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AGENCE DE LA TRANSITION ÉCOLOGIQUE

Characterising solar PV projects on agricultural land and agrivoltaism

Executive summary

July 2021

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SUMMARY

CONTEXT OF STUDY

The development of solar renewable energy in the agricultural sector has now become a widely shared objective in order to achieve the objectives set by the Energy Transition Law. However, this development cannot take place without taking into account the need to preserve agricultural land.

As a result, and to preserve the agricultural vocation of these projects, the notion of "agrivoltaism" has emerged in the solar PV sector in France, in large part thanks to the government's call for tenders, operated by the CRE, to develop the "construction and operation of innovative electricity-producing facilities from solar energy," the first details of which were published in 2017. In these calls for tender, agrivoltaic installations are defined as photovoltaic installations coupled with primary agricultural production, by means of a demonstrable synergy.

This agrivoltaic sector is financially backed by the State, and garners interest on the part of project developers. Given the wide variety of technical solutions available on the market, the agricultural synergy of these systems is not always obvious or demonstrable, and not all systems necessarily meet the prerequisites to be defined as agrivoltaism.

Therefore, in light of the growing interest for this new market sector from solar PV developers, this study aims to set out what characterises solar PV activity on agricultural land and define precisely the concept of agrivoltaism. The study was based on a bibliographic review, interviews with farmers and solar PV project developers and the expertise of a committee of experts, specifically set up to monitor this work.

This document summarises the main results of this study, contained in the three reports produced within the framework of the study and published on the ADEME website: a bibliographic review, a collection of feedback and a guide proposing a classification of photovoltaic projects on agricultural land and a definition of agrivoltaism.

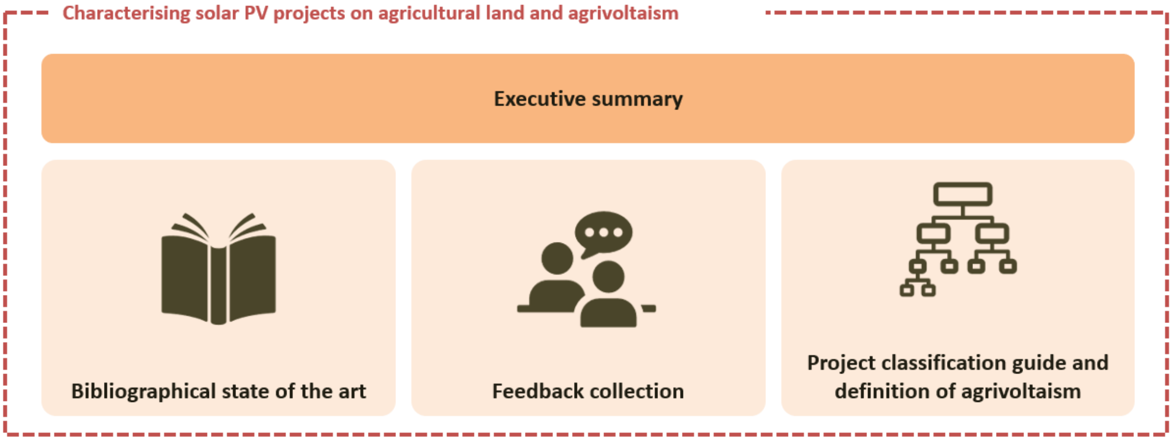


Figure 1: Constitutive elements of this study

1. Methodology

1.1. The different steps of the study

This study was carried out in three steps:

- A state of the art of solar PV systems used in the agricultural sector (in France and abroad) including a typology of these systems and their current level of development, but also a bibliographical study on the impact of each type of project. This work also included a review of the existing regulatory framework for solar PV systems on agricultural land, in France and abroad, to compare regulatory approaches across countries;
- A survey of farmers and developers to compile feedback and summary data sheets for a dozen photovoltaic systems. These sheets compile, in addition to the elements obtained via this survey, the information from the bibliographic study: they include a description of each system, a presentation of the impact observed on agriculture, on the economic results of the farms, and an assessment of the strengths, weaknesses, threats and opportunities;
- An in-depth analysis phase, in consultation with stakeholders, leading to the elaboration of a classification of photovoltaic projects on agricultural land, a definition of agrivoltaism and recommendations for stakeholders.

In order to take into account the multiple facets of solar PV systems on agricultural land (agriculture, photovoltaism, agricultural land, the landscape, biodiversity, the environment, etc.), a number of stakeholders were consulted throughout the study (actors in the photovoltaic and agricultural sectors, as well as public authorities and organisations), directly or indirectly (via interviews, presentations or interventions). In addition, a multidisciplinary committee of around forty experts was set up specifically for the study (in addition to the study steering committee) and regularly called upon to provide its expertise throughout the work and thus monitor and discuss the study's orientations and conclusions.

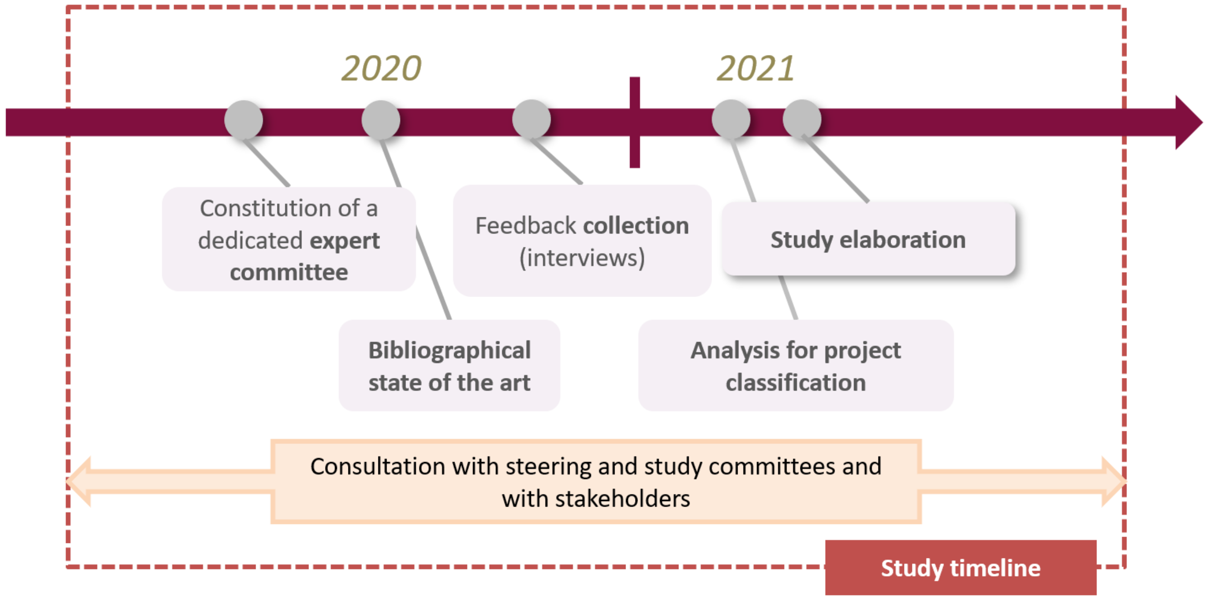


Figure 2: Study timeline

1.2. State of the art of solar PV systems on agricultural land[1]

In particular, this state of the art was based on a bibliographical analysis: 106 publications were identified, 75 of which were considered of interest, and therefore included in this state of the art. Most of the documents studied in the state of the art are scientific articles (67%) and technical documents (13%).

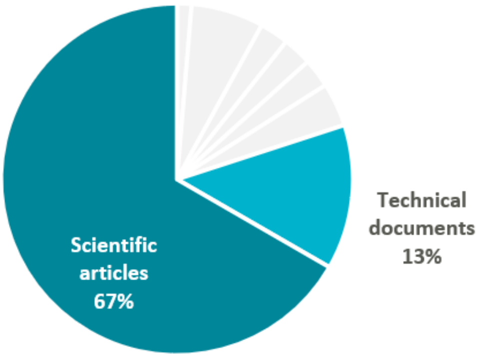


Figure 3: Types of documents analysed (other types of documents: reports, literature review, posters, websites, press articles, student thesis papers)

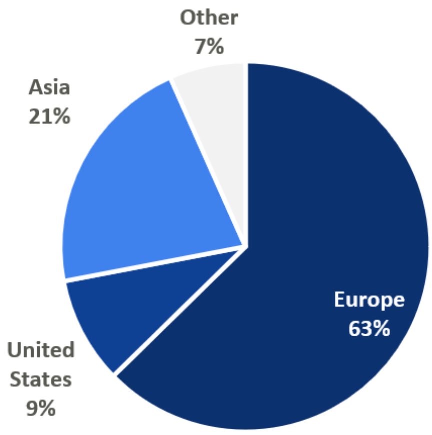


Figure 4: Geographic perimeter of document

The recency of these reports is also an important fact: 56% were published after 2015, 35% between 2010 and 2015, and only 7% of the publications were published prior to 2010. These dates point to an acceleration in the research and development of PV projects on agricultural land in recent years. It is therefore reasonable to assume that the state of knowledge will continue to evolve in the coming years.

