SOLAR ENERGY SECTOR IN TURKEY

AgriPV

FEBRUARY **2023**

SOLAR3GW.ORG

Our aim is
3 GW
of solar power every year

ABOUT US

Who are we?

In an effort to solve the climate crisis, we are stakeholders in Turkey's solar energy sector who have come together with the understanding that renewable energy should be the sole source in the areas of power generation, transportation, and heating.

What is our aim?

We aim to raise our country's awareness of climate change and solar energy in order to keep up with the "energy revolution" that is taking place in our century simultaneously with the world. In this way, we aim to create the necessary technical and regulatory infrastructure to connect a regular solar energy capacity to our grid every year.

Our Mission

Ensuring that at least 3 GW of solar power is connected to the grid each year by converting aged capacity or creating entirely new capacity.

Our Vision

Supporting the growth of capacity in a stable and sustainable framework by creating solutions that are technologically innovative and legally beneficial to all stakeholders.

CONTENT

ABBREVIATION AND RESOURCES

Abbreviations

AgriPV: Agrophotovoltaics / Agrivoltaics

SPP: Solar Power Plant

EPC: Engineering, Procurement and Construction (refers to the contracting companies)

RERA: Renewable Energy Resource Areas

PAR: Photosynthetically Active Radiation

Resources

- Meteorology Office, mgm.gov.tr
- Fraunhofer ISE, https://www.fraunhofer.de
- National Renewable Energy Labarotory, https://www.nrel.gov/
- METU GÜNAM https://odtugunam.org/
- PV Magazine, https://www.pv-magazine.com/
- Springer Link, https://link.springer.com/
- Science Direct, https://www.sciencedirect.com/
- University of Sheffield, https://www.sheffield.ac.uk/
- Company Websites: MetSolar, Sun'Agri2B, Next2Sun, Enel Green Power, BayWa, Enel, The Guardian, REM Tec
- Ravi S, Macknick J, Lobell D, Field C, Ganesan K, Jain R, Elchinger M, Stoltenberg B (2016) Colocation opportunities for large solar infrastructures and agriculture in drylands. Appl Energy 165:383–392.
- Agrivoltaics provide mutual benefits across the food–energy–water nexus in drylands by Barron Gafford and colleagues https://www.nature.com/articles/s41893-019-0364-5
- Solar 3GW stakeholders opinions and models

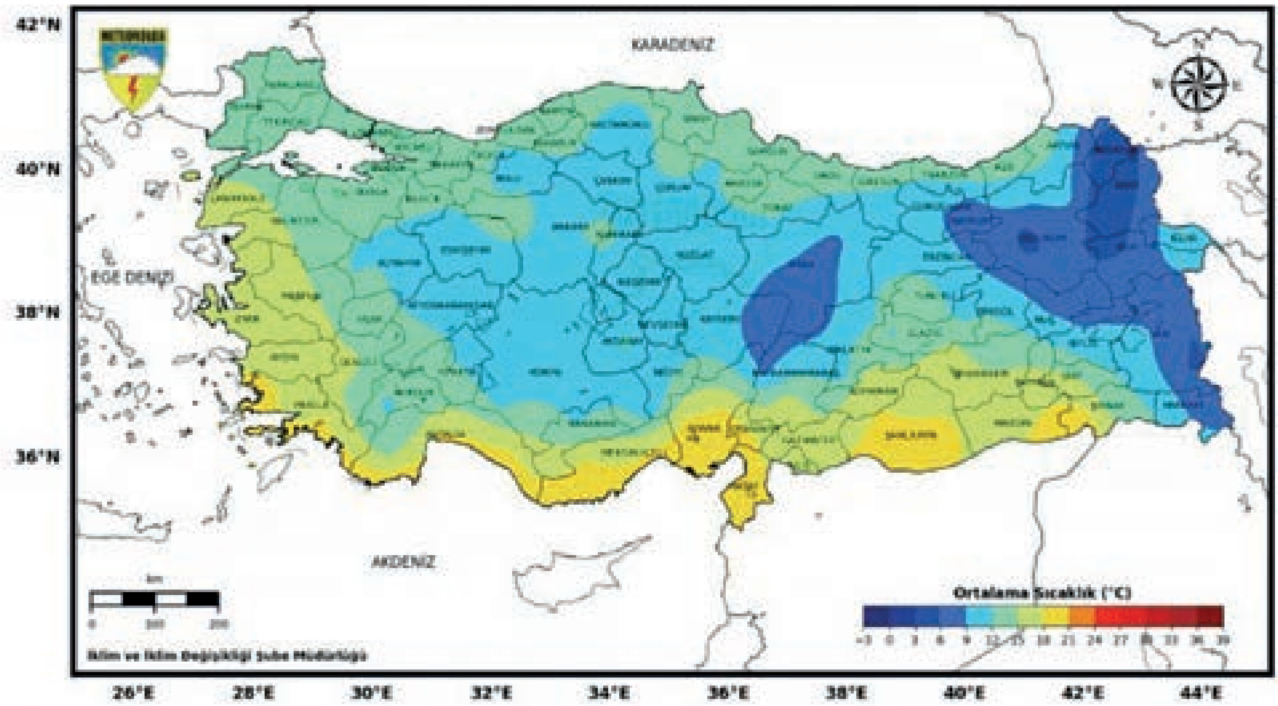
INTRODUCTION
A fresh solution to dwindling and scarce sources: AgriPV

Due to climate change, the earth is gradually falling short of its capability to offer us a place of habitation. Because of increasing temperatures, the amount of precipitation on earth at varying degrees, extreme weather events such as storms and tornadoes, and dwindling vital resources like water, technologies and applications geared towards getting more efficiency from fewer resources have become increasingly important in the current period.

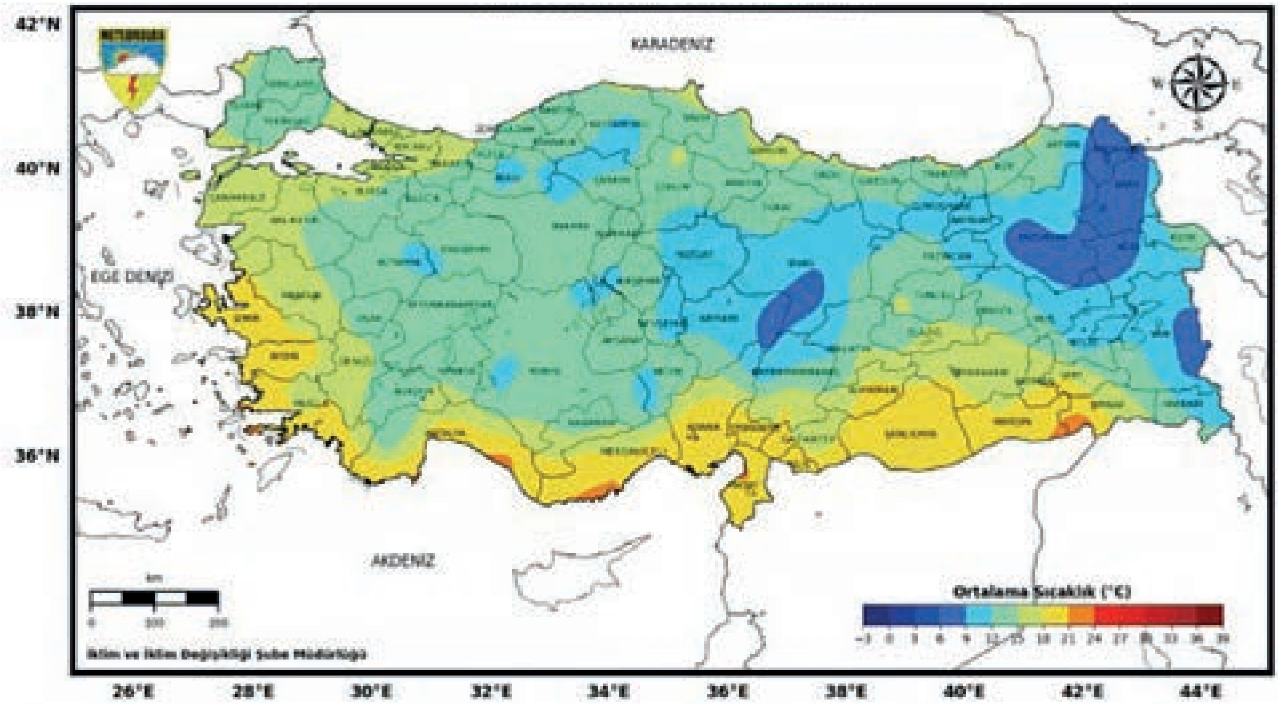
AgriPV is an application offering an innovative solution to the management of dwindling resources, as it can produce electricity and crops from the same piece of land. The PV modules can also be advantageous for social policies because they allow the farmer to harvest crops with protection from harsher climate conditions, optimize a costly input like electricity, and even use the surplus into a source of revenue. Featuring different methods of application depending on the drought, increasingly scarce usable lands, and economic policies of countries, agriPV is, therefore an essential instrument in the fight against climate change. What matters is to utilize this instrument in the most proper way tailored to the country's needs.

Turkey, like many countries in recent years, is fighting against the economic crisis, which has recently deepened with the pandemic, while facing problems that arise in the power supply due to energy dependency. Ensuring the highest possible production with its resources is evidently the most rational solution for getting out of this crisis. Furthermore, agriPV, which enables the most efficient use of existing resources, is a practice that needs to be utilized, especially in this process for our country.

