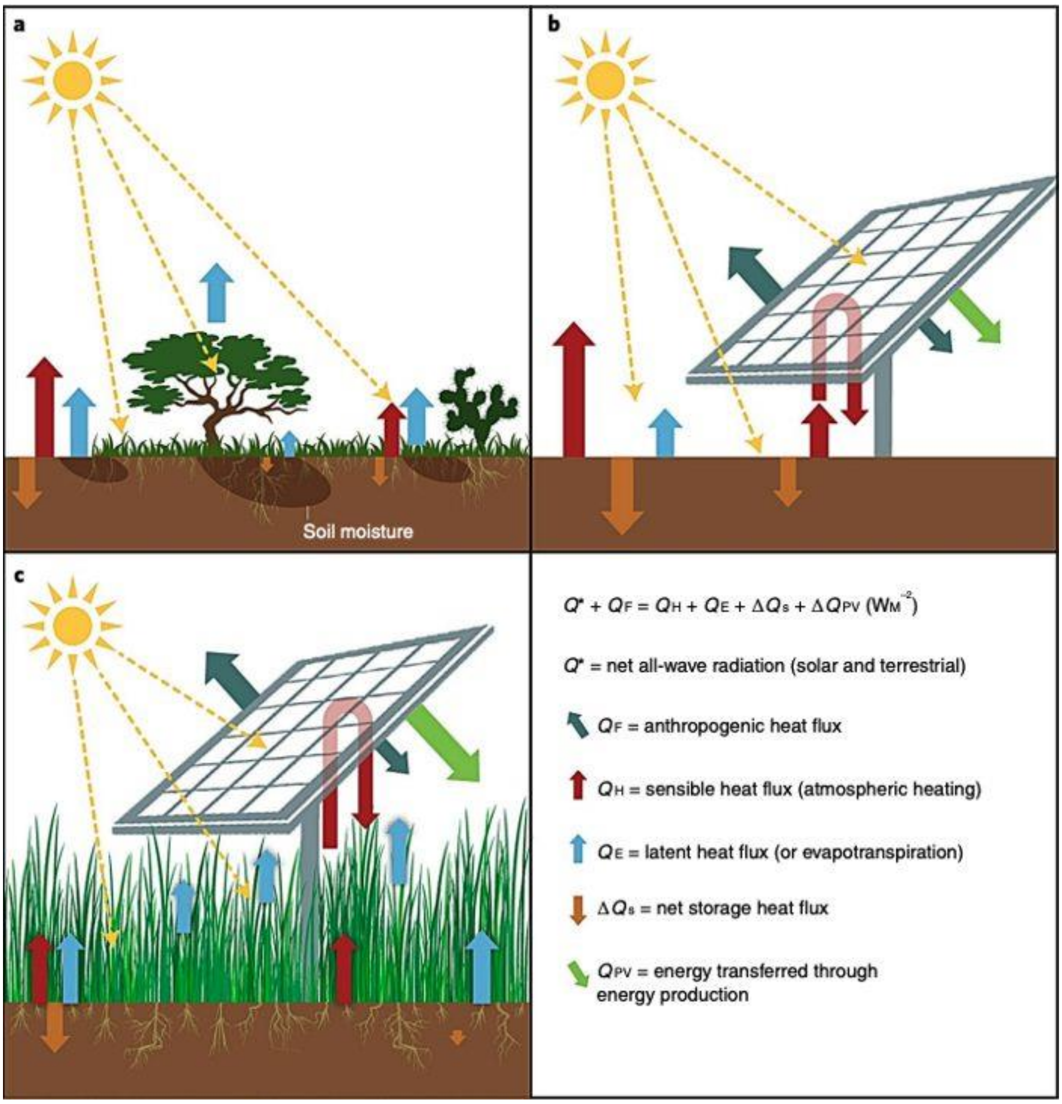
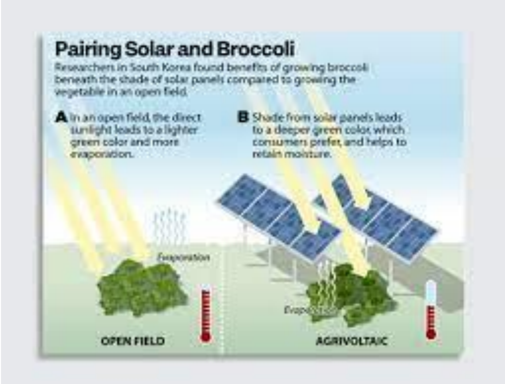
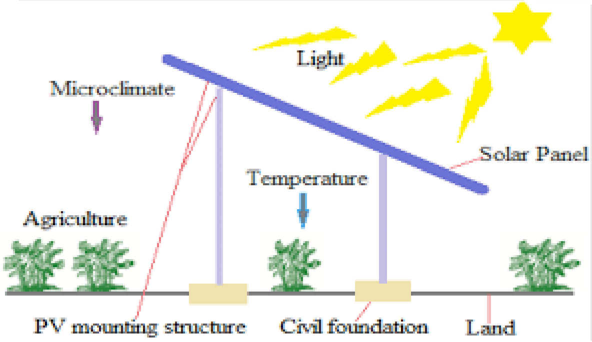
AGRI VOLTAIC