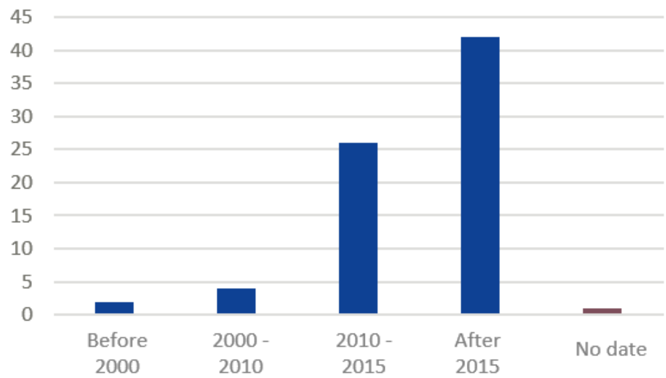


Figure 5: Publication date of documents used in the state of the art (number of documents published)

These publications come mainly from France and Europe (63%), the United States (9%) and Asia (21%). From a technical perspective, the PV systems which were studied most were fixed shades (30% of publications), greenhouses (26%) and ground-mounted plants (22%). Furthermore, the types of crops that were studied most are market gardening (32% of state-of-the-art publications), field crops (13%) and grasslands (10%).

[1] ADEME, I Care & Consult, Ceresco, Cétiac. 2021. Caractériser les projets photovoltaïques sur terrains agricoles et l'agrivoltaïsme – Etat de l'art bibliographique

The majority of those studies (95%) focus on the impact of PV projects on crops (the yield and quality of crops). 21% also address the economic implications of agrivoltaism, while only a minority (16%) investigate the impact of coupling on energy production. 16% of the studies address the issue of land use efficiency in relation to this dual production, using the Land Equivalent Ratio (LER) indicator.

In addition, there were approximately 15 interviews with PV developers to cover the entire breadth of the proposed systems, business models and methods.

Finally, to anticipate the work of the next phase of the study, a survey of agrivoltaic projects in France and abroad (notably Japan, the United States, Germany, Italy, China and Vietnam) was carried out.

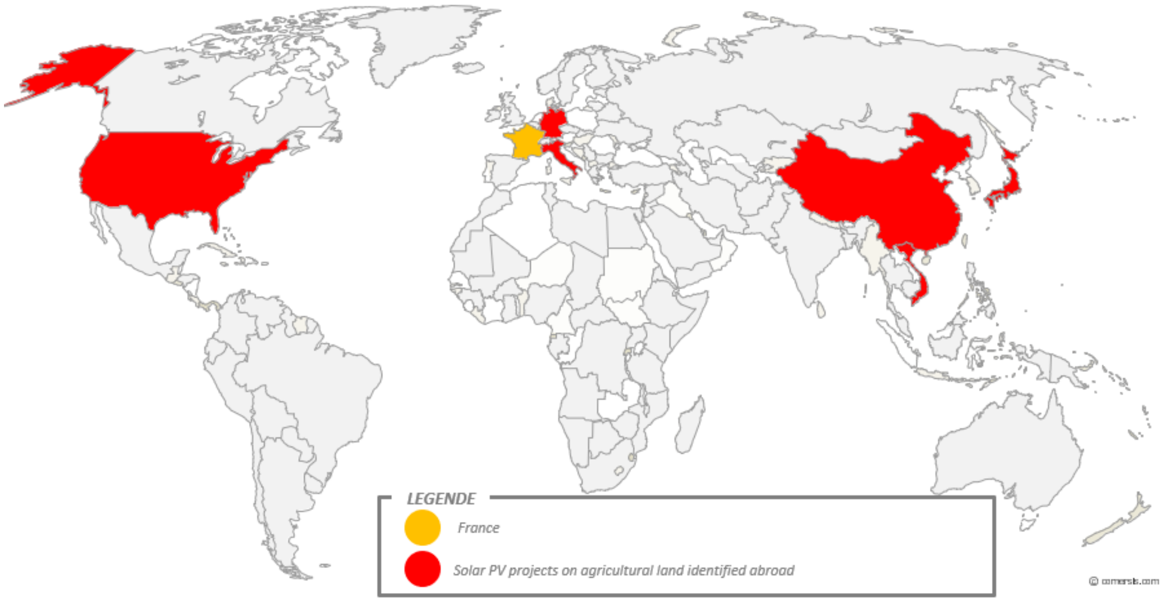


Figure 6: Geographic perimeter of study

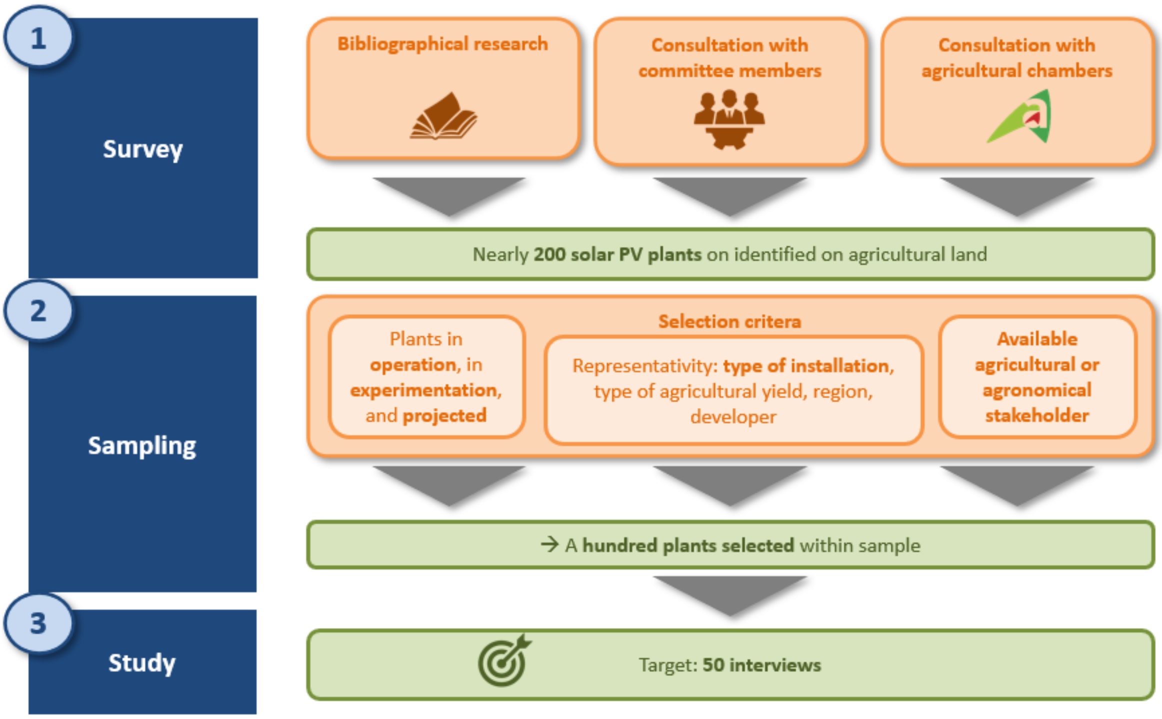
The information once collected and analysed, was used to:

- Make an exhaustive overview of the type of solar PV systems that can be installed on agricultural land, taking into account the different ways in which to couple solar PV and agricultural production;
- Review the scientific literature on the energy, agricultural and environmental performance of these systems;
- Establish a first counting of existing solar PV projects on agricultural land in France;
- Study the policies that regulate agrivoltaism (the regulation, support mechanisms, and jurisprudence), as well as the expectations that the solar PV industry forms for agrivoltaism, and French and European initiatives on agrivoltaism;
- Carry out a state of the art of these systems in a few countries, and in particular the definitions and applicable regulation, to allow for a cross-national comparison.