Average Temperature Map (1981-2010, Turkey)



Average Temperature Map (2021, Turkey)

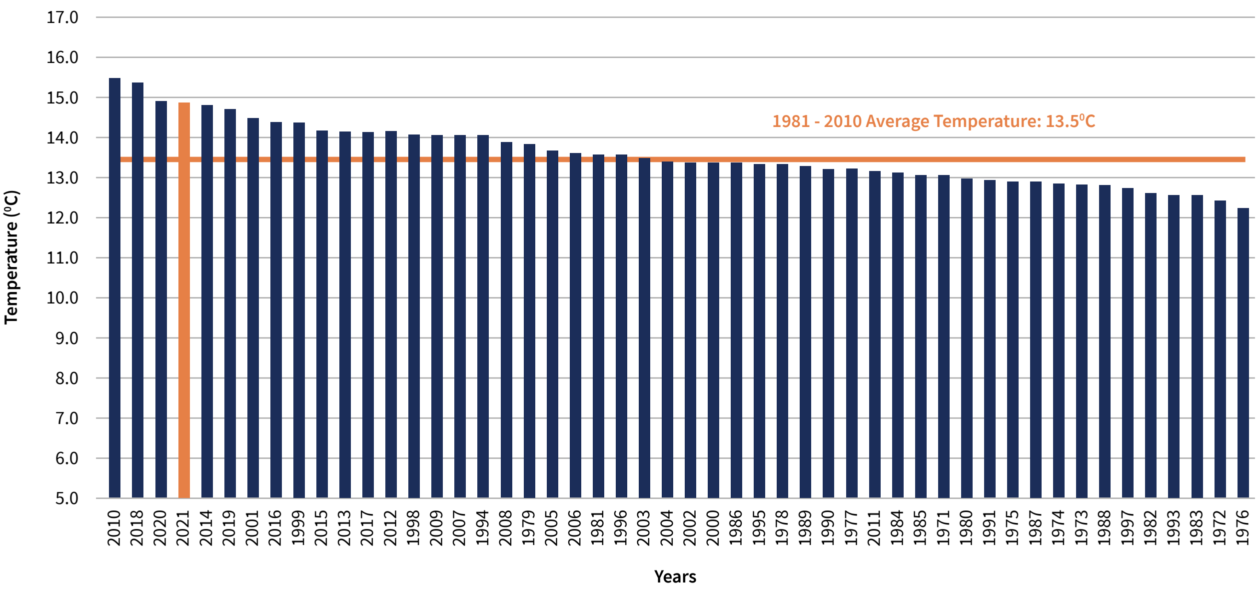


Kaynak: MGM

While the average temperature between 1981 and 2010 was 13.5°C, the average in 2021 was 14.9°C, up by 1.4°C.

2021 is the warmest fourth year since 1976, with an average temperature of 14.9°C. Looking into the warmest years, we can see that the years following 2010 are leading in this ranking. From the climate change perspective, this can be considered an essential indicator of temperature gradually increasing.

Annual Average Temperature Ranking (1976-2021, Turkey)



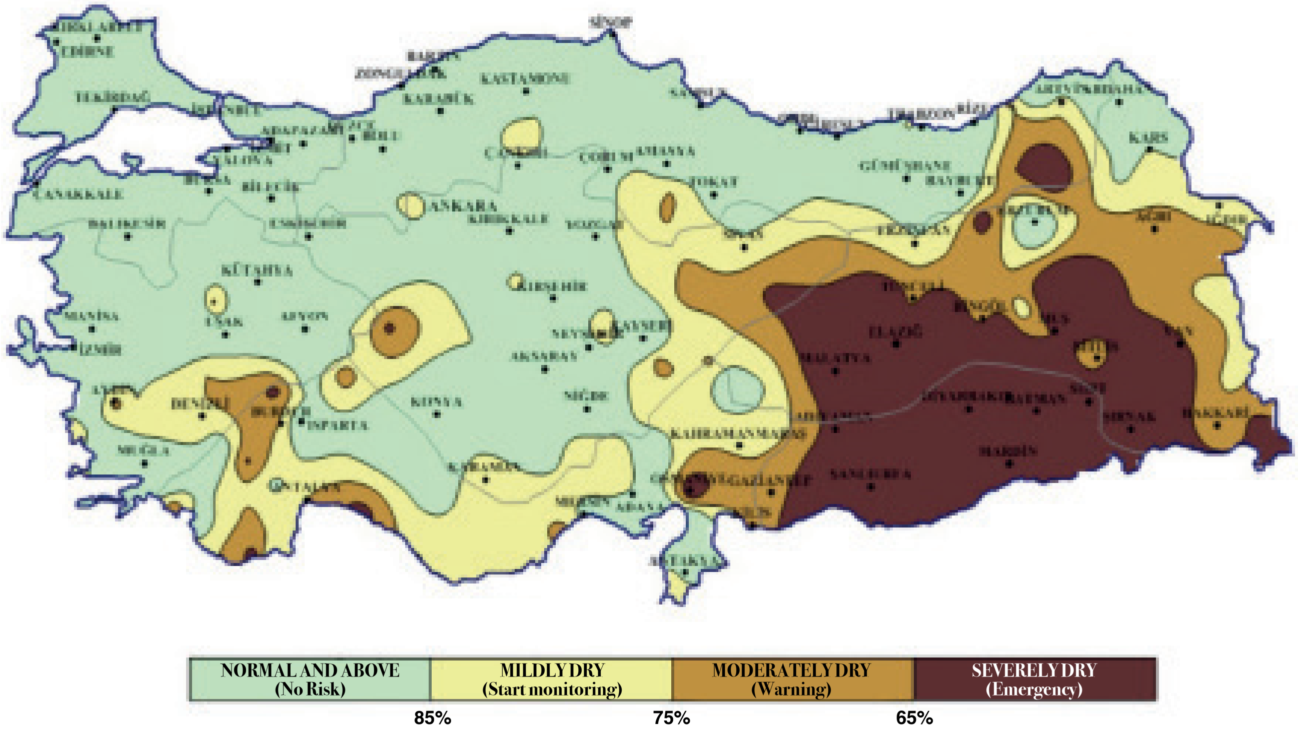
Source: MGM

The winter season in 2020-21 averaged 6.2°C, which is 2.6°C above the average of 3.6°C for 1981-2010. The summer average was 1.3°C above the seasonal normals compared to the 1981-2010 average.

A significant reduction in precipitation also marked 2021. The total areal precipitation, which was 524.8 mm in 2021 is 9% below the 1991-2020 normal, which was 574 mm.

Turkey is a high country with an average altitude of 1,100m. More than 55% of our country's surface area belongs to areas that are higher than 1000 m. This physical condition has a determining effect on the climate conditions of Turkey. The fact that Turkey has a high level of continentality also plays a crucial role in the drought in the country.

Drought Map Using the Percent of Normal Index Method (2021, Turkey)

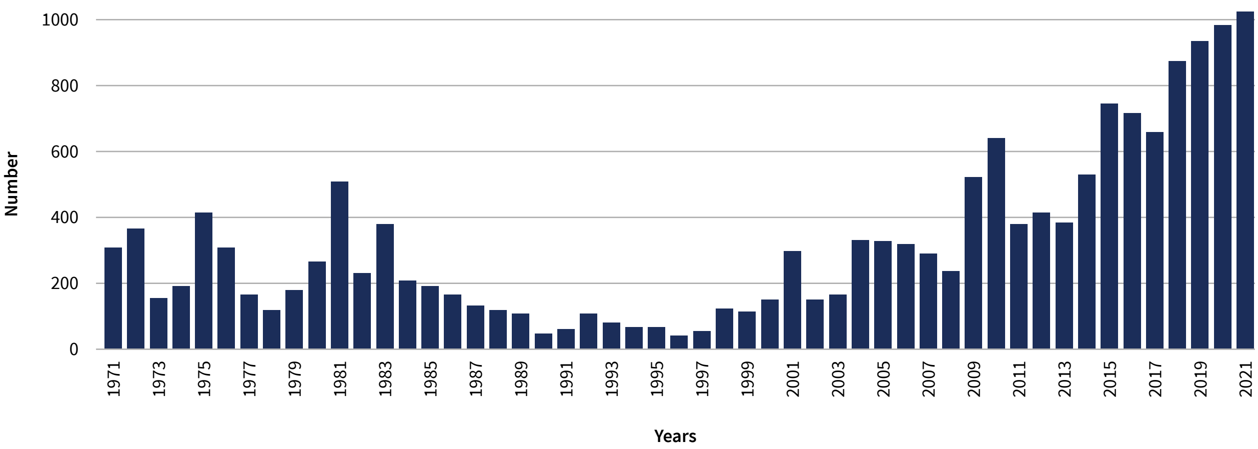


Source: MGM

According to the drought map above, there is a severe meteorological drought in varying degrees in the Southeastern Anatolia, Eastern Anatolia and Central Anatolia regions.

There were 1024 extreme weather events in 2021, the year marked by the most extreme weather events since 1971. The graph below shows how the number of extreme weather events has gone up consistently in recent years.

Annual Extreme Weather Events (1971-2021, Turkey)



Source: MGM

Of the extreme weather events in 2021, 40% occurred in the form of storms, 28% were heavy rainfall-flood, 13% were hail and 7% were heavy snow.

How we use the resources and plan the future are now more critical than ever in the face of the climate change process, which manifests itself in our country in the form of increasing temperatures, increasing drought, dwindling rainfall amounts, and increasing extreme weather events. Thus, using agricultural lands with low or restricted efficiency for both agricultural and electricity production is going to form an essential step in efficient use of resources. AgriPV does not serve the purpose of opening the agricultural lands for electricity use; what matters is to open up a channel to use the existing lands with the most optimal efficiency.

What is AgriPV?

It is an integrated system installation for the simultaneous use of solar energy and agricultural lands.

According to standard no. 91434 defined, by the German Standardization Institute for agriPV systems, it refers to the use of the same land for a secondary purpose of electricity production, with priority being given to agricultural production.

Although the definitions on this subject differ from one region to another, Fraunhofer, one of the leading research institutions on the subject, divides agriPV into three main categories;

1. Fields: lands where fruit, vegetables, viticulture, and arable agriculture farming are carried out
2. Meadows, Pastures
3. Greenhouses

In addition, agriPV applications can also be made in areas where horticultural crops are grown and in fish farms, although it is less common.

