ISSN 1831-9424

European Commission

JRC SCIENCE FOR POLICY REPORT

Overview of the Potential and Challenges for Agri-Photovoltaics in the European Union

Chatzipanagi, A., Taylor, N., Jaeger-Waldau, A.

2023

Joint Research Centre

EUR 31482 EN

Contact information
Name: Anatoli Chatzipanagi
Address: European Commission, Joint Research Centre, Ispra, Italy
Email: anatoli.CHATZIPANAGI@ec.europa.eu

EU Science Hub
https://joint-research-centre.ec.europa.eu

JRC132879

EUR 31482 EN

Online ISBN 978-92-68-02431-7 ISSN 1831-9424 doi:10.2760/208702 KJ-NA-31-482-EN-N

Luxembourg: Publications Office of the European Union, 2023

How to cite this report: Chatzipanagi, A., Taylor, N. and Jaeger-Waldau, A., *Overview of the Potential and Challenges for Agri-Photovoltaics in the European Union*, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/208702, JRC132879.

Contents

Abstract

Agri-Photovoltaics (Agri-PV) consists in the simultaneous use of land for both solar photovoltaic power generation and agricultural production. It is an innovative form of PV deployment that has attracted attention worldwide and now also in the EU. It is highly relevant to a range of policies, including those related to the energy transition, agriculture, environment and research & innovation (R&I), and directly supports the goals of the European Green Deal (EGD). This report investigates the technical potential of Agri-PV systems in the EU and finds that using only 1 % of the EU's Utilised Agricultural Area with Agri-PV systems could allow 1 TW of PV capacity, for instance well above the 590 GW foreseen by 2030 in the recent EU Solar Strategy communication. The study also maps the current situation in relation to the definition of Agri-PV and to related standards and guidelines, and draws attention to the challenges faced by developers for implementing projects. Furthermore, it explores the synergies between the agricultural, environment and energy policies and identifies the R&D challenges. Last but not least, the report makes recommendations regarding future steps to support the expansion of Agri-PV in the EU. The main points include a clear and concrete definition of Agri-PV, potentially as part of a European standard for Agri-PV systems, the promotion of Agri-PV at policy level through the Common Agricultural Policy (CAP) plans as well as the Member States' national energy strategies (financial support, dedicated capacity targets, etc.), the simplification of permitting and grid connection procedures, the engagement of the rural communities to the planning and decision making and the assurance of the welfare of the farmer (economic benefit, security of property, etc.). Continued research and development, in particular cross-cutting studies that take into account energy, crop yield and biodiversity aspects, will be essential to overcome technical challenges and ensure fully sustainable solutions for the future.

Acknowledgements

The authors would like to thank the following European Commission colleagues for their constructive review and comments:

— Sandor Szabo (DG JRC);

— Charles Cleret de Langavant and Paula Miranda Dorado (DG ENER);

— Penelope Vlandas, Veronika Madner and Antanas Karbauskas (DG AGRI).

The authors would like to acknowledge the valuable input received from:

— Max Trommsdorff (Fraunhofer Institute for Solar Energy Systems ISE);

— Alessandra Scognamiglio (ENEA, AIAS);

— Eva Vandest (Amarenco, SolarPower Europe Agri-PV Workstream);

— Adrien Alexandre (France Agrivoltaïsme);

— Wiebren Santema and Stephan Schindele (BayWa r.e. AG).

The authors would also like thank the participants to the workshop *Agri-Photovoltaics - achieving its full potential in the EU Energy Transition* held in March 2022: European Commission staff from DG JRC, DG ENER, DG RTD, DG AGRI, EISMEA, SolarPower Europe (AgriSolar Workstream), Amarenco (AgriSolar Workstream), Nature And Biodiversity Conservation Union (NABU), University of Hohenheim, Fraunhofer Institute for Solar Energy Systems, Next2Sun GmbH, REM Tec, France Agrivoltaïsme Association, ENEA (Agrivoltaico Sostenibile), Iberdrola, BayWa r.e. Solar Projects GmbH, Agro-voltaics working group of the Polish Photovoltaics Association, Institute for Renewable Energy of Poland (IEO).

Authors

Anatoli Chatzipanagi

Nigel Taylor

Arnulf Jaeger-Waldau

Executive summary

Agri-Photovoltaics (Agri-PV) consists in the simultaneous use of areas of land for both solar photovoltaic power generation and agriculture. It is an innovative form of PV deployment and its multi-use of land has the potential to make a major contribution to achieving the targets set in the European Green Deal (EGD).

Policy context

Agri-PV interacts with a range of policies related to clean energy, energy transition, sustainable agriculture, food security, biodiversity, rural development and research & innovation, all of which underpin the goals of the European Green Deal (EGD). The EU Solar Energy Strategy calls for an additional photovoltaic capacity of 450 GWp between 2021 and 2030, which would require a roughly fourfold increase of the nominal capacity to over 720 GWp by 2030. Approximately 50% of this capacity is expected to be deployed as ground-mounted system in agricultural areas.. Indeed the Strategy also identifies the potential barriers and challenges in the solar energy sector and outlines some actions necessary to accelerate the deployment of solar technologies. It explicitly includes Agri-PV in the defined innovative forms of photovoltaic (PV) deployment. Furthermore, the Commission will elaborate guidance to Member States in order to promote the development of these innovative forms of solar energy deployment identified in the EU Solar Energy Strategy (Agri-PV, floating PV, installation of PV in transport infrastructure, Building-Integrated PV and Vehicle-Integrated PV).

Key conclusions

It is important to set a clear and concrete definition of Agri-PV, together with a European standard for Agri-PV systems that will follow harmonised Agri-PV policies across the EU. In addition, it is crucial that agricultural activities continue and agricultural land does not lose its characteristic with the installation of Agri-PV systems and therefore remains eligible for potential agricultural subsidies foreseen under the Common Agricultural Policy (CAP). The CAP Strategic Plans should promote Agri-PV and support the inclusion of such systems within their framework. Research and Development (R&D) programmes, together with pilot programmes are essential to overcome technical challenges in the Agri-PV sector by taking into consideration energy, crop yield and biodiversity at the same time. Agri-PV should receive its own capacity targets and financial support through the individual Member States' national energy and/ or CAP Strategic plans. The deployment of Agri-PV systems will be facilitated through spatial planning and simplification of the permitting and grid connection procedures. The economic benefit and the security of property as well as investments for the farmer should be at the centre of the efforts to promote Agri-PV and public awareness and acceptance.

Main findings

The potential of Agri-PV in the EU is significant. A coverage of only 1 % of Utilised Agricultural Area (UAA) with Agri-PV system translates into roughly 944 GW (assuming an installed capacity per land area of 0.6 MW/ha), which is half of the amount yielded by traditional ground-mounted PV systems (around 1 809 GW) and approximately 5 times more than the EU installed capacity in 2022. EU's New Policy Trends NECP PV target for 2030 can be achieved with only 0.6 % of UAA coverage. One of the main challenges for Agri-PV is related to the absence of a clear and EU-harmonised definition, which could lead to land characterisation changes when Agri-PV systems are installed on agricultural land. This change could have an impact on the eligibility to agricultural subsidies. In fact, in several cases, the land is excluded from the CAP subsidies. Many Member States are general in their plans regarding the support for investments in renewable energy. Support for Agri-PV is not explicitly mentioned in most of the Member States CAP Strategic Plans and only a few have included it explicitly in their plans (without defining specific targets and/or providing dedicated financial support). Technical challenges as well as challenges regarding the permitting and grid connection procedures have been also identified. In addition, there has been an increase in land prices impacting the welfare and security of the farmers. Finally, regardless of the technological advancements, there are still technical challenges that need to be addressed in order to maximise the electricity production while taking into consideration the biodiversity and without compromising significantly the crop yield.

Related and future JRC work

Following a dedicated workshop organised by the JRC in March 2022 with key stakeholders, this report uses the discussions and main messages of the workshop to elaborate further on the current status of Agri-PV in the EU. Future work will involve a more detailed analysis on the potential of Agri-PV, greenhouses and built

environment within the Utilised Agriculture Areas (UAAs) for CORINE land cover sub-classes. The support to Member States regarding the legal framework and challenges of Agri-PV will also be continued.

Quick guide

This report assesses the potential of Agri-PV, maps the advancements in the most active Member States, identifies the challenges and explores the synergies between agriculture, environment and energy policies and finally proposes recommendations for a rapid and secure Agri-PV deployment.

1 Introduction

Agri-photovoltaics (Agri-PV), or Agro-photovoltaics or Agrivoltaics or Agrovoltaics, consists in the simultaneous use of areas of land for both solar photovoltaic power generation and agricultural activities. Agri-PV interacts with a range of policies related to the energy transition, agriculture, environment and research & innovation, all of which support the goals of the European Green Deal (EGD).

From a renewable energy perspective, the European Union (EU) aims to rapidly accelerate the deployment of solar PV to contribute to its goal of decarbonisation by 2050. PV installations are expected to grow from the current level of almost 200 GW ([1]) to approximately 730 GW by 2030 and several TWs by 2050. Although considerable capacity can be installed on roofs, in urban areas, on brownfield sites and on infrastructure, approximately 50% (SolarPower Europe, 2022a) are expected to be ground mounted systems using land in agricultural areas ([2]). Indeed agricultural land is already extensively used for energy: bioenergy crops occupy approximately 10 Mha ([3]) at present, accounting for around 2.4 % of the total EU land area (Strapasson *et al.*, 2020)), whereas existing utility-scale ground mounted PV systems (approximately 92 GW) use 0.1 Mha. Nonetheless a future significant expansion of PV must respect food security requirements, as well taking into account public acceptance issues with regard to the landscape and environmental impact. Agri-PV offers a compromise solution, albeit with an economic cost ([4]).

The EU's recent Solar Energy Strategy (European Commission, 2022c) identifies the potential barriers and challenges in the solar energy sector and outlines some actions necessary to accelerate the deployment of solar technologies. It explicitly includes Agri-PV among the innovative forms of photovoltaic (PV) deployment. According to the strategy, Agri-PV installations consist in a form of multiple use of space that could alleviate the concern over land competition for agricultural activities. Member States (MS) are encouraged to integrate the concept of Agri-PV in their Common Agricultural Policy (CAP) Strategic Plans, provide incentives and design support frameworks for its promotion (European Commission, 2022a). In addition to these recommendations, the Commission has committed to develop a guidance (likely to be released in 2024) regarding the development of innovative forms of PV deployment as a mean to support MS in this task.

From an agricultural perspective, the new CAP legal framework (European Commission, 2022g), adopted in December 2021, introduces simplification and flexibility in the EU agricultural policy, by enabling Member States to design their interventions depending on their local specificities and needs. The new CAP also sets specific objectives including ensuring food security, reducing environmental footprint, strengthening resilience and sustainability of the food system. In addition, the new CAP will contribute to climate change mitigation and adaptation, as well as sustainable energy production. Therefore, MS have included in their CAP Strategic Plans targets related to the intended production of renewable energy for the period between 2023 and 2027.

Agri-PV can also support a better future for the EU's rural areas by contributing to the Action Plan envisaged in the "A long-term Vision for the EU's Rural Areas - Towards stronger, connected, resilient and prosperous rural areas by 2040" (European Commission, 2021a). This Action Plan notes specifically that "*renewable energy production, is an opportunity for rural areas to combat energy poverty provided that ecosystem services are appropriately valued and business models retain value within rural communities*".

The EC also intends to help Agri-PV through its Research and Innovation (R&I) programs, such as launching specific calls in Horizon Europe. For the 2022 Work Programme call on "Sustainable, secure and competitive energy supply", research topics dealing with renewables in agriculture and integrated applications of PV are the "Renewable energy incorporation in agriculture and forestry" (European Commission, 2022f) and "Advanced manufacturing of Integrated PV" (European Commission, 2022d) topics. However, Agri-PV is directly supported within the "Novel Agro-Photovoltaic systems" topic with a budget of EUR 10 million (European Commission, 2022e), which supports three projects ("PV4Plants", "REGACE" and "SYMBIOSYST").

---

1 Power is expressed in direct current watts W_{DC} henceforward, unless otherwise specified.

2 The Corine Land Classification includes 1. Artificial Surfaces, 2. Agricultural areas, 3. Forest and seminatural areas, 4. Wetlands and 5. Water bodies.

3 The EU land area used for bioenergy crops (10 Mha) would alternatively provide for 6 GW PV (assuming 0.6 MW/ha). Also the PV energy yield is much higher: 0.6 MW/ha would provide approximately 2400 GJ/ha, compared to biofuels in the range 30 to 100 GJ/ha.

4 The CAPEX for Agri-PV installations is expected to be at least 20% higher than that for a standard ground mounting with the same power.

Hence, Agri-PV is a particularly interesting and promising form of PV deployment that combines innovation, efficiency and cost-effectiveness. It contributes to several Commission policies pertaining to two very different but equally important and demanding sectors, energy and agriculture. It is therefore crucial to analyse and monitor how Agri-PV activities can be facilitated for a rapid and large-scale deployment. With this goal in mind, the present report:

— analyses the technical potential ([5]) of Agri-PV in the EU;

— maps the situation in the three EU countries that are most active in the field of Agri-PV;

— identifies barriers for the expansion of the Agri-PV sector;

— investigates agricultural and energy synergies through the Common Agricultural Policy (CAP) strategic plans;

— lists an overview of the available tools developed for the planning of Agri-PV systems;

— provides recommendations for further analysis and consideration on how to overcome the current obstacles and deliver a faster deployment of Agri-PV.

It is based on the results of published reports and guidelines on Agri-PV from national authorities and stakeholders, EC data, EU strategies and recommendations, as well as input from stakeholders and own analysis.

[5] Technical potential is the 2nd level in the progression from physical potential of a renewable energy resource, its technical potential (the amount of resource that can be converted to energy or a fuel), economic potential (the economically viable part in terms of costs) and market potential (taking into account user preferences, social factors, public acceptance etc.).

2 Potential Role in the EU Energy Transition

2.1 PV Power Density

PV can be deployed in a variety of ways:

- Ground-mounted systems: typical for utility scale (>5 MW) and other larger systems, but also potentially including Agri-PV systems for multi-use of land in the future. Such systems are typically installed in agricultural areas (Corine Land cover class 2) or on agriculture land (Eurostat, utilised agricultural areas, UAA);
- Rooftop systems, using either residential or commercial buildings;
- Building-integrated solar;
- Infrastructure PV, using space associated with existing transport infrastructure e.g. parking areas, roads, motorways, railway lines etc.
- Vehicle-integrated PV;
- Floating PV on inland lakes and reservoirs, and in the future on the sea.

Here we focus on ground-mounted systems, which are expected to make up 50% of future PV capacity by 2030 (SolarPower Europe, 2022a). The land usage varies according to many factors, including the module technology energy conversion efficiency and the installation layout and design. Overall we note:

- A recent assessment of ground mounted systems gave a global average of 0.87 MW_p/ha (Bolinger and Bolinger, 2022);
- Estimates for Agri-PV systems vary widely according to system design. The latest guideline for Agri-PV from Fraunhofer ISE includes the estimation that if only 4 % of Germany's farmlands were covered by PV modules, the potential capacity would be 1 700 GW_p, assuming an installed capacity of 0.25 MW/ha. Next2Sun declares that the installed capacity of their Agri-PV systems on grasslands is 0.4 MW/ha. From a wide variety of realised Agri-PV projects, the obtained range for the installed PV power is between 0.2 and 0.9 MW/ha, depending on the system design. In the following we assume a value of 0.6 MW/ha;
- For reference, PV modules with an efficiency of 20 % have power to area ratio of 200 W/m^2, which translates to 2 MW/ha.

2.2 Technical potential of Agri-PV

According to Eurostat (Eurostat, 2022), at EU level, the Utilised Agricultural Area (UAA) ([6]) is almost 158 million hectares. This area includes around 98 million hectares of arable land, 49 million hectares of permanent grassland and meadow, 10 million hectares of permanent crops and 290 thousand hectares of market gardens.

Table 1 shows the capacities that could be achieved for the different land area categories and with different land area coverage percentages with an assumed installed power density of 0.6 MW/ha. In Annex 1 the potential is presented for other power densities ranging from 0.2 to 0.9 MW/ha.