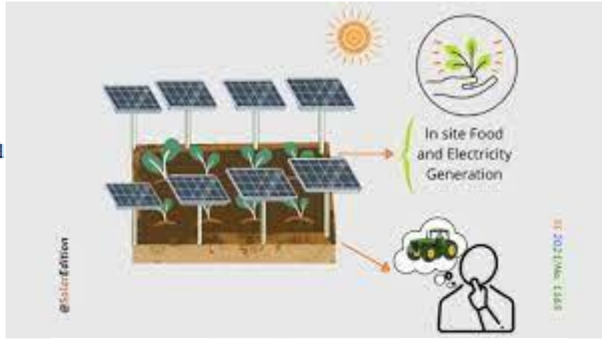
Can crops grow better under solar panels? Here's all you need to know about 'Agri voltaic farming'




Pairing Solar and Broccoli
Researchers in South Korea found benefits of growing broccoli beneath the shade of solar panels compared to growing the vegetable in an open field.
A In an open field, the direct sunlight leads to a lighter green color and more evaporation.
B Shade from solar panels leads to a deeper green color, which consumers prefer, and helps to retain moisture.
Evaporation
OPEN FIELD
AGRIVOLTAIC


Evaporation
Electricity
Open field
Agrivoltaic
High Quality Broccoli Production
Food+Energy


Light
Microclimate
Solar Panel
Temperature
Agriculture
PV mounting structure
Civil foundation
Land


In site Food and Electricity Generation


Conventional Solar Plants
- Big Land-Use Footprint
- Deforestation (Worst Case)
Mix Farms & PV Panels
+ Farmers Revenue
+ Increase in Crop Yields


Agrivoltaics

Agrivoltaics, from competition to complementarity

Overview of the technological, economic and environmental challenges of producing solar energy on agricultural land.

The deployment of agrivoltaics is conditioned by the capacity of the infrastructures to create value for both the farmer and the energy company.

Feeding populations has always been a major challenge for humanity. The prospect of a world population reaching 11 billion people announces an increased resurgence of **competition for land**, whether it is intended for crops and livestock or to produce

the energy necessary for life on earth. Faced with this challenge, a promising coupling seems to be taking shape between photovoltaics and the agricultural field.
In the space of ten years, **solar energy has become the cheapest energy on the electrical market and one of the most attractive energy sources**. France's ambition, set in the latest energy plan is to install 100GW of photovoltaic (PV) capacity by 2050.
This target raises the question of the space available on the ground and therefore of the competition for the use of these spaces. Indeed, even if part of the new installations will be on roofs, car parks or integrated into other elements of urban infrastructure, part will be on the ground, in natural and/or agricultural areas.