1.3. Fieldwork study and feedback[2]

The second phase of the study consisted in deepening the results of the literature review through a survey of farmers and solar PV developers.

A survey of solar PV installations on agricultural land in France and abroad was carried out, resulting in a list of approximately 200 installations. From this list, 100 installations were sampled out to survey approximately 50 installations that encompassed all relevant types of solar PV installations on agricultural land. This sample was made with the intention of being as representative as possible of existing solar PV systems on agricultural land: representativeness of systems, regions and associated agricultural production.



As many as 70 interviews were conducted (in majority with farm owners, as well as solar PV developers). Those interviews covered 50 agricultural fields, to ensure wide representation of agrivoltaic projects, both in terms of geographic distribution and in terms of the diversity of PV systems.

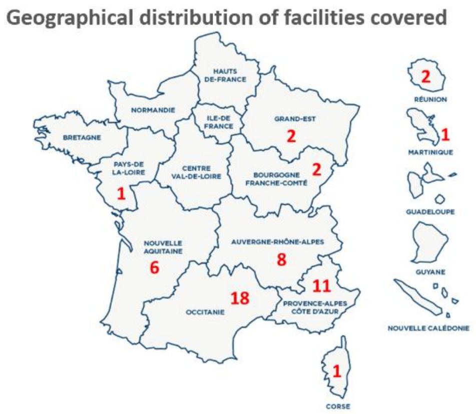


Figure 7: Geographic distribution of relevant existing agricultural fields (not represented: 3 in Germany)

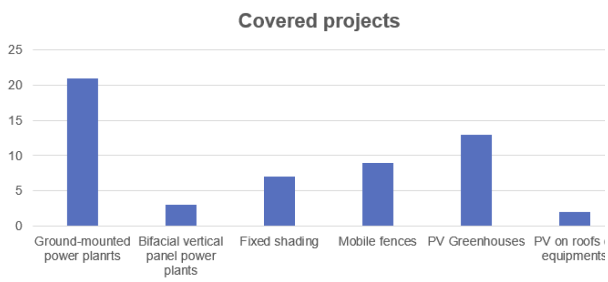


Figure 8: Types of systems studied

[2] ADEME, I Care & Consult, Ceresco, Cétiac. 2021. Caractériser les projets photovoltaïques sur terrains agricoles et l'agrivoltaïsme. Recueil de retours d'expériences et fiches techniques récapitulatives.

The surveys collected the following information for each installation:

- A description of the system: type of structure, capacity, installed surface, quantities consumed by the farmers, etc;
- The history of the project set-up, and the way in which contacts between farmers and developers and any negotiations were conducted;
- The business models of the solar PV systems alongside a description of the stakeholders and their involvement in the project;
- The agricultural technical and economic model: whether any specifications were made with respect to agricultural production, the agronomic impact of the solar PV modules, the adaptation of the systems to the new constraints linked to the modules, the integration of the project in the functioning of the farms;
- Off-farm effects, i.e. the local acceptability of projects, their environmental impact on the land and on the agricultural sector;
- The general level of satisfaction of farmers and the development potential associated with the projects.

This study was key in identifying the strengths, weaknesses and good practices for each system, and will contribute to the optimisation of the advantages and the limitation of the negative impact. All of this information, compiled with the data obtained from the literature review in phase 1, is summarised in technical data sheets for each of the ten photovoltaic systems[2].

1.4. Methodology to classify projects

The first two phases of the study were instrumental in defining the criteria for characterising solar PV projects on agricultural land, taking into account the risks associated with these installations.

The identification of the interactions (positive and negative) between agricultural production and solar PV production was then used to classify projects (called gradient), on the basis of objective criteria. The criteria and the gradient were then compared with the feedback from the study and submitted to the study's expert committee for further refinement.

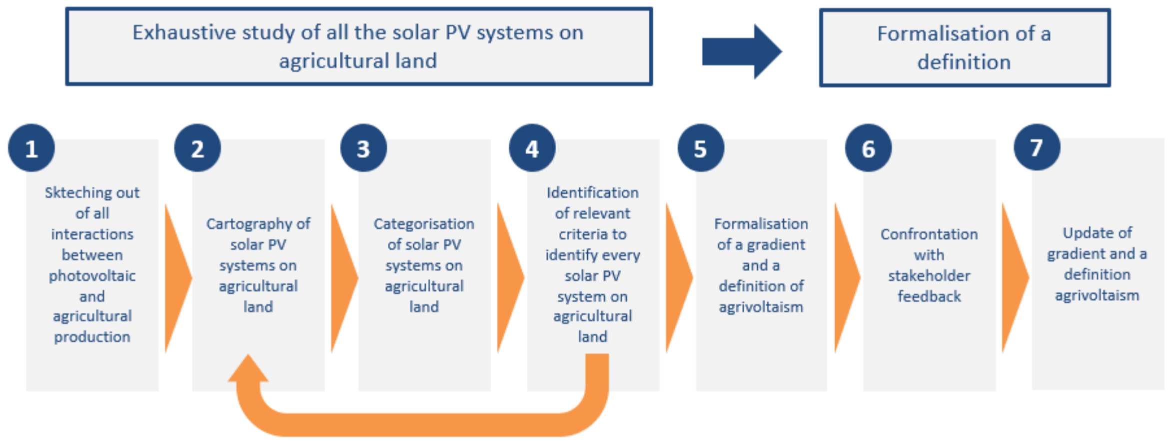


Figure 9: Methodology to classify projects

These elements are summarised in another deliverable of the study called "Classification guide of projects and definition of agrivoltaism"[3].

[3] ADEME, I Care & Consult, Ceresco, Cétiac. 2021. Caractériser les projets photovoltaïques sur terrains agricoles et l'agrivoltaïsme – Guide de classification des projets et définition de l'agrivoltaïsme.

2. Main findings

2.1. Main results of the bibliographical state of the art

The results, sourced and detailed from numerous references, are available in the state-of-the-art report[3]. The following paragraphs present an extremely synthetic version of those results.

As both activities (agriculture and energy) have to share the available space and sunlight, the respective yields of the two activities are strongly influenced by the characteristics of the photovoltaic installation: the density, the type of module, the tilt, the controllability, etc.

In general, the energy performance of solar PV systems on agricultural land is lower or equal to systems without agricultural activity. Indeed, as one of the objectives of these systems is to maintain "acceptable" agricultural yields or to integrate animal welfare for livestock, the production of electricity via solar PV panels is mechanically constrained. The lower the photovoltaic performance on the farmland, the higher the levelized cost of energy.

The installation of solar PV panels has, in general, neutral or negative effects on agricultural production. Agricultural production is influenced by four main factors, which can have either positive or negative effects on its yield, quality and homogeneity. Those four factors are the solar irradiation, the temperature, the evapotranspiration and the water efficiency. Thus, the success of an agrivoltaic installation will depend on the physical interactions between the crop and the modules, which directly influence the four aforementioned factors.

This coupling can have both favourable or disfavourable implications for the agricultural land: they can enhance, or undermine agricultural production, via those four factors. For example: agrivoltaism can protect the crop against various climate threats. In any case, the agrivoltaic coupling requires an adaptation of the two components as presented in the diagram below.

