INDIA AGRIVOLTAICS ALLIANCE

India Climate Collaborative

Farmer's Handbook on Agrivoltaics

Holistic Perspective of Co-Locating Agriculture and Solar

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Organization
The India Agrivoltaics Alliance is a collaborative platform of 48 organisations anchored at the NSEFI secretariat in New Delhi. The IAA aims to build partnerships and platform voices from the agriculture and solar sectors to address issues at the nexus of food-energy-water, including carbon emissions, rising food insecurity, and a need to enhance agrarian livelihoods and land productivity.

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1.1. What is Agrivoltaics?

Agrivoltaics, also known as Agro photovoltaics or Solar sharing, is an innovative approach that involves the co-location of solar photovoltaic (PV) panels with agricultural activities on the same area of land. This integration offers several advantages that contribute to sustainable development across multiple sectors. As per the studies conducted by Fraunhofer Institute for Solar Energy Systems ISE; "The approach of agrivoltaics denotes use of agricultural land to simultaneously produce agricultural crops and generate PV electricity. (Trommsdorff, 2024)

Agrivoltaics covers a wide spectrum of intensity and type of agricultural use and the corresponding additional costs for the construction of the PV system. This spectrum ranges from the cultivation of specific crops and intensive arable crops with special PV mounting systems to using land for extensive grazing with marginal adjustments on the PV side." As a result, agrivoltaics preserves productive arable land for agriculture while improving land-use efficiency and allowing the development of PV capacity. (Trommsdorff, 2024)

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In the conventional or traditional agriculture practices, the land is allocated towards agriculture activities or in some cases for energy generation. Agrivoltaics as an effective solution that can overcome the problem of land availability for both the necessities. By strategically positioning solar panels in such a way that the panels work as shading structure to the crops grown under the system. Simultaneously, Agrivoltaics systems helps in reducing the effect of water evaporation and helps in improving ground water level and soil health by forming microclimate under the panels.

Agrivoltaics systems can shield the crops from extreme weather conditions and mitigate the effect of changing climatic conditions by forming a microclimate under the panels. By providing shade to crops under the panels, agrivoltaics systems can help reducing water evaporation from the soil, leading towards improving water-use efficiency and potentially reducing frequency irrigation required. This is especially beneficial in water-scarce regions or in drought prone areas. The shade provided by solar panels can also protect crops from excessive heat and sunlight, potentially mitigating heat stress and improving quality of crop and increasing yield. The microclimate created beneath the solar panels can extend growing seasons for some crops and provide protection against extreme cold weather events like frost or snow faced in hilly regions of the country.

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2. TYPE OF AGRIVOLTAICS SYSTEMS

2.1. Elevated Agrivoltaics System

An elevated agrivoltaics system is characterised by a solar panel mounting system that is elevated structure of height 2-5 meters or above from the ground level to permit agricultural or farming activities below the system. Elevated agrivoltaics systems provide shade to the crops with activities like cattle grazing under the panels. Although the height of these panels placement varies, they are usually raised to a point where crops or animals may be grazed below the solar panels.

A farmer can consider elevated agrivoltaics system while opting the dual utilization of his land to maximize the land efficiency and provide shade to especially taller plants and improve plant growth and reduce water utilization in hot climates. The elevated design of the structure allows for unhampered agricultural activities under the panels, ensuring that agricultural productivity is not compromised.

Figure 9: Turmeric, 2.5 MW, Elevated Agrivoltaics Site, Najafgarh

A. Advantages of elevated agrivoltaics systems

I. Improve Agricultural Yield

Elevated agrivoltaics systems helps in improving the agriculture yield by providing optimal light conditions and reducing the temperature stress on the plants especially in extreme summer. For example, in the study conducted by the university of Arizona it is observed that the lettuce grown under the elevated agrivoltaics systems resulted in approximately 65 percent increase in the yield of the crop in comparison with traditional agriculture. (C. Dupraz, 2011)

II. Improvement in Water Level

The elevated agrivoltaics systems can positively impact the water table by slow down the process of evapotranspiration rates and minimizing water loss from the soil surface. For example, sunmaster agrivoltaics site in Najafgarh, Delhi. It is observed that there's an improvement in ground water level. Similarly, the elevated agrivoltaics system installed by sunseed there's a 20-25% water savings.