Since the 2000' s, **agrivoltaics has offered a new model of electricity production that might transform competition for land into an opportunity for mutually beneficial cohabitation.** Also called Agri-PV, this technique consists of mixing the production of photovoltaic electricity and agricultural production in the same area, by raising the solar panels above the cultivated ground, or cultivating crops in between rows of PV panels.
According to the Flash report of the French Senate Information Mission on agrivoltaics, "*The development of agrivoltaics can provide concrete and rapid solutions to a series of challenges facing France and the agricultural world*". This report notes "*an enthusiasm for the subject, in particular on the part of farmers and energy companies*". A study by researchers at Oregon State University suggests that it would be enough to cover 1% of the Earth's agricultural land to meet global electricity demand. This observation naturally arouses curiosity.

Global interest in Agri-PV technology

Since the first projects implemented, **agrivoltaics were massively deployed in Japan** between 2004 and 2017, with more than 1,000 agrivoltaic power plants in operation. Agrivoltaics then spread to other areas in Asia, particularly **in China where the practice is used to protect soils from desertification**.
In Europe, photovoltaic greenhouses were the first projects to be tested in the early 2000s. Since 2010, PV panel systems on steel structures in open fields have emerged, sometimes equipped with sun trackers.

In the United States, agrivoltaics are on the rise and benefit from the support of the Department of Energy, which has planned to devote 7 million dollars to projects in the sector.

In France, agrivoltaics do not meet any legal or regulatory definition, it even seems to be no consensus on what agrivoltaics are. AFNOR is probably the most widely-recognized entity that provides some guidelines on Agrivoltaics. The Flash report, however, defines it as a "*production of carbon-free electricity of photovoltaic origin on agricultural land that can be used for cultivation or livestock. This implies the coexistence of significant electricity production and significant agricultural production, on the same land holding.*"
However, **France remains a very interesting playground for agrivoltaics**. The potential land that can be mobilized for a photovoltaic installation is estimated at 16 million hectares, or just over 50% of the land. Everywhere in France projects are being set up,

even if some regions are more advanced than others In New Aquitaine, for example, many calls for projects are launched because the area is particularly favourable.

Strengths and weaknesses of a new operating model

The strength of agrivoltaics is based on its ability to combine photovoltaic electricity production and agricultural production, to the benefit of overall efficiency. **The deployment of agrivoltaics is thus conditioned by the capacity of the infrastructures to create value for both the farmer and the energy company,** since the installation of the infrastructures represents a significant investment in both capital and time.

The dominant operating model in this sector in France is an "agriculture first" model. In France, as the Flash report specifies, it is even mandatory: "*Photovoltaic production must not take over agricultural production, which would only be a simple alibi. Even if it can, in some cases, lead to a slight drop in crop yields due to the reduction in light input, agricultural production must be significant. Agrivoltaism must neither lead to diverting agricultural land from its primary purpose, namely food production, nor to distort the core of the farming profession.* »

Increasing the overall yield of land is therefore the basis of the coupling between photovoltaic and agriculture and even has a specific index, the LER (Land Equivalent Ratio) which makes it possible to **measure whether the combined value of agricultural yield and solar energy is equal to or greater than it would be with the singular land use**.

Maximizing electricity production requires optimizing parameters such as panel tilt angles, orientation and slope. The integration of PV in agricultural activities represents a permanent challenge, because energy performance sometimes comes into conflict with the optimal development of crops as well as with the preservation of the landscape. As a result, **agrivoltaics systems have very distinct production models from conventional PV installations.**

Many designs are being experimented with to determine the ideal spacing between PV module strips and their distance from the ground. In open fields there are many solutions, the height and spacing of the modules can be adjusted to grow different types of crops depending on the light, humidity, temperature and space required by the plants. Technical solutions are evolving in the solar industry, with obvious repercussions in the long term on the productivity of panels: dynamic luminosity monitoring (trackers), semi-transparent and mobile PV modules.

Two economical options for agrivoltaics

There are 2 main categories of agrivoltaics:

- **Elevated agrivoltaics**: the PV modules are placed on steel structures at heights that typically range between 2 and 6 meters, the price of which is higher than standard ground-mounted PV. This model of Agri voltaism allows the use of agricultural machinery and the development of crops without height limitation.

