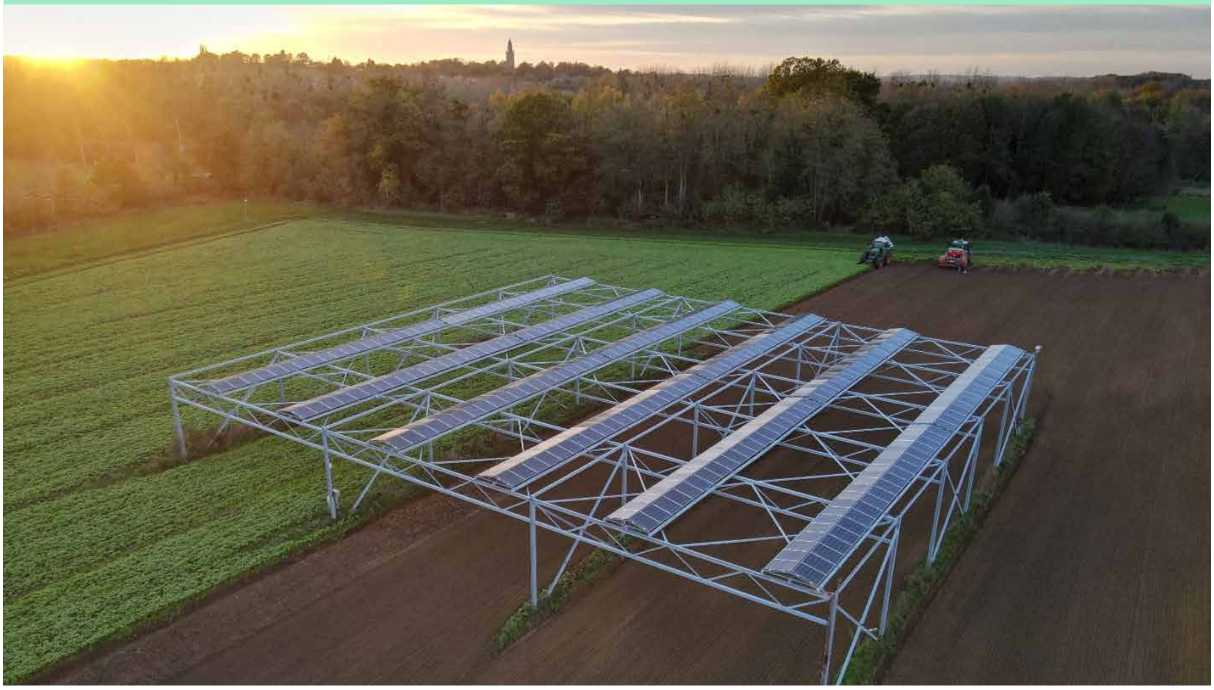
Technical Features
The structure is made up of a straightforward elevated design, reaching a height of 5m spanning 13m per section. To limit the size of the steel structure, panels are placed in a pitched roof shape of 12°. In this setup, ground coverage ratio can be adjusted annually or seasonally to fine-tune shading to the relevant crops at that time.

Agricultural acitivity
Rotation with wheat combined with other field vegetables.

Business Model
A research project carried out by KU Leuven. The PV system is operated by KU Leuven itself; the agricultural activity is managed by KU leuven TRANSfarm (their agricultural research platform). The PV system was installed by Solare under the supervision of KU Leuven technical services.

Environmental Benefits
The research will monitor variety of aspects, including:

- Ambient temperature, wind speed, wind direction, humidity
- Rain
- Relative humidity at different heights
- Permanent and variable PAR sensors
- Ambient temperature and humidity at canopy



©KU Leuven

ARCHETYPE 2: INTERSPACE CROP-PV

Interspace Crop-PV covers PV systems installed in the space between crops. These types of systems are adjusted to the specific requirements of agricultural machinery for sowing, spraying and harvesting the yield in between the PV panels throughout the season.

Likewise, these solutions are well adapted to fit with the regular crop rotation by adjusting tracking systems or developing mobile PV solutions. Interspace PV systems can be fixed-tilted systems, tracking systems, or bi-facial vertical PV installations.

Business case

Interspace Crop-PV is a novel and emerging business model in Europe with great potential to accelerate in coming years. In terms of costs, this type of Agri-PV solution is a viable business model due to the lower costs required for developing and operating the PV system. However, larger amounts of land may be required to ensure economic viability of the energy production.

The most common business scheme applied for Interspace Crop-PV is where the energy producer owns and operates the project (in agreement with a farmer).

The most common remuneration scheme provided for these solutions are land lease payments as well as land lease free cultivation. In the area of vertical bifacial systems, so-called cooperation projects are also not uncommon, in which the farmer shares the investment and consequently, the financial project income with the company developing and operating the project.

Other types of remuneration are possible and will vary case-by-case. Costs related to construction and operation of these PV systems are relatively smaller than those of Elevated Crop-PV. This is due to the height and composition of the PV structures.

Impact on agriculture

The few operational Interspace Crop-PV projects show promising results in terms of agricultural yields where panels provide shade to the crops. However, the number of operational projects of this kind in Europe is limited, which means we have little data on the impact on agriculture, but pilot projects are becoming prominent in Europe.

Impact on agricultural land stemming from these types of configurations will depend on spacing between the PV modules and the Ground Coverage Ratio (GCR) of these systems.

Regulations at national level can also make a difference, where maximum land coverage by PV is determined, as well as the minimum yield and land area that needs to be maintained for agricultural purposes. Relatively low impact on land and therefore crops, and the space between the rows, ensures only marginal impact on agricultural practice.

Interspace Crop-PV similarly to Elevated Crop-PV has the potential to provide multiple services to agriculture, including livestock well-being, water savings, soil erosion risk mitigation, and adaptation to climate change, all of which are crucial for maintaining and/or improving agricultural production.

Environmental benefits

Elevated solar panel installations enhance water retention capabilities, reduce evapotranspiration rates, and mitigate increases in mean ground temperature. These measures collectively benefit crop productivity, while conserving water resources. Biodiversity strips can be sown, and alternative ecological farming practices can be applied, such as a reduction in pesticide use.

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Case Example 2

Eco-Solar Biotope, Pöchlarn, Lower Austria; RWA

Installed Capacity
4090.6 kW

Technical Features

- 3x rows of Fixed-Tilt
  - South-facing ground-mounted panels
  - Flowering strips 2m
  - 13m pitch between PV-rows with winter wheat

- 2x rows of Tracking
  - East-West tracked panels
  - Flowering strips 2m
  - 13m pitch between PV-rows with winter wheat

Business Model

- The land is owned by RWA AG. Cultivation of winter wheat is managed in cooperation with the Higher Federal Institute of Research and Education (HBLFA Josephinum Wieselburg) and the University of Natural Resources and Life Sciences (BOKU). RWA owns and operates the PV system. The farmer receives remuneration for the agricultural activity performed.

- This project is part of a research project; the farmer is contracted for specific agricultural activity, no land lease payments are applicable.

Environmental Benefits

- Reduction in water use due to panel shading.
- Reduction in soil erosion due to shading and retention of soil moisture.

Other benefits

- Use of the site as a testing facility for various agricultural techniques, and help to identify effective methods for integrating farming with solar.

- Use of the site as an example to educate the wider public.

©RWA

Case Example 3

Symbizon - ecologically friendly strip farming, Netherlands, Vattenfall

Installed Capacity
0.7 MW

Technical Features
Single-axis trackers, bifacial PV modules

Land
Ground coverage ratio (including reference area) is approximately 10%. The row distance between trackers is 15m and 9m (two different row distances are used for research purposes).

Agricultural activity
Different types of crops will be sown such as potatoes, sugar beet, grass clover, oats, celery etc.

Business Model
The land is owned by the governmental organisation Rijksvastgoedbedrijf (RVB), while ERF/HEMUS provides the agricultural function. Vattenfall develops and operates the PV system. The project was connected to the grid in autumn 2024. The farmer will have the possibility to steer the trackers. The farmer will receive a land lease payment via RVB.

Environmental Benefits
The project is expected to be connected to the grid in 2024. From 2024 onwards, data will be monitored on the soil and crop quality, as well as the agricultural output. The project foresees that no chemicals or pesticides will be used in the field. In addition, biodiversity strips will be seeded underneath the PV modules.