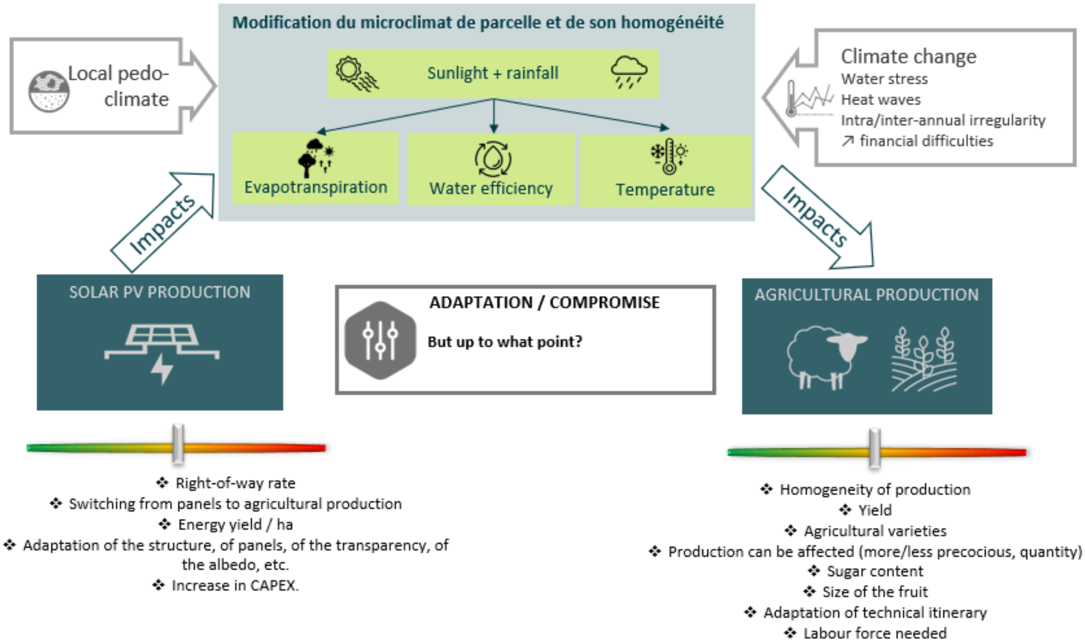


Figure 10: Schematic representation of the interactions between solar PV energy and agricultural production (CERESCO, 2020)

The reduction in sunlight due to the solar PV modules is the main eco-physiological constraint on the productivity of plants.[4] The modules can reduce the quantity, intensity and/or duration of light that nearby plants can receive. Based on their position, the solar PV modules can also create alternations of shade and light, that would otherwise not exist in agricultural land. Importantly, the sensitivity of plants to shade differs from one species to the next. The spatial heterogeneity of luminosity can also vary: checkerboard structures have a better distribution of light than linear structures.

The decrease in evapotranspiration, due to the decrease in radiation and temperature during most of the year, can have beneficial effects, and in particular improve water efficiency (i.e. the ratio between the relative variation of dry matter and actual evapotranspiration), especially in hot weather conditions. This can limit the need for additional water, and thus save on irrigation (from 12 to 34% in the Piolenc (84)[5] vineyard trials). However, this improvement is not systematic, and depends on the species, varieties and soil and climate conditions. Overall, several authors point out that in the context of climate change and water scarcity, PV panels have a potential role to play in mitigating climate stress and saving water in the future. The key issue is to improve water efficiency while maintaining yields,[6] which can be achieved for some crops in some climates through shading.

As solar modules cover a large proportion of the surface, it can reasonably be assumed that they influence the spatial distribution of rainfall by concentrating the flow of water. The information available in the literature on the impact of modules on water distribution and erosion is relatively limited, with difficulties in comparing results, due to differences in soil and climate situations across the available literature. The state of the art shows that the spatial heterogeneity of water under modules is generally significant, and highly dependent on the height and geometry of the photovoltaic structure as well as its ability to stand parallel to the rain in the case of controllable photovoltaic modules. The modules generate strong contrasts in the distribution of water in the ground, with the formation of a "bulb" of water in the ground below the panel, as the water spreads by means of gravity but also on the sides by means of diffusion.

To summarise, the impact of photovoltaic panels seems to vary significantly, depending on local soil and climate conditions. There are two possible scenarios:

- Light is the limiting factor for plant growth: in this case, increased shading has negative consequences for plant growth;
- Water is the limiting factor for plant growth: in this case, improved water efficiency can counteract the effects of shading, and yields can be higher than those obtained without photovoltaic panels.

Thus, the results obtained on yields depend very much on the pedoclimatic conditions of the projects, the crops (which have variable sunlight and water requirements) and the characteristics of the associated photovoltaic structures (coverage rate, panel orientation, height, etc.).

Finally, it should be noted that the bibliographic references are incomplete and difficult to compare, particularly for photovoltaic greenhouses. The state of the art also reveals a lack of multi-year data or experience from pilot projects.

2.2. Main findings from the fieldwork study

This section summarises the main findings from the interviews with farmers and solar PV developers. The results are detailed, system by system, in the dedicated report of the study entitled "Feedback and summary data sheets"[2].

Among the difficulties that are frequently reported, this survey phase highlighted a lack of knowledge of the effects of shading on crops and a lack of agronomic feedback. Many farmers mentioned the scarcity of existing feedback and therefore the difficulty in capitalising on previous experience, which forces them to engage in experiments of their own. This difficulty is sometimes aggravated by a lack of advice and support from developers on the adaptation of crops. This observation must, however, be nuanced as some developers offer agronomic support to farmers. This support, when offered, is appreciated by farmers.

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[4] Dupraz, C., H. Marrou, G. Talbot, L. Dufour, A. Nogier, Ferard Y., 2011. Combining Solar Photovoltaic Panels and Food Crops for Optimising Land Use: Towards New Agrivoltaic Schemes. Renewable Energy, Renewable Energy: Generation & Application, 36, 10: 2725-32.

[5] Feedback from interviews with farm owners with experimental agrivoltaic projects, and developers

[6] Wallace, 2000. Increasing agricultural water use efficiency to meet future food production. Agriculture Ecosystems & Environment

Additionally, the interviews highlighted potentially profound changes in the production cycles of the crops, particularly when the agricultural activity under the photovoltaic panels is no longer the activity foreseen initially.

In addition, the financial benefits sometimes associated with this type of project can lead to land speculation.

Finally, although lifetime of the PV installations remains a point of negotiation, their dismantlement is often foreseen and taken care of by PV developers, and farmers can choose to keep the power plants at the end of the lease.

According to the farmers who were interviewed, the main advantages of these projects for developers are: access to agricultural structures at zero or negative cost, access to additional land, protection against various hazards (particularly meteorological) and economic support for the development of a constrained land base or for the perpetuation of a farm.

3. Formulation of a classification gradient of solar PV projects on agricultural land

3.1. Methodological approach

The analysis of both the bibliography and the stakeholder feedback revealed concrete elements that help characterise photovoltaic installations on agricultural land.

Indeed, solar PV installations on agricultural land beg several questions, not only on the direct interactions between these two productions but also on the economic, social and territorial implications. Moreover, as seen in the literature review, the agronomic consequences depend on many parameters and in particular on the pedoclimatic context. As a result, a categorisation of agrivoltaism by type of photovoltaic system and/or crop is probably not realistic.

Therefore, a cross-sectional analysis of the various schemes and interactions identified important questions, from which a set of criteria emerged to help characterise these projects.

These criteria were then prioritised and classified into two groups:

- Three "qualification criteria," to establish the agricultural synergies between photovoltaic production and agricultural production;
- Seven "attention criteria," on the necessary complementarity and general coherence and relevance of the agrivoltaic coupling and possible areas of fragility.

EVALUATION CRITERIA of SOLAR PV SYSTEMS ON AGRICULTURAL LAND	
Qualification criteria	**Attention criteria**
Characterise the links and effects between photovoltaic production and agricultural production (thus identifying potential agricultural synergies and potential relevance for agriculture)	*Shed light on the other dimensions of the project to question its solidity or, conversely, identify possible areas of fragility, and assess any potential positive externality*
- Services provided to agricultural production - Impact on agricultural production - Income for the farm owner	- Agricultural vocation and sustainability of the project - Reversibility and dismantling of the PV system - Territorial suitability - Environmental and landscape effects - Impact on the soil - Adaptability of the system - Technical flexibility

Figure 11: Table of the different criteria

These criteria englobe each type of coupling between PV systems and agricultural land. The hierarchical classification of these criteria and their categorisation into different levels of relevance made it possible to establish a gradient of project classification, identify the most virtuous projects and define agrivoltaism.

In this hierarchy, the concept of agrivoltaism is based on the highly selective notion of synergy between agricultural production and photovoltaic production. However, the classification gradient also points to other ways to couple agriculture and PV systems, in ways that might be of interest for agriculture, although they do not respect strictly this notion of synergy.

In any case and for all projects, an exhaustive case-by-case analysis of all the different criteria must be conducted to judge the relevance of any project in the context of its local and territorial implantation.

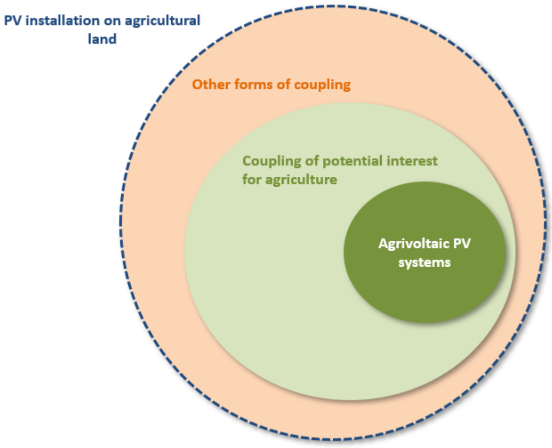


Figure 12: Schematic representation of the categorisation of solar PV systems on agricultural land

3.2. Qualification criteria

The three criteria that qualify and define the synergies between photovoltaic and agricultural production rank projects on the basis of the mutual benefice between the two activities. They have to be evaluated one after the other in order to position the projects in the classification gradient, presented below.