The state-of-the-art photovoltaic modules ensure efficient dual use of agricultural lands. PV modules are positioned according to the light exposure need, or they are preferred in technologies with light transmittance and the light yield of the crop grown underneath the construction, obtained from photosynthesis, both increases production efficiency and ensure protection against adverse weather conditions. In addition, the water loss of plants and soil underneath the modules decreases. Besides, the perspiration of plants creates a cooling effect on modules, increasing the electricity production efficiency.

Moreover, the agriPV projects add value to the regions where farmers, small and medium-sized enterprises install them and encourage rural development.

What is Not AgriPV?

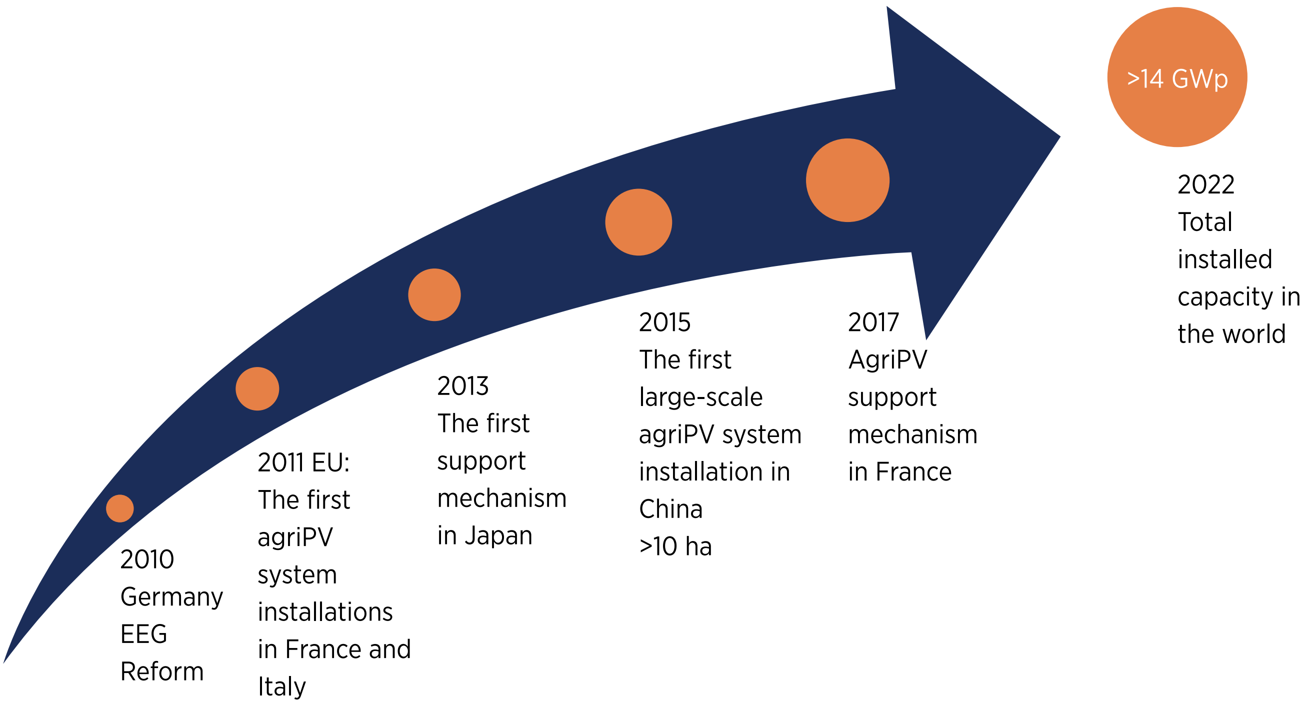
- It is not agricultural irrigation; however, an irrigation solution can be integrated as an option to agriPV to be installed.
- It is not about growing fruits or vegetables right next to a standard PV field; it is growing an agricultural product under a load-bearing construction by producing electricity from PV modules in a way to protect the crop and makes sure it is exposed to the light it needs.
- AgriPV securely addresses farming livestock as well as agricultural products in the field.

Source: Wikimedia Commons

Historical Evolution

- AgriPV installation for interest and testing purposes has rapidly grown in the past years. It is possible to come across applications from poor African countries like Kenya to countries like Sweden, which receive the least sunshine.
- The agriPV applications, which have increased exponentially in terms of installed capacity, have reached a total capacity exceeding 14 GWp across the world from 5 MWp in 2012.
- Currently, the funds provided by the state have had an important effect on the agriPV development; Japan (since 2013), China (since 2014), Korea (since 2016), France (since 2017), USA (since 2018).
- In Germany, there is estimated 1,700 GW agriPV potential.
- Japan is one of the leading countries in agriPV applications. More than 3,000 applications have been made in the country up until now.

AgriPV From 2010 Up Until Now



Source: Fraunhofer ISE

The Contributions of AgriPV Applications to Agriculture and Sector

- Photovoltaic modules provide moisture balance in soil by preventing water loss in soil and plants underneath and increase the harvest and quality of some crops in areas of drought.
- PV modules increase photosynthesis by protecting agricultural products against damages caused by light.
- The transpiration of plants underneath creates a cooling effect on modules and thus boosts the electricity production efficiency.
- It protects against crop losses resulting from hail, frost, and heavy rainfall.
- It mitigates the plant stress by providing shade for crops such as tomato, broccoli, cabbage, and spinach, which are adversely affected by the temperatures increasing with climate change and, thus, help achieve a more efficient harvest.
- In areas of drought, in particular, rainwater is collected with a suitable system design to be used in irrigation and PV module cleaning.
- The income flow of the farmer is boosted, which makes the production more sustainable in the long term with predictable electricity cost.
- It provides an opportunity for growth in the sector in terms of construction. Potential for reduction in water use can be achieved by improving it with the irrigation option.
- An agricultural revival can be experienced by filling in topographically degraded lands.
- It contributes to the development of the regional economy.

Benefits of AgriPV Applications and Challenges Ahead

Benefits

1. To be able to use the areas suitable for application more efficiently in terms of crop, energy, and water
2. Protecting agricultural production against the possibilities of hail, frost, and drought
3. Increasing the performance of modules as the crops grown underneath the PV modules keeps the soil temperature low
4. Diversifying the sources of income of agricultural land owners, contributing to the electricity costs
5. Offering an advantage to utilize the land to serve both purposes of agriculture and electricity production
6. Offering an advantage to benefit from the rainwater, especially in dry geographies
7. Offering a solution that is suitable for the energy transformation about the on-site prosumption

Challenges Ahead

1. The dual-purpose area use is not foreseen in the legislation
2. Prejudices towards the AgriPV application

Source: Fraunhofer ISE

Benefits of AgriPV Applications

1. To be able to use the areas suitable for application more efficiently in terms of crop, energy, and water

In the R&D studies, the following observations are made in the designated geography;

CROP

- The hot pepper production has tripled
- The water use efficiency in cherry tomato production is up by 65%, and total production has doubled.

WATER

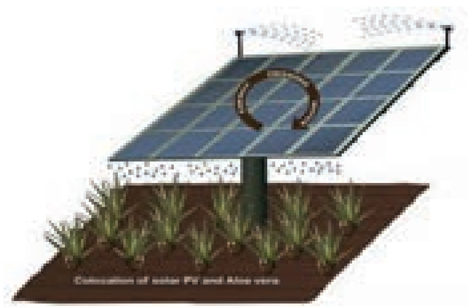
- In AgriPV applications, in irrigations made once in two days, the soil retains its moisture 15% more, and in irrigations made daily, it retains its moisture 5% more
- Water use is down by 65%

ENERGY

- The PV modules used in agriPV applications warm up by about 9°C less throughout the day and perform better. compared to conventional PV modules

Source: NREL

In an agriPV application made in India, calculating that the amount of water used in cleaning the PV module is similar to the water required to achieve efficiency in aloe vera grown underneath the modules, it is revealed that the integration of two systems may be used to a maximum extent in terms of the use of land and water resources. This integration creates economic and social benefits for the more efficient use of lands that are already dry or gradually getting drier.

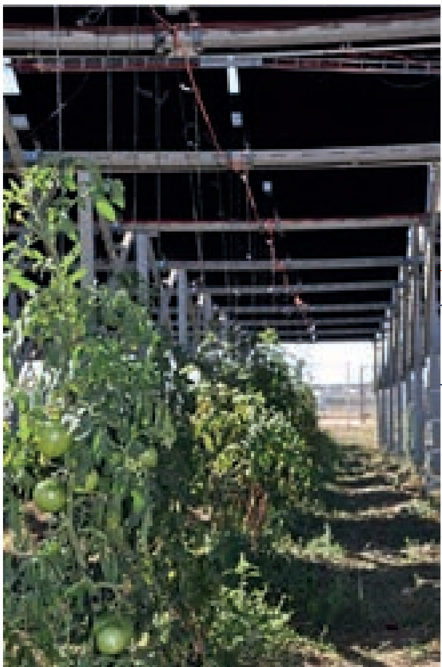


Source: Ravi S, Macknick J, Lobell D, Field C, Ganesan K, Jain R, Elchinger M, Stoltenberg B (2016) Colocation opportunities for large solar infrastructures and agriculture in drylands. Appl Energy 165:383–392.

2. Providing protection against the possibilities of hail, frost and drought for agricultural production

The intense solar radiation, increasing temperature, and extreme weather events such as hail and frost, which gradually happen more frequently affect agricultural efficiency more and more negatively. Instead of the networks providing protection against the hail, what kind of a system configuration will be used to match the PV modules with which crops and to what extent there will be protection over the crops are investigated by the research institutions such as Fraunhofer ISE. The priority here is to understand to what degree the networks providing the protection of crops can be replaced by the PV modules and hence continue the production to maintain the former efficiency as much as possible. The other targets to be achieved simultaneously include high-quality crops and the production of solar power at the same time.

With the shading of PV modules, the stress factor for some drought-sensitive products is mitigated, and the environment can maintain a more constant temperature day and night.