Other benefits
Reports will be published based on the research results from the field; these papers will provide substantial data on Agri-PV in the Netherlands.

©VATTENFALL

Case Example 4

Agri-Solarpark Merzig-Wellingen, Merzig-Wellingen, Germany, Next2Sun

Installed Capacity
5.3 MW

Technical Features
Vertical bifacial PV installation; distance from the ground to the PV module is approx. 0.8m, height of the system – is approx. 3m. Most rows of modules are installed parallel to each other with a row spacing of 10m (East-West orientation). The system also integrates some other orientations, and some rows have the role of fencing the facility. The system covers less than 1% of the agricultural land, and is operated in combination with a stationary electrical storage system (nominal power of 400 kW and capacity of 1300 kWh).

Land
Ground coverage below 1%. About 10% of land is used for flower strips, 90% of the land is farmed.

Agricultural activity
Crop rotation consists of winter wheat, winter barley, and peas, with additional greening of catch crop before the peas.

Business Model
- Next2Sun has built the plant and provided their patented racking system, as well as their optimised modules.
- Ökostrom Saar Wind GmbH runs the system and has rented the area to develop and operate the Agri-PV system.
- Land lease payments from Agri-PV operators are provided to the farmers.
- The owners of the land are 2 farmers who are also cultivating the area rent free.
- The farmers continue receiving CAP subsidies.
- The farmers also takes part in the research project and receive payment for the agricultural services provided.

Agronomic results
- The yield studies conducted in 2024 as part of the accompanying research carried out at the Wellingen site by the project, VAckerBio 2, produced very different results:
    - o University of Hohenheim found that despite the above-average dark and wet year, barley achieved tolerable losses in line with the weather conditions. While peas showed a significant yield loss within the Agri-PV system, the wheat developed a slightly better grain yield within the system.
    - o In addition to the wet weather conditions, this may also be due to differences in soil quality inside and outside the Agri-PV system. As the research project has just started, further and more reliable results can be expected over the coming years.

Environmental Benefits

- On 10% of the project area, both flowering and old grass strips have been established under and next to the module strips, which are being monitored by the German Julius-Kühn-Insitute (JKI).
- Initial early results by JKI indicate that the biodiversity measures have led to a higher abundance of flying insects within the Agri-PV system, despite conventional management including the use of pesticides.

Other benefits

- Several landscape features are integrated into the project:
    - o A walking path north of the Agri-PV project: Implementing a reduced height (only 1 PV module per element) in the upper part (near the path), ensures a minimal visual impact and an unobstructed view.
    - o A meadow with fruit trees has been implemented between western and southern sections – these are used by wild animals to bypass the park.

FLOWER STRIP, UNIVERSITÄT HOHENHEIM © NEXT2SUN

OAT THRESHING © NEXT2SUN

ARCHETYPE 3: ECO-PV

Eco-PV refers to commonly applied PV solutions which are recognised as the most nature-friendly form of PV installation (Tölgyesi et al.,2023). Eco-PV integrates ecological principles with PV technology and has numerous environmental benefits (Sturchio & Knapp, 2023; Semeraro et al., 2018). Eco-PV prioritises minimising ecological footprint and maximising biodiversity benefits, making them pivotal in sustainable agrisolar initiatives. Eco-PV includes PV systems combined with ecosystem services that can be developed on productive or non-productive agricultural land (set aside fallow land), allowing the farmer to benefit from additional revenue streams and/or implement nature-friendly practices on their land. These types of PV systems on productive agricultural land are widespread and are applicable to large-scale projects. However, there are less well-known projects being developed on fallow lands. Eco-PV can be combined with Agri-PV practices by alternating areas of agricultural production and areas for soil restoration and biodiversity proliferation.

A common Agri-PV evaluation methodology of the Eco-PV system is recommended, if not necessary, to meet the optimal agricultural land-use requirements in the long term, e.g. in the event of necessary land-use changes (organic meadow to mowed pasture or necessary ploughing of the area to maintain the grassland status) or for the reintegration of the land into productive agriculture.

The Common Agricultural Policy specifically provides requirements for the fallow land or set-aside land for EU farmers. These basic requirements are laid out under the CAP regulation and set baseline conditions that need to be met and are known as Good Agricultural and Environmental Conditions (GAEC) (European Commission, 2024). GAEC standard 8 requires, among other things, an allocation of a minimum share of arable land to non-productive areas (lying fallow). Following protests from the agricultural sector, the European Commission reviewed this GAEC rule in spring 2024. Therefore today, all European farmers are exempted from the obligations provided that other measures such as growing Nitrogen Fixing Plants or catching crops, on 7% of their land, will be implemented. Farmers who continue setting aside fallow land can potentially benefit from developing Eco-PV given no restrictions on national or regional level exist.

Other forms of additional remuneration schemes for farmers also exist. CAP Eco-schemes (art. 31 of Reg 2021/2115) aim to reward active farmers or groups of active farmers who commit to agricultural practices beneficial to the climate, landscapes and environment, and animal welfare. A farmer introducing Eco-PV could benefit from direct CAP subsidies, specifically from the voluntary eco-schemes (applicable for permanent cropland and arable lands) where actions on biodiversity enhancements, soil protection or

Business case

The Eco-PV business model is a common solution applied throughout Europe due to its economic feasibility and environmental benefits. Even though the costs for this type of solution are viable (Eco-PV has the lowest cost implications in comparison to other Agri-PV configurations), the main challenge to the rollout of this business model is the legal implications related to accessing CAP subsidies and having these multi-land use solutions recognised as compatible with agricultural practices.

The most common business scheme applied for Eco-PV is where the energy producer owns and operates the project (in agreement with a farmer).

In cases where a farmer manages the agricultural activity, they can receive a remuneration for land lease as well as for other types of the services provided by the farmer, for instance environmental practices.

Impact on agriculture

Impact on agriculture is minimal since Eco-PV is primarily destined for set-aside land. Other benefits can include improved ecosystem services on agricultural land. A main barrier for deploying Eco-PV is the access to CAP subsidies (in relation to GAEC 8 and eco-schemes) and compatibility of PV installations on fallow lands, which may vary across Member States.

Environmental benefits

Fallow land is arable land that is commonly set aside for a rest period before it is cultivated again. The ecological improvements in these sites can be high, provided that the right system design is used. For instance, improvements on reduction in soil erosion, water retention and biodiversity enhancements are possible. However, more data from operational studies is required.

©WATTMANUFACTUR

Case Example 5

Sustainable solar parks – Enel Green Power

Technical Features
Standard Ground Mounted-PV modules (height of 2.2-2.5m).

Land
Different types of land have been used to test various tailor-made agrozootechnical solutions (agricultural land, marginal unused land, etc). The characteristics of the land were based on different criteria – sites with different operational years, different soil characteristics, to assess the feasibility and impact within the selected area in different climate zones.

Agricultural activity
Crops with boosting effect on biodiversity and ecosystem services have been implemented in the experimental host sites, as leguminous crops as vetch enabling the nidification for birds' steppe and flower mixes and aromatics species, that are beneficial for pollinators (both domestic and wild ones).

Business Model
This is a research project, developed by Enel Green Power S.p.A., with an open and collaborative multi-stakeholder approach, through partnerships with universities and research institutes, industrial companies, engineering firms, non-profits and start-ups, agricultural partners on the basis of the Open Innovability® approach, which aims at seeking out the best ideas and resources also outside of the company. In this way, very specific and complementary fields of expertise have been brought onboard to ensure a global approach in the definition of the demo programme.

Environmental Benefits
Monitoring sites in:

Spain
- Implementation of habitats for wild and domestic pollinators
- Implementation of habitats to protect steppe birds

Greece
- Creation of ecological corridors
- Implementation of habitats for wild and domestic pollinators

Italy
- Implementation of flower strips and aromatics to enhance wild and domestic pollinators (bumble bees, etc)

3.2 FARMING ON PERMANENT CROPLAND

Typically, land under permanent crops is defined as land cultivated with crops that occupy the land for long periods and do not need to be replanted after each harvest cycle. In Europe, permanent crops represent around 7.1% of total agricultural use. Standard agricultural activities on permanent cropland are perennial crops (fruit trees, vines, citrus and nut trees, etc.).