Three qualification criteria were identified and examined, in the following order of importance:

1. Services to agricultural production;
2. Impact on agricultural production;
3. Impact on farm income.

3.2.1. Criterion 1 – services provided to the agricultural production

This first criterion aims to answer the following question: "*Does the PV project provide a service to the farm? Of what kind?*".

To justify its presence on agricultural land, an agrivoltaic installation must satisfy a need expressed by the farmer and provide an agricultural synergy between photovoltaic production and agricultural production through an agronomic service.

However, these services can be of different forms, involving more or less strong agronomic interactions on the farm. They have thus been classified into 4 categories:

- Category 1: direct plot-level services: adaptation to climate change, protection against hazards (in particular meteorological hazards), animal welfare improvement or specific agronomic services (limitation of abiotic stress, etc.).
- Category 2: Indirect plot-level services: access to technical equipment with PV plants: photovoltaic greenhouse, barns or any relevant farming infrastructure with rooftop PV units….

Technical equipment refers to equipment traditionally used in the agricultural sector and which can be deployed on a farm without the addition of photovoltaic modules: greenhouses, livestock buildings, barns, etc.

- Category 3: other services, rendered at the farm level or disconnected from agronomy: securing land or access to additional land, perpetuation of the farm.
- Category 4: no service provided

The figure below summarises the classification of these four types of services:

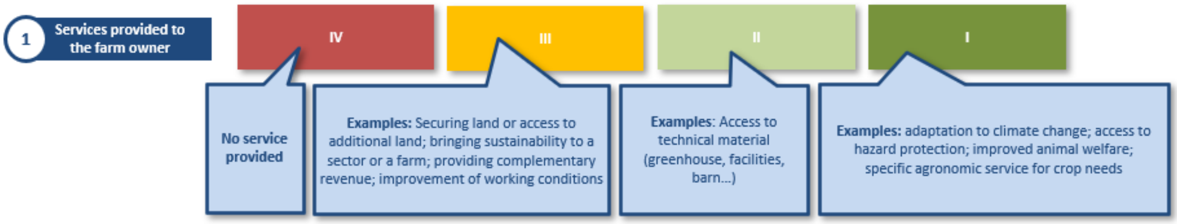
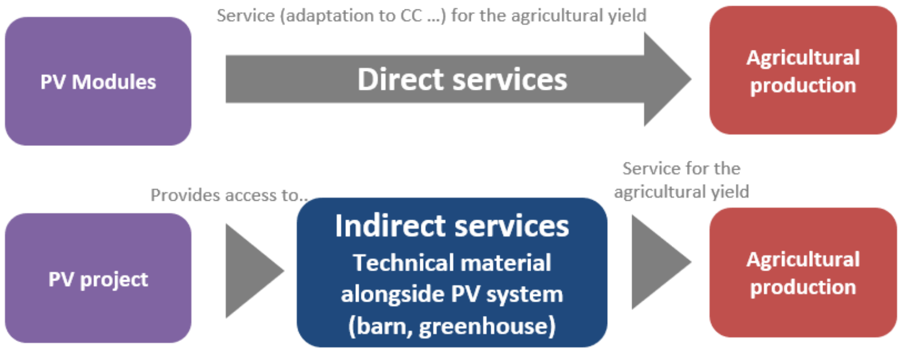


Figure 13: The different types of services provided to the farm

This first criterion is fundamental to define agrivoltaism: only those solar PV installations that can demonstrate a direct contribution to the agricultural production, at the plot level, can be characterised as agrivoltaic.

The distinction between services 1 and 2 is based on the "direct or indirect" nature of the services provided. In the first case, the service is rendered directly by the photovoltaic modules on the agricultural land; in the second case, the service is rendered by technical equipment, which is acquired through the photovoltaic project. The diagram below illustrates this distinction.



Technical equipment refers to equipment traditionally used in the agricultural sector and which can be deployed on a farm without the addition of photovoltaic modules: greenhouses, livestock buildings, barns, etc.

Figure 14: Distinction between direct and indirect services

Those services must therefore be:

- **Justified**, by responding to a justified agricultural need;
- **Proven**, with demonstratable results (bibliographic or convincing feedback): improvement in the quality or quantity of production, reduction of certain losses in the field, reduction in the amount of certain inputs, the improvement of animal welfare evaluated by an independent body, etc. A justification by means (provision of shade, protection etc.) is not sufficient alone;

And they must not lead to negative externalities on other dimensions of the project.

3.2.2. Criterion 2 – Incidence on agricultural yields

The second major criterion aims to answer the question: "*How does the solar PV system impact, qualitatively, and quantitatively, the agricultural production?*".

It aims to assess the impact of the solar PV system on the overall agricultural production. It quantifies two indicators in parallel: the "quantities produced" and the "quality of this yield," compared to an identical agricultural production without a solar PV system on it.

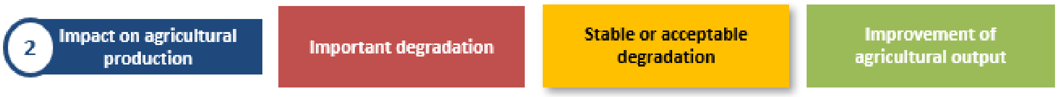


Figure 15: Evaluation of the criteria « Incidence on agricultural yields

Only those PV plants that can increase agricultural yield (green category) or maintain, or degrade it within acceptable proportions (yellow category) can qualify as "agrivoltaic."

3.2.3. Criterion 3 – Incidence on the revenues of the farm owner

The third criterion addresses the question: "*How does the solar PV system impact the revenues of the farm owner?"*.

This criterion requires an assessment of agricultural revenues both before and after the PV system is installed, such that the revenues of the farm owner can be compared with what they were before the installation of a solar PV system. The reference must be the initial revenues of the farm owner.

Furthermore, a distinction must be made between the evolution of the agricultural revenues and the potential revenues that can come in addition to them, thanks to the solar PV system (rent, commercialisation of electricity, etc.)

Figure 16: Evaluation of the criteria "Revenues of the farm owner"

Maintaining or even improving global income, without loss of farm income, is a prerequisite for being able to qualify as agrivoltaic.

Thus, the yellow and green categories in the above diagram are the only ones eligible to be defined as agrivoltaic: the agricultural revenues must be at least maintained and the overall income can be either maintained or improved by the PV activity.

The situations in which the overall revenues increase (with a decrease in agricultural revenue but a larger increase in revenue from the PV project) were excluded from the definition of agrivoltaism. However, these are systems that can be of interest for agriculture, provided that they meet the attention criteria (see §5).

3.3. Classification gradient of solar PV projects on agricultural land

On the basis of the three above criteria, a gradient of classification of solar PV projects on agricultural land was established: from the least virtuous to the most virtuous in terms of agricultural synergy. This gradient allows an initial categorisation of projects, presented in a hierarchical manner. It should be used as a decision tree, starting with the evaluation of criterion n°1, then going down to evaluate criterion n°2 until arriving at the evaluation of criterion n°3 to qualify the project. As a general rule of thumb, the projects located furthest to the left of the gradient are the projects where there is the least synergy, while the projects located on the right-hand side of the gradient are the projects where the synergy is strongest. However, this gradient does not include the attention criteria (cf. §5), which should nevertheless be studied later to ensure the overall relevance and consistency of the project.