These systems of "high" panels are quite present in France because they have been supported by the public authorities. This system is particularly suitable for high-value crops, such as grapes, berries, fruit trees, etc. From an economic point of view, PV panels advantageously replace or complement protective nets or tarpaulins that have to be changed very often, but nevertheless involve a very important initial investment.

• Inter-row agrivoltaics are represented by systems closer to the ground, between rows of panels, essentially linked to the production of lower value crops or fodder. ENGIE has launched a pilot on a project of this type, **the Camelia project**, which aims to study the service provided by the installation of vertical bifacial solar panels on a pasture while analysing the impacts on electricity production. The objectives of this pilot project are multiple:

- Measure the agronomic effects of the installation: aboveground and underground microclimates, growth, biomass production and quality of fodder resources, soil fertility and carbon stocks,
- Study the behaviour of cattle and the compatibility of vertical structures with the use of agricultural machinery,
- Assess the effects on biodiversity.
- Model the energy production of this type of solar technology.

Another “low cost” model uses a tracker linked to a motor which allows the panel to be oriented to follow the sun. Compared to the Camelia model, this tracker model also generates energy production at noon. The technology of these trackers is very widespread worldwide, with several hundreds of gigawatts installed. This is not new and the installations are becoming more and more economical.

A dominant technology versus alternative paths

The industry is still dominated by silicon technologies which represent more than 90% of all installations in the world and have just reached the bar of one terawatt installed in the world.

A few other technologies are becoming more relevant, such as thin films, CIGS, perovskite, organic PV, but all these technologies are still currently more expensive than silicon technology.

In Spain, Italy, Israel and France, tests of "next generation" cells integrated into shade houses or roofs have taken place, as well as tests of low-cost plastic greenhouses or polytunnels integrating photovoltaic cells. It should be noted that some of these solutions have shown similar durability problems as plastic films.

Very-high-irradiance zones such as the Middle East are interesting test grounds for high-tech greenhouses integrating less opaque photovoltaic films. Spectral selective PV devices and luminescent solar concentrator technologies can focus different wavelengths of the solar spectrum onto plants and modules.

Agrivoltaics projects Examples

Agrivoltaics represent an asset for ENGIE to achieve its renewable energy production objectives of 400 GW by 2030. It can be noted that ENGIE is techno-agnostic, with some BUs working with high PV, others with less expensive solutions, or even with greenhouses. ENGIE Green is notably a partner of Sun Agri in France.

As says James Macdonald: "*The GBU Renewables has recently built a 104 MWp agrivoltaic project in Sicily. This is a real first step for the Group in this sector. We are still defining the agricultural model, but the majority of the surface will be dedicated to hay. It is planned to be sown as soon as the photovoltaic plant starts up, in mid-June. This project will give us feedback on how the panels affect the life of the farmer, what is the impact on agricultural yields and what is the perception of the community. We believe that in a fairly dry region like Sicily, there is a strong possibility that yields may increase, providing shade and thus avoiding the afternoon "sunburn" that tends to dry out the grass. On a small percentage (2-5%) of the surface, we will plant aromatic herbs first, and then we will proceed to other tests. On the periphery of the land are planted hedges of olive and almond trees which provide additional income as well as camouflage the PV plant, so it is not visible from the road.* »

On April 29, ENGIE Green and the Syndicat Mixte Lozérien de l'A75 inaugurated th**e photovoltaic solar park in La Tieule** (48). This investment of 13 million euros is the largest ground-based solar power plant in the department, with 35,000 photovoltaic panels over 18 hectares, but above all the site intends to promote new activities, in connection with agricultural businesses in the area, such as beehives, flocks of sheep and the development of 900 linear meters of aromatic hedges and pollinator-friendly plants. "*With the La Tieule park, we wanted to try co-usage with agricultural activities, says William Arkwright, managing director of Engie Green. But there are several ways to integrate the agricultural world and solar power plants, while respecting everyone's work. True agrivoltaism can be done on larger surfaces, where the photovoltaic panels have less influence on the ground. We often criticize the influence of our facilities on agricultural land, but we need only 2000 km2 per year, dedicated to solar or wind power to achieve the objectives set by the State's public energy policy.* »