Agri-PV potential of installed capacity is at TW scale for the two main land categories of arable land and permanent grassland and meadow assuming that they are covered by 10 % and 5 % with Agri-PV systems. If the 10 % of EU's UAA is covered with Agri-PV systems, the installed capacity could be between 3.2 and 14.2 TW, while only 5 % of coverage would lead to a total capacity comprised between 1.5 and 7 TW.

If 1 % of the EU's UAA was covered with Agri-PV systems, the potential would be between 315 and 1 415 GW (depending on the power density). Even the lower limit of this potential is very close to the overall Fit-for-55 (FF55) target for PV. The potential for the same percentage of land coverage (1 %) for the categories of

[6] Includes arable land, permanent grassland, permanent crops and market (kitchen) gardens (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Utilised_agricultural_area_(UAA))

arable land and permanent grassland and meadow is in the range of 196-881 GW and 98-439 GW respectively.

Table 1. Technical potential for installed capacities of Agri-PV systems for the UAA and the different land area sub-categories and with different area coverage percentages for the EU. This is based on 0.6 MW/ha power to land area ratio.

	10 % area coverage		5 % area coverage		1 % area coverage	
	Area (ha)	Potential (GW)	Area (ha)	Potential (GW)	Area (ha)	Potential (GW)
Utilised agricultural area	15 726 214	*9 436*	7 863 107	*4 718*	1 572 621	*944*
Arable land	9 793 456	*5 876*	4 896 728	*2 938*	979 346	*588*
Permanent grassland and meadow	4 877 482	*2 926*	2 438 741	*1 463*	487 748	*293*
Permanent crops	1 026 726	*616*	513 363	*308*	102 673	*62*
Market gardens	28 577	*17*	14 289	*9*	2 858	*2*

Source: JRC analysis based on Eurostat.

2.2.1 PV Potential in comparison to the 2022 PV installed capacity

An alternative perspective on the Agri-PV potential can arise from a comparison with the current installed capacity of PV. Table 2 compares the ratio of technical potential for Agri-PV to the installed capacity in 2022, for different area coverage percentages and different land area categories for the EU countries with the highest cumulative installed PV capacities in 2022. The 2022 cumulative installed capacities are estimated values (SolarPower Europe, 2022a). The results assume an average Agri-PV power to land use value of 0.6 MW/ha.

The country with the highest cumulative installed PV capacity in 2022 in the EU is Germany with 68.5 GW, followed by Spain with 26.4 GW and Italy with 24.7 GW. In the fourth position the Netherlands with 18 GW and in the fifth position is France with 16.1 GW.

According to Table 2 and Figure 1, if only 1 % of its UAA was covered with Agri-PV systems, France could reach ten times its 2022 cumulative installed capacity, whereas Spain could reach five times its 2022 cumulative installed PV capacity. Italy's Agri-PV potential with 1 % coverage of UAA is three times its 2022 installed capacity while Germany, with the same land coverage, could achieve its 2022 installed capacity.

Table 2. Ratio of the technical potential for Agri-PV systems with a power density of 0.6 MW/ha to the cumulative installed PV capacity in 2022 for different land area categories and different coverage percentages for France, Spain, Italy, Germany, the Netherlands and the EU as a whole.

% of area coverage	Country	Utilised agricultural area	Arable land	Permanent grassland and meadow
10 %	France	103	69	31
	Spain	53	26	18
	Italy	29	16	8
	Germany	15	10	4
	Netherlands	6	3	3

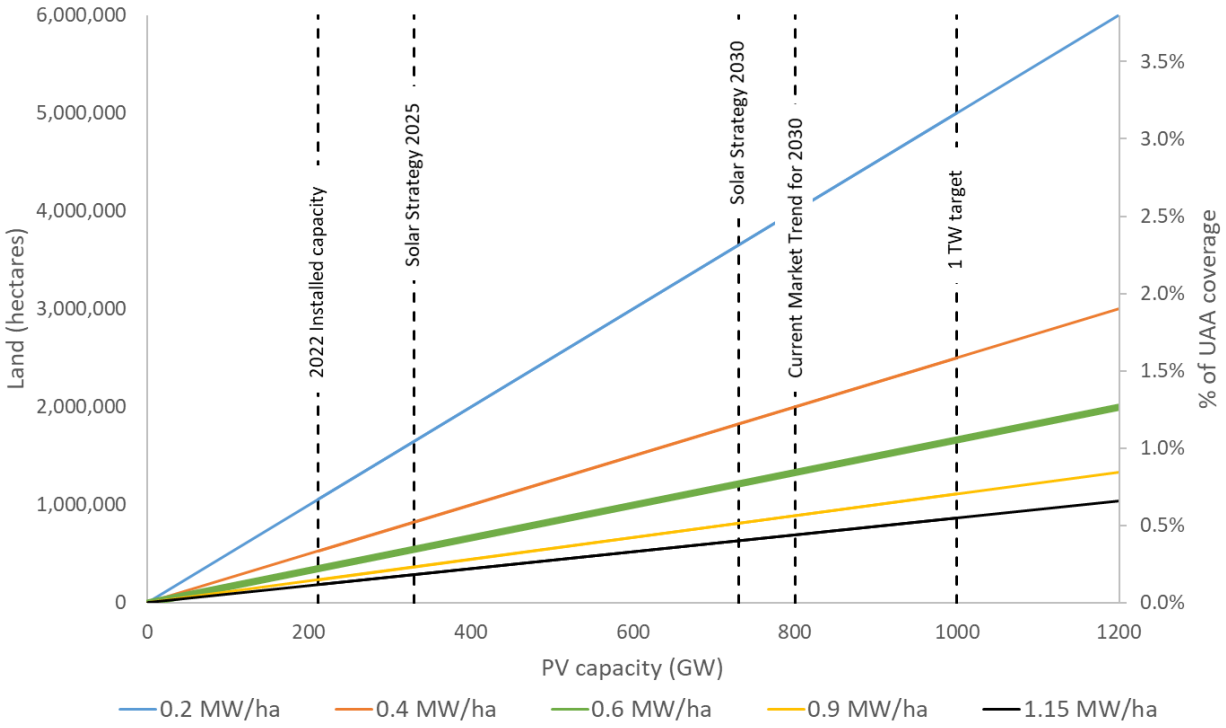
% of area coverage	Country	Utilised agricultural area	Arable land	Permanent grassland and meadow
	EU	45	28	14
5 %	France	52	34	15
	Spain	26	13	9
	Italy	15	8	4
	Germany	7	5	2
	Netherlands	3	2	1
	EU	23	14	7
1 %	France	10	7	3
	Spain	5	3	2
	Italy	3	2	1
	Germany	1	1	0
	Netherlands	1	0	0
	EU	5	3	1

Source: JRC analysis based on Eurostat and (SolarPower Europe, 2022a).

The EU as a total would be able to reach five times its 2022 installed PV capacity by using just 1 % of its UAA for Agri-PV systems. For 1 % coverage of arable land and permanent grassland and meadow, the EU Agri-PV potential is triple and equal to the 2022 installed PV capacity respectively. For higher percentages of land coverage, the potential of Agri-PV systems is significantly increased.

Figure 1 presents the land requirements for the accomplishment of the different EU PV installation targets if only Agri-PV were taken into account for PV deployment for different power density considerations. To meet the current (2022) installation capacity of 211 GW, the necessary percentage of UAA coverage varies between 0.15-0.65 %, depending on the power density (0.2-0.9 MW/ha). Achieving the EU Solar Energy Strategy target for 2025 (around 330 GW), the percentage of UAA coverage ranges between 0.25-1.05 %, while the corresponding range for the Solar Strategy 2030 target (around 730 GW) is 0.5-2.3 %. However, the current market trend for the 2030 PV capacity in the EU is approximately 800 GW. If only Agri-PV systems were to accomplish this capacity, 0.55-2.55 % of UAA coverage would be sufficient. Between 0.7 and 3.15 % of UAA coverage by Agri-PV systems would result in achieving the 1 TW target.

Figure 1. Land requirements and percentage of UAA coverage for Agri-PV systems for the accomplishment of the different EU PV installation targets.



Source: JRC analysis based on Eurostat and (Chatzipanagi and Jaeger-Waldau, 2023).

Assuming an average 0.6 MW/ha as power density, the individual PV targets could be accomplished by Agri-PV systems only covering the following percentages of EU's UAA:

- EU PV installed capacity in 2022 (~211 GW): 0.22 % of UAA coverage;
- EU Solar Energy Strategy 2025 (~330 GW): 0.35 % of UAA coverage;
- EU Solar Energy Strategy 2030 (~730 GW): 0.77 % of UAA coverage;
- Current market trend for 2030 (~800 GW): 0.85 % of UAA coverage;
- 1 TW in 2030 (1 000 GW): 1.06 % of UAA coverage.

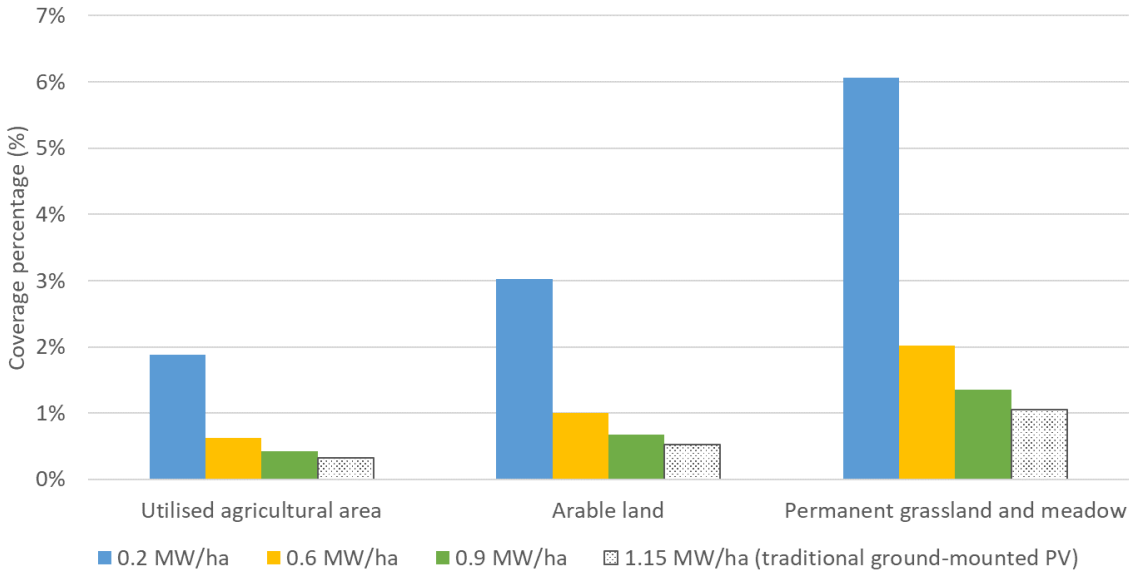
2.2.2 Potential comparison to the PV NECP planned capacity

Another comparison that puts the Agri-PV potential into perspective is with regard to the National Energy and Climate Plans (NECP) of the individual Member States. The NECP for the period 2021-2030 consists in a description of how each Member State intends to achieve its climate and energy targets. In particular, for PV, the Member States reported their ambitions for the projected installed capacity, in accordance to the RED II. In the meantime, several countries have since announced new (and more ambitious) values of planned installed capacity (Kougias *et al.*, 2021a). In addition, the EU's REPowerEU and solar strategy communications have raised the overall ambition on solar PV to almost 600 GW_{AC} (~730 GW_{DC}) by 2030. However since there is no breakdown of this new ambition at Member State level, the following analysis uses the 2019 NECP ([7]) data supplemented with all subsequent declarations made by some Member States on increased installation targets, hereafter denoted as New Policy Trends NECP PV 2030.

[7] Member States will submit draft updated NECPs to the Commission by 30 June 2023.

As demonstrated in Figure 2, the EU as a whole could reach the entire installed PV capacity foreseen for 2030 by the New Policy Trends NECP PV 2030 (592 GW) with only Agri-PV systems being deployed in 0.6 % of EU's UAA or 0.8 % of EU's arable land or 1.7 % of EU's permanent grassland and meadow, assuming an installed capacity of 0.6 MW/ha for the Agri-PV systems. For the lowest assumed installed capacity of 0.2 MW/ha, the EU New Policy Trends NECP PV 2030 capacity can be reached with 1.9 % of UAA coverage or 2.5 % arable land coverage or approximately 5 % permanent grassland and meadow coverage. In the case of installing 0.9 MW/ha (similar to traditional ground-mounted PV installations), the required coverage of UAA, arable land or permanent grassland and meadow is 0.4, 0.6 or 1.1 % respectively. Annex 2 lays out the results of the Agri-PV systems potential with regard to the New Policy Trends NECP PV 2030 of the individual Member States with an assumed installed capacity of 0.6 MW/ha.

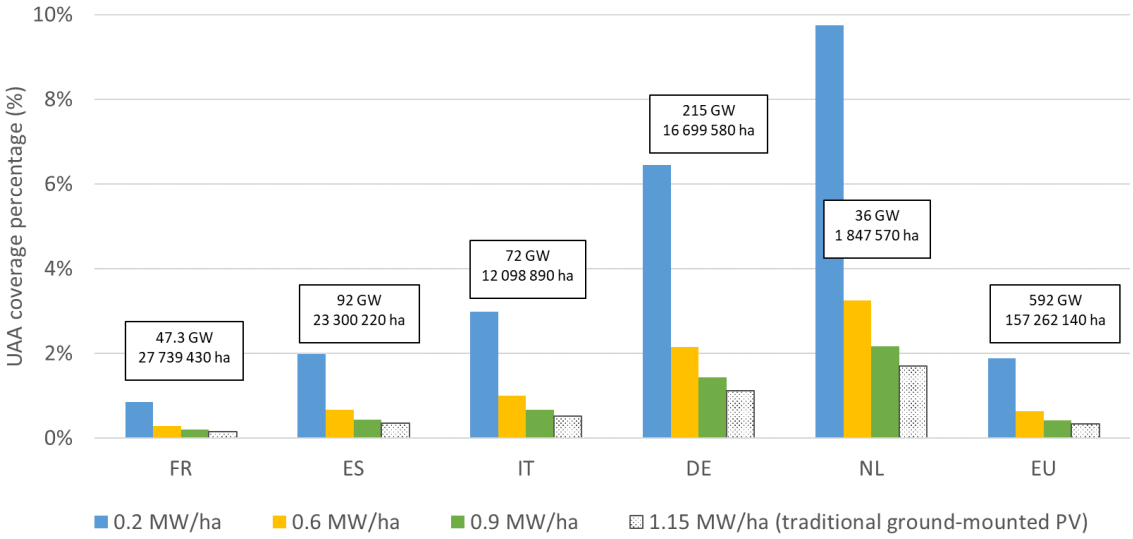
Figure 2. Required percentage of different land coverage for Agri-PV systems for the accomplishment of the EU total New Policy Trends NECP PV 2030 target for different assumed installed capacities.



Source: JRC analysis based on Eurostat and (Kougias *et al.*, 2021b).

The countries with the highest New Policy Trends NECP PV 2030 targets for 2030 in the EU are Germany (215 GW), Spain (92 GW), Italy (72 GW), France (47.3 GW) and the Netherlands (36 GW). The required UAA covered with Agri-PV systems for the accomplishment of their New Policy Trends NECP PV 2030 targets is presented in Figure 3. Different installed capacities are considered and traditional ground-mounted PV systems area requirements per MW installed is presented for comparison. Based on the different assumed installed capacity for Agri-PV systems, Germany would need to cover between 1.4 % and 6.4 % of UAA land with Agri-PV systems to reach its New Policy Trends NECP PV 2030 target. With traditional ground-mounted PV systems, its 200 GW New Policy Trends NECP PV 2030 target for 2030 could be reached with only 1 % of UAA coverage.