III. Improvement in Soil Health

Elevated agrivoltaics systems can prevent soil erosion and nutrition depletion over a period of time. For example, sunmaster agrivoltaics site in Najafgarh, Delhi. It is observed that there's an improvement in soil health and can grow more crops in various seasons under the solar panels.

IV. Access to Electricity

Installing a agrivoltaics site in rural regions of the country can help in solving the problem of access to electricity. For example; the Sunmaster agrivoltaics improved access to electricity to the nearby region.

B. Disadvantages of elevated agrivoltaics systems

I. Increased Installation and Maintenance Cost

Inn case of elevated agrivoltaics systems the panels are placed at the height of 2-5 meters above the ground. This leads to the additional cost of structural framework of the system. Furthermore, the maintaining and accessing elevated solar panels for cleaning and repairs may also be more challenging and expensive.

II. Shadowing and reduced light Penetration

The crops below may receive shadows from the structure supporting the solar panels placed on the elevated structure, which might restrict the amount of sunshine that reaches the plants. Crop development and yield may be affected by this shadowing effect, especially with light-sensitive plants.

III. Complexity of Design and Implementation

Careful planning is required for the design and implementation of elevated agrivoltaics systems to ensure optimal crop exposure with sunlight, structural stability, and effective energy output. Due to its complexity, installation may provide difficulties and call for specialised knowledge.

C. Existing pilots of elevated agrivoltaics systems

I. Sunmaster Issapur Agrivoltaics System

The Sunmaster Agrivoltaics site was installed by the Saev Pvt Ltd on 26th march 2021 in Najafgarh, Delhi with the installed capacity of 2.5 MW. The solar panels are placed on a structure of height 3.5 meters without tracker. The major crops experimented under the agrivoltaics structure are lettuce, turmeric, coriander, raddish, kale and beet. The agriculture yield, water level, and soil health has been improved after installing agrivoltaics system.

Table 1: Sunmaster Agrivoltaics site

Name of the APV Plant	**Sunmaster Issapur**
Date of Installation of the Plant/Operational Date of the Plant	**26/03/2021**
Location of the Plant	**Najafgarh**
Land Utilized for the installation of the plant	**Agriculture**
Installed Capacity of the Project	**2.5 Mwp**
Type of Structure installed	**Hot Dip Galvanised**
Type of modules used	**Waaree Mono Facial**
Height of the Structure	**3.5 Mtr**
Impact on the agricultural yield after installing Agrivoltaics Structure	**Improve**
Solar Yield of the Project	**1.3 Million kwh/yr**
Impact on Agriculture	**Increase by 6 times**
Crops grown under Agrivoltaics System	**Lettuce, Turmeric, Coriander, Raddish, Kale, Beet**
Impact on water level	**Improve**
Impact on Soil fertility	**Improve**
Observations	**Good Practices**

Figure 10: Turmeric,2.5 MW, Sunmaster Agrivoltaics Site in Najafgarh

Figure 11: Turmeric,2.5 MW,Sunmaster Agrivoltaics Site in Najafgarh

II. Sunseed agrivoltaics system

The sunseed is divided into two agrivoltaics sites i.e. agrivoltaics plant in Parbhani installed in 2022 and Agrivoltaics plant at Sahyadri Farms in 2024. The agrivoltaics site 1 in Parbhani, Maharashtra was installed in 2022. The site spreads in 5 acres of land with the installed capacity of 1.4 MW. Bifacial panels installed on the site leads to produce 5 percent additional solar yield on annual basis. Around 20-25 percent of water is saved by installing agrivoltaics site. Positive in all crops in the 3.75m elevation section and negative in the below panel region of the 1.75m sections. Cherry tomato, capsicum, cucumber, betel leaves, basil, spinach, methi, coriander, rose, chrysanthemum, tuberose, marigold, watermelon, muskmelon are the crops grown in the site. The agrivoltaics site 2 installed in Nasik, Maharashtra at Sahyadri Farms in 2024. The site is installed in 1 acre of land with an installed capacity of 250 KW. Grapes, citrus trees, sugarbeet are grown in this site installed by sunseed. In case of elevated agrivoltaics system nearly every crop which is shade tolerant or sensitive towards climate change can be easily grown.