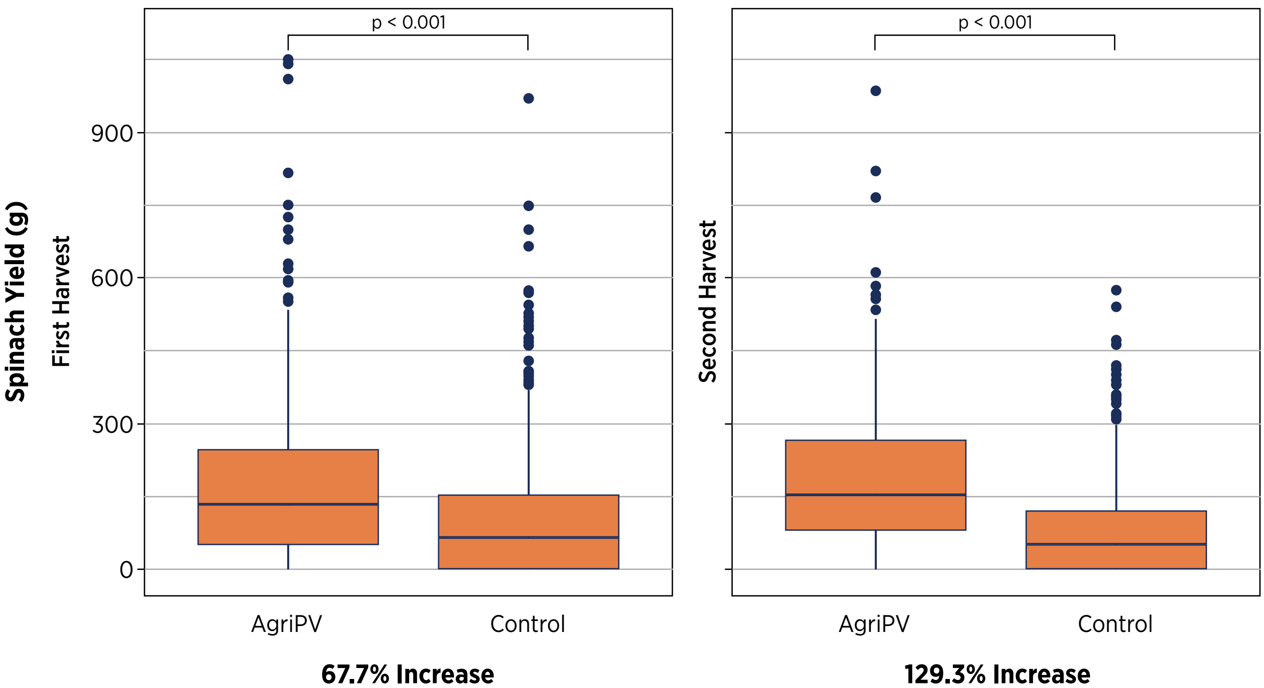
APV-Resola AgriPV Project

With the APV-Resola project, the purpose is to investigate the technical building blocks of the AgriPV application and to reveal its feasibility.

Source: Fraunhofer ISE, Wikimedia Commons

Tanzania Sustainable Agriculture Project

In the sustainable agriculture project carried out in Tanzania, it is noted that there has been an increase in spinach yield over the years.

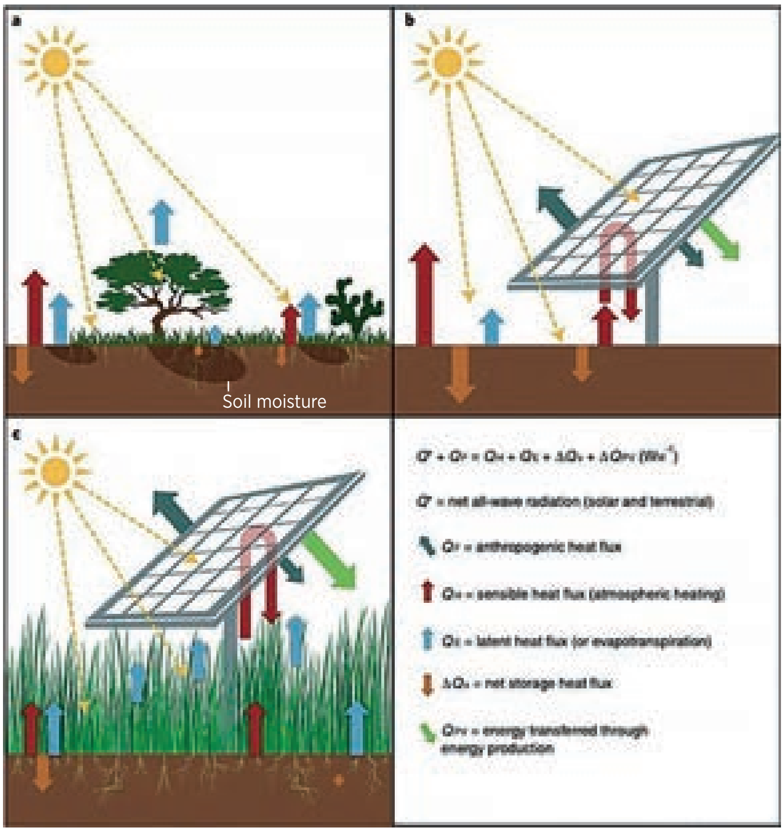


Source: J.Maro & A. Mbele

3. Increasing the performance of modules as the crops grown underneath the PV module keeps the temperature of soil low

The perspiration of plants is known to create a cooling effect on the PV modules, thus providing a marginal development in electricity production. It is seen that the AgriPV installation in the same location produces more electricity by one percent annually compared to the standard PV installation. This increase reaches three percent in the summer months.

Display of Changes in the Midday Energy Exchange in AgriPV Application

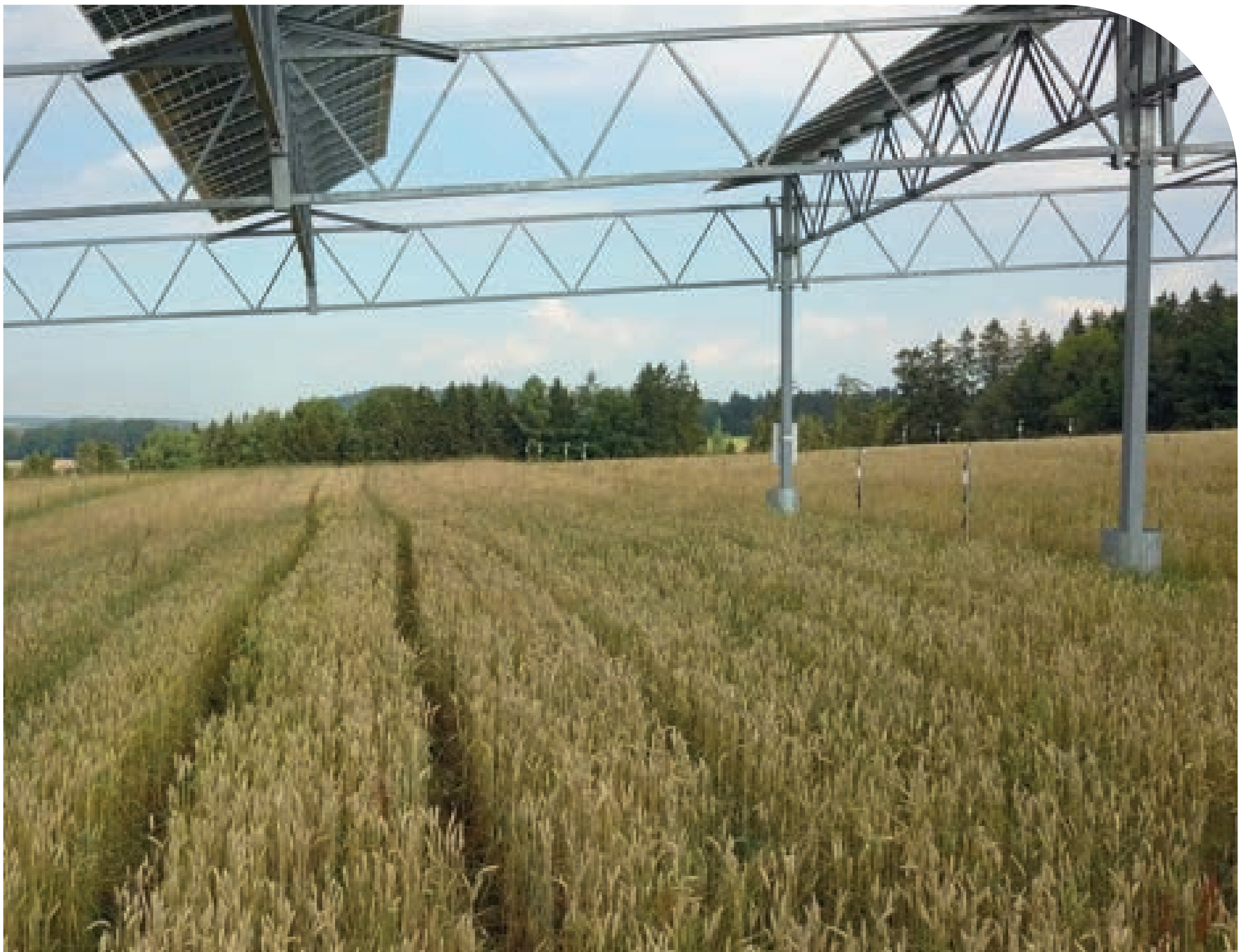


a,b: Assuming that the energy coming from the sun is in equal ratios (dotted yellow arrows), a transition from a plant-covered ecosystem (a) to a solar PV installation(b) would change the energy flow dynamics of the region to a significant degree as the flora and latent heat flux shown by blue arrows disappear. This leads to larger sensible heat fluxes (red and orange arrows), providing higher localized temperatures.
c: Recultivating the flora which is agricultural plants in this case, would restore the latent heat fluxes and reduce the sensible heat loss to the atmosphere. The image also shows reradiation of the energy through PV modules (light blue arrows) and energy transferred to electricity (green arrows). The size and number of the arrows refer to the size of the effect.