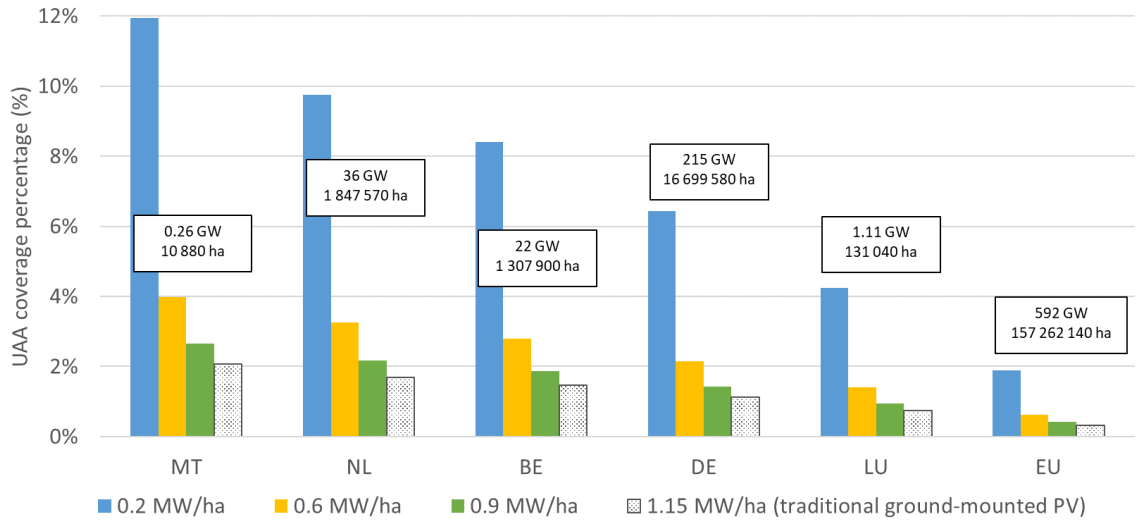
Figure 3. Required percentage of UAA coverage for Agri-PV systems for the accomplishment of the New Policy Trends NECP PV 2030 target with different assumed installed capacities for the 5 EU countries with the highest New Policy Trends NECP PV 2030 targets. The boxes in the figure present the New Policy Trends NECP PV 2030 targets and UAA of each country.



Source: JRC analysis based on Eurostat and (Kougias *et al.*, 2021b).

Spain has the second highest New Policy Trends NECP PV 2030 target for 2030 (92 GW) which can be accomplished with only 0.35 % of UAA coverage for traditional ground-mounted PV systems (1.15 MW/ha), while with the application of Agri-PV systems the land coverage ranges between 0.44 % and 2 %. In the case of Italy, while only 0.5 % of UAA is needed to reach the 72 GW target using traditional ground-mounted PV systems, in the case of Agri-PV deployment, the target can be reached with a land coverage in the range of 0.7 % to 3 %. France is the country with the fourth highest New Policy Trends NECP PV 2030target (47.3 GW) and could achieve it if only 0.15 % of its UAA land is covered with traditional ground-mounted PV systems. If this target is to be reached with Agri-PV systems, the required UAA coverage should range between 0.2 % (for a 0.9 MW/ha power density) and 0.9 % (for a 0.2 MW/ha power density). In the Netherlands, between 2 % and 10 % of UAA used for the installation of Agri-PV systems can provide the country's 36 GW New Policy Trends NECP PV 2030 target. Traditional ground-mounted PV systems would require 1.7 % of UAA coverage. For the EU as a whole, 0.35 % of UAA coverage with traditional ground-mounted PV systems would satisfy the EU New Policy Trends NECP PV 2030 target, while the necessary percentage of UAA coverage for Agri-PV systems ranges between 0.4 % and 1.9 %.

Figure 4. Required coverage of UAA with Agri-PV systems to reach the New Policy Trends NECP PV 2030 target with different assumed power densities for the 5 EU countries with the lowest UAA / New Policy Trends NECP PV 2030 for 2030 ratio.



Source: JRC analysis based on Eurostat and (Kougias *et al.*, 2021b).

As the smallest EU country by land area, unsurprisingly Malta also has the lowest available UUA. Nonetheless given the country's New Policy Trends NECP PV 2030 of 0.26 GW and an available UAA of 10 880 ha, according to Figure 4 Malta could achieve its New Policy Trends NECP PV 2030 target if 2 % of the UAA is covered with traditional ground-mounted PV systems (assumed installed capacity 1.15 MW/ha). If Agri-PV systems are considered, the required covered UAA should be between 3 % and 12 % (assuming an installed capacity of 0.9 and 0.2 MW/ha respectively). Other countries with low ratio of UAA / New Policy Trends NECP PV 2030 target are the Netherlands, Belgium, Germany and Luxembourg and for these countries as well, Agri-PV can be particularly relevant. On the other hand, countries like Latvia, Ireland, Estonia, Romania and Croatia have a higher ratio of UAA to their current PV deployment targets, and Agri-PV could be an effective way to increase their use of ground-mounted PV in future.

3 Definitions, standards and guidelines

Up to now there is no universally accepted definition of Agri-PV. Despite a widely shared opinion that this could facilitate the planning and financing of large-scale deployment of such installations, some see a danger in potentially excluding concepts that may be economically viable and socially acceptable in a given country or region. Indeed, efforts to produce legal definitions, standards and guidelines are primarily driven by national authorities and organisations/associations. The most active EU countries in Agri-PV are Germany, France and Italy. SolarPower Europe has also issued general guidelines on the best practices for Agrisolar (SolarPower Europe, 2021). These include the potential and challenges of combined solar PV with agriculture in general, as well as information on the different configurations and technology trends.

In the following sections, a brief summary of the main points regarding standards and guidelines published in each of the above-mentioned Member States are presented.

3.1.1 Germany

Germany has made the first step towards standardisation with a technical specification, the *DIN SPEC 91434:2021-05 Agri-photovoltaic systems - Requirements for primary agricultural use* (German Institute for standardization, 2022) that was published in May 2021. In this technical specification, some basic concepts are defined and some requirements are applied. The standard is applicable to Agri-PV systems of specific categories according to aspects like the structure, the PV module tracking system, the applications and agricultural products existing on the land. The definition of Agri-PV according to the standard is:

Agrivoltaics is the combined use of the same land area for agricultural production as the primary use and for electricity PV production as the secondary use.

One of the most important requirements is that the simultaneous production of energy from PV modules in agricultural land must not decrease the agricultural yield by more than one third of its reference yield (i.e. when no PV system is present). The technical specification also defines two categories of Agri-PV systems depending on the location of the PV panels:

- *Category I*: overhead with vertical clearance above 2.1 m and less than 10 % land loss with the PV system installation;
- *Category II:* interspace with vertical clearance below 2.1 m and less than 15 % land loss with the PV system installation.

It is also important that erosion and damage of the soil is avoided and the dismantling of the PV systems is done without any permanent damage to the land.

The Fraunhofer Institute for Solar Energy has also published a guideline document for Agri-PV projects in Germany (Hermann *et al.*, 2022). These cover all relevant parameters, from agriculture-related aspects, such as crop selection and farm business models, to technology-related aspects like PV module technologies, mounting solutions and installation and operation. Apart from the technical features, the guidelines analyse the economic aspects of Agri-PV systems compared with traditional PV systems in terms of capital (CAPEX) and operating costs (OPEX) and as well as Levelised Cost of Electricity (LCoE) and touch upon the societal and legal framework for Agri-PV projects in Germany.

Since 2021 Agri-PV is given recognition under German legislation, thanks to the revision of German Renewable Energy Sources Act, EEG. In this it was associated with floating PV and PV for parking roofs in a joint tender of 150 MW_p. Currently, the eligible categories, denominated as special solar systems in the EEG are: arable Agri-PV ([8]), horticulture Agri-PV ([9]) and grassland Agri-PV ([10]). In addition, compliance to the DIN SPEC 91434 will be necessary for the participation in the tender (Trommsdorff *et al.*, 2022).

In contrast to arable farming or horticulture, the use of grassland, apart from grazing, often serves the purpose of landscape management and/or the provision of biodiversity services. In this sense, the DIN SPEC

[8] Arable land that is not peatland with simultaneous cultivation of crops on the same area.

[9] Land that is not peatland with the simultaneous agricultural use in the form of cultivation of permanent or perennial crops on the same land.

[10] Grassland that is not peatland soil with simultaneous agricultural use through the use of permanent pasture.

requirements are inappropriate and criteria for species and biotope protection should be used instead. A dedicated standard for Agri-PV with animal husbandry will be elaborated in the next months.

3.1.2 Italy

In the case of Italy, there is no official standard or technical specification for Agri-PV installations but several reports and guidelines have been published by different stakeholders. Most significantly, a carefully designed guideline entitled ***"Guidelines on Agri-PV systems"*** was published in June 2022 by the Italian Ministry of the Environment and Energy Security (MITE, 2022). This has four main categories of requirements for Agri-PV projects:

- Requirement A: The definition of Agri-PV
  - Agricultural surface (covered with crops) of less than 70 % of the total surface;
  - Percentage of area covered with PV modules less than 40 %.
- Requirement B: The synergy between the production of energy and the production of agricultural yield
  - Continuity of the agricultural activity;
  - Electricity production by the Agri-PV system more than 60 % of the electricity produced by a standard PV system.
- Requirement C: The Agri-PV system adopts innovative integrated solutions with modules raised off the ground
  - Type 1 Inclined PV modules overhead;
  - Type 2 Inclined PV modules between the crops;
  - Type 3 Vertical PV modules between the crops.
- Requirement D and E: Monitoring systems
  - for water savings (requirement D);
  - for agricultural continuity (requirement D);
  - for soil fertility recovery (requirement E);
  - for microclima (requirement E);
  - for resilience to climate change (requirement E).

Compliance with requirements A and B is necessary for the characterisation of a PV system in an agricultural land as Agri-PV system.

Compliance with requirements A, B, C and D is necessary to enter the category of "advanced Agri-PV plant" and give access to state incentives based on electricity tariffs.

Compliance with A, B, C, D and E is essential and works as a pre-condition for access to contributions from the PNRR (Recovery and Resilience Plan). The PNRR foresees a dedicated project of EUR 1.1 billion for the development of Agri-PV (UIPA, 2023). However, additional criteria may be applied if required.

A new working group of the standards technical committee CT 82 CEI (Solar energy photovoltaic conversion systems) on Agri-PV has been established and a project "Agri-PV norm" has been launched by UNI (Ente Nazionale Italiano di Unificazione), with the participation of REMTec, Università Catolica del Sacro Cuore & ENEA. The CEI-PAS 82-93-Agrivoltaic plants has been published and is now available for public consultation until mid-April (Comitato Elettrotecnico Italiano, 2023).

According to the main stakeholders, Agri-PV projects of 20-30 GW_p capacity are in the process of applying for administrative authorisations under the national permitting process. In addition, the department of Ecological Transition is working on suitable areas for Agri-PV.

In February 2023, an implementation decree that mentions Agri-PV has been approved. However, it is still in the process of becoming a law (Gazzetta Ufficiale della republica Italiana, 2023).

3.1.3 France

The jurisprudence of the French Conseil d'Etat accepts the coexistence of an activity of agricultural production and of photovoltaic production, as long as the agricultural project is real and credible. Two cases have been distinguished.

First, following a case entitled "Cne de Bellegarde" ([11]), the Council of State issued a ruling on 12 July 2019 ([12]). In the case of "agricultural constructions", a real and credible agricultural activity exists without seeking to determine whether it is preponderant. Then, regarding constructions or installations necessary to collective equipment in agricultural areas, and as long as these installations allow a significant agricultural activity, the co-location of both agricultural and photovoltaic production is allowed according to the provisions of the penultimate paragraph of Article L. 123-1 of the Urban Planning Code, enlightened by the preparatory work of the law of 27 July 2010 on the modernisation of agriculture and fisheries. If there is the possibility of carrying out agricultural, pastoral or forestry activities and the absence of prejudice to the protection of natural areas and landscapes, the judge can assess these criteria to determine whether a project can be done or not.

The Agency for the Ecological Transition (ADEME) published a guideline document entitled ***"Characterising solar PV projects on agricultural land and agrivoltaism"*** in July 2021. This document collects science-based evidence of the performance of Agri-PV systems, classifies the different types, lists good practices at global level and gives recommendations regarding the management, deployment and operation of such systems.

The proposed French definition of Agri-PV according to the Ademe guideline is as follows (Ademe *et al.*, 2021):

A solar PV system can be considered agrivoltaic when the solar PV modules are located on the same area of plot as the agricultural production, and when they impact the agricultural production by providing, without any intermediary:

- *climate change adaptation;*
- *hazard protection;*
- *animal welfare;*
- *specific agronomic services (limiting abiotic stresses, etc.),*

without inducing any significant degradation of the agricultural production (both qualitatively and quantitatively), or any farm income loss.

Beyond these major characteristics, the agrivoltaic project must also ensure its agricultural vocation (by allowing the farmer to be involved in its design, and even its investment), guarantee the sustainability of the agricultural site throughout its lifetime (independently of any potential change in farm owner: there must always be an active farmer), its reversibility and its adequacy with local and territorial development (especially for the valorisation of crops), while limiting its impact on the environment, the soils and landscapes. Finally, based on any form of potential agricultural vulnerability, the agrivoltaic installation must be adaptable and flexible in order to respond to possible evolutions through time (i.e. modification of the species and varieties that are being grown).

The three criteria evaluated for the characterisation of an Agri-PV project are:

- Criterion 1 Contribution to the agricultural production

  The PV systems must have a justified and proven direct contribution to the agricultural production (e.g. protection of crops, welfare of animals, etc.);

- Criterion 2 Incidence on agricultural yields

  The PV system must increase, maintain or decrease within acceptable proportions the agricultural yield;

- Criterion 3 Incidence on the revenues of the farm owner

[11] Conseil d'Etat, 2nd - 7th chambers combined, 03/10/2016, 390716
[12] Council of State, 6th - 5th joint chambers, 12/07/2019, 422542

The PV system must maintain or improve the farmer's income.

In addition, the Association Française de Normalisation (AFNOR) organisation provides a "Positive Agrivoltaics" label that aims to certify the positive impact of Agri-PV projects (i.e. improvements to agricultural production). This label could serve as a proof of quality for the project stakeholders (farmers, public authorities, etc.). Under the scheme, projects should be monitored from design to up to 5 years after commissioning. A second AFNOR certification on Agri-PV systems for animal farms is expected soon.

Furthermore to the guideline mentioned above, with the acceleration law for renewable energy ([13]), the French legislator chose to cover a large range of Agri-PV systems in order to ensure an adaptation and complementary of both agricultural and photovoltaic productions. The article 54 of the law amends the energy code by adding an article L. 314-36 dedicated to the definition of "agrivoltaics installations":

- *I. - An agrivoltaic installation is an electricity production installation that uses radiative solar energy and whose modules are located on an agricultural parcel where they contribute sustainably to the installation, maintenance or development of agricultural production.*
- *II. - Is considered as agrivoltaic an installation which brings directly to the agricultural parcel at least one of the following services, by guaranteeing to an active farmer or to a farm with educational vocation managed by an establishment relevant to the 1st title of the book VIII of the rural code and of the maritime fishing a significant agricultural production and a durable income being stemmed from it:*
  - *1. Improvement of the agronomic potential and impact;*
  - *2. Adaptation to climate change;*
  - *3. Protection against hazards;*
  - *4. Improvement of animal welfare.*
- *III. - A facility that substantially impairs any of the services referred to in paragraphs 1 to 4 of section II or impairs only two of those services may not be considered agrivoltaic.*
- *IV. - An installation may not be considered agrivoltaic if it has at least one of the following characteristics:*
  - *1. It does not allow agricultural production to be the main activity of the agricultural parcel;*
  - *2. It is not reversible.*

Article 54 of the law also amends the planning code adding a section 9 for *"Photovoltaic energy production facilities on agricultural, natural and forest land"*. A sub-section 1 concerned agrivoltaics installations at art. L. 314-36 of energy code and *"the installation of greenhouses, sheds and shadehouses for agricultural use supporting photovoltaic panels must correspond to a need linked to the effective exercise of a significant agricultural, pastoral or forestry activity"*. A sub-section 2 relates to *"Facilities compatible with the exercise of an agricultural activity"*. The compatibility with the exercise of an agricultural, pastoral or forestry activity of the production works of electricity from solar energy is assessed on the scale of all the land in one piece, forming part of the same agricultural, pastoral or forestry operation.

Moreover those facilities must not have a lasting effect on the ecological functions of the soil, in particular its biological, water and climatic functions as well as its agronomic potential. Four decrees in the Council of State are expected to determine the terms of application of this article 54.

The French law does not specify quantitative criteria for Agri-PV in contrast to some other MS guidelines and proposals, which include concepts such as the minimum ensured crop yield, the maximum possible coverage by PV modules or the minimum electricity production. All these parameters will be verified on a case-by-case basis during the permitting procedure. The main reason for this lies in the different and specific necessities, regulations and characteristics of each region. More specifically, building on agricultural land requires one additional permit from the CDPENAF (Commission départementale de préservation des espaces naturels, agricoles et forestiers).