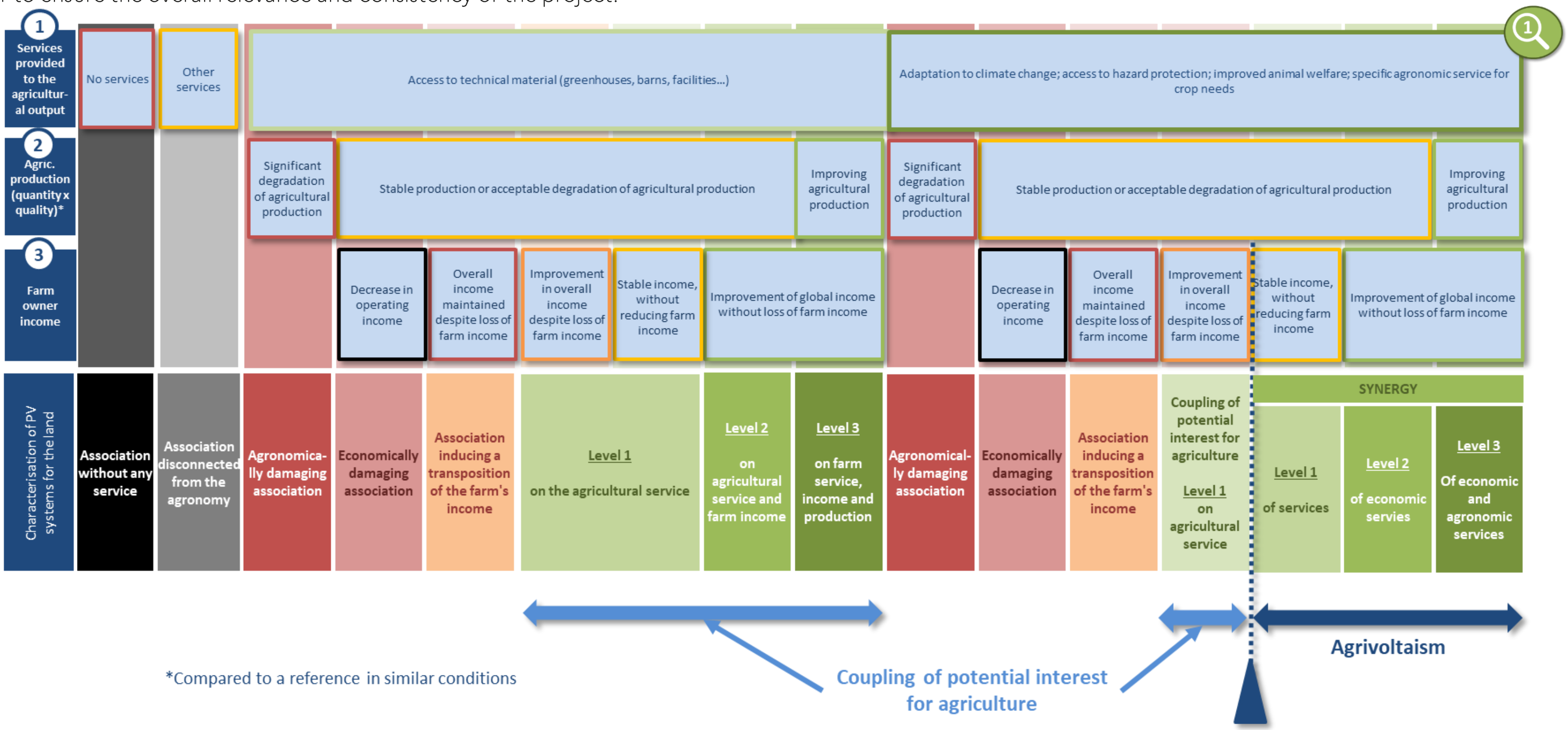


Figure 17: Classification gradient of solar PV projects on agricultural land

As explained in the previous paragraphs, agrivoltaic projects must, at a minimum:

- provide a direct service to the agricultural production, at the plot level (category 1: adaptation to climate change, protection against hazards (especially weather hazards), improvement to animal welfare or specific agronomic service for the needs of the production);
- improve or maintain agricultural production, or degrade agricultural production but within acceptable bounds;
- maintain or even improve farm income.

The projects that meet these conditions are visible on the right-hand side of the gradient (zoom 1), which distinguishes three levels of agricultural synergy:

- Level 1: Synergy of services provided;
- Level 2: Synergy of services provided and economic synergy;
- Level 3: Synergy of services provided and agronomic and economic synergy.

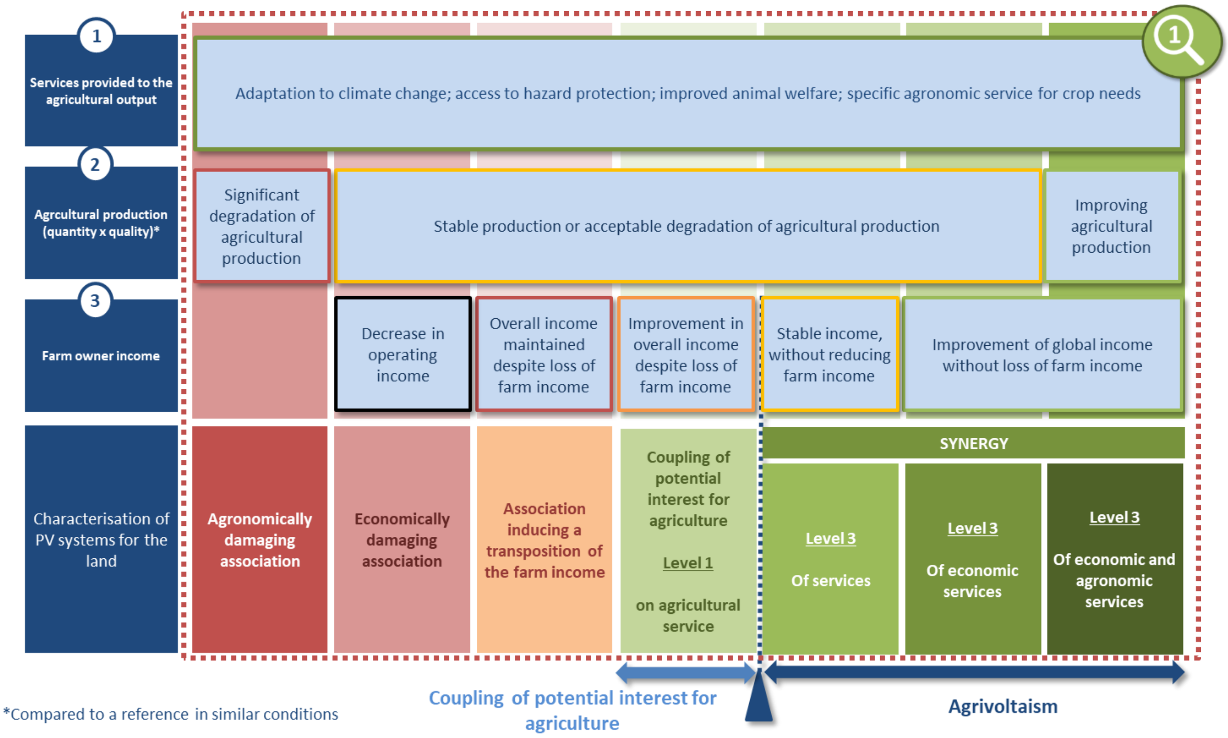


Figure 18: Zoom 1 on the gradient to qualify agrivoltaic projects

In those cases when the service provided to the farm is indirect (access to farm equipment / zoom 2), different classifications are still possible. Among these projects, some are of interest for agriculture, although they are not classified as agrivoltaic.

Among the couplings of potential interest for agriculture, three levels of interest are again distinguished:
- Level 1: Coupling of potential interest for agriculture through the provision of an agricultural service;
- Level 2: Coupling of potential interest for agriculture through the provision of an agricultural service and the improvement of farm income provided;
- Level 3: Coupling of potential interest for agriculture through the provision of an agricultural service and the improvement of farm income and agricultural production provided.