Similarly to arable land, PV installations can be well designed to fit the agricultural needs of growing crops on permanent lands without impacting or altering the farming processes. These types of applicable PV configurations are known as Perennial-PV. This chapter will provide an overview of the following three archetypes:

- **Elevated Perennial-PV;**
- **Interspace Perennial-PV;**
- **Eco-PV;**

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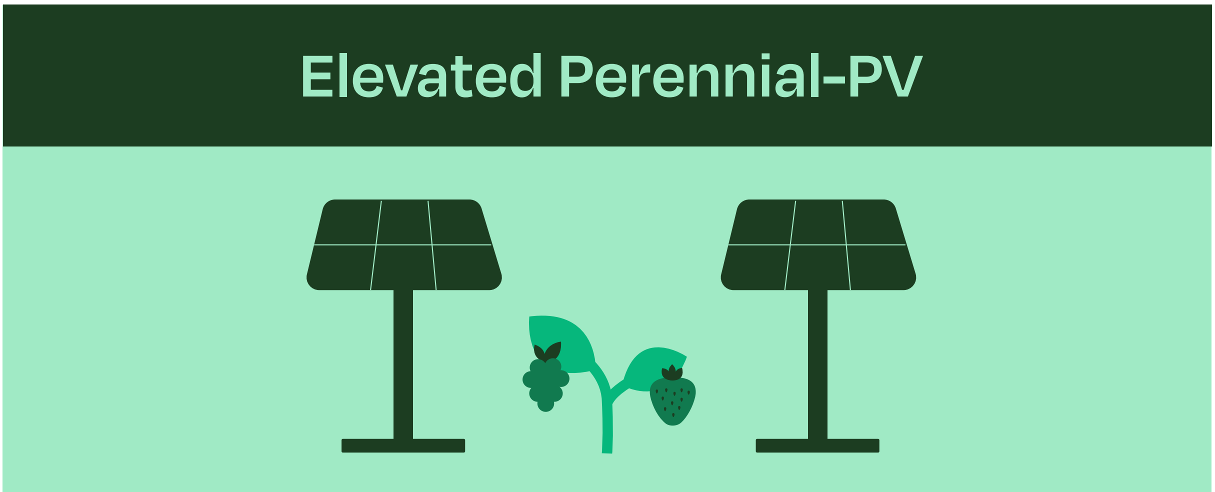
ARCHETYPE 4: ELEVATED PERENNIAL-PV



Elevated perennial-PV is defined as PV modules placed above crops in the form of shelter, and are combined with various types of permanent crops by well-designed and adapted PV systems to fit the climatic and technical conditions, as well as the light conditions for the different cultures; these systems often deploy semi-transparent PV modules. Semi-transparent PV modules allow for modulated radiation on crops, which can be altered depending on crop needs (shade or light loving crops) to preserve the crop yield. These types of systems are well-established in Europe and have been operational for many years.

Business case

An applicable business scheme for Elevated Perennial-PV can be either: a) where the energy producer owns and operates the project (in agreement with a farmer); or b) where the farmer owns the project fully. Currently, these types of projects are small-scale projects with the potential to scale up. Elevated Perennial-PV can require higher investment costs due to increased material costs, which can be 30-50% higher than other Agri-PV configurations. (BayWa r.e. 2023). The most common remuneration scheme provided for these solutions are land lease payments. In addition, for some high-end crops using protective structures, the provision of dual solar production or agricultural protection installations, can also be part of the business case; instead of the farmer purchasing protective equipment, the energy producer provides the farmer with an integrated protective structure, i.e. integrating the solar modules.

Impact on agriculture

These systems can protect crops from adverse climate impacts such as frost or high temperatures, and maintain or, where possible, provide higher yield during adverse weather events. However, improvements in crop yield will vary case-by-case. Impact on land uptake by solar installations is minimal and can vary depending on the technology or applicable national requirements.

Environmental benefits

Elevated solar arrays contribute to improved water retention in the soil and mitigate extremes in microclimatic conditions, protecting crops from damage due to hail or heavy rainfall, and ensuring optimal growing conditions for perennial crops. These systems show promising results in terms of water savings (up to 25%) and reduction in pesticide use due to better ventilation underneath the PV modules.

Case Example 6

Elevated Perennial-PV: Babberich raspberry plants in the Netherlands, BayWa r.e.

Installed Capacity
2.7 MW on 3.3 ha; powers approx. 1,250 households.

Technical Features
Fixed tilt, semi-transparent PV modules.

Agricultural activity
Raspberry cultivation.

Business Model
The land is owned and managed by the farmer who receives land lease payments. The operation and maintenance of the PV system is provided by the developer who sells the electricity to the grid. The farmer also receives remuneration for additional greenkeeping services provided.

Agronomic results
- Increase in crop yield due to PV panel protection against strong winds and adverse weather condition.
- Same fruit weight in terms of g/fruit observed under the PV modules and in the reference area.
- In 2024 during the heavy rain season, more production of red currants was observed in comparison to the field reference.

Environmental benefits
- Observed better livelihood of bees underneath the panels (whereas in plastic tunnels more mortality of bees is observed).
- Water savings of 25% underneath the PV modules.
- Less pesticide use due to rain protection and better ventilation.

Other benefits
- In periods with temperatures above 30°C, maximum temperature observed under the PV modules was 1.8°C lower than under the plastic covers, providing better working conditions.
- Farmer does not have to replace plastic covers every 3 years and wooden poles every 7 years.

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Case Example 7

Tresserre – Dynamic Agri-PV with solar erasure, Tresserre, France, Sun'Agri

Installed Capacity
2.1 MW

Technical Features
Single axis, AI piloted trackers.

Land
4.5 ha Agri-PV installation and 3 ha control area. Ground coverage ratio is approximately 37%. Row distance between trackers is 2.25m, panel height is 4.5m.

Agricultural activity
Three different grape varieties (Grenache B, Chardonnay and Marselan).

Business Model
The farmer manages the agricultural activity, whereas the PV system is managed by the developer. The farmer can also participate in the management of the PV system through a phone application (under certain circumstances). The project is installed free of charge for the farmer and provides them with significant agronomic services. Notably, the energy is sold to the grid. Currently, the farmer does not receive CAP subsidies. However, the farmer will be able to receive CAP payments under the new French Decree [19] .

Agronomic results

- This project demonstrates that dynamic Agri-PV with solar erasure (light sharing between PV and crops) can boost crop yield by 10% to 20% under panels compared to the control plot.

- The installation effectively protects against climatic hazards. In winter, temperatures under the panels are up to 2°C higher, which helps prevent crops from freezing. In summer, dynamic panels reduce leaf sunburn and extend the growth period of vines.

- The installation significantly enhances the final quality of wine. By regulating sun exposure, it reduces the sugar concentration, increasing acidity by 9% to 14%, limiting the impact of climate change on wine quality. Limited heat exposure also promotes the development of aromatic compounds.

- The shade provided by the installation reduces water consumption by 20%.

Biodiversity benefits

- This site has no negative impact on local biodiversity. It even provides shelter for certain local avian and reptilian species.

[19] According to French Law (Art 54 – APER), Agri-PV installations are compatible with CAP direct payments.

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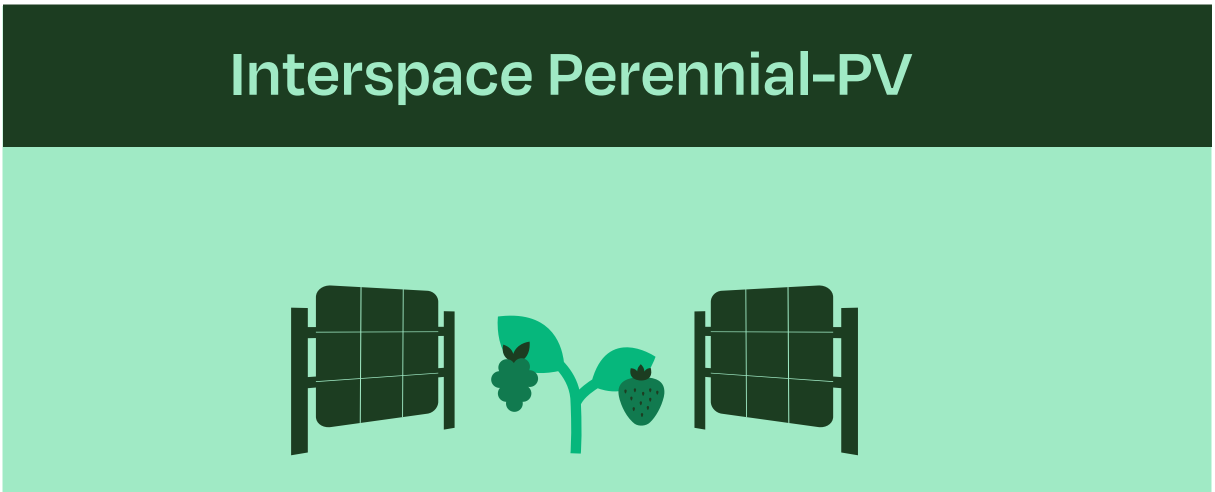
ARCHETYPE 5: INTERSPACE PERENNIAL-PV



Interspace Perennial-PV refers to PV modules placed between crops and can be combined with various types of permanent crops through well-designed and adapted PV systems using fixed-tilt or tracking PV systems. These systems can also protect crops from adverse climate impacts and maintain or, where possible, provide higher yield during adverse weather events by, for instance, using the tracking systems to adapt to the physiological needs of the crops as well as to optimise PV production. These types of systems can also be adjusted to the specific requirements of agricultural machinery to harvest the yield.