[13] https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000047294244/

3.1.4 Other Member States

Several other EU Member States are active in the Agri-PV sector and the information available is summarised below.

Spain

Although there is no regulation or on-going legislative initiatives taking place in Spain at the moment, the Spanish energy agency (IDAE) is developing definitions and categories aiming to work at future support mechanisms. The permitting procedures as well as the grid connection of Agri-PV projects are the same as for standard PV projects. According to experts' opinion during the JRC workshop on Agri-PV, a fast-track permitting process and a definition of grid connection quota dedicated to Agri-PV would facilitate the deployment of Agri-PV projects in Spain.

Poland

Currently, as far as permitting and regulations are concerned, Agri-PV in Poland falls in the category of traditional ground-mounted PV. The Polish Photovoltaics Association aims at treating Agri-PV as infrastructure related to agricultural production. This approach will require minor legal changes and will ensure that no "greenwashing" will occur. In addition, this would avoid changing the characterisation of the land and thus also the current taxation regime applicable to Agri-PV system installations. The Association is working on a report for public administration bodies, parliament members and senators with the aim of introducing the concept of Agri-PV, explaining its benefits, presenting best practices and proposing regulatory solutions in order to promote Agri-PV in the country.

In January 2023 Poland announced a PIn 1 bn (EUR 213m) Energy for the Countryside programme to support investments in renewable energy sources in rural areas, including co-financing of renewable energy projects including PV installation. However it is not known if or to what extent Agri-PV will be eligible.

The Netherlands

The country has a fast growing PV market and is actively promoting PV as a preferred renewable energy source. In addition, it has a large agricultural economy and hosts more than 10 Agri-PV projects (where fruits are grown below solar panels). However, at the same time the National Environmental Vision (NOVI) states a preference for solar energy on roofs and states that the installation of PV on agricultural and natural land should be considered as a very last resort, with the exception of projects where solar panels do not influence the agricultural use of the land.

For regular PV installations on agricultural land nearly always a zoning plan change is needed. For Agri-PV, it depends if there are already existing structures, which are used to protect against extreme weather. In half of the Agri-PV cases, a zoning plan is required.

In general, land solely used for PV installations will lose its agricultural function and hence will not qualify for certain tax measures that apply to the agricultural sector. The installation of solely PV on agricultural land is essentially changing the land characterisation and therefore, excludes the farm from tax reductions and exemptions (Rijksdienst voor Ondernemend Nederland, 2022).

For Agri-PV, the multiple use of agricultural space is recognised in agricultural regulations. As long as the area for the agricultural function does not change, the installation of solar panels has no consequences for agricultural rights. This concerns rights such as production or manure space and agricultural payments. (Rijksdienst voor Ondernemend Nederland, 2022)(Rijksdienst voor Ondernemend Nederland, 2022)(Rijksdienst voor Ondernemend Nederland, 2022)(Rijksdienst voor Ondernemend Nederland, 2022)(Rijksdienst voor Ondernemend Nederland, 2022) According to the Dutch CAP plan, the agricultural land remains eligible if solar panels do not hinder agricultural activities, as mentioned above.(European Commission, 2022b)(European Commission, 2022b)(European Commission, 2022b)(European Commission, 2022b)(European Commission, 2022b)

According to the Climate Agreement, in case the farmer is only leasing or renting out (roof or land) and is not involved in the energy production, the PV system is considered to support the sustainability of the energy sector and not that of the agricultural sector (Rijksdienst voor Ondernemend Nederland, 2022).

4 Challenges for Agri-PV

The development of Agri-PV is actively discussed in Europe and internationally. In March 2022 the JRC hosted a workshop *Agri-Photovoltaics - achieving its full potential in the EU Energy Transition* (Chatzipanagi *et al.*, 2022), which gathered representatives from the European Commission, agriculture, construction and photovoltaic research and industry sectors ([14]) in an attempt to identify the opportunities and challenges related to Agri-PV systems. The International Energy Agency Technical Cooperation Programme on PV Power Systems also held a workshop in 2022 on legal aspects of Agri-PV in France, Germany, Italy and Israel. The discussions gave insights on the current legislations as well as the future expected developments in the different Member State laws regarding Agri-PV ([15]).

The results of the two above-mentioned workshops, as well as the on-going discussions with the stakeholders have highlighted the main hurdles encountered during the realisation of Agri-PV projects that need to be resolved.

— The first major barrier for the expansion of Agri-PV systems is, as already mentioned, the lack of a clear, robust and universal definition at EU level, as well as the absence of a dedicated standard. The efforts towards the establishment of an Agri-PV definition and a related standard are currently undertaken at Member State level and lack harmonisation at EU level. In addition, the lack of a concrete definition and standard may result in the exploitation of Agri-PV for "greenwashing" (characterisation of conventional PV on agricultural land as Agri-PV because they satisfy partially the requirements).

— It is essential that the agricultural activity is maintained at all times as reflected also in the legislation developed by Member States on the issue. However, it has been reported that in several Member States the land characterisation may change after the realisation of an Agri-PV installation, thus introducing legal obstacles for the farmer. In addition, such a change may result in an exclusion from the CAP. Uncertainties and financial consequences may result in a perception of legal insecurity and possible loss of income for the farmer or the investor.

— As the large-scale deployment of Agri-PV needs to consider and ensure the welfare and income of farmers, the price effects on agricultural land need to be assessed. In France the prices for land that can host Agri-PV systems has increased in the last years. A special commission will be created in order to investigate the effect of this price increase as farmers (especially new ones who are entering the agricultural sector) complain from this effect.

— Public awareness and acceptance amongst farmers and the rural communities is identified as a pivotal parameter that directly influences the large-scale deployment of Agri-PV. All the above-mentioned barriers, if not addressed, will create insecurity for stakeholders and ultimately undermine their willingness to invest in Agri-PV.

— Even though research on Agri-PV systems has increased in the last years, there are still technical challenges to be addressed in order to maximise electricity generation while ensuring the lowest possible impact on crop yield production. There are several aspects to this question, and the validation of potential solutions needs further R&D through pilot projects to investigate crucial parameters such as partial shading and other important aspects for crop growth, photovoltaic yield of different configurations as well as biodiversity impacts and effects on the surrounding ecosystem.

— It has been noted by all stakeholders that Agri-PV is still not well incorporated in the member state CAP national strategic plans and national policies. The role of Agri-PV as an innovative form of PV deployment supporting both electricity and crop production should be given more attention. In addition a specific dedicated financial support for Agri-PV would be welcomed.

— Finally, stakeholders identify that permitting and connection to the grid of Agri-PV systems follow different approaches depending on the country. Different requirements exist for each Member State and they are usually similar to those of traditional PV systems, thus facing limitations (depending on the local

---

[14] European Commission staff from DG JRC, DG ENER, DG RTD, DG AGRI, EISMEA, SolarPower Europe (AgriSolar Workstream), Amarenco (AgriSolar Workstream), Nature And Biodiversity Conservation Union (NABU), University of Hohenheim, Fraunhofer Institute for Solar Energy Systems ISE, Next2Sun GmbH, REM Tec, France Agrivoltaïsme Association, ENEA (Agrivoltaico Sostenibile), Iberdrola, BayWa r.e. Solar Projects GmbH, Agro-voltaics working group of the Polish Photovoltaics Association, Institute for Renewable Energy of Poland (IEO).

[15] https://iea-pvps.org/events/workshop-on-legal-frameworks-for-agrivoltaics-in-france-germany-italy-and-israel/

regulations) and taking too much time. A clear definition of Agri-PV will be helpful for the facilitation of the land permitting and grid connection procedures. In addition, Agri-PV is expected to be addressed in EC guidelines on permitting for renewables, foreseen for 2024.

5 Synergies for Agriculture, Environment and Energy Policies

5.1 Common Agricultural Policy

A quick scan of the MS CAP plans was performed in November 2022 ([16]). The purpose of this scan was to identify the consideration given to renewable energies and PV in particular in the CAP national plans. Upon an initial analysis of the CAP plans, two indicators were identified as relevant to renewable energies and climate change support.

These indicators are:

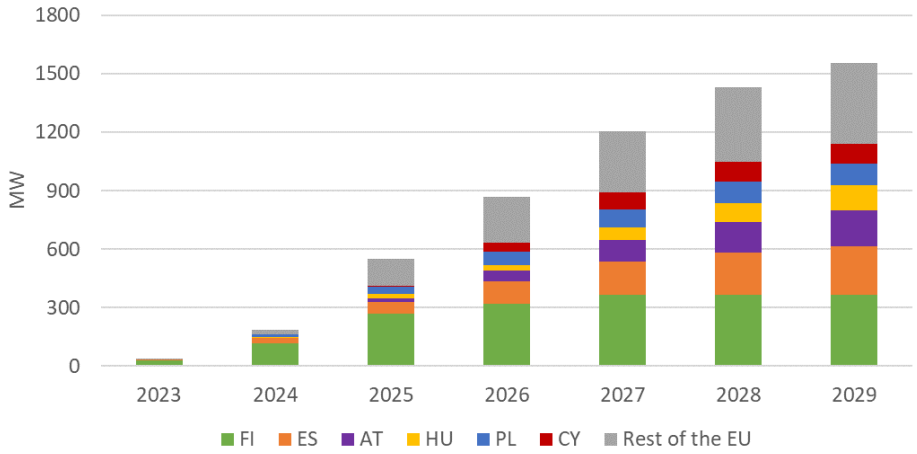
- *R.15 Renewable energy from agriculture and forestry and from other renewable sources – Supported investments in renewable energy production capacity, including bio-based (in MW)* and
- *R.16 Investments related to climate - Share of farms benefitting from CAP investment support contributing to climate change mitigation and adaptation, and to the production of renewable energy or biomaterials.*

In addition, the CAP plans were searched for the key words "*Agri-Photovoltaic* or *Agri-PV* or *Agrivoltaic*", "*Photovoltaic*", "*Renewable*" (in relation to solar/photovoltaic) and "*Solar*" with the purpose of identifying specific actions planned.

All 28 CAP plans (Belgium has two: one for Wallonia and one for Flanders) are formally approved and published. These plans are in force since 1st January 2023 (European Commission, 2022b).

The R.15 indicator values for the different countries (reported by 22 countries) are presented in detail in Annex 3. The combined total of the individual CAP targets for energy production by renewables in 2029 is 1 556 MW.

Figure 5. Renewable energy production capacity (Indicator R.15) reported in the Strategic CAP plans for the EU.



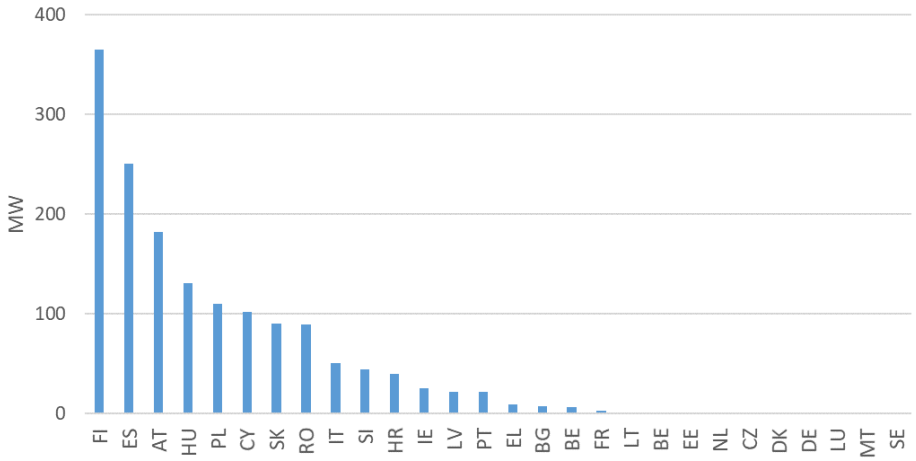
Source: JRC analysis based on (European Commission, 2022b).

Figure 5 shows the evolution of the target for the production of renewable energy (Indicator R.15) in the EU from 2023 until 2029. From a target of 38 MW in 2023, the Member States have set an overall EU target of 1 556 MW by 2029, corresponding to a compound growth of 86 %. Between 2025 and 2029, the targeted renewable energy production capacity in the EU will grow by three times. The figure also presents the six Member States that, from 2025 onwards, account for 75 % of the EU total. These Member States are Finland, Spain, Austria, Hungary, Poland and Cyprus. However, it has to be taken into account that until 2025 a parallel implementation of Rural Development Programmes and the CAP Plans will be taking place. Therefore, some

[16] The national CAP plans were accessed in their official language and were translated with the help of online translation tool where necessary.

MS might not start supporting investments in RES from 2023. Therefore, Figure 6 shows the planned renewable energy capacity of each Member State as an overall target (2023-2029). Finland, Spain and Austria together account for approximately 800 MW of the EU's 1 556 MW overall target for Indicator R.15, thus contributing by 50 %. The overall EU target of 1 556 MW in 2029 is basically achieved by the top 10 Member States (Finland, Spain, Austria, Hungary, Poland, Cyprus, Slovakia, Romania, Italy and Slovenia). The rest of the Member States contribute with only 10 %.

Figure 6. Member State targets for renewable energy production capacity (Indicator R.15) reported in the Strategic CAP plans for 2029 (and overall target).

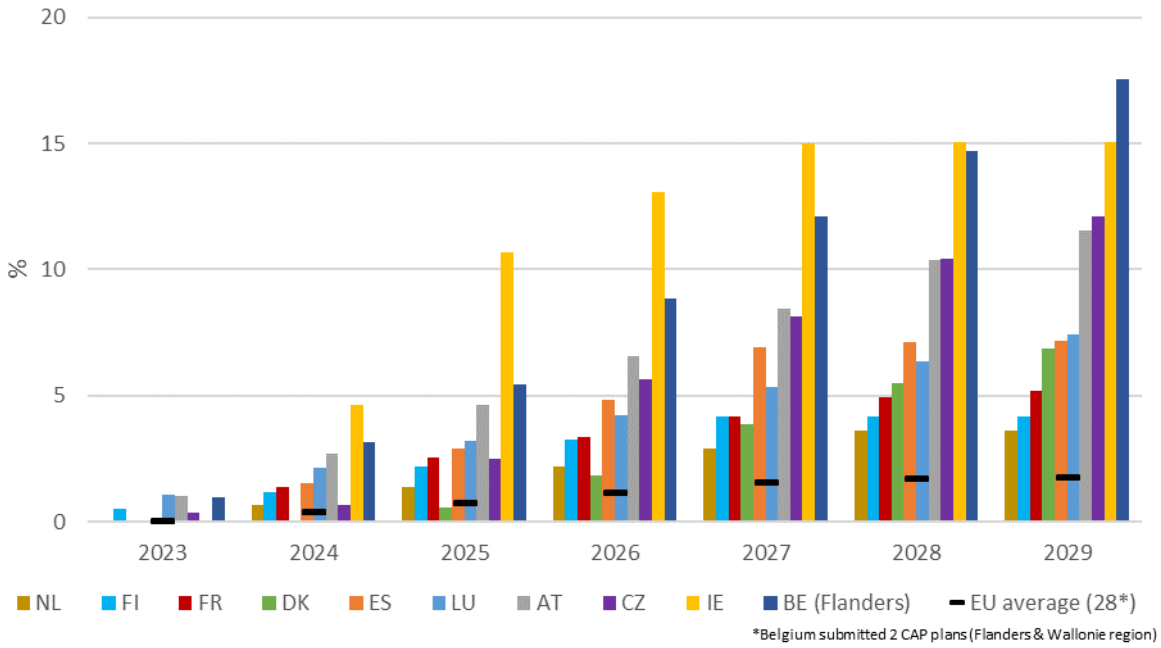


Source: JRC analysis based on (European Commission, 2022b).

For indicator R.16, all countries report their planned share of farms benefitting from CAP investment support contributing to climate change mitigation and adaptation, and to the production of renewable energy or biomaterials. The individual values can be found in Annex 4. On average 1.76 % (overall target) of farms should benefit from investments.