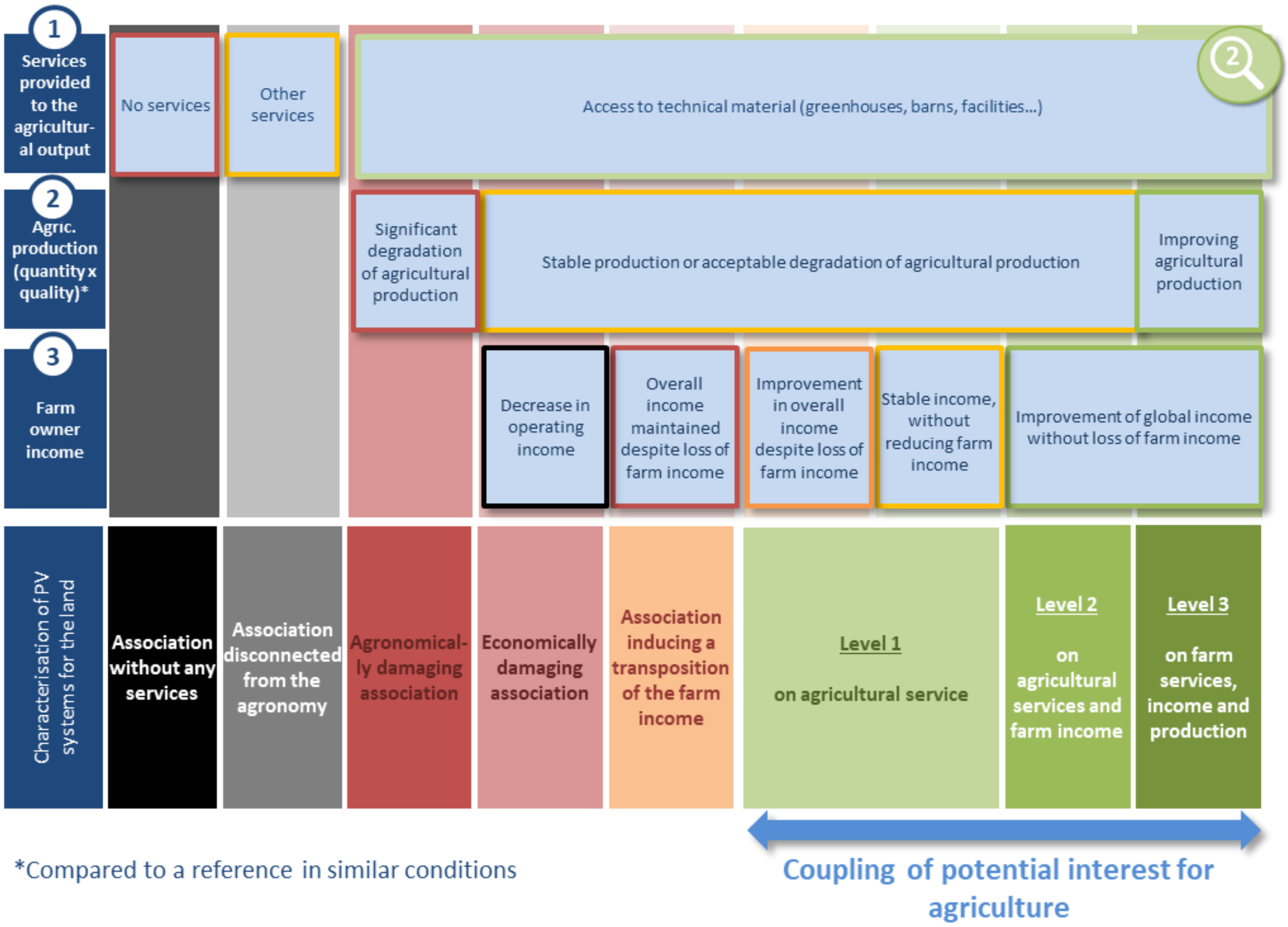


Figure 19 : Gradient of projects with indirect services

The feedback collected showed a great deal of variability from one project to another with regard to these three criteria. The positioning of a project on the gradient is therefore done on a case-by-case basis. The type of PV system used for the project does not define the position of the project on the gradient. In other words, for a given type of system (greenhouse PV panels, ground-mounted panels, etc.), some projects could be considered of potential interest for agriculture, or even agrivoltaic, and others not.

4. Definition of agrivoltaism

Based on the above, the following definition of agrivoltaism can be derived, based on the three criteria underpinning agricultural synergy, but also on the attention criteria that will be detailed in the following paragraphs.

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

- ***Climate change adaptation***
- ***Hazard protection***
- ***Animal welfare***
- ***Specific agronomic services (limiting abiotic stresses etc.)***

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 in 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 soil 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).

****Cf. Chapter 3.2.1 for more details on this notion.***

Furthermore, given the current state of knowledge, for any agrivoltaic project under development, it is essential that a control zone be set up during the design of the project. The control zone must have identical pedo-climatic conditions, a representative size, must be grown under the same conditions (varieties, density) and without photovoltaic modules, and must undergo agronomic (or zootechnical) monitoring over several years by an independent professional or scientific organisation. This would allow, at the very least, for ongoing comparison between the agricultural production under the agrivoltaic zone and agricultural production in the control zone.

5. Attention criteria on possible externalities

Beyond the question of agricultural synergy, other issues must be taken into account to ensure the virtuousness of the project: social, economic, environmental, landscape and territorial issues… Solar PV projects on agricultural land can provide positive externalities to their wider environment, and those externalities must be acknowledged.

The attention criteria can thus complete the assessment of the projects. They cover the other effects (positive or negative) that PV projects can have on agricultural land, beyond the three qualification criteria already detailed.

These attention criteria are summarised in the following figure. For more information on the content of each of these criteria, the reader may refer to the "Guide to the classification and definition of agrivoltaism".[3]

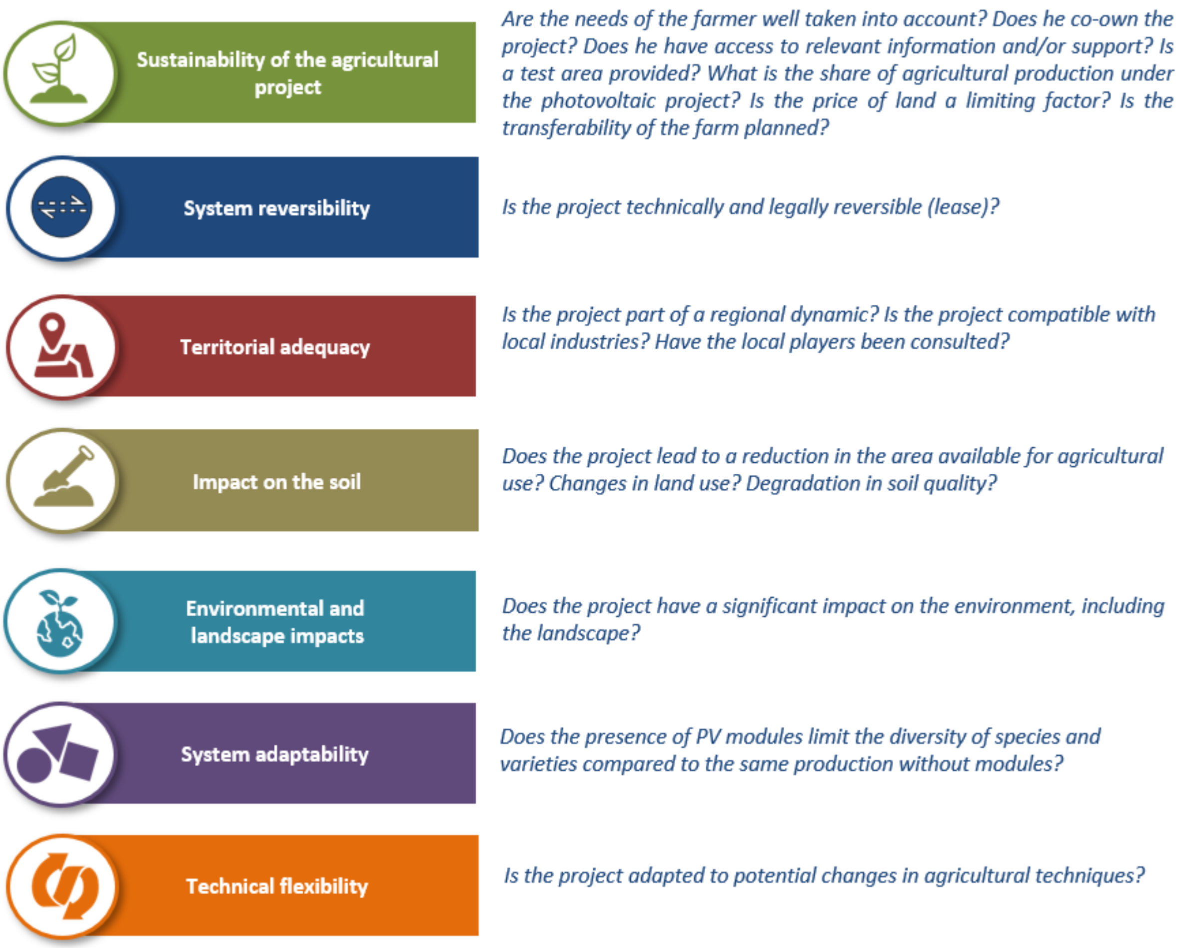


Figure 20: Attention criteria and corresponding questions

6. Main recommandations

The recommendations from this study are addressed in particular to public authorities and developers of photovoltaic projects on agricultural land. They are summarised in the diagram below, according to the chronology of the development of a project. In general, these recommendations aim to:

- Encourage and promote the deployment of "agrivoltaic" projects and projects of potential interest for agriculture;
- Continue to work on expanding existing knowledge (especially agronomic knowledge) of projects combining agricultural production and photovoltaic production;
- Capitalise on current and future feedback, in order to enable continuous improvement of these projects and their practices;
- Support farmers and guarantee the vocation and sustainability of agricultural activity for all solar PV projects on agricultural land;
- Propose a roadmap on the authorisation and instruction of photovoltaic projects on agricultural land.