Table 2: Sunseed Agrivoltaics site in Maharashtra

Name of the APV Plant	**Agrivoltaics plant** **Agrivoltaics plant at Sahyadri Farms**
Date of Installation of the Plant/ Operational Date of the Plant	**12/11/2022** **01/01/2024**
Location of the Plant	**Parbhani, Maharashtra** **Nashik, Maharashtra**
Land Utilized for the installation of the plant	**5 acres** **1 acre**
Installed Capacity of the Project	**1.4 MW** **250 kW**
Type of Structure installed	**Site 1- Elevated Site 2- Below and Interspace Site 3- Interspace** **elevated single axis trackers**
Type of modules used	**Bifacial** **Bifacial**
Height of the Structure	**Site 1- 3.75, Site 2- 1.75, Site 3- 1.25** **4m**
Solar Yield of the Project	**Additional bifacial gain of 5% annualized** **Not yet measured**
Impact on the agricultural yield after installing APV Structure	**Positive in all crops in the 3.75m elevation section and negative in the below panel region of the 1.75m sections**
Crops grown under APV	**Cherry Tomato, Capsicum, Cucumber, Betel Leaves, Basil, Spinach, Methi, Coriander, Rose, Chrysanthemum, Tuberose, Marigold, Watermelon, Muskmelon, Grapes, Citrus Trees, Sugarbeet**
Impact on water level	**20-25% water savings**

Figure 12: 1.4 MW, Sunseed Agrivoltaics site in Maharashtra

Figure 13: Grapes,1.4 MW, Sunseed Agrivoltaics site in Maharashtr

III. Renkube Agrivoltaics Site

Telangana AgriPV pilot was installed by Renkube in 2022 in Hyderabad. The agrivoltaics sites in installed in 5000sq ft of land with an installed capacity of 10 KW. Carrot, beans, groundnut, cabbage, brocolli, palak, amaranthus, blackgram, greengram, tomato, maize, cotton, chilli, brinjal are already cultivated in the site. 105% Crop yield for Palak in summer crop. Drip irrigation method was followed. The solar yield after installing the agrivoltaics is 4.25 Kehr/Day and the crop yield genersated from the site is around 95-100 percent.

Figure 14: Leafy Vegetables, 10 KW, Renkube Agrivoltaics site in Karnataka

Figure 15: 10 Kw, Renkube Agrivoltaics site in Karnataka

Table 3: Renkube Agrivoltaics site in Karnataka

Name of the APV Plant	**Telengana AgriPV Pilot**
Date of Installation of the Plant/Operational Date of the Plant	**16/11/2022**
Location of the Plant	**Hyderabad**
Land Utilized for the installation of the plant	**5000 Sq Ft**
Installed Capacity of the Project	**10 KW**
Type of Structure installed	**Elevated Structure**
Type of modules used	**Monoperc - Renkube Module**
Height of the Structure	**3.2 m**
Solar Yield of the Project	**4.25 Kwhr/Day**
Impact on Agriculture	**95-100% Crop yield**
Crops grown under Agrivoltaics System	**Carrot, Beans, Groundnut, Cabbage, Broccoli, Palak, Amaranthus, Blackgram, Greengram, Tomato, Maize, Cotton, Chilli, Brinjal**
Impact on the agricultural yield after installing Agrivoltaics Structure	**0-5%**
Observations	**105% Crop yield for Palak in summer crop. Drip irrigation method was followed.**

Recommendations

Elevated Structures with Renkube Panels provide the best results for AgriPV, with 100% land availability for agriculture purposes and 95% crop yield

2.2. Ground-Mounted Agrivoltaics System (Non-Elevated Agrivoltaics System / Conventional Solar)

When solar panels are placed at a standard height i.e. less than 2 meters above ground level, the system is referred to as a "normal height agrivoltaics system." These type of agrivoltaics systems typically operate at a height of 1-3 metres above the ground, while the precise height might vary depending on unique design factors and system needs. This height permits effective solar energy production and leaves enough room below the solar panels for agricultural use especially herbs, shrubs, or crops with height less than 2 meters. Optimising energy output while guaranteeing correct cultivation of crops below the panels is the main aim of normal height agrivoltaics systems.