Fifteen EU Member States exceed the average overall 1.76 % share of beneficiary farms. The top ten are shown in Figure 7. The Flanders region of Belgium has the highest reported indicator R.16, approximately 18 %, thus being the region with the highest share of farms benefitting from renewable energy investments and with an overall renewable energy production capacity (R.15 indicator) target of 6.3 MW. Ireland is following with 15 %. Czech Republic and Austria also have a share over 10 %, with 12 % and 11.5 % respectively. Above 4 % share of beneficiary farms is observed also in Luxembourg, Spain, Denmark, France and Finland, with the latter having the highest overall production capacity planned with 365 MW by 2029. The Netherlands, Slovakia, Hungary, the Wallonia region of Belgium, Germany and Slovenia have R.16 targets above the EU average and between 2 % and 3.6 %.

Figure 7. Share of farms benefitting from CAP investments support contributing to climate change mitigation and adaptation, and to the production of renewable energy or biomaterials (Indicator R.16) of the Strategic CAP plans for the top 10 EU countries.



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

As regards the link between these two indicators, the data in Annexes 3 and 4 evidences that five Member States exceed simultaneously the average values of R.15 and R.16 indicators for the EU. These are Finland, Spain, Austria, Hungary and Slovakia. More specifically, Finland is aiming for 365 MW overall planned capacity and 4.16 % of farms receiving investment by 2029. In the case of Spain, the overall planned capacity is 251 MW overall planned capacity and the percentage of farms receiving investment by 2029 is 7.19 %. Austria plans a 182.25 MW overall planned capacity and 11.54 % of farms receiving investment by 2029. The corresponding plans for Hungary are 131.29 MW and 3.16 % of farms receiving investment by 2029, whereas Slovakia plans 90.04 MW of renewable energy capacity and 3.45 % of farms receiving investments by 2029.

A search for the terms "Agri-photovoltaics" (or its other versions), "Photovoltaics", "Solar" and "Renewables" (in relation to photovoltaics and / or solar energy) was performed in the CAP documents in order to identify to what extent photovoltaics are mentioned in the Member States' plans. Annex 5 reports the results. Most of the CAP plans refer to the promotion of renewable energies in general and a lot of them focus on the potential of biomass of agricultural and forestry origin for energy production. In almost all, the production of energy is required to be aligned with the energy needs of the farms and restricted to self-consumption. In most of the cases, the landscape and landscape preservation are important aspects to be taken into consideration.

The term photovoltaics was found in fourteen CAP plans (Austria, Belgium (Wallonia), Bulgaria, Cyprus, Czech Republic, France, Germany, Ireland, Italy, Luxembourg, Malta, the Netherlands, Slovenia and Spain) and the deployment of this technology is primarily promoted for installations on agricultural-related buildings, such as warehouses, packaging plants, material storage buildings and agri-food facilities.

Only four CAP plans used the term "Agri-photovoltaics" (or other versions referring to the multi-use of land for energy and food production). These Member States are Germany, Italy, the Netherlands and Slovenia.

In particular, according to the German CAP plan, there is a clear distinction between PV installations in agricultural buildings and Agri-PV installations on arable land and areas with permanent crops. The plan promotes the installation of elevated PV systems that do not compromise the use of land for agricultural purposes.

Similarly the Italian CAP plan draws a distinction between Agri-PV and PV installations. However, this distinction is only mentioned and the Italian CAP plan does not provide for more specifications. As far as PV

installations are concerned, their deployment is promoted through Italy's National Recovery and Resilience Plan and more specifically the "Parco agrisolare" and its EUR 1.5 billion fund dedicated to the installation of PV modules on the roofs of agricultural and agro-industrial structures, in addition to other actions related to energy efficiency and intelligent management systems. Italy's National Recovery and Resilience Plan also foresees the "Development of biomethane, according to criteria to promote the circular economy" with the aim of supporting the conversion and efficiency of the existing agricultural biogas plants towards the production of biomethane according to criteria of promotion of the circular economy, the construction of new plants and the construction of structures for the correct management of biomass. The foreseen budget is EUR 1.9 billion.

The Netherlands' CAP plan, is keener on promoting PV compared to other renewables, and in particular PV on buildings related to agricultural activity. The plan does, acknowledge and promote Agri-PV as an innovative form of PV deployment. It defines that the modules must not interfere with agricultural activities and are limited to a maximum of 100 distributed PV modules per hectare, with a maximum size of 100m^2. Clusters of PV modules (above 10m^2) are not considered eligible agricultural land and are deducted from the eligible areas.

Slovenia references and promotes Agri-PV but specific details are not included in its CAP plan.

Annex 6 presents a summary of the investigation of references to Agri-PV in the CAP plans. However, it has to be mentioned in this context that the level of details in the CSP (sometimes very general) does not allow for a more detailed analysis of which support will go directly to Agri-PV systems.

5.2 Biodiversity

In addition to energy and crop yield-related considerations, Agri-PV also needs to take into account its impact on the biodiversity.

One of the key commitments for nature protection within the EU Biodiversity Strategy for 2030 is that, for the good of our environment and our economy, and to support the EU's recovery from the COVID-19 crisis, we need to protect more nature. For this reason, at least 30% of the land and 30% of the sea should be protected in the EU (European Commission, 2020a). The Natura 2000 network of protected areas covers 18% of the EU's land and 8% of its seas. National protection schemes cover an additional 8% of land and 3% of sea. Member States will therefore need to collectively protect a further 4% of their land and 19% of their seas in order to reach the 30% target set by the 2030 Biodiversity Strategy (European Commission, 2021b).

Agri-PV systems ought to avoid conflicts with nature conservation, which implies that no installations can be deployed in protected areas (Natura 2000) and Agri-PV should comply with the 30 % target of EU Biodiversity Strategy.

The European Commission has published a report on the potential impacts of PV applications on the ecosystem and the biodiversity (European Commission, 2020b). The possible negative impacts of Agri-PV are similar to those of traditional ground-mounted PV systems (solar farms) and are site-specific. There consist in habitat loss and degradation, fragmentation and incidents of disturbance and displacement effects on birds and bats. However, there may also be excellent opportunities for biodiversity creation or enhancement. In fact in many EU countries habitats are created between the solar panels (like wildflowers strips) or around the borders of the site (like hedgerows) (European Commission, 2020b).

As regards the soil, the EU biodiversity strategy specifically acknowledges that solar panel farms may provide biodiversity-friendly soil cover as a win-win solution for energy and biodiversity (European Commission, 2020a).

SolarPower Europe has published guidelines for best practices to enhance the biodiversity and land use efficiency through PV installations (SolarPower Europe, 2022b). PV installations on agricultural land can increase the biodiversity of the area and improve soil health that has been altered due to several years of agricultural activities. It is therefore important to assess the specific site's ecological characteristics at the initial phase of the Agri-PV project (SolarPower Europe, 2022b). Such proactive approaches aim at applying the correct actions to enhance biodiversity through the installation of Agri-PV systems rather than trying to only minimise their impacts.

6 The EU Agri-PV Ecosystem

6.1 Research and Development

The technologies for Agri-PV systems depend primarily on the particular design of the system. PV modules can be either monofacial or bifacial. Monofacial PV modules can be used mainly for overhead systems, whereas bifacial PV modules are more suited for vertical installations. Regarding the energy production from the PV system, the research is on-going and is exploring all the possible solutions for installations that maximise the electricity produced for the particular case of Agri-PV systems where the area covered by PV modules is smaller than in the case of traditional ground-mounted PV systems. Many companies are active in the planning and realisation of Agri-PV systems sector with special mounting systems. The companies may act as product providers, project designers but also as Engineering, Procurement and Construction (EPC) contractors.

Research regarding the effects of Agri-PV systems on the crop yield has developed in the last years. Researchers have been testing pilot Agri-PV systems to identify the improvements or losses in yield that a PV system may bring depending on the specific needs of different crop types (sunlight, humidity, temperature, irrigation, etc.). For example, it is possible to indicate which types of crops may benefit from reduced temperatures due to shadowing by the PV modules (like potatoes, tomatoes, peppers, lettuce, broccoli and corn) (Amaducci, Yin and Colauzzi, 2018; Barron-Gafford *et al.*, 2019; Sekiyama and Nagashima, 2019; Thompson *et al.*, 2020; Weselek *et al.*, 2021) or which ones may suffer from the smaller amount of solar radiation reaching them (like spinach and wheat) (Beck *et al.*, 2012; Hudelson and Lieth, 2021). This way, the farmer can choose the most suitable crop type to grow and the Agri-PV installer can plan how best to design and construct the system.

Research has also focused on the planning of Agri-PV systems that acknowledge less technical considerations, such as economic, nature and landscape parameters.

Horizon Europe is supporting the SYMBIOSYST ([17]) project that started in January 2023 with the aim to combine energy supply issues with the needs of the agricultural sector. It is coordinated by Eurac Research (Italy), and the consortium includes Interuniversitair Micro-Electronica Centrum - IMEC (Belgium), Technische Universiteit Delft (Netherlands), Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile - ENEA (Italy), Aleo Solar GmbH (Deutschland), KU Leuven (Belgium), Centro di Sperimentazione Laimburg (Italy), Südtiroler Bauernbund (Italy), ETA Florence - Renewable Energies (Italy), Universitat Politecnica de Catalunya (Spain), Physee Products B.V. (Netherlands), Kubo Innovations BV (Netherlands), Convert Italia SPA (Italy), Lucisun (Belgium), 3E (Belgium), Belgisch Laboratorium Van Elektriciteitsindustrie (Belgium), EF Solare Italia SPA (italy) and Above Surveying LTD (United Kingdom).

Another area of R&I is for IT tools to support Agri-PV planning. The following are a few of the most known:

AGRIPV tool ([18])

Designed by KU Leuven University (KU Leuven, 2022), this tool is one of the deliverables of HyPErFarm, a Horizon 2020 funded project (Task 1.1 within the WP1 Agrivoltaic system design). The input parameters of the tool are the location, the structure of the system (such as height, tilt, etc.) and the crop specifications in terms of shadow tolerance. As an output, the tool provides the installed power, energy yield, the relative crop yield, the LCoE and others.

AgriPV Modeling

The Institute for Solar Research of the German Aerospace Center (Deutschen Zentrums für Luft- und Raumfahrt, DLR) is developing a modeling tool (Institute for Solar Research (DLR), 2022) for the determination of the best economical Agri-PV design that will combine the maximum agricultural yield ad the maximum power generation simultaneously. The model's inputs are the meteorological conditions of the location, the type of crops, the PV system design and other economical influencing parameters, like potential subsidies. The output results are then compared to traditional PV systems.

AgriPV Suitability Map

[17] https://www.eurac.edu/en/institutes-centers/institute-for-renewable-energy/news-events/symbiosyst-project
[18] https://agrivoltaics.one/website_AgriPV/tool.html

The tool is developed by the National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) in Italy. Based on ArcGIS, the tool employs several layers defined by geophysical, technical, environmental, economical, socio/political and landscape criteria and aims to identify the ideal areas for the deployment of AgriPV systems in Italy, as well as their potential capacity.

Others have elaborated a complete analysis regarding the multi-functionality of solar power plants (also Agri-PV) taking into account energy, economic, nature and landscape aspects can produce a typology tool that can assist in decision-making processes with quantitative as well as qualitative targets (Oudes, van den Brink and Stremke, 2022).

Outside the EU, some interesting tools for Agri-PV planning are:

SPADE Agrivoltaic Design Software

Developed by Sandbox Solar, the tool (SANDBOX Solar, 2022) predicts agricultural and photovoltaic production, air temperatures, soil moisture, and estimated water savings. Its application is limited to the United States.

nanoHUB Agrivoltaic Simulation

The tool is offered on the nanoHUB.org website run by Purdue University. The nanoHUB Agrivoltaic Simulation (nanoHUB, 2022) tool has two simulation modes. One mode is the design of an Agri-PV farm and the other one gives the possibility to set the design parameters for specific farming needs. The input parameters are the PV system (such as PV modules dimensions, orientation, pattern and electrical parameters) and the location and date. As an output the tool provides the power spatial density and the irradiance for the configurations selected as input.

Some publications have addressed the issue of simulation for complex systems planning, mostly considering bifacial PV modules addressing the ground albedo reflection (Zohdi, 2021).

The IEA has a dedicated programme, the IEA-PVPS, whose objectives relate to reliable PV power system applications for the sustainable energy transition. Within the PVPS Task 13, there is a subtask (2.2) dedicated to Agrivoltaics. In December, the IEA PVPS Task 13 – Subtask 2.2 Agrivoltaics organised the *Workshop on Legal Frameworks for Agrivoltaics in France, Germany, Italy, and Israel*, dealing with the legal requirements and hurdles regarding Agri-PV systems in the above-mentioned countries in an attempt to clarify the situation ([19]).

6.2 Industry

Some of the major European companies involved in the Agri-PV sector, either on R&D activities or for the planning and realisation phases, are ([20]):

Project development

- Amarenco (IE-FR) (projects)
- BayWa r.e. AG (DE) (projects)
- EF Solare Italia (IT) (projects)
- Iberdrola (ES) (projects)
- kiloWattsol (FR) (projects)
- Sun'Agri (FR) (projects)
- SUNFarming GmbH (DE) (projects)
- Sun'R Groupe (FR) (projects)
- STEAG Solar Energy Solutions GmbH (DE)
- Next2Sun GmbH (DE) (Agri-PV system)

[19] https://iea-pvps.org/events/workshop-on-legal-frameworks-for-agrivoltaics-in-france-germany-italy-and-israel/

[20] The list is not exhaustive.

— REM Tec (IT) (Agri-PV system)

Mounting system

— Axial Structural Solutions S.L (ES) (mounting systems)

— IDEEMATEC GmbH (DE) (mounting systems)

— PMT-Premium Mounting Technologies (DE) (mounting systems)

— Goldbeck Solar GmbH (DE) (modular arcs, creating a system that can be moved flexibly)

— Zimmermann (DE) (Agri-PV system)

— Next2Sun GmbH (DE) (Agri-PV system)

— REM Tec (IT) (Agri-PV system)

6.3 Associations, workshops and conferences

The high potential of Agri-PV systems and the advantages they bring to the water-energy-food security nexus, has resulted in various collaborations between the PV and agriculture sectors, academic research, industry participants, national authorities and policy makers. Organisations and associations at national and international level have been formed in order to exchange information on technical and regulatory aspects, identify the opportunities and barriers and ultimately promote Agri-PV by issuing recommendations.

The most active Agri-PV community can be found in Germany. A dedicated website ([21]) on research and policy recommendations has been developed by Fraunhofer ISE.

In Italy, the promotion of Agri-PV started with the initiative "Agrivoltaico Sostenibile" ([22]), which helds webinars on the Agri-PV situation in Italy. Recently, the "Associazione Italiana Agrivoltaico Sostenibile" (AIAS) ([23]) was founded.

The France Agrivoltaïsme ([24]), the French association has six working groups: labels and standards, regulations, agrivoltaic technologies, corporate social responsibility (CSR), international and finance and insurance of Agri-PV.

The AgriVoltaics conference ([25]) takes place every year over the past four years. Agri-PV is also part of the European Photovoltaic Solar Energy Conference and Exhibition (EU-PVSEC) ([26]).

SolarPower Europe initially formed the AgriSolar Workstream for the promotion of Agri-PV. The AgriSolar Workstream has now become the Land Use & Permitting Workstream, tasked with addressing the wider topics of project access to land and permitting and helping deploy innovative use of land by projects, such as AgriSolar, AgriPV, or Floating PV ([27]).

The European Network for Rural Development (ENRD) within its mission of monitoring and improving rural development policies in the EU has a thematic work entitled "Greening the Rural Economy". Within this thematic, the "European Green Deal and Rural Areas" sub-theme's work on the CAP post-2020 objectives of climate action, environmental care and preserving landscapes and biodiversity considers Agri-PV as one of the clean energy solutions with co-benefits for climate and environment supporting the clean energy transition in the agriculture and forestry sectors (ENRD, 2021).

21 https://agri-pv.org/en/
22 https://www.agrivoltaicosostenibile.com/news/nasce-aias-associazione-italiana-agrivoltaico-sostenibile/
23 https://www.agrivoltaicosostenibile.com/
24 https://france-agrivoltaisme.org/
25 https://www.agrivoltaics-conference.org/
26 https://www.eupvsec.org/
27 https://www.solarpowereurope.org/events/solar-power-europe-workstreams-2023

7 Conclusions

Agri-PV - the simultaneous use of areas of land for both solar photovoltaic power generation and agricultural activities - is an innovative form of PV deployment that increases the land use efficiency. It has the potential of contributing significantly to the EU energy transition without occupying additional land but by bringing advantages to the already existing agricultural activities.