Business case

These types of installations are not commonly deployed in Europe, with only a few research projects operational in some of the Member States. Theoretically, a common business scheme applied for this type of system would entail the energy producer owning and operating the PV project, in agreement with a farmer. Other types of ownership schemes are also possible (see case example 6). Interspace Perennial-PV can be a viable economic business model due to cheaper costs for the system. However, for optimal energy production, more land might be required. Land lease payments are an applicable business model.

Impact on agriculture

These systems can protect crops from adverse climate impacts such as frost or high temperatures (for instance with tracking systems) and maintain or, where possible, provide higher yield during adverse weather events.

Environmental benefits

In permanent crop settings, the interspace placement of PV modules fosters enriched local vegetation, thereby promoting biodiversity and encouraging greater wildlife activity underneath the panels. This configuration reduces soil disturbance, preserves carbon storage, and improves water retention while lowering evapotranspiration, therefore enhancing ecosystem resilience. These systems show promising results in terms of water retention (up to 20%). However, further monitoring of soil and biodiversity benefits needs to take place.

Case Example 8

Winesolar, Toledo, Spain, Iberdrola

Installed Capacity
40.5 kW

Technical Features
3 rows of trackers with 16.5m distance between rows; trackers are interspersed every 4 rows of vineyard. Rotation of the panels is automated using software developed specifically for this project.

Land
Area covered by the panels is close to 360m2, while the vineyard area involved on the Agri-PV system is 606m2.

Agricultural activity
Cultivation of high-performance vineyard whose production is dedicated to distillate for spirit drinks.

Business Model
Land is owned by the farmer who manages the farmland. The PV system was installed by Smart Solar Iberdrola. The project is owned and operated by the farmer (Viñedos del Río Tajo, which is a joint venture of Group Emperador and Gonzales Byass).

The income is based on two revenue streams:

- Self-consumption of energy produced
- Increase in production of grapes
- A possibility to obtain grid permit is under assessment and might create an additional revenue stream for the farmer

The farmer can continue receiving CAP subsidies (if these rights were previously held and in compliance with strict environmental standards).

Environmental benefits
Data on water savings and impact on agricultural production has been assessed at the end of the harvest year (in September 2024). An indicative data shows:

- Less burnt leaves in shade areas (under PV panels)
- 20% reduction in water consumption

Other benefits

- Decarbonisation of the production process: PV system produces 60 MWh/year and equals to non-emitted CO2 of 14.76 kg
- This Agri-PV system also powers a charging facility for electric vehicles free of charge (for the employees of the company)

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3.3 FARMING ON CULTIVATED PERMANENT MEADOWS & PASTURES

Permanent meadows and pastures are lands that are permanently used for 5 or more years through cultivation of grass fodder crops, forage or energy crops, or through natural regeneration (self-seeding). Permanent meadows and pasture are not included in the farm crop rotation, and can be used for grazing, mowing or hay production. In Europe, permanent meadows and pastures take up vast amounts of land, covering 30.5% of European agricultural land.

PV systems are well-designed to fit the farming activity that takes place on permanent meadows or pastures. These types of PV solutions are known as PV with livestock grazing and can be divided as follows:

- **Elevated PV with livestock grazing;**
- **Interspace PV with livestock grazing;**
- **Hay-PV;**

ARCHETYPE 6: ELEVATED PV WITH LIVESTOCK GRAZING

Elevated PV with livestock grazing involves PV modules placed above the livestock in the form of a shelter. Some common solar applications include grazing with sheep and cows or other larger animal livestock. Usually, PV systems will be adapted to the needs of the farmers and to the livestock, so they can graze underneath the PV modules or seek shelter in extreme weather conditions.

Business case

Elevated PV with solar grazing is a common type of solution used in Europe. Elevated PV with solar grazing can be a viable economic solution but can vary depending on the type of livestock. The cost for higher elevated PV systems (including those applicable to larger livestock) will be higher and increase Levelised Cost of Electricity (LCOE) by 20-40%). Whereas elevated PV systems for poultry will be lower due to reduced costs for the installation and materials used.

Impact on agriculture

These systems can improve the wellbeing of livestock due to the shade or cover provided which provide protection from adverse weather conditions. The system should be designed in such a way that livestock can continue to take place on the land. The effects of the PV system on the microclimate should therefore also be taken into account when designing the system, in a similar way to Crop-PV systems.

Environmental benefits

Elevated agrisolar configurations contribute to animal welfare by providing shaded areas that mitigate heat stress during hotter months. These configurations can also provide improvements in soil health and a reduction in water usage.

Case Example 9

Elevated PV systems with solar grazing: Tützpatz solar park in Germany, Vattenfall

Power
77 MW

Technical Features
South-facing fixed modules with high inclination; single-axis tracking.

Land
90% of the land is actively farmed.

Agricultural activity
Organic free-range chicken (fixed modules), grass (trackers).
Different types of crops are based on crop rotation for the area with single-axis tracking systems.

Business Model
The farmer owns and manages the land; Vattenfall develops and operates the PV system (the farmer is able to steer the trackers); project has a signed Power Purchase Agreement (PPA).

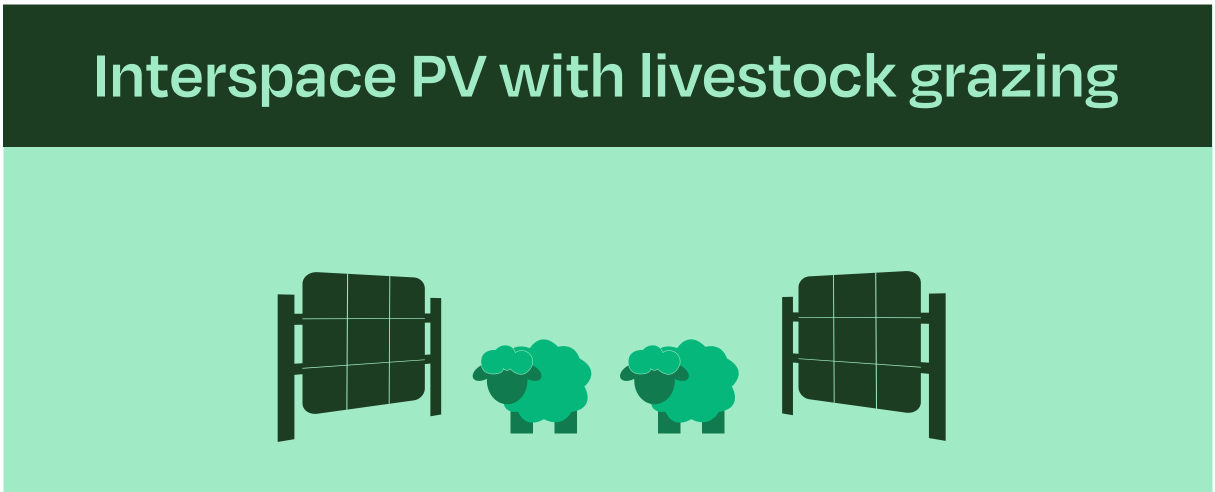
Revenues
- Farmer receives additional revenue from PV developer paid through a fixed fee per ha for leased land.
- Farmer will have a small share in the project.
- Additional revenues will be secured for the farmer by providing greenkeeping and operational activities.