Source: Agrivoltaics provide mutual benefits across the food–energy–water nexus in drylands by Barron-Gafford and colleguaes

4. Diversifying the sources of income of agricultural land owners, contributing to the electricity costs

The AgriPV applications provide land owners with the opportunity to produce and sell electricity thanks to the PV system and make money from the crops. This should not be only considered as electricity sales but also as a subject that largely contributes to the electricity costs of the farmer, in other words, self-consumption expenses. This enables the farmer to sustain their economic activity in the face of the challenging conditions caused by climate change and the economic crisis in recent years. The agriPV application is one of the ways to prevent foreign dependency on agriculture and contribute to the welfare of the farmer.



© Wikimedia Commons

5. To be able to use the land to serve both purposes of agricultural and electricity production

The term ‘Agrivoltaic’ was first used by a group of scientists led by Christophe Dupraz. In their research on ‘agrivoltaic’ which is agriPV application, this group has revealed that the efficiency of the soil increases by 35% to 73%.

The scientists within Fraunhofer also research how solar radiation and agricultural production may take place in more synergy with various projects. This project conducted by Fraunhofer was realized in Lake Constance, which has borders with Switzerland, Germany and Austria, and within this scope, a system with a total installed capacity of 194 kWp was installed; within this system 720 bifacial PV modules were used.

The researchers placed PV modules five meters up so that the crops would be exposed to nearly as much sunlight as they would have received without application; thus, the techniques employed for production could continue as usual. According to the results of this project installed in 2016, which were obtained in 2017 and 2018, the utilization efficiency of the land increased by 60% and 84%, respectively.

Fraunhofer ISE AgriPV Research Project in Constance Lake

© Fraunhofer ISE

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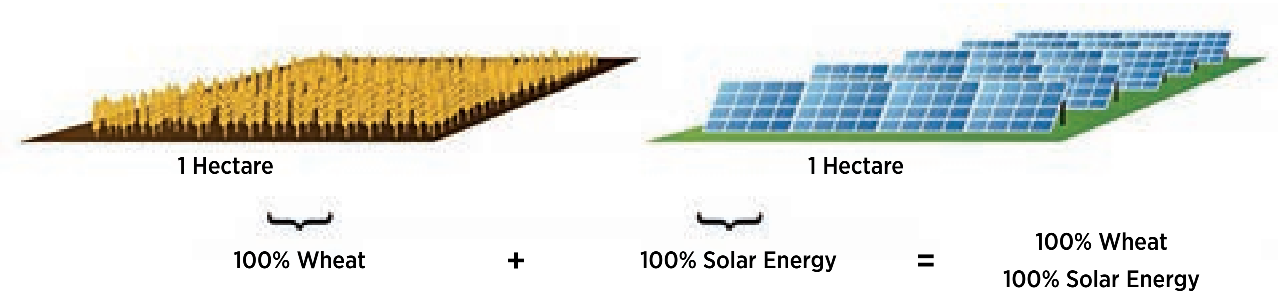
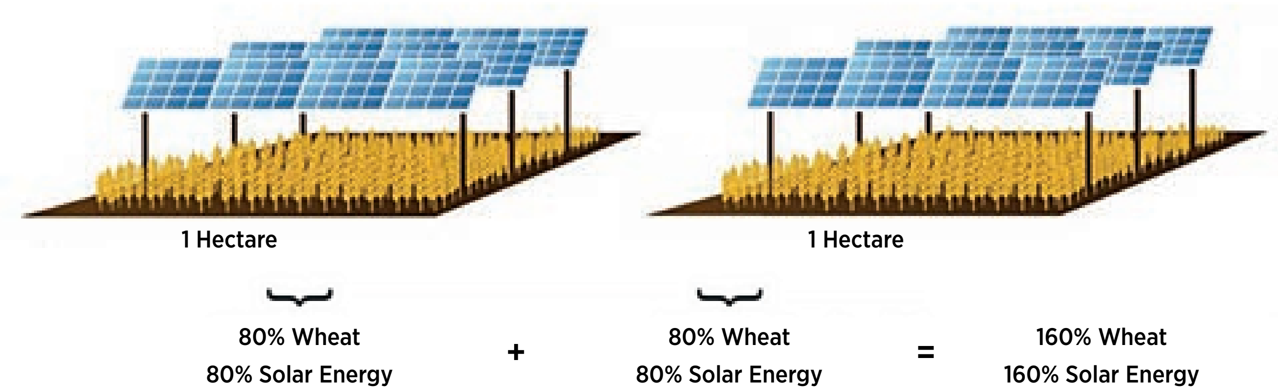
Source: metsolar.eu, Fraunhofer ISE

Efficiency in Lands Used for the Same Purposes



Efficiency in Lands used for Both Purposes



Source: Fraunhofer ISE

Using agricultural land to serve both purposes increases land utilization efficiency by over 60%. Even though at first glance it appears that the utilization of land, which needs to be considered as a source of critical importance for both electricity and food production, decreases the efficiency in terms of singular use, it increases the efficiency of the source in terms of serving a dual use.

6. Offering the advantage of benefiting from the rainwater, especially in dry geographies

Another advantage of AgriPV systems is that in geographies where water is scarce, rainwater can be collected and used for irrigation and panel cleaning purposes. System designs are made with V-shaped or different inclinations that provide flux to the placed channels, creating an efficient loop in terms of water. In this regard, under the leadership of EU and Prima, the WaterMed 4.0 project, which was launched in Algeria in 2019 and is still ongoing, integrated with the 'Internet of Things' has been implemented. At the same time, five prototype systems focused on the triangle of water, energy and food were established in the APV-MaGa Research project in Mali and Gambia in 2020.

7. Offering a solution suitable for energy transformation in terms of on-site prosumption

Turning to only marginal dry agriculture lands for PVs increasingly distances power plants from residential and industrial areas. In this direction, the agriPV offers the following benefits for energy transformation regarding on-site prosumption.

- Increased grid efficiency by bringing electricity production closer to consumption
- Reduced operating costs
- Being able to produce the energy for agricultural activities such as irrigation pump, lighting, heating etc., on-site in the most inexpensive manner.

Challenges Ahead of the AgriPV Applications

1. The dual-purpose area use is not foreseen in the legislation

The AgriPV application to simultaneously provide agricultural and electricity production has yet to be mentioned in the legislation. To the contrary, it is not possible to use lands that have agricultural land characteristics for electricity production. For applications based on PV, a document is obtained from the relevant provincial or district offices stating that it does not cover the areas that disrupt the integrity of the agricultural use. AgriPV applications do not disturb the integrity of the agricultural areas; actually, they are applications that are geared towards using the same site more efficiently and contribute to the farmer's economy. In the practices to be realized in this direction, idle agricultural lands with no crop grown on it can be used; in addition, agriPV projects can be developed for lands where crops are produced at the initiative of the land owner. Moreover, standards such as 80% minimum photosynthetic active radiation (PAR), 30% maximum area use can be determined at a minimum level. Including agriPV projects such as hybrid plants into the legislation in terms of definition and quota will make another channel more available for energy independence of our country and benefit the agriculture economy.

2. TarımGES uygulamalarına dair önyargılar

TarımGES uygulamalarıyla tarım yapılacak arazilerin aslında görünürde tarıma hizmet vereceği ama geri planda sadece ticari amaçlı elektrik üretimine hizmet vereceği yönde bir bakış açısı bulunmaktadır. Bazı çevrelerde ise bu uygulamalarla tarım toprağının zarar göreceğine dair bir kanı da oluşmuştur. Tüm bu önyargı ve görüşler, elektrik üretimi konusunda mevzuatta oldukça detaylı olarak yer verilen koşullar ve standartlar kapsamında bu uygulamalar özel olarak ele alınarak ve tanımlanarak aşılabilir. TarımGES uygulamalarının her iki amacı da belirlenen düzeyde, toprağın da korunarak karşılayabileceği koşullar tanımlanabilir.

Areas of Use of AgriPV Electricity

As in the self-consumption PV model, it is possible to supply electricity provided by the agriPV directly to the grid. The electricity produced by agriPV will be used for internal consumption first for irrigation pumps, lighting and other needs and the excess can be sold. In the sales model, there has yet to be an incentive practice in place that is exclusive to agriPV yet. The electricity produced can be sold based on the electricity market trading price based on the current tariff.

AgriPV Applications and Equipment Used

PV Module

In terms of agricultural production efficiency, the use of bifacial glass-to-glass photovoltaic modules with high light transmittance can be preferred. If a framed panel is used, the construction design and panel angle can be modified depending on the light requirement of the agricultural crop to be grown underneath.

Solar Cable

There is no difference in the solar cable to be used.

Inverter

The fanless ones should definitely be preferred for better operation in the inverter.

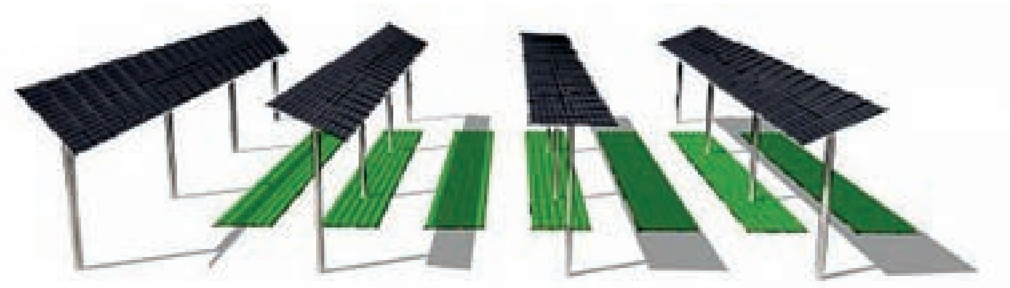
Construction

Heavy steel structures are used, which are suitable for tall vehicles and vehicles like a tractor in the construction in standard practices. In addition, if the wind load calculated while designating a site is too high, this can increase the construction cost. Preferably, an irrigation feature can also be added to the construction.