Even though it is not a new concept, the interest for this form of PV deployment has increased rapidly over the last few years mainly due to the increasing need for electricity production and the limited availability of new land due to the increasing global food demand. Agri-PV manages to combine two very important activities of the modern world; electricity and food production with limited impacts of one on the other.

However, there are still some parameters hindering Agri-PV's full exploitation and large-scale deployment.

Further actions to be taken include:

- setting a clear and concrete definition of Agri-PV at the EU level together with a European standard for Agri-PV systems that will follow harmonised Agri-PV policies across the EU;
- ensuring continuation of agricultural activity and the maintenance of the land characterisation after the deployment of Agri-PV installations;
- ensuring that farms with certified deployed Agri-PV systems will not be excluded from CAP strategic plans subsidies;
- securing the inclusion of farms with Agri-PV systems in CAP provisions even in the event that the energy production is managed by a third party (different from the farmer);
- promoting further Agri-PV through the CAP strategic plans;
- ensuring that taxes/transfer rights will not be disadvantageous in case of inheritance of the farm;
- further developing R&D, R&I and pilot schemes to overcome technical challenges related to energy and food production, reduce the costs and de-risk the investments;
- planning Agri-PV systems by taking into consideration the energy, crop yield and biodiversity at the same time;
- providing dedicated financial support for Agri-PV systems through the Member States' national policies;
- including dedicated capacity targets for Agri-PV systems in the Member State national policies;
- identifying / classifying potential agricultural land for Agri-PV deployment through spatial planning;
- raising awareness and ensuring training and technical support to the identified locations mentioned above;
- preventing "greenwashing" with a clear and robust differentiation between Agri-PV systems and PV systems on agricultural land (traditional ground-mounted);
- simplifying the permitting processes and prioritising the grid connection for Agri-PV systems;
- developing an Agri-PV Quality Standard, including a third-party monitoring system;
- keeping the farmers and the rural communities at the centre of Agri-PV promotion and at the same time ensuring their economic benefit and security of property;
- boosting public awareness and acceptance with respect to all the above-mentioned actions.

References

Ademe *et al.* (2021) *Characterising solar PV projects on agricultural land and agrivoltaism - Executive Summary*. Available at: https://librairie.ademe.fr/energies-renouvelables-reseaux-et-stockage/4992-caracteriser-les-projets-photovoltaiques-sur-terrains-agricoles-et-l-agrivoltaisme.html.

Amaducci, S., Yin, X. and Colauzzi, M. (2018) 'Agrivoltaic systems to optimise land use for electric energy production', *Applied Energy*, 220(January), pp. 545–561. doi:10.1016/j.apenergy.2018.03.081.

Barron-Gafford, G.A. *et al.* (2019) 'Agrivoltaics provide mutual benefits across the food–energy–water nexus in drylands', *Nature Sustainability*, 2(9), pp. 848–855. doi:10.1038/s41893-019-0364-5.

Beck, M. *et al.* (2012) 'Combining Pv and Food Crops To Agrophotovoltaic – Optimization of Orientation and Harvest', *27th European Photovoltaic Solar Energy Conference and Exhibition*, (January), pp. 4096–4100. doi:10.4229/27thEUPVSEC2012-5AV.2.25.

Bolinger, M. and Bolinger, G. (2022) 'Land Requirements for Utility-Scale PV: An Empirical Update on Power and Energy Density', *IEEE Journal of Photovoltaics*, 12(2), pp. 589–594. doi:10.1109/JPHOTOV.2021.3136805.

Chatzipanagi, A. *et al.* (2022) *Agri-photovoltaics (Agri-PV): how multi-land use can help deliver sustainable energy and food*. Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC129225.

Chatzipanagi, A. and Jaeger-Waldau, A. (2023) 'The European Solar Communication -Will it pave the road to achieve 1 TW of Photovoltaic System Capacity in the European Union by 2030?', *Sustainability*, 15(8), p. 6531. doi:https://doi.org/10.3390/su15086531.

Comitato Elettrotecnico Italiano (2023) *CEI PAS 82-93*. Available at: https://mycatalogo.ceinorme.it/cei/item/0000019155?sso=y (Accessed: 4 April 2023).

ENRD (2021) *Effective approaches for facilitating a transition to clean energy in the agriculture and forestry sectors using the CAP*.

European Commission (2020a) *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, EU Biodiversity Strategy for 2030, European Commission*. Available at: https://eur-lex.europa.eu/resource.html?uri=cellar:a3c806a6-9ab3-11ea-9d2d-01aa75ed71a1.0001.02/DOC_1&format=PDF (Accessed: 3 March 2023).

European Commission (2020b) *Potential impacts of solar, geothermal and ocean energy on habitats and species protected under the birds and habitats directives*. Available at: https://ec.europa.eu/environment/nature/natura2000/management/docs/POTENTIAL IMPACTS OF SOLAR_ GEOTHERMAL AND OCEAN ENERGY ON HABITATS AND SPECIES PROTECTED UNDER THE BIRDS AND HABITATS DIRECTIVES - Final report.pdf.

European Commission (2021a) *Communication from the Commission to the EUropean Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A long-term Vision for the EU's Rural Areas - Towards stronger, connected, resilient and prosperous rur*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0345 (Accessed: 12 January 2023).

European Commission (2021b) *EU Biodiversity Strategy for 2030*.

European Commission (2022a) *Annex to the EU Solar Energy Strategy*.

European Commission (2022b) *CAP Strategic Plans, 2022*. Available at: https://agriculture.ec.europa.eu/cap-my-country/cap-strategic-plans_en (Accessed: 25 November 2022).

European Commission (2022c) *Communication From the Commission To the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, EU Solar Energy Strategy*. Available at: https://eur-lex.europa.eu/resource.html?uri=cellar:516a902d-d7a0-11ec-a95f-01aa75ed71a1.0001.02/DOC_1&format=PDF (Accessed: 3 March 2023).

European Commission (2022d) *Funding & tender opportunities: Advanced manufacturing of Integrated PV, TOPIC ID: HORIZON-CL5-2022-D3-01-03*. Available at: https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl5-2022-d3-01-03 (Accessed: 10 February 2023).

European Commission (2022e) *Funding & tender opportunities: Novel Agro-Photovoltaic systems, TOPIC ID: HORIZON-CL5-2022-D3-01-06*. Available at: https://ec.europa.eu/info/funding-

tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl5-2022-d3-01-06 (Accessed: 10 February 2023).

European Commission (2022f) *Funding & tender opportunities: Renewable energy incorporation in agriculture and forestry, TOPIC ID: HORIZON-CL5-2022-D3-02-07*. Available at: https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-search;callCode=HORIZON-CL5-2022-D3-02;freeTextSearchKeyword=;matchWholeText=true;typeCodes=1;statusCodes=31094501,31094502,31094503;programmePeriod=null;programCcm2 (Accessed: 25 November 2022).

European Commission (2022g) *The new common agricultural policy: 2023-27*. Available at: https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/new-cap-2023-27_en (Accessed: 6 December 2022).

Eurostat (2022) *Land use: number of farms and areas of different crops by type of farming*. Available at: https://ec.europa.eu/eurostat/databrowser/view/EF_OLUFT/default/table?lang=en&category=agr.ef.ef_main.ef_olu (Accessed: 5 December 2022).

Gazzetta Ufficiale della republica Italiana (2023) 'Decreto-Legge 24 febbraio 2023, n. 13'. Available at: https://www.gazzettaufficiale.it/eli/gu/2023/02/24/47/sg/pdf.

German Institute for standardization (2022) *DIN SPEC 91434: Agri-photovoltaic systems - Requirements for primary agricultural use*. Available at: https://www.din.de/de/wdc-beuth:din21:337886742 (Accessed: 30 November 2022).

Hermann, C. *et al.* (2022) *Agrivoltaics : Opportunities for Agri- culture and the Energy Transition Publishing notes*. Available at: https://www.ise.fraunhofer.de/content/dam/ise/en/documents/publications/studies/APV-Guideline.pdf.

Hudelson, T. and Lieth, J.H. (2021) 'Crop production in partial shade of solar photovoltaic panels on trackers', *AIP Conference Proceedings*, 2361(June). doi:10.1063/5.0055174.

Institute for Solar Research (DLR) (2022) *AgriPV Modeling*. Available at: https://www.dlr.de/sf/en/desktopdefault.aspx/tabid-9315/22258_read-76617/ (Accessed: 6 December 2022).

Kougias, I. *et al.* (2021a) 'The role of photovoltaics for the European Green Deal and the recovery plan', *Renewable and Sustainable Energy Reviews*, 144(February), pp. 1–8. doi:10.1016/j.rser.2021.111017.

Kougias, I. *et al.* (2021b) 'The role of photovoltaics for the European Green Deal and the recovery plan', *Renewable and Sustainable Energy Reviews*, 144(April), pp. 1–8. doi:10.1016/j.rser.2021.111017.

KU Leuven (2022) *AGRIPV tool*. Available at: https://iiw.kuleuven.be/apps/agrivoltaics/index.html (Accessed: 1 December 2022).

MITE (2022) *Linee Guida in materia di Impianti Agrivoltaici, Parte IV*. Available at: https://www.mite.gov.it/sites/default/files/archivio/allegati/PNRR/linee_guida_impianti_agrivoltaici.pdf.

nanoHUB (2022) *Agrivoltaic Simulation*. Available at: https://nanohub.org/resources/agpvsim (Accessed: 1 December 2022).

Oudes, D., van den Brink, A. and Stremke, S. (2022) 'Towards a typology of solar energy landscapes: Mixed-production, nature based and landscape inclusive solar power transitions', *Energy Research and Social Science*, 91(December 2021), p. 102742. doi:10.1016/j.erss.2022.102742.

Rijksdienst voor Ondernemend Nederland (2022) *Zonne-energie in agrarisch gebied*. Available at: https://www.rvo.nl/onderwerpen/zonne-energie/agrarisch (Accessed: 30 January 2023).

SANDBOX Solar (2022) *SPADE Agrivoltaic Design Software*. Available at: https://sandbox-solar-preview.default.apps.staging.pollination.cloud/ (Accessed: 1 December 2022).

Sekiyama, T. and Nagashima, A. (2019) 'Solar sharing for both food and clean energy production: Performance of agrivoltaic systems for corn, a typical shade-intolerant crop', *Environments - MDPI*, 6(6). doi:10.3390/environments6060065.

SolarPower Europe (2021) 'Agrisolar Best Practices Guidelines', pp. 1–52.

SolarPower Europe (2022a) *EU Market Outlook for Solar Power 2022-2026*. Available at: https://api.solarpowereurope.org/uploads/5222_SPE_EMO_2022_full_report_ver_03_1_319d70ca42.pdf?updated_at=2022-12-19T08:21:34.541Z.

SolarPower Europe (2022b) *Solar, Biodiversity, Land Use: Best Practice Guidelines*. Available at: https://www.solarpowereurope.org/insights/thematic-reports/solar-biodiversity-land-use-best-practice-guidelines.

Strapasson, A. *et al.* (2020) 'EU land use futures: modelling food, bioenergy and carbon dynamics', *Energy Strategy Reviews*, 31(August), p. 100545. doi:10.1016/j.esr.2020.100545.

Thompson, E.P. *et al.* (2020) 'Tinted Semi-Transparent Solar Panels Allow Concurrent Production of Crops and Electricity on the Same Cropland', *Advanced Energy Materials*. doi:10.1002/aenm.202001189.

Trommsdorff, M. *et al.* (2022) *Agrivoltaics: solar power generation and food production*, *Solar Energy Advancements in Agriculture and Food Production Systems*. doi:10.1016/b978-0-323-89866-9.00012-2.

UIPA (2023) *Agricoltura e energie rinnovabili: Gli incentivi all'agri-voltaico*. Available at: https://www.uipa.it/agricoltura-e-energie-rinnovabili-gli-incentivi-allagrovoltaico/ (Accessed: 13 February 2023).

Weselek, A. *et al.* (2021) 'Agrivoltaic system impacts on microclimate and yield of different crops within an organic crop rotation in a temperate climate', *Agronomy for Sustainable Development*, 41(5). doi:10.1007/s13593-021-00714-y.

Zohdi, T.I. (2021) 'A digital-twin and machine-learning framework for the design of multiobjective agrophotovoltaic solar farms', *Computational Mechanics*, 68(2), pp. 357–370. doi:10.1007/s00466-021-02035-z.

List of abbreviations and definitions

ADEME	Agence de la transition écologique (Agency for the Ecological Transition)
Agri-PV	Agri-photovoltaics
AIAS	Associazione Italiana Agrivoltaico Sostenibile (Italian Association for Sustainable Agrivoltaic)
CAP	Common Agricultural Policy
CAPEX	Capital Expenditure
CDPENAF	Commission départementale de préservation des espaces naturels, agricoles et forestiers (Departmental commission for the preservation of natural, agricultural and forest areas)
CEI-PAS	Italian Electrotechnical Committee (Comitato Elettrotecnico Italiano)-Public Available Specification
CSR	Corporate Social Responsibility
EC	European Commission
EEG	Erneuerbare-Energien-Gesetz (Renewable Energy Sources Act)
EGD	European Green Deal
ENEA	Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (National Agency for New Technologies, Energy and Sustainable Economic Development)
ENRD	European Network for Rural Development
EPC	Engineering, Procurement and Construction
EU	European Union
EU-PVSEC	European Photovoltaic Solar Energy Conference and Exhibition
FF55	Fit-For-55
IA	Innovation Action
IDAE	Institute for Diversification and Saving of Energy (Spain)
IEA-PVPS	International Energy Agency-Photovoltaic Power Systems Programme
LCoE	Levelised Cost of Electricity
MS	Member states
NECP	National Energy and Climate Plan
OPEX	Operating Expenditure
PNIEC	Piano Nazionale Integrato per l'Energia e il Clima (National Energy and Climate Plan)
PNRR	Piano Nazionale di Ripresa e Resilienza (National Recovery and Resilience Plan)
PV	Photovoltaics
R&D	Research and Development
R&I	Research and Innovation
UAA	Utilised Agricultural Area
UIPA	Unione Italiana Professionalità in Agricoltura

---

ha	hectare
Mha	megahectare
MW	megawatt
GW	gigawatt

GW_{AC}	gigawatt alternating current
GW_{DC}	gigawatt direct current
GWp	gigawatt peak
TW	terawatt

List of figures

List of tables

Annexes

Annex 1. Potential of Agri-PV systems for different land area categories and different area coverage percentages for the EU as a total. The low value is based on an assumed installed capacity of 0.2 MW/ha, while the high value on 0.9 MW/ha.

		Utilised agricultural area	Arable land	Permanent grassland and meadow	Permanent crops	Market gardens
10 % area coverage	Area (hectares)	15 726 214	9 793 456	4 877 482	1 026 726	28 577
	Potential (GW)	3 145 – 14 154	1 959 – 8 814	975 – 4 390	205 – 924	6 – 26
	Average Potential (GW)	*8 650*	*5 400*	*2 700*	*550*	*16*
5 % area coverage	Area (hectares)	7 863 107	4 896 728	2 438 741	513 363	14 289
	Potential (GW)	1 573 – 7 077	979 – 4 407	488 – 2 195	103 - 462	3 - 13
	Average Potential (GW)	*4 300*	*2 700*	*1 300*	*280*	*8*
1 % area coverage	Area (hectares)	1 572 621	979 346	487 748	102 673	2 858
	Potential (GW)	315 – 14 15	196 - 881	98 - 439	21 - 92	1 - 3
	Average Potential (GW)	*865*	*540*	*270*	*55*	*1.6*

Source: JRC analysis based on Eurostat.

Annex 2. Potential and required area percentage coverage of Agri-PV systems for different land area categories with regard to the MS NECP PV 2030 (new policy trends), with an assumed installed capacity of 0.6 MW/ha.