While a farmer considering to install agrivoltaics site on his farm land he can consider ground-mounted/ non-elevated agrivoltaics system as it provides plenty amount of shade to the plants and creates micro-climate under the panels to provide an adequate or favourable conditions to the certain crops which can lead to increase in yield and crop quality.

Figure 16: Chilli, 105 KW, Ground-Mounted Agrivoltaics System (Non-Elevated Agrivoltaics System/Conventional Solar), Rajasthan

A. Advantages of Ground-Mounted Agrivoltaics System (Non-Elevated Agrivoltaics Systems/Conventional Solar)

I. Provides shade to crops

The Ground-Mounted Agrivoltaics System (Conventional Solar) systems providing partial shade to the crops grown under the solar panels.

II. Improves water level

The shade provided by the panels slow down the evaporation process and helps in maintaining water table of the region the site is installed.

III. Improve Agricultural Yield

Ground-Mounted Agrivoltaics System (Conventional Solar) systems help in improving the agriculture yield by providing optimal light conditions to the crops and reducing the temperature stress in case of extreme summer. For example, in the Ground-Mounted Agrivoltaics System (Conventional Solar) system installed by CAZRI in Rajasthan. Crops like Mung bean, clusterbean, mothbean, isabgol, cumin, chickpea, aloe, brinjal, etc were experimented under this agrivoltaics system. (Poonia S. , 2021)

IV. Double use of Land

These systems maximise land utilisation and give farmers and landowners alternative revenue streams by enabling the simultaneous production of solar energy and agricultural products on the same area of land.

V. Slowdowns Soil Erosion

Due to installation of panels and cultivation of crops can help in reducing the erosion of soil mainly caused by running water and strong winds.

B. Disadvantages of Ground-Mounted Agrivoltaics System (Non-Elevated Agrivoltaics Systems/Conventional Solar)

I. Not suitable for every crops

As the height of this type of agrivoltaics systems is less than 2 meters. It is suitable for small crops, herbs, shrubs etc.

II. Possibility of setting down dust on panels

Agricultural activities such as, cultivating, harvesting, and livestock grazing etc. are might increase the possibility of soiling or harming the solar panels, and improves the frequency of cleaning or maintaining the solar panels.

III. Shading effect of the solar panels

The effect of shade by the panels negatively affect the crop if the panels are not designed and placed properly.

C. Existing pilots of Ground-Mounted Agrivoltaics System (Conventional Solar)

I. CAZRI Agrivoltaics System

The agrivoltaics site installed by cazri in Jodhpur, Rajasthan in 2017. The site spreads in 1 acre of land with installed capacity of 105 Kwp. Major crops cultivated were mungbean, mothbean, clusterbean, isabgol, cumin, chickpea, Aloe vera, sonamukhi, sankhpuspi, chili, cabbage, onion, garlic. (Poonia, 2021)

Table 4: Agrivoltaics site installed by CAZRI in Rajasthan

Name of the APV Plant	**CAZRI Plants**
Date of Installation of the Plant/Operational Date of the Plant	**12/08/2017**
Location of the Plant	**Jodhpur, Rajasthan**
Land Utilized for the installation of the plant	**1 acre**
Installed Capacity of the Project	**105 kWp**
Type of Structure installed	**Interspace ground mounted structure**
Type of modules used	**Monofacial**
Height of the Structure	**Array 1- 1.22m** **Array 2- 1.94m** **Array 3- 2.66m**
Solar Yield of the Project	**420 kWh unit of electricity per day**
Crops grown under Agrivoltaics System	**Mungbean, Mothbean, Clusterbean, Isabgol, Cumin, Chickpea, Aloe Vera, Sonamukhi, Sankhpuspi, Chili, Cabbage, Onion, Garlic**

Figure 17: Chilli, 105 KW, Agrivoltaics site installed by CAZRI in Rajasthan

Figure 18: Aloevera, 105 KW, Agrivoltaics site installed by CAZRI in Rajasthan

II. Abellon Energy Plant

The abellon energy plant was installed by Abellon Cleaning Energy Ltd in Gujarat in 2012 with the installed capacity of 1 MW. Major crops grown were bottle gourd, lady finger, watermelon, turmeric, ginger, chili.