The indirect benefits of solar panels on agriculture

Regardless of the PV technology used, the electricity produced by an agrivoltaic power plant is more valuable when it is self-consumed, because it directly reduces external electricity purchases. At a commercial electricity price of 14 to 16 cents per kWh for agrivoltaic and a levelized electricity cost of around 9 cents/kWh, for example, savings of 5 to 7 cents per kWh can be realized.

Despite the diversification of technical solutions, **some crops lend themselves better to agrivoltaic than others**. According to the Fraunhofer Institute, viticulture, orchards and vegetable crops probably offer the greatest potential for synergistic effects. However, there does not seem yet to be a consensus on a standardized system for experimentally comparing crop productivity under field conditions.

Despite clear progress in improving the productivity of panels, **the major argument in favour of the development of Agri PV mainly highlights the indirect advantages of the modules**. Some improvements have been noted on the **kinetic protection of plantations**, because the panels serve as **direct protection against environmental influences** (rain, hail, wind). In addition to **reducing the use of protective films for crops**, photovoltaic panels also prevent **the photosynthetic saturation of plants in some cases**. Finally, depending on the project format, agrivoltaic systems promise a **significant reduction in crop irrigation needs** by slowing down the evaporation of water in the ground, but also by allowing the collection of rainwater.
It is interesting to note that the benefits extend in the opposite direction: indeed, it has been shown that **the yield of PV panels could be improved by the presence of vegetation on the ground**, because the latter limit the "heat island" effect by cooling the PV panels by convection. This approach of thinking about Agri voltaism based on the pre-existence of solar fields, which favours solar production while growing low vegetation is a preferred model at ENGIE NorAm, which highlights biodiversity by planting flowers for pollinators in photovoltaic parks.

Significant challenges for deployment at scale

Despite the undeniable advantages of Agri voltaic technologies, **the massive deployment of the sector is slow due to numerous difficulties that remain to be overcome.**

- **Uncertainty about the operating mode**l: the complexity of an Agri voltaic business model often exceeds that of a ground-based PV project. Several stakeholders are generally involved in the implementation of projects: the land supplier, the agricultural manager, the developer of the PV system (owner or investor) and its operator. Experts from the Fraunhofer Institute argue that a concentration of Agri PV functions within a single entity would allow for greater agility and adaptation.
- **Remuneration for electricity production**: beyond the prospects for self-consumption, agrivoltaic could greatly benefit from easier access for producers to the network. The Fraunhofer Institute points out: “*EEG remuneration is currently only possible when the agrivoltaic power plant is built on strips along highways or railways. For power plants with a nominal power greater than 750 kWp, participation in a call for tenders is also compulsory and self-consumption is not authorised.* »

Towards a more sustainable agricultural economic model?

Agri voltaism makes it possible to combine income from farming and income from electricity production. While agricultural yields are strongly correlated to climatic conditions, solar electricity production is much more predictable, year after year.
As the Senate Flash Report mentions: “*Agricultural income depends on a large number of variables ranging from the price of agricultural raw materials to the vagaries of the weather. As a result, Agri voltaism can provide farmers with additional income that allows them to secure their economic model. (…) Agri voltaism can contribute to helping farmers to diversify their production, to modify crop rotations, which in turn can enable them to reduce their*

needs for phytosanitary products and therefore have a positive effect on biodiversity. It can also support a process to improve soil quality. »

In this sense, **agrivoltaic seems to be an obvious evolution of agricultural methods towards harmonious and sustainable models:** *“Farmers, for 12,000 years, have been working as harvesters of photons, transforming them into agricultural products that they sell. From this perspective, it seems logical to sell the energy produced by the panels in addition to the agricultural products if the panels do not hinder agricultural yield and do not pose ergonomic problems*." concludes James Macdonald.