Country		NECP PV 2030 (GW)	NECP PV 2030 (new policy trends) (GW)	Area for NECP PV 2030 (new policy trends) (ha)	Utilised agricultural area (ha)	Arable land (ha)	Permanent grassland and meadow (ha)	Utilised agricultural area %	Arable land %	Permanent grassland and meadow %
Austria	AT	12.00	13.00	21 667	2 726 890	1 363 860	1 296 270	0.8	1.6	1.7
Belgium	BE	11.00	22.00	36 667	1 307 900	799 810	486 600	2.8	4.6	7.5
Bulgaria	BG	2.90	3.20	5 333	4 650 940	3 279 390	1 271 320	0.1	0.2	0.4
Croatia	HR	0.77	0.77	1 283	1 571 200	878 430	618 070	0.1	0.1	0.2
Cyprus	CY	0.80	0.80	1 333	109 330	80 120	1 850	1.2	1.7	72.1
Czech Republic	CZ	3.98	3.98	6 633	3 491 470	2 492 110	960 080	0.2	0.3	0.7
Denmark	DK	7.84	7.84	13 067	2 619 340	2 397 220	195 480	0.5	0.5	6.7
Estonia	EE	0.42	0.42	700	957 510	628 310	324 560	0.1	0.1	0.2
Finland	FI	1.20	1.20	2 000	2 257 630	2 223 230	30 670	0.1	0.1	6.5
France	FR	25.00	47.30	78 833	27 739 430	18 466 200	8 242 240	0.3	0.4	1.0
Germany	DE	70.51	215.00	358 333	16 699 580	11 875 890	4 620 980	2.1	3.0	7.8
Greece	EL	8.00	13.00	21 667	4 856 780	1 816 800	2 102 380	0.4	1.2	1.0
Hungary	HU	6.00	6.50	10 833	4 656 520	3 800 820	702 720	0.2	0.3	1.5
Ireland	IE	1.50	1.50	2 500	4 959 450	1 041 970	3 915 770	0.1	0.2	0.1
Italy	IT	51.12	72.00	120 000	12 098 890	6 728 360	3 316 430	1.0	1.8	3.6

Country		NECP PV 2030 (GW)	NECP PV 2030 (new policy trends) (GW)	Area for NECP PV 2030 (new policy trends) (ha)	Utilised agricultural area (ha)	Arable land (ha)	Permanent grassland and meadow (ha)	Utilised agricultural area %	Arable land %	Permanent grassland and meadow %
Latvia	LV	0.50	0.50	833	1 877 720	1 204 140	654 260	0.0	0.1	0.1
Lithuania	LT	1.53	1.53	2 550	2 861 250	2 277 830	560 100	0.1	0.1	0.5
Luxembourg	LU	1.11	1.11	1 850	131 040	62 600	66 900	1.4	3.0	2.8
Malta	MT	0.26	0.26	433	10 880	8 570	0	4.0	5.1	-
Netherlands	NL	36.00	36.00	60 000	1 847 570	1 037 860	773 090	3.2	5.8	7.8
Poland	PL	7.30	30.00	50 000	14 409 870	10 759 570	3 206 310	0.3	0.5	1.6
Portugal	PT	9.00	10.00	16 667	3 641 590	1 100 860	1 816 580	0.5	1.5	0.9
Romania	RO	5.89	5.89	9 817	13 055 850	8 197 590	4 398 350	0.1	0.1	0.2
Slovakia	SK	1.20	1.20	2 000	1 901 610	1 363 420	518 340	0.1	0.1	0.4
Slovenia	SI	1.65	1.65	2 750	485 760	172 690	284 780	0.6	1.6	1.0
Spain	ES	44.00	92.00	153 333	23 300 220	11 294 620	7 962 040	0.7	1.4	1.9
Sweden	SE	2.50	3.50	5 833	3 035 920	2 582 290	448 650	0.2	0.2	1.3
Total	EU	313.98	592.15	986 917	157 262 140	97 934 560	48 774 820	0.6	1.0	2.0

Source: JRC analysis based on Eurostat and (Kougias *et al.*, 2021b).

Annex 3. Indicator R.15: Renewable energy from agriculture and forestry and from other renewable sources - Supported investments in renewable energy production capacity, including bio-based (in MW).

Member state		2023	2024	2025	2026	2027	2028	2029	Overall CAP target value (MW)
Austria	AT			20.70	55.00	109.15	155.25	182.25	182.25
Belgium (Flanders)	BE	0.80	1.69	2.92	4.15	5.44	5.87	6.30	6.30
Belgium (Wallonia)	BE	0.00	0.16	0.29	0.53	0.97	1.23	1.26	1.26
Bulgaria	BG		0.24	1.20	2.64	3.84	6.00	7.20	7.20
Croatia	HR		0.50	7.00	17.00	27.00	38.00	40.00	40.00
Cyprus	CY	0.00	0.00	0.88	45.88	89.88	101.88	101.88	101.88
Czech Republic	CZ	*Not reported*							
Denmark	DK	*Not reported*							
Estonia	EE	0.00	0.40	0.50	0.70	0.90	1.00	1.00	1.00
Finland	FI	30.00	118.00	270.00	320.00	365.00	365.00	365.00	365.00
France	FR	0.00	0.30	1.11	2.34	2.78	3.11	3.23	3.23
Germany	DE	*Not reported*							
Greece	EL			4.70	8.51	9.39	9.39	9.39	9.39
Hungary	HU		2.23	21.31	29.73	64.67	97.98	131.29	131.29
Ireland	IE	0.30	1.94	3.74	14.74	25.54	25.54	25.54	25.54
Italy	IT	0.00	0.00	8.00	20.00	33.00	44.00	51.00	51.00
Latvia	LV	0.00	13.00	22.00	22.00	22.00	22.00	22.00	22.00
Lithuania	LT		0.32	0.64	0.96	1.28	1.60	1.60	1.60
Luxembourg	LU	*Not reported*							
Malta	MT	*Not reported*							
Netherlands	NL		1.00	1.00	1.00	1.00	1.00	1.00	1.00
Poland	PL	0.00	15.56	38.32	66.28	92.52	110.36	110.36	110.36
Portugal	PT			4.40	8.80	13.20	17.60	22.00	22.00
Romania	RO	0.00	0.00	63.00	87.00	89.00	89.00	89.00	89.00

Member state		2023	2024	2025	2026	2027	2028	2029	Overall CAP target value (MW)
Slovakia	SK	0.00	0.01	6.01	21.52	40.52	72.03	90.04	90.04
Slovenia	SI	0.00	1.76	11.46	24.93	35.05	42.18	43.99	43.99
Spain	ES	6.60	27.91	59.31	115.65	171.60	219.73	251.00	251.00
Sweden	SE	*Not reported*							
EU (28)* *Belgium (Flanders and Wallonia)		38	185	548	869	1 204	1 430	1 556	1 556

Source: (European Commission, 2022b)

Annex 4. Indicator R.16: Investments related to climate - Share of farms benefitting from CAP investment support contributing to climate change mitigation and adaptation, and to the production of renewable energy or biomaterials.

Member state		2023	2024	2025	2026	2027	2028	2029	Overall CAP target value (%)
Austria	AT	1.03	2.69	4.63	6.55	8.46	10.38	11.54	11.54
Belgium (Flanders)	BE	0.96	3.14	5.43	8.87	12.12	14.70	17.55	17.55
Belgium (Wallonia)	BE	0	0.46	0.97	1.58	2.13	2.69	2.73	2.73
Bulgaria	BG	0	0.01	0.04	0.09	0.13	0.20	0.24	0.24
Croatia	HR	0	0.01	0.04	0.1	0.16	0.19	0.20	0.20
Cyprus	CY	0	0	0.14	0.29	0.44	0.48	0.89	0.89
Czech Republic	CZ	0.38	0.66	2.51	5.67	8.16	10.44	12.11	12.11
Denmark	DK	0	0.02	0.59	1.83	3.85	5.52	6.85	6.85
Estonia	EE	0	0.55	0.69	0.83	1.06	1.18	1.35	1.35
Finland	FI	0.5	1.19	2.17	3.25	4.16	4.16	4.16	4.16
France	FR	0.03	1.37	2.54	3.36	4.18	4.96	5.17	5.17
Germany	DE	0	0.36	0.80	1.33	1.71	2.28	2.44	2.44
Greece	EL	0	0	0.01	0.03	0.03	0.03	0.03	0.03
Hungary	HU	0	0.02	0.54	0.83	1.68	2.51	3.16	3.16
Ireland	IE	0.04	4.61	10.69	13.08	14.98	15.05	15.05	15.05
Italy	IT	0	0	0.02	0.06	0.10	0.12	0.13	0.13
Latvia	LV	0	0.51	0.88	0.97	1.07	1.07	1.07	1.07
Lithuania	LT	0	0.03	0.05	0.08	0.11	0.14	0.14	0.14
Luxembourg	LU	1.06	2.13	3.19	4.25	5.32	6.38	7.44	7.44
Malta	MT	0.01	0.02	0.04	0.07	0.09	0.12	0.14	0.14
Netherlands	NL	0	0.65	1.40	2.21	2.91	3.62	3.62	3.62
Poland	PL	0	0.13	0.34	0.70	0.98	1.12	1.12	1.12
Portugal	PT	0	0	0.08	0.17	0.25	0.33	0.42	0.42
Romania	RO	0	0	0	0	0	0	0	0
Slovakia	SK	0.20	0.55	0.60	2.14	2.51	3.18	3.45	3.45
Slovenia	SI	0	0.09	0.38	1.06	1.69	2.03	2.14	2.14

Member state		2023	2024	2025	2026	2027	2028	2029	Overall CAP target value (%)
Spain	ES	0.08	1.52	2.93	4.86	6.94	7.13	7.19	7.19
Sweden	SE	0	0.01	0.11	0.26	0.42	0.55	0.60	0.60

Source: (European Commission, 2022b)

Annex 5. Keyword search of MS draft CAP strategic plans for **"Agri-Photovoltaic", "Photovoltaic", "Renewable" and "Solar".**

Member state		**Keyword reference "Agri-photovoltaic", "Photovoltaic", "Renewable" (in relation to solar/photovoltaic), "Solar" terms in the CAP** plans
Austria	AT	• Selection criteria: Projects that primarily serve to generate renewable energies without using resources (photovoltaic systems, thermal solar systems) receive a higher number of points than systems that generate renewable energy, but using renewable resources (wood heating). Projects to increase energy efficiency are also rated higher. • Progress and experiences have also been made in the expansion of other renewable energy sources, in particular thermal solar energy and photovoltaics. In particular, the use of biomass in regional biomass heating plants and via small-scale biomass plants is responsible for large added value and job effects in rural areas. "The problem is that the preservation and further development of even existing biogas plants are currently not secured.
Belgium (Flanders)	BE	• Investments in the context of natural resources - energy management: solar panels, wind turbines, heat pumps, relighting, cogeneration, geothermal energy, energy storage and buffer systems, waste heat recovery systems, conversion of cold stores to more efficient and environmentally friendly systems, ... • In addition, agricultural companies can also contribute to the production of renewable energy, in particular through the fermentation of manure and the production of wind energy.
Belgium (Wallonia)	BE	• Production of renewable energy in the proportion of the self-consumed part (biomethanization, <10 kW, photovoltaic, wind, ...). • Promoting renewable energies for an amount of €49 million (including a project aiming to set up a centralized platform for the collection, treatment and drying of biomass (€2.5 million) and another aiming to draw up an action plan to professionalize the wood-energy sector (€500,000). • The only measure of the CAP strategic plan contributing to indicator R.15 is the productive investments of the EAFRD. During the 2014-2022 program, over five years, 51 files concerning solar panels were selected and 4 files concerning wind turbines were selected. The former had a maximum installed power of 1.22MW and the latter 0.04MW. We plan to start from these figures (1.26MW) for the 2023-2027 programming.
Bulgaria	BG	• Climatic conditions in Bulgaria are favorable for the development of the renewable energy sector, as the main renewable energy used in the country is biomass, whose share represents 87% of the final renewable energy consumption. • Solar photovoltaic installation to promote self-consumption in warehouses or facilities for the food industry.
Croatia	HR	*No information*
Cyprus	CY	• Photovoltaic systems to cover the energy needs of packaging plants.
Czech Republic	CZ	• Support for energy from renewable sources in accordance with the directive (EU) will focus on the construction and reconstruction of renewable energy sources for public buildings (acquisition of photovoltaic and solar-thermal systems, heat pumps and biomass boilers), construction of reconstruction of renewable energy sources for ensuring system energy supplies in the public sector, replacing inadequate combustion sources in households with solid fuels and optimizing their operation. The RES area will be supported from the SP SZP within the framework of investments in non-agricultural activities, namely by supporting the construction and modernization of equipment for the production of shaped biofuels (intervention 45.73) and partially also through support for the roofing of final storage facilities for agricultural BPS

Member state		**Keyword reference "Agri-photovoltaic", "Photovoltaic", "Renewable" (in relation to solar/photovoltaic), "Solar" terms in the CAP** plans
		digestate (intervention 37.73). Support for energy from renewable sources in accordance with Directive (EU) 2018/2001, including the sustainability criteria set out in the said directive, will include a number of activities, e.g. support for solar thermal systems; support for photovoltaic power plants on business buildings, including sheds (e.g. for cars, construction equipment, material storage, etc.); support for small hydropower plants; support for wind farms; ... • Criteria for determining the predominance of agricultural activity in the event that the land is also used for non-agricultural activities. Land on which agricultural and non-agricultural activities coexist (e.g. a temporary summer tent camp on a meadow or a grassy area that is also used as golf course) is used mainly for agricultural activities if: • the non-agricultural activity is of a one-off or temporary nature, while its duration does not prevent the proper economic cultivation of the land with regard to the specific culture and the agrotechnical operations usually carried out here (duration criterion) and the farmer fulfills all the conditions for providing the subsidy (mowing, etc.), or • if the non-agricultural activity is of a permanent nature, such non-agricultural activity does not prevent the proper economic cultivation of the land with regard to the specific culture and agrotechnical operations usually performed there (criterion of intensity), and the farmer fulfills all the conditions for providing the subsidy.
Denmark	DK	• The CAP plan will contribute to already established long-term national goals for renewable energy, which is particularly set out in its national environment and climate plan.
Estonia	EE	• When encouraging the use of renewable energy in agriculture, alternatives outside of the agricultural land must be preferred. • Investments for the establishment of environmentally friendly renewable energy solutions for the agricultural enterprise, whose production capacity does not exceed the beneficiary's annual self-consumption.
Finland	FI	• In addition to bioenergy, other renewable energy sources such as solar, wind and geothermal energy also have untapped opportunities for an economical and reliable energy system. • Increase of renewable energy use to more than 50% of final energy consumption by 2020 (currently at 40%) in line with the National Energy and Climate Strategy for 2030 in order to achieve carbon neutrality by 2035 (goal set by the Finnish government).
France	FR	• Promotion of renewable energy and biomaterials of agricultural and forestry origin to reduce overall emissions: Develop agricultural, agroforestry and forestry (methanation, biogas, sustainable biofuels, biomass recovery, solar thermal and photovoltaic on buildings), develop the sustainable bioeconomy and substitute materials, while maintaining food priority and the quality of the environment. • The admissibility of surfaces covered with photovoltaic panels will also be specified in national regulations. • Areas not used primarily for agricultural purposes (such as roundabouts, areas around warehouses or factories, immediate areas around airport runways, golf courses) are not eligible. The admissibility of surfaces covered with photovoltaic panels will be specified in this context.
Germany	DE	• In addition to saving energy through modernization, a funding priority is the generation of renewable energy for use in agriculture and horticulture, for example photovoltaics (PV) for self-consumption or biomass heating for heat requirements. • In the EEG 2023, for example, there is a joint tendering segment for photovoltaic (PV) open space and agricultural PV systems with payment of a technology bonus for elevated systems. Agri-PV systems according to the