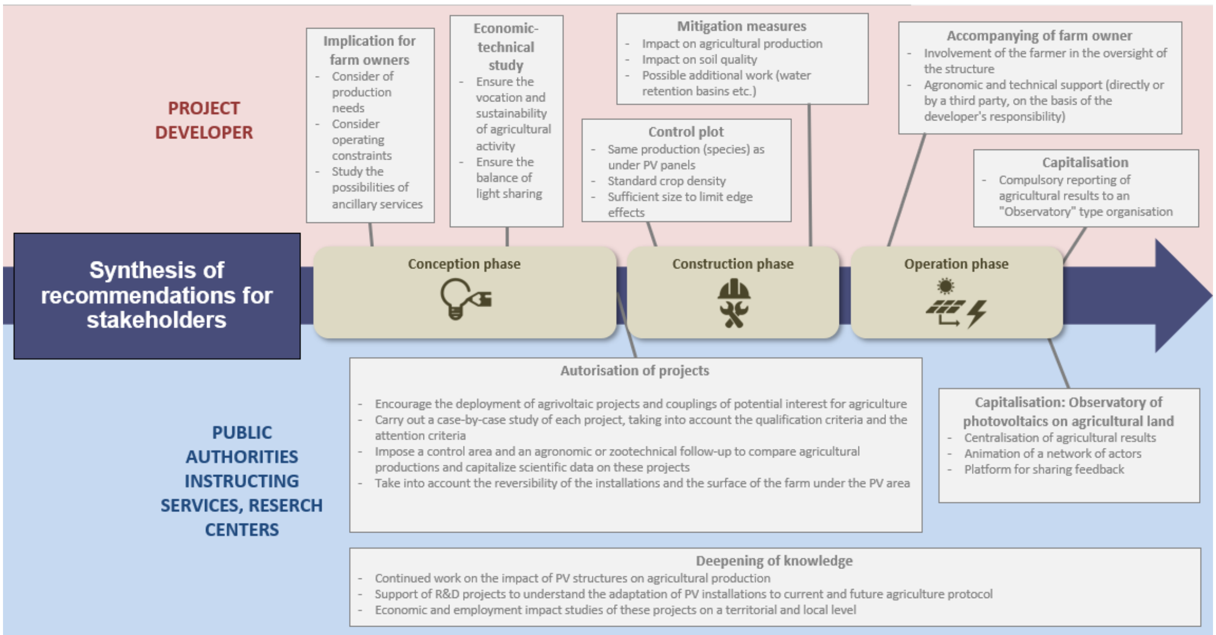


Figure 21: Succinct synthesis of recommendations, on the basis of the temporality of the project

Conclusion

Solar PV systems on agricultural land are a potential answer to the issues generally associated with either one of the photovoltaic and agricultural sectors. However, this requires a delicate balance and compromise between agricultural production and photovoltaic energy production.

This study has helped to shed light on this equilibrium, on the basis of the most up-to-date knowledge and a wide-ranging consultation involving all the relevant stakeholders. The discussions carried out have made it possible to identify three major qualification criteria, and assess the required level of agricultural synergy of a project. Beyond these criteria, the study also highlighted the many issues surrounding positive and negative externalities of these projects. This work has identified several essential yardsticks to evaluate each project, verify any deleterious impact on the agricultural sector, the environment or the territory.

In addition to classifying different types of photovoltaic projects on agricultural land, this study has led to the formulation of an in-depth definition of agrivoltaism, characterising the synergies between agricultural production and photovoltaic production and taking into account all the issues surrounding this novel concept.

Moreover, the gradient of classification of photovoltaic projects on agricultural land also pinpointed how some projects, with a lesser synergy, can nevertheless remain relevant for agriculture, provided that they also meet all the attention criteria (the "couplings of potential interest for agriculture").

Finally, the findings of the study have led to a number of recommendations for the management, deployment and operation of PV systems on agricultural land.

However, this study is the first of its type, in a still complex and evolving environment. Research, feedback and regular monitoring will therefore be essential in order to solidify the existing knowledge base.

LIST OF ILLUSTRATIONS

ACRONYMS

ADEME	The French Agency for Ecological Transition
AO CRE	Acronym of the French PV tenders, organised by the Energy Regulation Commission
CAA	Appeals Court
CAPEX	Capital Expenditure
CC	Municipal Map
CDPENAF	Departmental Commission for the Preservation of Natural, Agricultural and Forest Land
CRE	Energy Régulation Commission
CTIFL	Interprofessional Technical Center of Fruit and Vegetable
DDT	Departmental Direction for Territories
DGEC	General Directorate for Energy and Climate
DTA	Territorial Management Directives
EPA	Initial Agricultural Study
ETP	Full Time Equivalent
FNO	National Sheep Federation
GW	Gigawatt
ha	Hectare
IDELE	Livestock Institute
INAO	National Institute of Origin and Quality
INRAE	National Research Institute for Agriculture, Food and the Environment
kW	Kilowatt
LCOE	Levelized Cost Of Energy
LER	Land Equivalent Ratio
Modules OPV	Organic Photovoltaic Modules
MTES	Ministry for Ecological and Solidarity Transition
MW	Megawatt
OPEX	Operational Expenditure
PCAET	Territorial Climate-Air-Action Plan
PLU	Local City Planning
PNR	Natural Regional Parcs
POS	Land Use Plan
PPA	Power Purchasing Agreement
PPE	Multi-Annual Energy Plan
PV	Photovoltaic
SCOT	Territorial Coherence Plan
SDAGE	Water Management and Development Plan
SIQO	Official Signs Identifying Quality and Origin
SRADDET	Regional Plan for Spatial Planning, Sustainable Development and Territorial Equality
SPE	Solar Power Europe
SYNALAF	National Trade for French Poultry Labels
ZAN	Zero Net Artificialisation

ADEME IN BRIEF

At ADEME - the French Agency for Ecological Transition - we are firmly committed to the fight against global warming and resource degradation.

On all fronts, we mobilise citizens, economic players and regions, giving them the means to move towards a resource-efficient, low-carbon, fairer and more harmonious society.

In all areas - energy, air, circular economy, food, waste, soil, etc. - we advise, facilitate and help finance many projects, from research to sharing solutions.

At all levels, we put our expertise and foresight capacities at the service of public policy.

ADEME is a public institution under the supervision of the Ministry of Ecological Transition and the Ministry of Higher Education, Research and Innovation.

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THEY DID IT
ADEME catalyst: Actors share their experiences and know-how.

EXPERTISE
ADEME expert: It reports on the results of research, studies and collective achievements carried out under its supervision

HORIZONS
ADEME looks to the future: It proposes a forward-looking and realistic vision of the challenges of energy and ecological transition, for a desirable future to be built together.

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EXPERTISES

Characterising solar PV projects on agricultural land and agrivoltaism

This study aims to characterise photovoltaic projects on agricultural land and to provide a precise definition to the notion of agrivoltaism.

It was based on a literature review, interviews with farmers and developers, and the expertise of a committee of experts, specifically constituted to audit and advise the conduct of this piece of work.

This executive summary is one of four documents produced as part of the study, along with a literature review, a collection of feedback interviews and a guide to classify PV projects on agricultural land.

Executive summary of this study

This executive summary describes the overall methodology of the study and the main findings of each work phase.

It briefly explains the characterisation and attention criteria that need to be studied in order to assess a project and to position it in the classification gradient of photovoltaic projects on agricultural land, which was established during this study.

Finally, it includes the main recommendations formulated in the "classification guide" for the supervision, deployment and operation of photovoltaic systems on agricultural land for public authorities and project developers.