Agronomic results:
- To be monitored once the project is operational (2024).
- Less nitrogen accumulation in smaller places, as a result of poultry manure being more evenly spread across the field due to the mobility of chicken boxes.

Environmental benefits
- Results on evaporation will be monitored.
- Improvements in animal wellbeing due to shade and protection provided by PV modules.

Other benefits
- Involvement of local parties to showcase the variety of Agri-PV projects applicable to different farming systems, and sharing knowledge at local and regional levels.

ARCHETYPE 7: INTERSPACE-PV WITH LIVESTOCK GRAZING



Interspace PV with solar grazing involves PV modules placed in rows where livestock can freely move between the rows, or underneath the PV modules. Similarly, as described above, the most common applications include grazing with sheep. However, animals such as pigs, poultry, and other smaller livestock animals can also cohabit on solar PV sites. Usually, PV systems will be adapted to the needs of the farmers, and particularly to the livestock, so that they can graze in between or below the PV modules.

Business case

Interspace PV with solar grazing is a commonly used solution across Europe. This type of solution is a viable business model and has a marginal increase in costs for construction and operation (LCOE increase between 0-10%). The most common business model applied for this type of system is where the energy producer owns and operates the PV project (in agreement with the farmer). Common remuneration schemes for farmers include land lease payments. The farmer can also receive additional remuneration for services provided such as grass cutting around the PV modules.

Impact on agriculture

These systems can improve the wellbeing of livestock due to the shade or cover provided to protect from adverse weather conditions. In addition, switching to more sustainable farming practices such as livestock grazing can provide better quality and higher yields for longer periods. The system should be designed in such a way that livestock can continue to take place on the land. The effects of the PV system on the microclimate should also be taken into account when designing the system, in a similar way to Crop-PV systems.

Environmental benefits

In pasture-based agrisolar systems, PV modules situated in interspaces contribute to reduced soil disturbance and allow for increased animal abundance. The areas beneath the panels, the latter being placed closer to the ground, are not grazed by livestock and can be used by birds, reptiles and mammals as a shelter and nesting place. This setup creates favourable conditions for solar energy production, livestock management, and biodiversity. Thanks to these systems, improvements in soil health (reduction in soil erosion), and reduction in water use can be observed.

Case Example 10

Interspace PV with livestock grazing: Fontenet Agri-PV project with sheep grazing in Charente Maritime, France, BayWa r.e.

Installed capacity
12 MW

Technical Features
PV modules (mounted on steel tables) are placed at a height about of 2.50m; rows of the tables are spaced about 4.5m in width.

Agricultural activity
Sheep and meadows (sown in agreement with the farmer).

Business Model
BayWa r.e. developed and operates Fontenet 2 and 3; the Fontenet 1 site was constructed and is operated by BayWa r.e. France.

BayWa r.e. provides and manages environmental services. Sheep farmers perform agricultural activity (sheep grazing) following technical and environmental guidelines.

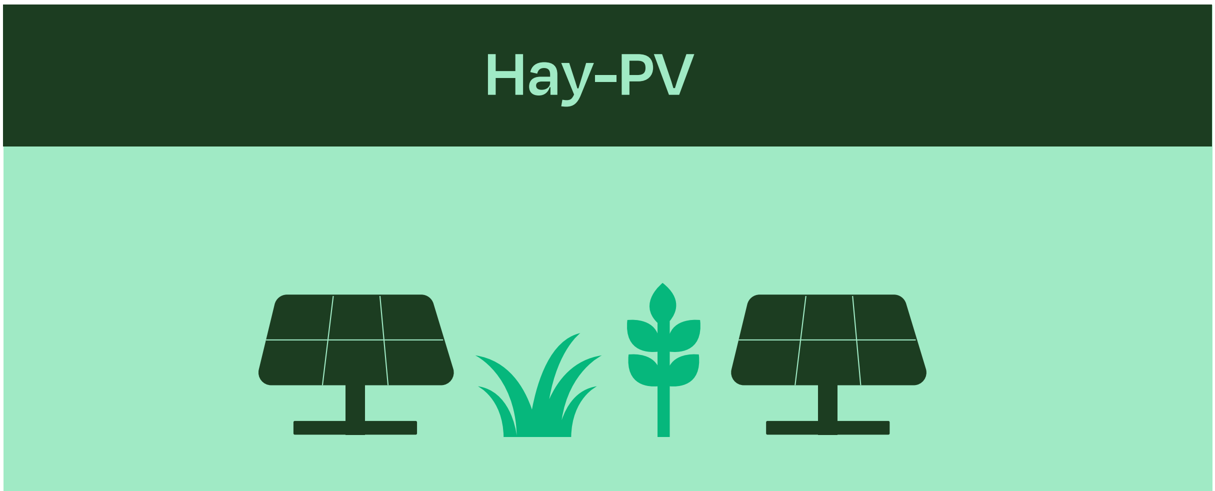
Revenues
- The farmer receives the land free of charge and, due to such an arrangement, is able to expand his sheep flock.
- The farmer and the service providers signed a usage-loan agreement. Based on this contract, the farmer receives additional revenues for services provided, including:
  - Grazing maintenance on the site.
  - Other services based on agreed terms and equipment available, e.g. shredding unwanted vegetation, maintaining adjacent areas, localised mechanical mowing for forage.
  - Water costs are not borne by the farmer.

Environmental results
- Former military site undergone pyrotechnical decontamination of site plots.
- Rehabilitation of the site, which has not been used for agricultural purposes in over 50 years, to a grazing site.
- Rehabilitation of artificial areas (e.g. concrete) to natural zones.
- The presence of numerous dry grasslands containing the thyme blue butterfly.
- Creation of ecological corridors (hedges and shrublands) and reservoir areas (woodlands, dry grasslands).

Other results
- 20-60% shading rate in-between rows, 80-90% below the modules.

Social benefits
- Involved partners to provide local seeds.
- Environmental consultancy to conduct ecological studies.

ARCHETYPE 8: HAY-PV



Hay production is recurrent agricultural production in Europe. Producing and storing hay is part of management practices in pasture and meadow landscapes. Hay is collected and stored to dry and later be used as animal feed. Hay is very compatible with PV installations, and can be sown and grown in between PV modules and harvested with agricultural machinery. There are several installations deployed and operational around Europe, showcasing the potential of this PV solution. Commonly used applications include fixed-tilted, vertical PV, or PV installed on tracking systems. These PV solutions are adapted to the requirements of the farmer, for example, by ensuring adequate row distances and height to suit the machinery used for harvesting the hay.

Business case

Hay-PV is a solution deployed in Europe with the potential to scale up in the coming years. Hay-PV can be a viable business solution and have a marginal increase in costs for construction and operation depending on the type of technical features. Generally, costs for Hay-PV are relatively low compared to, for instance, Elevated Agri-PV configurations, with an average increase in LCOE of between 10-20% (BayWa r.e., 2023). The most common business model applied for this type of system is where the energy producer owns and operates the PV project, in agreement with a farmer. Common remuneration schemes for farmers are land lease payments.

Impact on agriculture

Like other interspace configurations, Hay-PV systems can provide benefits to the crop (forage) through sustaining multiple services, including but not limited to: adaptation to climate change and protecting crops from adverse weather; water savings; and providing improvements in soil health.

Environmental benefits

In pasture-based agrisolar systems, PV modules situated in interspace contribute to reduced soil disturbance and facilitate a growth in wildlife populations. The areas beneath the panels, which are not grazed by livestock, can be used by birds, reptiles, and mammals as shelter and a nesting place. This setup creates favourable conditions for solar energy production, livestock management, and biodiversity. Thanks to these systems, improvements in soil health (reduction in soil erosion), and reduction in water usage can be observed.