Table 5: Agrivoltaics site installed by Abellon in Gujarat

Name of the APV Plant	Date of Installation of the Plant/Operational Date of the Plant	Location of the Plant	Height of the Structure
Abellon Energy Plant	**28/01/2012**	**Gujarat**	**Less than 2 m**
Installed Capacity of the Project	Type of Structure installed	Type of modules used	Crops grown under Agrivoltaics System
1 MW	**Ground mounted structure**	**Poly crystalline**	**Bottle Gourd, Lady Finger, Watermelon, Turmeric, Ginger, Chili**

Figure 19: Chilli, 3 MW, Ground-mounted agrivoltaics Site, Gujarat (Abellon)

2.3. Greenhouse Agrivoltaics System

When agriculture combined with solar energy generation inside a greenhouse structure is known as a greenhouse agrivoltaics system. This system combines the advantages of solar energy generation with the benefits of traditional greenhouses, such as offering a regulated environment for plant development inside the greenhouse or polyhouse structure while generating solar energy from the panels installed on the roof of greenhouse. Agrivoltaics in greenhouses seek to maximise land use efficiency, boost energy output, improve crop yields. Solar panel integration in greenhouses may assist reduce energy consumption, without hampering crop growing conditions, and make agriculture more productive and ecological.

Farmer can consider installing greenhouse agrivoltaics system to multitude the agricultural productivity and stability under the greenhouse structure. The structure provides partial shading, and protect crops from extreme weather conditions such as excessive heat by creating a more controlled and favourable microclimate inside the greenhouse protect crops and improve yield quality.

Figure 20: Maize, 1.2 MW, Greenhouse Agrivoltaics Systems, Madhya Pradesh

A. Advantages greenhouse agrivoltaics systems

I. Effective use of resources

Effective use of solar and other natural resources can be seen in greenhouse agrivoltaics system.

II. Protection of crops from extreme weather conditions

Plants in greenhouses agrivoltaics system are shielded from inclement weather, including frost, torrential rain, high winds, and extremely high or low temperatures. This reduces the possibility of crop damage and guarantees a steadier and dependable crop yield.

III. Extended growing season

Regardless of the outside climate, plants can be grown year-round in greenhouses agrivoltaics system because they create a controlled atmosphere. By doing this, the growing season is prolonged and crops can be produced outside of their regular growth seasons.

IV. Controlled pollination and crop diversification

Pollination can be managed and enhanced in greenhouses agrivoltaics system, increasing crop quality and yields of fruits and vegetables. A greater variety of crops, including ones that are not well adapted to the local outdoor climate, can be grown in greenhouses, allowing for crop diversification and the exploration of new market potential.

V. Slowdowns Soil Erosion

Due to installation of panels and cultivation of crops can help in reducing the erosion of soil mainly caused by running water and strong winds.

B. Disadvantages of greenhouse agrivoltaics systems

I. Higher Installation Cost

Installing solar panels on greenhouse structures can be expensive, requiring a substantial upfront investment in equipment and infrastructure.

II. Dual Shading effect of greenhouse and solar panels

The integration of solar panels into greenhouse structures can create shading patterns that may not be optimal for certain crop types or growth stages, potentially affecting plant growth and yield.

III. Increase Complexity

The integration of solar energy generation systems with greenhouse farming systems leads to the challenges for system design, operation, and maintenance, perhaps necessitating specialised knowledge and training.

IV. Operations and Maintenance

The combined cost of maintenance and repair requirements for both greenhouse structure and solar panels can lead to higher long-term operational costs for the greenhouse agrivoltaics system.

C. Existing pilots of greenhouse agrivoltaics systems

I. Indra solar farms by Khare Energy Plant

The indra solar plant was installed in Madhya Pradesh by Khare Energy Private Limited in 2022. The site is setup in 6 acres of land with the installed capacity of 1.2 MW. Wheat, Corn, Brijnal, Greengram, Chilli, Groundnut, Broccoli arecultivated in the Agrivoltaics site installed by khare energy pvt ltd. 4.5 units per day of electricity is generated from Agrivoltaics systems.