Member state		**Keyword reference "Agri-photovoltaic", "Photovoltaic", "Renewable" (in relation to solar/photovoltaic), "Solar" terms in the CAP** plans
		EEG 2023 draft are therefore permitted on arable land and areas with permanent crops (e.g. orchards). Agri-PV technology contributes to defusing the competition for land, since power generation with Agri-PV max. • Due to increasing competition for land use and the progressive reduction of agricultural land, the installation of photovoltaic systems should be focused on roof and structural wasteland and areas that are still not usable for agriculture. • Areas used for a non-agricultural activity include areas on which systems for the use of solar radiation energy are located, unless the business owner can prove that it is an agri-photovoltaic system.
Greece	EL	*No information*
Hungary	HU	*No information*
Ireland	IE	• Increase energy efficiencies on farm through the uptake of new technologies and facilitate the production and use of renewable energy sources. • On-Farm Capital Investment Scheme (OFCIS).
Italy	IT	• Production of energy from renewable sources (RES) in synergy with the protection of the landscape, limiting the use and consumption of land and its fragmentation, with the aim of a better allocation of the land resource with respect to the development of Agri-PV, photovoltaic in business centres, warehouses, abandoned areas, or biogas, in relation to new or existing plants to be exploited and fed in a sustainable way. • Encourage the production and use of energy from renewable sources. • Territorial priorities: Plain (Qualifying), Hill (Complementary), Mountain (Complementary). • Parco agrisolare (M2C1 inv. 2.2) with a budget of 1.5 billion euros for the installation of photovoltaic panels on the roofs of agricultural and agro-industrial structures, the removal of dangerous materials, the redevelopment of production structures also with a view to energy efficiency, including the construction of insulated roofs, the creation of automated ventilation and/or cooling systems as well as intelligent flow and accumulator management systems. (Development of biomethane, according to criteria to promote the circular economy (M2C2. Inv. 1.4) with a budget of 1.9 billion euros). • The production of energy from renewable sources is commensurate with the total energy needs of the company. The Regions and Autonomous Provinces may establish the capacity limits within the regional implementation documents of this Plan.
Latvia	LV	• Promotion of energy from renewable sources – biomethane. • Installation of solar power generation equipment (at least 1MW), storage equipment and smart solutions related to their operation. • Support is available for energy production from renewable energy resources for self-consumption, including solar electricity production, in farms and cooperatives, agricultural product processing companies.
Lithuania	LT	*No information*
Luxembourg	LU	• Renewable energies are the responsibility of the Ministry of Energy. Their support is not provided by the PSN (National Strategic Plan). The production of photovoltaic energy can also be recommended on farms which lend themselves well to it, in particular with large roof surfaces on the infrastructures. However, given the limitation of the soil resource in Luxembourg, the support of large-scale projects on agricultural land is not considered. • The support for the construction of biogas plants is under the competence of the Ministry of Economy and is financed by state aid for the support of investments in the production of renewable energies, including biogas plants

Member state		**Keyword reference "Agri-photovoltaic", "Photovoltaic", "Renewable" (in relation to solar/photovoltaic), "Solar" terms in the CAP** plans
		and photovoltaic plants. In 2020, the Ministry of Spatial Planning and Energy introduced a new attractive pricing for photovoltaic installations above 30 kW up to a maximum of 200 kW which is now accessible to all beneficiaries. This adaptation is for the benefit of farmers and SMEs and is part of the government's objective to further support the development of solar energy in Luxembourg. Aid for this category of photovoltaic installations is now directly accessible to farmers without having to go through a civil society or cooperative. However, the cooperative societies keep a slightly preferential rate and larger projects will always be subject to a call for tenders.
Malta	MT	• Both roof-mounted solar PV, and anaerobic digestion plants generating energy from agricultural wastes and crop residues, have potential for further expansion. • For solar investments, individual producers may be able to contemplate them whereas for anaerobic digestion it is more likely that collective proposals will be needed. • Renewable energy offers significant scope for rural businesses to reduce energy costs. Farms and other rural enterprises need investment support for infrastructure associated with the installation and distribution of renewable energy (to the holding), and for energy generation using a range of technologies including biomass from manures and wastes, solar, and wind power. • Many farms in Malta suffer from a lack of investment in basic infrastructure, which if improved, could contribute to reducing labour and input costs of production. The main areas of support are land access, soil conservation and water management, and renewable energy.
Netherlands	NL	• The National Environmental Vision (NOVI) provides three guiding frameworks that are included in the RES guideline. Two of these are relevant for agriculture and nature. Firstly, in large-scale clustering, attention is drawn to nature-inclusive design and management in sustainable energy projects. In this way, disruption or damage to nature and biodiversity is prevented as much as possible. Secondly, the generation of renewable energy by means of solar cells is preferred over other forms and therefore serves as a guideline in the regional assessment. In agriculture, for example, solar energy can be generated by installing solar panels on company buildings. The choice of location and the landscape are very important in this respect. With the solar ladder, an assessment framework has been made for the construction of solar fields on agricultural land. The NSP also includes a conditionality for this. The Netherlands Environmental Assessment Agency monitors the progress of the RESs. Attention is paid here, among other things, to nature inclusiveness and the national and regional effects of the RES plans on landscape, nature and agricultural land. • Dutch agricultural sectors will contribute to the generation and application of renewable energy, as long as this is appropriate within landscape frameworks and contributes to their economically resilient revenue model. • There must be room for the application of innovative solutions to combine the installation of solar panels with agricultural activities. For this reason, agricultural land remains eligible if solar panels are spread over the plot, which in their location do not hinder agricultural activities. This exception applies to a maximum of 100 distributed solar panels per hectare, with a maximum size of 100m^2. Clusters of solar panels (above 10m^2) are not considered eligible agricultural land and are deducted from the eligible areas.
Poland	PL	• The assumed support under this measure will allow for the implementation of 2,342 projects related to investments in the field of energy production from agricultural biogas or solar radiation. As part of this intervention, it will also be possible to invest in systems improving the energy efficiency of farm buildings for agricultural production, which will cover approximately 2,111 farms. The total number of supported farms will be 4543, which is 0.31% of all farms in Poland.

Member state		**Keyword reference "Agri-photovoltaic", "Photovoltaic", "Renewable" (in relation to solar/photovoltaic), "Solar" terms in the CAP** plans
		• Support for installations producing energy from solar radiation up to 50 kW together with energy storage and energy management systems or with a heat pump - provided it is an integral part of the installation producing energy from solar radiation, installation costs of the above-mentioned energy production equipment • Investments in farms in the field of renewable energy and improvement of energy efficiency. • The scope of renewable energy sources using wind, sun and biomass for energy production are also included in other programs co-financed from EU funds and national funds, e.g. in the Cohesion Policy, the FEnIKS Program, My Electricity, Agroenergia, which should strengthen the implementation of the above-mentioned needs in rural areas. Aid may be granted only if the investment is economically justified on a given farm, including in terms of costs, and the generated energy (electricity, heat or gaseous fuels) will be used for the farm's own needs.
Portugal	PT	• Installation of renewable energies (PNEC2030 National Energy and Climate 2020-30). • For the R.15 indicator, the target of 22 MW was established. This indicator was associated with interventions to support productive investment (agricultural and non-agricultural) for modernization, to improve Environmental/climate performance, for prevention and restoration of productive potential, for collective infrastructures, etc. as long as there is an investment related to increasing the installed capacity of renewable energies (biomass, biogas, hydro, solar, geothermal, heat pump), even if it is not very significant in terms of project value. The programmed financial allocation of the interventions associated with this Result Indicator is 1106 Million Euros (16% of the PF). However, it is necessary to relativize since for this indicator were associated interventions that have investment related to the increase of the installed capacity of renewable energies, even if it is not very significant in terms of project value.
Romania	*RO*	• Investments in new electricity production capacities from renewable wind and solar energy sources, with or without integrated storage facilities, with an installed capacity of up to 0.2 MW are supported. • The production and use of energy (electrical and/or thermal) from renewable sources (solar, wind, aerothermal, hydrothermal, geothermal, etc.), as a secondary component of an investment project, and the energy obtained will be intended exclusively for own consumption, without the applicant to have the quality of prosumer.
Slovakia	SK	• Promotion of renewable energy production for own consumption and support of renewable energy sources (especially local) from agriculture and forestry, the use of energy grasses and alternative crops for energy production, the use of innovative technologies supporting the comprehensive use of biomass, innovations in the production and use of 2nd and 3rd generation biofuels, mechanical, chemical and energy processing of agricultural and forestry biomass into high value-added products. • A substantial part of the resources allocated to investments will be realized through financial instruments in the form of a combination of guarantees and grants. The financial allocation for financial instruments is 278.7 mil. EUR. of which 128.7 mil. EUR will be grants and 150 mil. EUR guarantee. Grants in the form of interest subsidies or forgiveness of part of the principal will support small (up to 150 ha) and young farmers in the amount of 31 mil. EUR and other farmers in the amount of 97.7 mil. EUR. In terms of focus, this plant will support special crop production (EUR 18 million) and livestock production (EUR 70 million). The rest (62 mil. EUR) will go to modernizing agriculture (cross-cutting objective) and renewable energy. • As part of the Recovery Plan, Slovakia will support the use of clean technologies for sustainable, affordable and smart energy, for which it will use a complex of tools including investment support for the construction of

Member state		**Keyword reference "Agri-photovoltaic", "Photovoltaic", "Renewable" (in relation to solar/photovoltaic), "Solar" terms in the CAP** plans
		new facilities (€103 million) and for the reconstruction (€63 million) of facilities for the production of energy from renewable sources. • Grants: • Basic aid intensity 50% • In special cases, the aid intensity is as follows: ...; technologies for using renewable energy sources 60%; ...
Slovenia	SI	• The potential of using geothermal energy, biogas, biomethane, photovoltaics and agrophotovoltaics will be improved. • Eligible investments are: investments in the arrangement of permanent plantations, which are carried out simultaneously with the construction of new private irrigation systems for one user or the purchase of irrigation equipment, the purchase and installation of nets against hail or photovoltaic panels that replace nets against hail and the purchase of equipment for anti-salt protection. Anti-hail nets include protective nets against hail, protective foils against fruit cracking and scalding, and protective nets against birds and insects, ... • Eligible costs are: ..., costs for investment in the production of electricity and thermal energy from renewable sources for the purpose of carrying out non-agricultural activities (eg: wood biomass, biogas, wind energy, solar energy, agrophotovoltaics), ...
Spain	ES	• Promotion of renewable energy installations (wind and solar, etc.) including floating photovoltaics on reservoirs. • The production of renewable energy will be used exclusively for the self-consumption of the farm. • The Directive on Environmental and Energy Guidelines (Communication of the Commission 2022/C 80/01) will be taken into account, for investments in renewable energy generation that exceed what is necessary for self-consumption and whose energy surplus can be marketed in accordance with national legislation in force and the rules on state aid. • Photovoltaic solar installation to promote self-consumption in warehouses or agri-food facilities. • 8 regional management authorities are committed to promoting investments that support the production capacity of renewable energy: Castilla-La Mancha, Navarra and the regional Supra program, reaching 251 Megawatts of installed capacity for the entire period of planning. These interventions seek to facilitate the supply and use of renewable energy sources, through the installation of all types of renewable energy for the farm's own consumption or to improve the efficiency of the agri-food industry (R.15 indicator). • 10 regional managing authorities with investments, productive or non-productive, related to the climate, where there will be projects that will install renewable energies that will be able to complete the R.15 even better, quantifying a number of more than 9,000 beneficiary farms (R.16 indicator). • ARAGÓN: For financial instruments, the eligibility conditions will be the same as for the subsidy, except for support for photovoltaic energy investments under PPA contracts (Power Purchase Agreement, long-term clean energy purchase agreement from a specific asset and a predetermined price) that may be beneficiaries: "Entities interested in investing in other entities, considered as the ultimate recipients of the investments (for example, entities from the agricultural sector or irrigation communities)." In any case, the eligibility of the investing entities would be conditional on their activity being exclusively the development of distributed renewable energy systems under the PPA regime to feed pumps. • CANTABRIA: The aid will be in the form of a subsidy with an aid intensity of 100% in the case of investments in underground power lines, a maximum of 80% for actions involving renewable energies in EELL (minimum 50%) and a maximum of 65 % for investments in electrification for individuals (minimum 40%). • GALICIA: Small infrastructures in renewable energies and related to energy

Member state		**Keyword reference "Agri-photovoltaic", "Photovoltaic", "Renewable" (in relation to solar/photovoltaic), "Solar" terms in the CAP** plans
		efficiency. The aid intensity will be modulated according to the type of project and the demand. The following maximum intensities between 60 - 80% are considered: Autonomous administration: up to 80%, Local public entities: up to 80%, Individuals or legal entities governed by private law: up to 60%, Associations and public-private groups: up to 60%, Non-profit organizations: up to 80%. • Investments in energy production facilities based on renewable energy and energy saving and efficiency in buildings intended for municipal public service of local entities: the requesting local entities must have a population of less than 15,000 inhabitants or, if higher, the building or facility must be located in a nucleus whose population as a whole is less than 1,500 inhabitants. • Projects related to the promotion of the use of renewable energy and cleaner energy technologies may only be located in those areas permitted by current legislation and part of the energy generated must be consumed in the immediate environment.
Sweden	SE	• Several needs that are partially met within the CAP are linked to the increased environmental and climate ambition. Among other things, it is about increasing the production of and making use of renewable energy and making energy use more efficient, which is mainly controlled by demand. In general, Sweden has chosen to promote renewable energy through support for the consumption of such energy, primarily through differentiated taxes and reduction obligations for fuel, which increases the possibilities for cost-effective solutions. Efficiency is mainly driven by forces other than CAP. • No measures within CAP that are specifically designed to support investments in renewable energy. There is national production support for biogas and investment support in the form of Klimatklivet which meets the need to encourage the production and utilization of raw materials for the production of renewable energy. • Increased use and production of renewable energy is mainly supported by the statutory reduction obligation for fuel, energy tax, carbon dioxide tax and through the national form of support Klimatklivet where agriculture is prioritized for support, e.g. for construction of biogas plants. A national production subsidy for biogas from, among other things, manure and a climate premium for work machines are other national subsidies that can contribute to the goal of increasing the contribution of rural areas in terms of the use and production of renewable energy. • Given the limited extent of agricultural land and other conditions, it is difficult to predict any dramatic increase in the share of renewable energy in the Swedish energy mix that comes from agriculture and which in the short term can respond to the Commission's recommendations in this regard. • Some supportive efforts can be made in the strategic plan to increase production and use, but mainly Sweden believes that the production of renewable energy raw materials and of renewable energy should be driven by demand and that other renewable energy types are more important at national level.

Source: (European Commission, 2022b) and online translation tool

Annex 6. Summary of Indicators R.15 and R.16 and keyword search of MS draft CAP strategic plans for **"Agri-Photovoltaic", "Photovolta**ic**".**

Member state		Indicator R.15	Indicator R.16	Keyword reference **"Agri-photovoltaic"**	Keyword reference **"Photovoltaic"**
Austria	AT	X	X		X
Belgium (Flanders)	BE	X	X		
Belgium (Wallonia)	BE	X	X		X
Bulgaria	BG	X	X		X
Croatia	HR	X	X		
Cyprus	CY	X	X		X
Czech Republic	CZ		X		X
Denmark	DK		X		
Estonia	EE	X	X		
Finland	FI	X	X		
France	FR	X	X		X
Germany	DE		X	X	X
Greece	EL	X	X		
Hungary	HU	X	X		
Ireland	IE	X	X		X
Italy	IT	X	X	X	X
Latvia	LV	X	X		
Lithuania	LT		X		
Luxembourg	LU		X		X
Malta	MT	X	X		X
Netherlands	NL		X	X	X
Poland	PL	X	X		
Portugal	PT	X	X		
Romania	RO	X	X		
Slovakia	SK	X	X		

Member state		Indicator R.15	Indicator R.16	Keyword reference **"Agri-photovoltaic"**	Keyword reference **"Photovoltaic"**
Slovenia	SI	X	X	X	X
Spain	ES	X	X		X
Sweden	SE		X		

Source: (European Commission, 2022b)

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct centres. You can find the address of the centre nearest you online (european-union.europa.eu/contact-eu/meet-us_en).

On the phone or in writing

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

— by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),

— at the following standard number: +32 22999696,

— via the following form: european-union.europa.eu/contact-eu/write-us_en.

FINDING INFORMATION ABOUT THE EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website (european-union.europa.eu).

EU publications

You can view or order EU publications at op.europa.eu/en/publications. Multiple copies of free publications can be obtained by contacting Europe Direct or your local documentation centre (european-union.europa.eu/contact-eu/meet-us_en).

EU law and related documents

For access to legal information from the EU, including all EU law since 1951 in all the official language versions, go to EUR-Lex (eur-lex.europa.eu).

Open data from the EU

The portal data.europa.eu provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of datasets from European countries.

The European Commission's science and knowledge service

Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub
joint-research-centre.ec.europa.eu

@EU_ScienceHub

EU Science Hub - Joint Research Centre

EU Science, Research and Innovation

EU Science Hub

EU Science

Publications Office
of the European Union