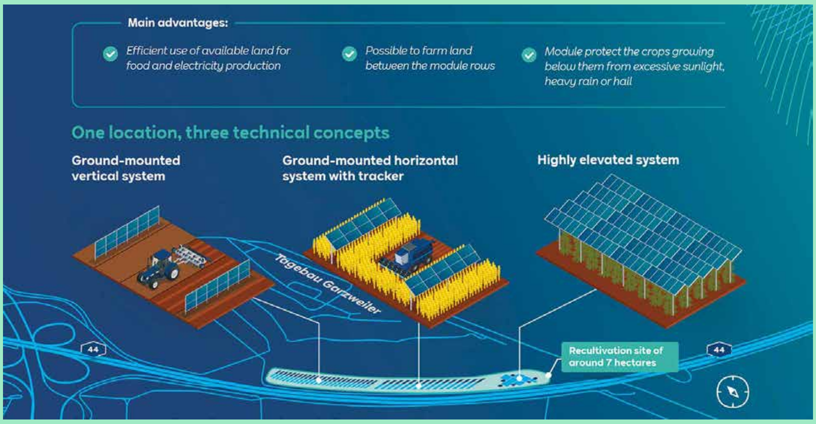
CASE EXAMPLE WITH COMBINATION OF ELEVATED PERENNIAL-PV AND INTERSPACE CROP-PV

Case Example 11

Agri-PV Demonstration Plant, Bedburg (North Rhine-Westphalia), Germany, RWE

Installed capacity
3200 kW

Technical Features



Land
The Agri-PV project was built in Bedburg on about 7 ha of recultivated land at the edge of the Garzweiler opencast mine.

Agricultural activity
Arable farming with **interspace systems:**
- Between the rows of modules, the agriculturists at the RWE-Schirrhof farm have sown a clover-grass mixture and alfalfa. These are robust crops that loosen the soil with their deep root system, and create the right conditions for growing cereals, root crops such as potatoes, and various types of vegetables in the coming years.

Horticulture with **elevated system**:
- Raspberry cultivation.

Business Model
The Agri-PV system is managed jointly by RWE's own agricultural operation and an external farmer. The system is owned and operated by RWE, who is responsible for its ongoing management. The primary focus of this project is to gain valuable insights and data, which will support the successful market expansion of utility scale Agri-PV projects over Europe.

Environmental benefits
- In the safety stripe and around the field a special biodiversity mix will be seeded.
- Research regarding the soil, wind, humidity, temperature below and between the modules will be carried out.
- Measurement will be taken to assess the raspberry's leaf.

Other benefits

The research activities, which are set to last at least five years, started in autumn 2024. The project's goal is to develop suitable cultivation methods and value-adding operational concepts for Agri-PV systems.

The Institute for Plant Sciences at Forschungszentrum Jülich and the Fraunhofer Institute for Solar Energy Systems are providing scientific expertise for the project. Over the years, the interplay between plant growth and PV technology will be monitored under a variety of seasonal weather conditions.

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3.4 LAND UNDER PROTECTIVE COVER

Land under protective cover encompasses agricultural activity in greenhouses, farm buildings, hangars and other types of buildings included on the farm. Standard agricultural activities in greenhouses include horticulture, arboriculture, market gardening and nursery houses. More specifically, crops like vegetables, flowers, ornamental plants and different types of fruit trees are grown in solar greenhouses.

PV systems can be designed to be placed on the greenhouse roofs and are called Elevated Solar Greenhouses. Similarly, PV systems can also be placed on other types of farm buildings; these are referred to as PV on Farm Buildings. For these systems, PV modules are placed on the greenhouses' roofs and can be combined with various types of permanent crops grown in the greenhouses by well-designed and adapted PV systems to fit the climatic and technical conditions for the different cultures. When deploying solar greenhouses, no land is covered by PV modules. However, PV modules can alter the direct sunlight that reaches the crops. PV panel technology and their distributions across the greenhouse roofs, can be adjusted to meet the crop's demand, depending on the shade or sunlight required.

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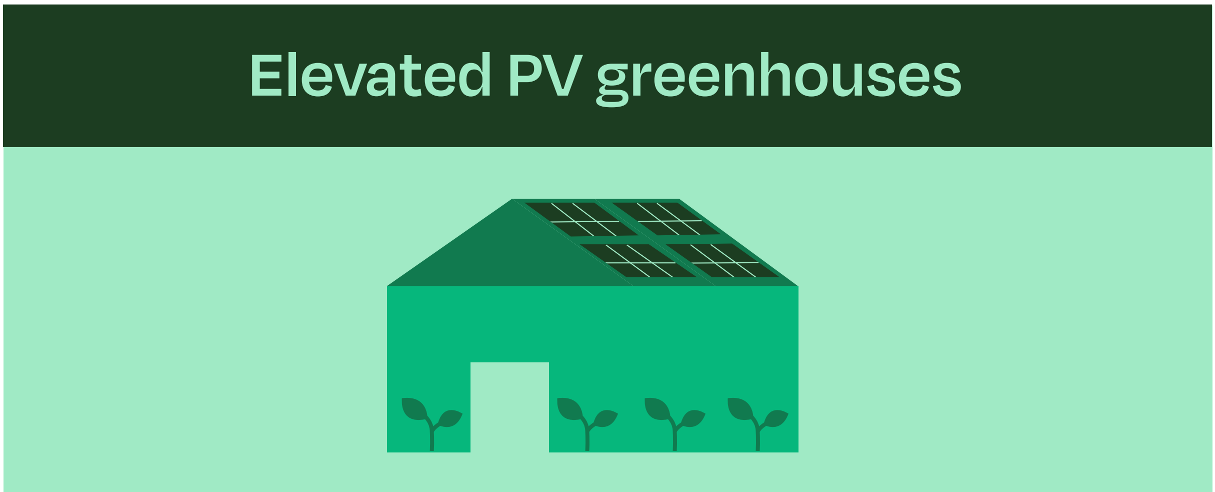
ARCHETYPE 9: ELEVATED SOLAR GREENHOUSES



Business case

Elevated Solar Greenhouses are a well-known solution deployed in Europe, with more developed markets in France and Spain. Elevated Solar Greenhouses have low economic feasibility due to higher costs for installations. The increase in LCOE can go up to 80% when comparing the LCOE with regular ground-mounted PV. Therefore, rent lease payments are often not a common business model applied for solar greenhouses. Farmers can be remunerated through the provision of installations (provided with a new infrastructure or for lower cost).

Impact on agriculture

Positive impacts on crop longevity and yield due to protection from adverse weather impacts such as wind, frost, heatwaves, etc. The crops can also be harvested earlier in the season and for a longer period.

Environmental benefits

Solar greenhouses can provide additional environmental benefits such as water reduction and increase in soil health (protection from frost and winds).

Case Example 12

Exotic fruits in Agroforestry in a Solar Greenhouse, Aillas, Gironde, France, Amarenco

Power
100 kW installed capacity

Technical Features
Multichapel greenhouse with semi-transparent bifacial panels (30% transparency) on the 3 south chapels and full bi-facial panels on the 3 north chapels. Greenhouse is unheated.

Crops
Bananas, Avocados, citrus, guavas, passion fruit, and physalis.

Business Model
The PV system is developed and operated by Amarenco. The farmer receives remuneration through the infrastructure's provisions

Agronomic results
- Allows gain of 1 to 2 zones in the USDA hardiness scale[20] and the cultivation of semi-hardy tropical plants (hardiness -5°C).
- Facilitates optimal growth temperature (25-35°C) for tropical plants from 4 to 8 months.

Other results
- Protection from rain, wind, and frost.
- Diffuse glass of semi-transparent modules and protects from the scorching sun during summer periods.
- Reduced maturing period.

Case Example 13

Exotic fruits under PV greenhouses, South of France, Amarenco

Power
2 MW installed capacity over 9 PV greenhouses

Technical Features
Alternation between PV panels and transparent panels on the roof of the greenhouses (chess board greenhouse). 7m height at the North and 2.5 m height at the South. 1000m2 each. Closed by insect proof net and polycarbonate liftable. 100 kW solar energy produce per greenhouse.

Crops
Exotic fruits (dragon fruit, guava fruit, bananas, passion fruit, chilli)

Business Model
The PV system is developed and operated by Amarenco. The farmer receives remuneration through the infrastructure's provisions. Income per hectare well above the average income per hectare (between 70 and 100% higher depending on the year).

Agronomic results
Fruits can be harvested in South of France (protected from frost) and over a longer period of time.

Environmental benefits
- 20-30% reduction in water usage.
- Protection of soil from strong winds and long periods of frost.
- Controlled irrigation, which is more effective than outdoors thanks to less evaporation.

Other results
- Products are sold locally in the region.
- Reduction of heatstroke and burns in summer and during hot spells.
- Improved working conditions for the workforce i.e. possibility of harvesting in the morning until 12-1pm.
- Enhancement of heritage.
- Protection of crops from pests.
- Release of bumblebees and predators for biological control.
- Crop protection in the event of bad weather such as hailstorms, tornadoes.
- Simplified mechanisation in a circumscribed, easily modelled environment.
- Roof water collection possible with integrated storage in flexible tanks.