According to the latest guidelines published in Japan by the “New Energy and Technology Development Organization”, the height of agriPV projects should not exceed 9 meters as per the building regulations. In addition, it is expected that the details regarding agricultural products that are the subject of agriPV projects or the animal husbandry to be practiced within these projects are determined during the project planning phase. Agricultural quality that is included after the planning of the project or construction processes are not considered within the agriPV scope.

Source: PV Magazine

The technical features of the agriPV projects vary depending on the region where they are applied and their sizes. In some agriPV projects, tracking systems are used, increasing the electricity production output and improving the light exposure needed by the crop for healthy growth.



The research has revealed that a tracking PV system achieves an improvement in energy and crop production performances. In the article in which the research results are evaluated, it has been observed that positive outputs regarding both electricity and lettuce production have been obtained in the agriPV application, which is integrated with the single-axis PV tracking system under which lettuce is grown.

In the standard tracking mode, the modules are automatically positioned in a way to optimize the electricity production depending on the angle of the sun and, at the same time, they receive the radiation coming from the sun more than a fixed system does. In the research, a controlled tracking system that is adaptive to the radiation coming from the sun during the daytime was also installed to increase efficiency by increasing the radiation transferred to the product, and an assessment was made. In the morning and late afternoon hours, PV modules were adapted so that crops could be shaded less, whereas at noon, the shading was increased to reduce and balance the evapotranspiration of the crops, the adverse effects of the high temperatures and the excessive radiation, which would affect the growth of products. As a result, while the crop biomass increased with controlled tracking, electricity production decreased compared to the uncontrolled tracking system.

Source: Springer Link, Science Direct

In addition to improving the efficient use of light for both PV modules and agriculture, the PV modules with a tracking system can also be used to regulate the distribution of the rainwater underneath the agriPV systems.

The AgriPV applications also benefit agricultural activities, including vineyard and intensive fruit cultivation. It has been revealed that positive results were obtained from the application made to the vineyard by SunAgri in France in 2018. In the application, 600 m^2 of the 1.000 m^2 vineyards was covered with PV modules with a tracking system. In total, a 84 Kw system made up of 280 modules was set up, the PV modules were placed above the constructions that are 4.2 m high. The modules were moved with a real-time application which used an artificial intelligence algorithm. The algorithm was able to detect the ideal inclination of the modules by considering the sunlight, water requirements of grapes, cultivation model of the crop, quality of the soil and weather conditions and when extreme weather conditions occur, the AI could control the modules in a way to protect the crops. For instance, when heat waves emerged, the grapes were shaded by the PV modules and, thus less water was needed.

Source: Springer Link, PV Magazine, Sun'Agri2B

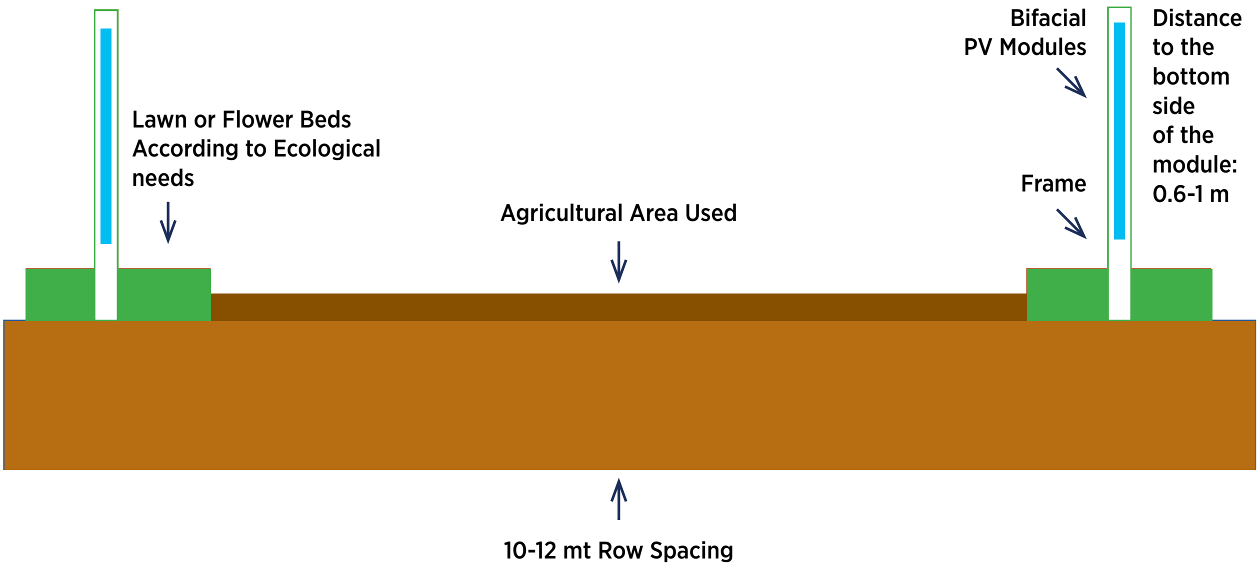
SunAgri AgriPV Application in Piolenc, France

Image: Antoine Bolcato (RPC)

In modelling made in another study investigating the potential in the vineyards in India, it has been revealed that the annual revenue of these vineyards will be doubled with the AgriPV application compared to conventional viticulture and the same amount of grape harvest would also be maintained. It has been calculated that if agriPV is to be applied on a total of 34,000 hectares of grape-growing land in India, there is a potential to be able to produce electricity that will meet the energy demand of 15 million people which is 16,000 GWh in total. At the same time, the agriPV application to be made in rural areas will also provide the electrification of the relevant region.

Another type of option observed in agriPV applications includes a vertical type application. In this application made entirely with vertically-placed modules, the total covered area accounts for only 1% of the land. Since the application is made vertically, only 10% to 20% of the sunlight reflects to the PV module. The PV modules have zero impact on steering the rainwater. In these types of applications, 90% of the land can be used efficiently for agriculture. This type of an agriPV application places the maximum priority on agriculture. Vertical applications provide equal or higher efficiency than bifacial south-facing PV modules with up to 15% inclination.

Vertical AgriPV Design



Source: Springer Link, Science Direct, Next2Sun

Advantages and Differences of AgriPV Compared to Conventional Agriculture

- Reduces the irrigation need to the extent that varies depending on the regional and product conditions.
- Able to collect rainwater for irrigation.
- Reduces wind erosion.
- Offers the option to use PV modules to replace protective nets or plates.
- Offers the ability to further optimize the sunlight with PV tracking systems for agricultural fruit-vegetable production.
- Provides a higher module efficiency with a cooling effect from plants grown underneath.
- Offers a permanent solution to plastic, glass, nondurable greenhouses which need to be renewed at specific intervals or after getting worn down under adverse weather conditions.
- There might be a loss in terms of the area compared to land-type PV production because as there needs to be a light transmittance, the panel layout is positioned according to the light exposure need of the crop underneath.

The Most-Commonly Grown Agricultural Crops Most Suitable for AgriPV

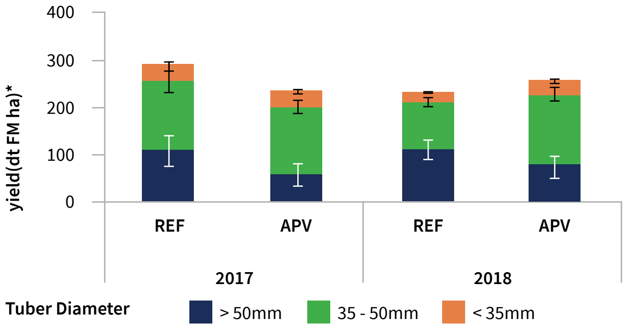
Crops selected for agriPV projects vary depending on the climate conditions and soil quality in the installation location.

The researches which have been carried out up until now show that aloe vera, tomato, pasture meadow and, lettuce have been grown successfully. While the yield of some lettuce varieties is much higher in the shade, some maintain the same yield they would have produced without the PV module.

According to the research conducted by the University of Arizona, it has been observed two or three times more crops are obtained from some fruits and vegetables with the shading of PV modules. Within the scope of this project, which lasted for several years, the production yield of hot pepper, Mexican pepper and cherry tomato in a dry region was evaluated.

In APV-RESOLA, the first arable agricultural land pilot project was carried out in Germany with clover, potato, winter wheat and celery as the selected crops to be planted.

2017-2018 Potato Yield in APV-RESOLA Project



* *Deciton of fresh yield per hectare*

- There was an 18% drop in the potato yield underneath the agriPV application in 2017, which marked the first year of the project, however in 2018, the second year, the yield was up by 11%:

- The tubers with a diameter of 35-500 mm have the highest share in the yield of both years.

Source: Farunhofer ISE, PV Magazine

Legislation and Incentives About AgriPV

Currently, there is no legislation in which agriPV applications are defined. AgriPV should enter the legislation in a way that SPP investment can be made by maintaining the agricultural land. The recommendations regarding the AgriPV legislation are provided below;

- AgriPV should enter the legislation to enable making an SPP investment by maintaining the agricultural land.
- AgriPV can also be described as "an application based on a renewable resource and supporting agriculture" with a relevant license to be incorporated into a license.
- The areas which are specially defined as agricultural land but currently not cultivated can be prioritized within the scope of an agriPV license. Thus, some lands in the class of qualified agricultural land that are not profitable alone, even if agriculture is practiced on them, can be added to the economy as they can be used to produce electricity.
- AgriPV should be designed so that the crop yield of the agricultural soil will not be reduced in the area where it is applied.
- A decision supplementary to the Ministerial Decision that bans SPP installations from being made in agricultural lands should be published; if it is stated that agricultural activity will be continued with SPP to be installed in the designated land, this should be qualified as an agriPV application and it can be stipulated that PV installation will be allowed. Within this scope, it shall be placed in a solid framework and details should be clarified.
- A maximum agricultural area loss for the land to be applied agriPV should be indicated, and losses should be regularly measured. A penal clause should be imposed for losses that exceed a specific limit.
- An article, ''If in addition to agriculture, energy production is also committed, agriPV shall also be allowed in lands outside of the marginal agricultural area. Within the scope of the related project, the control of the agricultural activity will be conducted by the Ministry of Agriculture and the control of energy production will be conducted by the Ministry of Energy" may be added to the Renewable Energy Resources Law. Similarly, the definition of agriPV should also be added to the definition part of the relevant law.
- The investor should have the planning confirmed by an accredited or genuinely competent and independent institution. The feasibility confirmed independently should include key evaluations, including soil assessment of the planned land, laboratory measurements, classification of crops which are planned to be produced, confirmation of their suitability with the project land, analysis as to how they would be affected by the planned PV, possible impacts of the construction process on the soil quality. At the same time, an audit obligation should also be imposed so that the process would be managed in a way that is not harmful to the agricultural land.
- PV for the purposes of an agricultural irrigation and agriPV distinction shall be clearly made in the legislation.
- There should be no restraint regarding the crop to grow and agricultural soil; this should be left to the investor's decision.
- To bring together the agricultural investors, the productions in the adjacent parcels should be able to be merged, the investor should be able to sell electricity to the points of consumption in the neighboring parcels. Thus, by prioritizing the generation of electrical energy where it is consumed, losses will be avoided, and distributed grid structure will be strengthened.

About incentives

- AgriPV incentive may be offered as a feed-in tariff or an additional support premium towards more frequently grown agricultural products. The support would help ensure agricultural sustainability. It will be sufficient to have the right to sell electricity produced within the scope of a licensed agriPV application to the free market. On the other hand, agriPV application should also be defined as having a self-consumption purpose within the unlicensed scope. In this framework, grant support can be provided if necessary.
- Grant can be offered, or an interest-free loan can be extended to prepare professional feasibilities. Thus, agriPV applications can run better with proper projects.
- Additional incentives can be offered for some imported products with a high economic value that require R&D such as coffee bean, blueberry, gojiberry.
- Investments which have been approved within a practical feasibility may be made with "zero interest or low interest" loan supports by falling within the scope of investment incentives, thus, paving the way for investors challenged by liquidity restraints.

AgriPV Applications in Turkey

Photovoltaic System Applications Integrated with Agriculture in Turkey

1. Ayaş AgriPV (Accepted)

Project ID	TR51/21/KIRSAL/0018
Project name	Innovative PV application suitable for dual use of the agricultural land
Applicant institution	Ayaş Agriculture and Forestry District Office
Partner institution	ODTÜ-GÜNAM
Cooperation	Farmer
Project location	Ayaş district, Akkaya village
Project area	1¾ decare (PV area) + 1¾ decare (Control area)
Project period	15 months
Photovoltaic size	100 kW
System structure	Tracking sun in East-West axis
Supporting Institution	Ankara Development Agency
Applied programme	Call for the year 2021, Rural Development Financial Support Programme

Cultivation	**Cultivation Zones**					
	1st Zone	**2nd Zone**	**3rd Zone**	**4th Zone**	**5th Zone**	**6th Zone**
First Cultivation	Tomato	Pepper (Bell)	Melon	Spinach	Common vetch (hungarian)	Common vetch (hungarian)
Second Cultivation	-	-	-	Spinach	Radish	Red Cabbage

2. Kayseri AgriPV (Accepted)

Project ID	22AG012
Project name	Solar power for green transformation in agriculture-fruit
Applicant institution	Middle East Technical University-GÜNAM
Partner institution	Erciyes University –Faculty of Agriculture
Cooperation	Ankara University – Faculty of Agriculture
Project Area	Erciyes University – Faculty of Agriculture Trial Orchard
Project location	½ decare (PV Area) + ½ decare (Control Area)
Project period	48 months
Photovoltaic size	45 kW
System structure	With bifacial module in fixed or east-west direction, software-supported positioning with agricultural efficiency priority (design will be finalized in project)
Supporting institution	TUBİTAK
Applied programme	1004
Crop to be assessed	Apricot

3. Mustafakemalpaşa AgriPV (Accepted)

Project ID	22AG012
Project name	Solar power for green transformation in agriculture-fruit
Applicant institution	Middle East Technical University(METU) -GÜNAM
Partner institution	TAT Gıda A.Ş.
Cooperation	Ankara University – Faculty of Agriculture
Project location	Mustafakemalpaşa – TAT Gıda Trial Orchard
Project area	½ decare (PV A-area) + ½ decare (Control area)
Project period	48 months
Photovoltaic size	>45 kW
System structure	With bifacial module in fixed or east-west direction, software-supported positioning with agricultural efficiency priority (design will be finalized in project)
Supporting institution	TUBİTAK
Applied programme	1004
Crop to be assessed	First crop tomato, second crop pea

4. PV4Plants (Accepted)

Proje ID	101096409
Project name	AgriPV system with climate, water and light spectrum control for safe, healthier and improved crops production
Applicant Institution	KalyonPV
Partner Institution	METU -GÜNAM, TAT, YTU, DTU, R2M, UoS and 8 other partners
Project Location	Turkey (Mustafakemalpaşa – TAT Gıda Trial Orchard), Spain, Denmark
Project area	½ decare (PV Area) + ½ decare (Control area)
Project period	48 months
Photovoltaic size	>20 kW
System structure	With bifacial module in fixed or east-west direction, software-supported positioning with agricultural efficiency priority (design will be clarified in project)
Supporting institution	Horizon Europe
Applied programme	HORIZON-CL5-2022-D3-01-06: Novel Agro-Photovoltaic systems (IA)
Crop to be assessed	First crop tomato, second crop pea

5. KOZ (Assessment is ongoing)

Project ID	101096409
Project name	Agricultural Photovoltaic Application Equipment with Control Suitable for Konya Plain Climate Conditions and Algorithm and Efficiency Analyses
Applicant institution	METU-GÜNAM
Partner Institution	TUBİTAK-MAM, TAGEM
Cooperation	Solar3GW
Project location	Konya Meram (TAGEM trial land)
Project area	>1½ decare (PV area) + >1½ decare (Control area)
Project period	24 months
Photovoltaic size	100 kW
System structure	With bifacial module in east-west direction, software-supported positioning with agricultural efficiency priority (design will be finalized in project)
Supporting institution	TUBİTAK, TAGEM and Solar3GW
Applied programme	1003 Priority area supporting programme
Crop to be reviewed	Wheat and vetch
Technology to be developed	Developing wireless hardware infrastructure which sensor kits can be connected to, digital agriculture software and farmer interface

SusMedHouse project

It is a sustainable, competitive, eco-friendly, and high-tech greenhouse project that is designed and constructed by AR&TeCS A.Ş. within the scope of the EU-supported HORIZON/PRIMA program. Within the scope of this project, an agriPV application was also made with a total installed capacity of 48 Kw to increase the greenhouse efficiency. In this line, after performing the light simulation of the shading effect of PV modules and finding the optimum direction and design of the PV system to provide suitable cultivation conditions for crops, 120 photovoltaic modules, each 400 Wp, were placed on the 700 m2 greenhouse to evaluate the feasibility of electricity. Next, its effect on the production and different crops were evaluated by AR&TeCS and Fraunhofer Solar Energy Systems Institute. Thus, it has become possible to reduce electrical energy consumption in heating and cooling by utilizing solar power and ensuring that the greenhouse maintains its optimum temperature with the shading effect in transitional seasons.

The project was built from artificial intelligence (AI) as the core of SusMedHouse, including high-tech greenhouse-specific optimization mechanisms and a sensory network to achieve ideal plant growth with limited resources regardless of the season and location. Thanks to the decision support system (DSS) to improve efficiency by providing real-time data and showing the expected results for actions; pest and pathogen monitoring, early warning system, situation improving algorithms, grid and market-dependent cost calculator, harvest estimate were available in the system. To increase the greenhouse efficiency, sunlight and lighting optimization was made including solar control coatings, low emission (low-E) coatings and agriPV panels. Real-time biosensor was developed to reduce resource consumption and efficiency.

The partners of the projects with the developed subsystems whose tests were also made; are as follows;
Fraunhofer Solar Energy Systems Institute (Fraunhofer ISE), Consiglio Nazionale delle Ricerche - Istituto per i Sistemi Agricoli e Forestali del Mediterraneo (CNR-ISAFOM), Associação de Viticultores do Concelho de Palmela (AVIPE), PROTEUS Ltd. (PROTEUS), Antalya Tarım Üretim Danışmanlık ve Pazarlama A.Ş. (Antalya Tarım), Water On- Line Analysis Europe S.L (WOLA). The design, manufacture, and assembly of PV modules in the project was carried out by İHSAN TÜRKELİ Makine Ltd. Şti..

Examples from the World

<table>
<tr><th>COUNTRY</th><th>PROVIDER</th><th>DETAILS</th></tr>
<tr><td rowspan="3">The NETHERLANDS</td><td rowspan="3">BayWa</td><td>Over 4,500 solar panels of 1.2 MWp</td></tr>
<tr><td>Solar power plant generates enough green energy to power around about 400 households every year.</td></tr>
<tr><td>A total of 4,500 facilities will produce an annual harvest of approximately 23 tons of blackcurrant.</td></tr>
<tr><td rowspan="2">SPAIN</td><td rowspan="2">Enel Green Power</td><td>About 60 million € investment in Los Naranjos and Las Corchas projects, each with an installed capacity of 50 MW.</td></tr>
<tr><td>It includes more than 250,000 solar panels, nine electrical conversion centers, one transformer center and a 4.5 km underground cable network.

In these two projects which were implemented with a sustainable construction model, a total of 100 MW, each 50 MW, of solar power system was installed and 258,120 bifacial modules were used for this. The projects realized with a 70 million euro investment provide an annual electricity production of 202 GWh, equivalent to the needs of 25,500 households. The animal husbandry activity carried out with shepherds from the local community at the facility also contributes to the power plant's maintenance.