[20] The USDA Plant Hardiness Zone Map is the standard by which gardeners and growers can determine which perennial plants are most likely to thrive at a location. The map is based on the average annual extreme minimum winter temperature. U.S. Department of Agriculture (2023): USDA Plant Hardiness Zone Map.

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Archetype 10: PV on farm buildings

Business case

Buildings are typically the second most important farm expense. 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. Moreover, providing a new agricultural building can support the modernisation of a farm, make it more aesthetically attractive, and support the diversification of the agricultural activities. Likewise, PV can also be built on farm buildings' existing rooftops.

The common business model applied is where energy producers provide PV systems in agreement with a farmer. Remuneration schemes are provided to the farmer through the development of a new infrastructure (or at a lower cost), or through the paying to rent the roof space. Nevertheless, self-consumption of the energy generated is another viable business model for a farmer. In these instances, energy injected into the grid for a supported tariff could also be feasible.

Impact on agriculture

New infrastructure can provide better conditions for storage of agricultural produce and machinery, and provide modernisation and long-term economic sustainability to the farm.

Environmental benefits

Negligible impact on biodiversity for the existing infrastructures. It also enables the deployment of solar PV capacities on artificial, man-made structures, as opposed to natural areas.

Case Example 14

Exotic fruits in Agroforestry in a Solar Greenhouse, Aillas, Gironde, France, Amarenco

Installed Capacity
284 kW rooftop system

Technical Features
Regular PV modules

Business Model
Energy producer invested in a project to build two 800m2 buildings to provide storage space for the farmer to store the equipment and fodder needed to breed Limousin cows on a 230 ha farm; construction of the hangar was financed by Amarenco. Due to new infrastructure provided, the farmer can save between 250,000 and 310,000 EUR.

Environmental Benefits
New buildings replaced the use of plastic sheeting and allowed for a reduction in fodder waste.

Other benefits
The building improved the comfort of the farmer who can now work under cover, protected from frost and bad weather.

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4

Biodiversity & Agronomic Considerations

PV modules extend their advantages beyond the realms of only reducing carbon footprint and reliance on fossil fuels (SolarPower Europe, 2022). Their integration into various environments adds complexity to ecosystems and brings about a multitude of ecological benefits while maintaining some potential risks, connected to bad management practices (Sturchio & Knapp, 2023).

These ecological benefits are relevant for the agricultural sector. On the one hand, the agricultural industry might either be required to have, or be rewarded for, agricultural systems that provide nature restoration or biodiversity benefits. Farmers already have such requirements: the Common Agricultural Policy (CAP) includes as one of its ten driving objectives that of "contributing to halting and reversing biodiversity loss, enhance ecosystem services and preserve habitats and landscapes", while the Nature Restoration Law, enshrined into European Law in July 2024, creates new obligations for farmers to increase fauna and flora population and improve soil organic carbon on agricultural lands. Alternatively, CAP eco-schemes could further reward farmers who provide practices beneficial to the environment, climate and overall animal wellbeing. However, the EU regulatory environment does not incentivise and facilitate the deployment of solar projects which provide ecological benefits. Cross-sectoral policy domains need to be better aligned and provide inter-disciplinary stakeholder engagements to support solutions such as Agri-PV with biodiversity measures and Eco-PV to be deployed on the ground.

On the other hand, biodiversity benefits stemming from, or enhanced by agrisolar solutions could also provide direct agronomical added value, profiting the farmer. Biodiversity added value could prove interesting as biodiversity is decreasing on agricultural land, due to climate change or land pollution. This is of course inseparable from a reflection on agricultural practices, and for instance the use of pesticides.

The following chapter therefore delves into the biodiversity-related benefits and risks of solar PV installation, highlighting the relationship to different farming systems and archetypes, suggesting indicators to measure benefits, and conditions to enhance them, while reducing risks. This review must however be continued and completed by a thorough and continuous collection of measured biodiversity data on agrisolar sites across Europe.

Research by Vervloesem et al. (2022), shows that if PV modules are elevated at least 0.5 meters above ground level, they enhance ecological complexity by creating new habitats that might benefit flora, fauna, soil, and microclimate. Therefore, this chapter is structured by identifying benefits (Figure 2) and risks linked to flora, fauna, soil, and microclimate. Categorising the benefits and risks across these four dimensions offers a comprehensive overview of the positive and negative ecological impacts of solar panel installations.

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4.1 BENEFITS

PV modules in Agri-PV configurations help to increase landscape heterogeneity, enhance local vegetation and increase diversity of floral species (Armstrong et al., 2016). Good management practices are needed to achieve these benefits, such as seeding local plants (Semeraro et al., 2018) and mowing them later in the season (note: mowing is not always compatible with agricultural practices) to avoid disrupting pollinator foraging habits (Tölgyesi et al., 2023). These improvements to flora can be tracked by measuring floral abundance, richness, functional diversity, and the percentage of native species, providing a comprehensive view of the local community composition (Blaydes et al., 2021). Public trait databases such as TRY, BiolFlor, and PADAPT can be consulted to select species with suitable height, flowering periods, or rooting systems.

Agri-PV installations can benefit local fauna, for example by increasing animal abundance (Figure 2). The presence of vegetation that flowers throughout the growing season supports pollinators by providing continuous access to resources (Blaydes et al., 2021). Pollinator presence and activity patterns can be measured using the Grassland Butterfly Index (Van Swaay et al., 2019). Bird communities might also respond positively to the changes in the landscape brought about by Agri-PV, which can provide nesting places and shelter. The impact of this technology on birds can be measured using the farmland birds index (Gregory et al., 2005). Monitoring birds is recommended because findings show significant declines in European bird populations due to agricultural intensification (Donald et al., 2001; Reif et al., 2024). This decline suggests that the farmland bird index can track broader biodiversity trends in agricultural systems (Gregory et al., 2005). The conditions necessary to benefit from solar PV include maintaining landscape connectivity and implementing effective management practices that ensure the availability of floral resources and nesting sites (Figure 2).

Beyond wild fauna, **PV modules can also benefit domesticated animals and contribute to the welfare of farm animals.** Maia et al. (2020) found that sheep preferred the shade from PV modules over traditional cloth shading. Providing sun protection through PV modules can therefore contribute to decreased heat stress in animals. Farmers can measure the prevalence of heat stress to ensure PV modules enhance animal welfare (Figure 2).

Agri-PV installations can benefit soil health, which is crucial not only for agriculture but also to mitigate climate change impacts. These benefits include reduced soil disturbance, enhanced carbon storage, and improved water retention (Figure 2). PV modules provide consistent cover over the ground that reduces soil disturbance. This minimised disturbance is especially beneficial in areas where there are concerns over soil erosion and degradation. By covering the soil, PV modules help maintain soil structure and prevent erosion caused by wind and water (Armstrong et al., 2016). The key conditions for achieving this benefit include the adoption of sustainable farming practices that implement ground cover vegetation around PV modules, use of light machinery and avoiding tillage (Time et al., 2024). PV modules can also contribute to enhancing carbon storage in soil (Tölgyesi et al., 2023). The presence of PV modules pushes the adaptation of agricultural activities towards less soil disturbing practices. Moreover, the establishment of ground cover vegetation under PV modules can also sequester additional carbon.

Conditions for maximising carbon storage include the use of native plant species that are effective at sequestering carbon in their root systems, minimisation of soil tillage and other disturbances that can release carbon, and sufficient ground irradiance to allow plants to photosynthesise and capture carbon dioxide (SolarPower Europe, 2022). PV materials that allow Photosynthetically Active Radiation (PAR) wavelengths to fully reach the plant canopy can boost plant productivity in agrisolar systems. These panels can maintain or even enhance energy production by absorbing the remaining incoming radiation that plants do not use for photosynthesis. However, these types of technologies are innovative and not yet deployed commercially. (Gomez-Casanovas et al., 2023).

Lastly, the shade provided by PV modules can improve soil water retention by reducing evaporation rates (Sturchio & Knapp, 2023). This benefit is particularly significant in arid and semi-arid regions where water conservation is critical (Vervloesem et al., 2022). By

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creating a microclimate under the panels, soil moisture levels can be better maintained, promoting healthier plant growth and reducing the need for irrigation (Vervloesem et al., 2022).vConditions necessary for this benefit include the strategic placement of panels to maximise shade without hindering plant growth, the use of water-efficient ground cover vegetation that thrives in shaded conditions, and implementation of soil moisture monitoring systems that measure water holding capacity (Soil Health Institute, 2022) and surface runoff (Peters et al., 2003) to track and manage water levels effectively (Figure 2).

PV modules can impact the microclimate below the panels, offering various benefits such as reduced damages from climate extremes, decreased evapotranspiration, and lower ground temperatures (Gomez-Casanovas et al., 2023) (Figure 2). PV modules can help mitigate the impact of climate extremes such as hail, snow, and heavy rain by providing a protective cover (Armstrong et al., 2016). This reduces damage to the soil and vegetation underneath. Conditions for achieving this benefit include a proper installation and spacing of PV modules to provide adequate protection without hindering natural processes (SolarPower Europe, 2022), as well as the use of the latest farming techniques and machinery.

The shade provided by PV modules reduces the rate of evapotranspiration from soil and plants to the atmosphere (Marrou et al., 2013). Lower evapotranspiration rates help crops consume water more efficiently alleviating heat stress. This is particularly advantageous in arid regions such as the Mediterranean (Semeraro et al., 2018). Conditions for achieving this benefit include the strategic placement of panels to optimise shading and minimise water loss (SolarPower Europe, 2022) and the regular measurement of evapotranspiration rates to track improvements (Peters et al., 2003). PV modules lower mean ground temperatures by providing shade, which reduces the amount of direct solar radiation reaching the ground. This helps maintain cooler temperatures reducing thermal stress on plants and improving the efficiency of PV modules. Conditions for achieving this benefit include proper alignment and orientation of panels to maximise shading efficiency, and monitoring mean surface temperature and ground irradiance to ensure optimal cooling effects (Vervloesem et al., 2022).

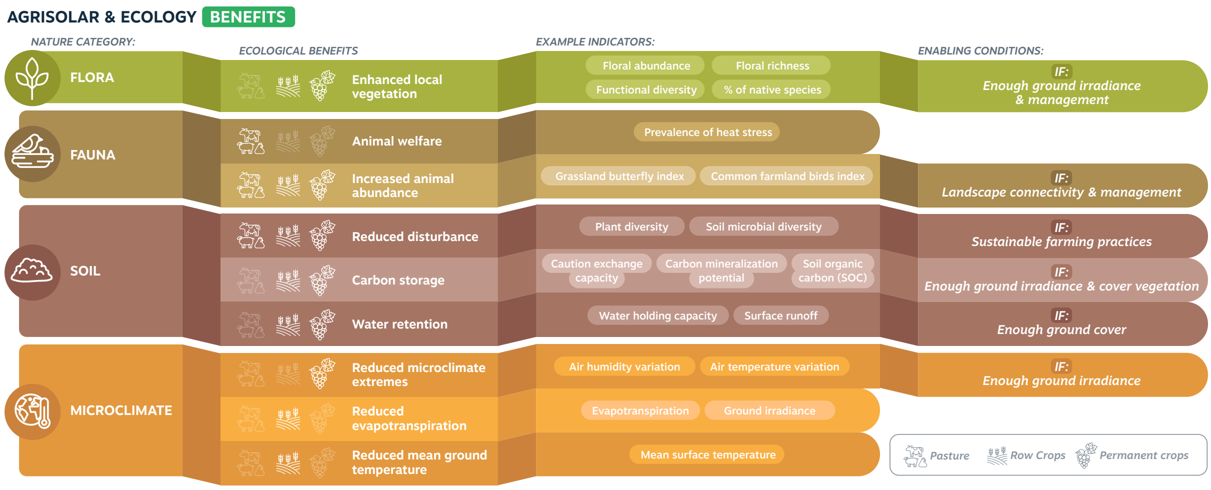

FIGURE 2: OVERVIEW OF POTENTIAL ECOLOGICAL BENEFITS OF AGRI-PV INSTALLATIONS IN PASTURE, ROW CROPS AND PERMANENT CROPS FARMING SYSTEMS ALONG WITH EXAMPLE INDICATORS AND ENABLING CONDITIONS.

In summary, by strategically integrating PV installations with agricultural practices, agrisolar systems contribute to renewable energy generation and can also enhance ecological resilience, support biodiversity, and improve farm productivity. These synergistic benefits underscore the potential of solar PV as a cornerstone of sustainable farming practices worldwide.

4.2 RISKS

Improper placement and management of PV modules can introduce risks including decreased crop yields, land degradation, and reduced biodiversity (Tölgyesi et al., 2023) as well as hindering the use of the latest farming techniques and machinery. These risks are not confined to specific solar archetypes and can impact diverse agricultural environments.

During the construction phase of PV installations, poor practices such as extensive ground excavation can lead to land degradation and a decline in biodiversity (Bennun et al., 2021). Factors contributing to this include the use of pesticides, frequent mowing, and the inadvertent introduction of invasive alien species. To mitigate these risks, it is crucial to adopt proper installation methods that reduce ground disturbance and avoid excessive use of chemicals. Maintenance practices should also focus on reducing soil compaction during panel servicing to preserve soil health and biodiversity.

Throughout the operational phase, solar farms can pose ongoing risks to wildlife and ecosystems. Solar arrays can alter natural landscapes through habitat fragmentation (Bennun et al., 2021). These risks are likely greater at utility scale projects with larger contiguous areas covered by solar arrays compared to more fragmented designs in agrisolar developments. These impacts can be minimised by improving landscape features such as planting trees and hedges in the surroundings (Froidevaux et al., 2019). Moreover, reduced ground irradiance under panels can lead to altered microclimates, impacting local flora and fauna (Vervloesem et al., 2022). The altered microclimate can also create the conditions for other microorganisms to appear and even plagues posing a risk to local fauna and to the crop. To address these concerns, operational strategies should prioritise wildlife-friendly designs and technologies that minimise direct impacts on biodiversity. Enhancing ground cover vegetation and managing solar panel heights can also mitigate microclimatic changes and

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promote ecosystem resilience. **However, the marginal impact of the agrisolar system could be negligible if a structure is already in place – for instance a plastic greenhouse or protective equipment above crops.** These types of impacts might need additional monitoring.

Risks to biodiversity can be monitored across several dimensions to understand the impacts of Agri-PV installations (Figure 2). Monitoring biodiversity using indicators such as species richness and abundance can provide early warnings of potential impacts on flora and fauna. Soil health assessments can also be carried out by measuring soil compaction, soil erosion and aggregate soil stability (Peters et al., 2003). Ground irradiance monitoring is crucial for assessing the long-term environmental impacts of solar installations, complementing microclimate monitoring efforts (De Bruin et al., 2021)

In conclusion, **proactive management practices during both construction and operation phases are essential to mitigate risks associated with solar panel installations.** By adhering to ecological principles and adopting responsible management strategies, solar energy projects can minimise their environmental footprint and align with the needs of agricultural and natural ecosystems.

A decision support tool to align nature and solar energy

A useful decision support tool (DST) to mention is the SPIES DST, created by Lancaster University. It informs potential ecosystem service benefits in response to management actions. When used alongside existing DSTs that mitigate environmental and ecological harm, the SPIES DST enhances ecosystem services and provides co-benefits during the planning, development, and operational stages of solar parks (Randle-Boggis et al., 2020).

This integrated approach not only supports sustainable solar energy practices but also fosters positive impacts on local ecosystems, demonstrating the potential for renewable energy projects to contribute positively to biodiversity conservation and ecosystem health.

5

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Annex

ANNEX A: FAO LAND USE MATRIX

Country area	**Land area** *Equipped for irrigation* *Actually irrigated*	**Agriculture** *Actually irrigated* *Organic*	**Agricultural land**	**Cropland** *Actually irrigated* *Organic* *Tillage*	**Arable land**	**Land under temporary crops**
						Land under temporary meadows & pastures
						Land with temporary fallow
					Land under permanent crops	
				Land under permanent meadows & pastures *Actually irrigated* *Organic*	**Cultivated**	
					Naturally growing	
			Land under protective cover *Farm buildings and farmyards*			
		Forest land *Forestry* *Forestry actually irrigated*				
		Other land				
	Inland waters *Aquaculture* *Capture fisheries*					
	Coastal waters *Aquaculture* *Capture fisheries*					
Exclusive Economic Zone *Aquaculture* *Capture fisheries*						

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