Beekeeping is also practiced in Las Corchas. It is equipped with smart hives, sensors, cameras and GPS systems. Beekeeping is a field of activity that has long been practiced in the region and has been integrated into the facility too. The honey that is produced also contributes to the social projects of the local community.</td></tr>
<tr><td>FRANCE</td><td>Sun'Agri</td><td>600 m² of 1,000 m² vine planted in Grenache Noir was covered by the solar panels developed by Sun'Agri. controlled by using algorithms tailored to the facility's needs, the panels tilt depending on the sunlight or shading requirements of the vines.

When the shade reaches the maximum level, the panels cover 66% of the surface area. They are placed at the height of 4.20 m above the ground allowing the harvester to pass. Water stress measured with the help of sensors, lower in shaded vines, ranges between 12% and 34% depending on the reduction in water requirements and systems.

Shading positively affected the grain weight, which was 17% higher for the protected vines.</td></tr>
<tr><td>AUSTRALIA</td><td>ENEL</td><td>It is the 121.6 MW Cardwarp Solar Farm located near Mildura developed by Canadian Solar, and 98.8 MW Winton Solar Farm, developed by the Spanish Fotowatio Renewable Ventures.</td></tr>
</table>

Source: BayWa, Enel Green Power, Sun'Agri, Enel

Examples of R&D AgriPV Projects

APV-RESOLA, Heggelbach, Germany (2016)

- In the installation made in Heggelbach, winter wheat, potato, celery and grass/clover crops were tested.
- Glass-to-glass modules were used, a wider distance was left between the module rows and modules were positioned in a south-west alignment with a height of more than seven meters.

APV-Obstbau, Germany (2020-2025)

- The project was initiated in 2020, designed as an agriPV research project on the yield of 8 varieties of apples.
- The project's total budget is 1.3 million euro and installed capacity is 258 kWp.
- Transparent PV modules are used in the system installed with two different configurations; fixed and tracking systems.

APV-2.0, Strukturwandel, Germany (2020-2025)

- The project is geared towards bringing about a structural change based on bio-economy in traditional coal mining sites.
- The project budget is 2.5 million euro and installed capacity is 300 kWp.
- In situ phenotypic* monitoring of various crops was designed to develop plant growth patterns suitable for heterogeneous light exposure conditions.

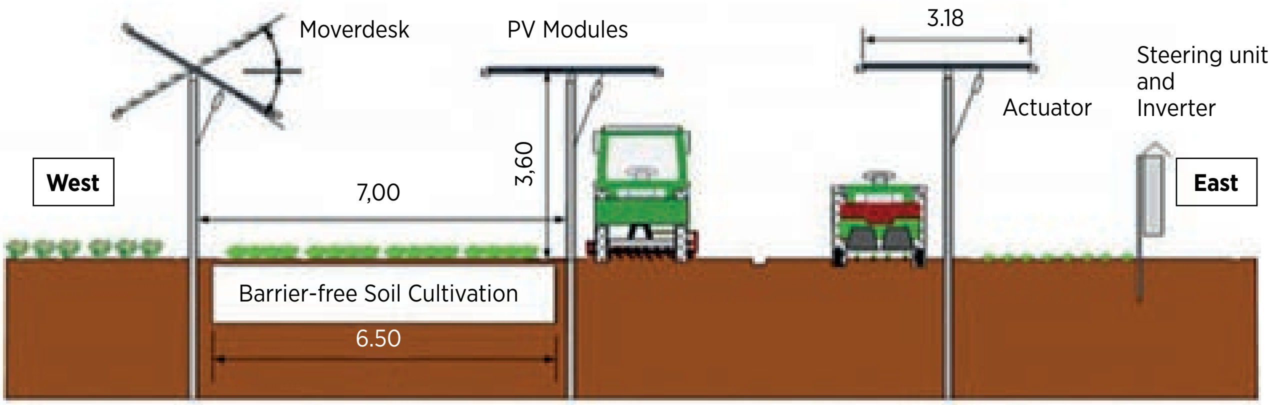
'Harvesting the Sun Twice' project by Sheffield University, Kenya (2020-2023)

- In this agriPV application conducted in Kenya, it is seen that cabbages placed under 180 345-watt panels were found to be one-third larger and healthier than cabbages planted in the control field and grown with the same amount of water and fertilizer.
- Similar results were obtained with aubergine, lettuce and corn too.

** Phenotypic: Extrinsic. The appearance of an organism due to its genetic structure and the effect of external factors.*

Source: Fraunhofer ISE

Weihenstephan, Germany (2013)



2013'de Weihenstephan'da kurulan bu sistemde fazla gölgeleme sorunu doğu-batı takipli tasarımla çözülmüş.

Technical Features of the System	
Area	21*23 m= 483 m^2
Moverdesk	3 pieces per 3.2 x 21 m per 30 PV modules per 1.6 m^2
Tracking	East-west, calendar controlled
PV Module	CSG 245 Wp; 200 Wp/m^2 (average value); 245 Wp x 90 = 22 kWp; 45 Wp/m^2
Annual Production	35,000 kWh
Use	Self-consumption, no feed-in tariff

In this research, tests were also conducted on what the optimal module distance would be in order to get the best harvest, and the following results were obtained in the Chinese cabbage production.

O cm between modules →	Chinese cabbage weight 1348 g →	50% of the conventional production
25 cm between modules →	Chinese cabbage weight 1559 g →	56% of the conventional production
66 cm between modules →	Chinese cabbage weight 1970 g →	71% of the conventional production
Grown without a PV system →	Chinese cabbage weight 2762 g →	Conventional production

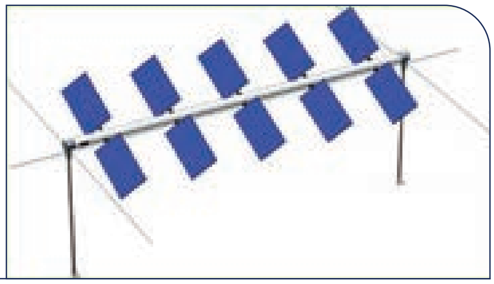
Source: The Guardian

Examples of Different Application Types of AgriPV

In AgriPV applications, a large variety of designs can be made according to the nature and need of the projects. Examples of some of these are provided below;

Tracker 10

- From 2.5 up to 4.35 kWp capacity per tracker
- 10 PV modules in each tracker
- 12 m tracker length
- 4-5 mt height



Tracker 2.1

- 16.8 kWp capacity per tracker
- Unifacial or bifacial 24 PV module in each tracker
- 14 mt tracker length
- 4-5 mt height

In these double-sided systems developed by REM Tec, modules are positioned at a height of 5 meters above the ground, and are designed to maximize the electricity production while leaving the land as free as possible for agriculture. It is aimed to increase electricity generation by using bifacial modules.

There are also agriPV applications with different tracking systems designed by different companies in addition to REM Tec according to the nature of the project.

Source: REM Tec

In addition to the agriPV applications with a tracking system, several different designs with fixed systems have also been implemented.

Image: Chloride Exide Ltd

AgriPV application which produces solar power, practices agriculture and collects rainwater on the same land. AgriPV R&D application made in semi-arid Kenya-Kajiado by Sheffield University and Latia Agripreneurship Institute.

Image: TSE

In this project, which was applied to 3 hectare-field developed by TSE in Northeast France, 2.4 MW PV application was made, and it was planned to grow soy, wheat, rye, barley and rapeseed on this arable land. The design is positioned high enough for the agriculture machinery to pass through.

Source: University of Sheffield, The Guardian, PV Magazine

AgriPV's Position Within Solar3GW's Recommendations

In the "Business Model Recommendations for Growth After 2020" report published in June 2021, Solar3GW has stated that in addition to existing models, the inclusion of the improved prosumer model and commercial "Green Power Purchase Agreements(PPA)" and "Tender-Free, Incentive-Free Licensed" business models into the sector dynamic is vital to achieve the annual 3 GW target minimum. AgriPV is an application that can easily be implemented with a light regulation within the scope of all these recommended models.

In this direction, while implementing the commercial models, the expression in place up until now, which "PVs can only be installed in lands that are in the class of marginal dry agricultural land", should be replaced with "if PV is intended to be installed on lands other than marginal dry agriculture land class, these PVs are designed and installed as an agriPV application" and the agriPV definition should be added to the legislation as described in this report. In the next stage, when a PV is to be installed based on a "tender-free, incentive-free licensed" or "Green PPA" model, it is sufficient to act only according to a class of land where PV will be installed. If the land belongs to a class other than the marginal dry agricultural land, it is necessary to design the PV by assuming that it will be installed with AgriPV, and zoning and permissions should be obtained accordingly. In this way, the investor can also include in its feasibility the additional costs that may come from agriPV and perhaps the cost reductions due to the shortness of transportation lines, in return, the additional income from the crop in the feasibility from day number one. Hence, publicly owned agricultural lands that are not actually used can also be allocated to agricultural production. With the same target in mind, if the public also wants to open these types of idle lands for agriculture, it can draw up agriPV RERAs by using the attraction of the income to come from energy.

Recommendations about AgriPV

- Urgent expropriation should be possible in lands where agriPV will be installed.
- A capacity should be defined and announced for areas where agriPV will be installed.
- Legislative regulation including installation standards for small scale (< 750 kWp[1]) and larger scale systems (> 750 kWp) should be made.
- In regions with land shortages, such as Marmara, a certain support tariff can be put in place for small-scale systems, and in this way, the most efficient way of using the land can be ensured.
- The installation of large-scale systems can be achieved by tender methods similar to RERA.
- A more effortless procedural flow can be defined to allow the approval of AgriPV projects to run separately and more quickly.
- A comprehensive R&D program about agriPV can be created. Long-term monitoring and assessing the large-scale projects in particular can be performed through this program.
- Studies that address the crops that can be grown in the relevant regions and systems which can be installed can be carried out; these studies can be communicated to raise awareness of the local community in the said regions.

[1] *This distinction is mentioned in the guideline prepared by Fraunhofer for Germany.*


"Our aim is
3 GW every year"