Table 6: Greenhouse Agrivoltaics System installed by Khare Energy in Madhya Pradesh

Parameter	Value
Name of the APV Plant	**Indra Solar Plant**
Installed Capacity of the Project	**1.2 MW**
Impact on the agricultural yield after installing APV Structure	**10%**
Date of Installation of the Plant/Operational Date of the Plant	**18-Nov-22**
Type of Structure installed	**Super Elevated, Polyhouse**
Solar Yield of the Project	**4.5 Units/day**
Impact on water level	**more than 40% water saving**
Location of the Plant	**Khargapur, MP, India**
Type of modules used	**Polycrystalline 335 Wp Mono perc Bifacial glass to glass - 545 Wp**
Impact on Agriculture	**90% Crop yield**
Recommendations	**Elevated structure with bi-facial panels**
Land Utilized for the installation of the plant	**6 Acre**
Height of the Structure	**4-5 meters**
Crops grown under Agrivoltaics System	**Wheat, Corn, Brinjal, Greengram, Chilli, Groundnut, Broccoli**

Figure 21: Banana, 1.2 MW, Greenhouse Agrivoltaics System installed by Khare Energy in Madhya Pradesh

Figure 22: 1.2 MW, Greenhouse Agrivoltaics System installed by Khare Energy in Madhya Pradesh

2.4. Vertical Agrivoltaics System

When the solar panels are arranged/placed in a vertical orientation along a north-south axis, the system is referred to as a vertical agrivoltaics system. With this particular placement, the panel's east and west faces are exposed with the solar rays. Under vertical system the possibility of capturing more energy with the bifacial modules is the best possible way. The purpose of installing vertical agrivoltaics system is to not to harness crops from shade.

Farmer can install vertical agrivoltaics system to optimize land use and enhance agricultural productivity. This innovative approach allows crops to be grown beside or between vertically installed panels promoting optimal use of small proportion of land and best suited for shade intolerant crops.

Figure 23: Vertical Agrivoltaics System

A. Advantages of vertical agrivoltaics systems

I. Wall like structure

The solar panels are placed vertically on the ground to collocate agriculture with energy production while protecting crops from strong wind.

II. Higher energy yield during sunrise and sunset

Compared to horizontal panels, vertical panels produce more energy as they can generate highest yield sunlight from sunrise to sunset.

III. Dual Face Functioning of the panels

Sunlight is absorbed by vertical bifacial panels from both the front and back sides of the panels. The ground's reflection, or albedo, contributes to an additional increase in energy production.

IV. Space efficiency and less dust on the panels

Installing vertical solar panels in confined places between crops is possible and requires a lower footprint. Their narrow shape allows for plenty of sunshine and space for farming. Due to the enhanced airflow and self-cleaning properties of rainfall, dust collection is reduced on vertical panels. As a result, performance is kept at its best. (Soleos, 2024)

B. Disadvantages of vertical agrivoltaics systems

I. Not beneficial with all type of crops

The efficiency to produce electricity of vertical agrivoltaics systems can be hampered in the case of taller crops crop like grains, wheats etc. (Farming, 2024)

II. Lesser energy generation

In case of vertical agrivoltaics systems the major chunk of energy generated during sunrise and sunset as compared during the day time.

C. Existing pilots of vertical agrivoltaics systems

I. NISE Vertically Agrivoltaics System

The Agrivoltaics site was installed by National Institute of Solar Energy (NISE) in Haryana. A 5kWp vertical bifacial PV module array installation is present at the location. Individual modules are being tested outdoors next to this installation, with the aim of investigating changes in module orientation and various types of ground surface. NISE has also installed a 5kWp bifacial and a 10kWp monofacial PV system, both oriented at a latitude tilt, in addition to the vertical APV system.

Table 7: Vertical Agrivoltaics Site installed by NISE

Name of the APV Plant	Installed Capacity of the Project	Location of the Plant	Type of Structure installed
Vertically Installed Bifacial PV Modules Pilot	**5 Kwp**	**Haryana**	**Vertical Agrivoltaics System**

Type of modules used
Bifacial (mono-PERC), Module Bifaciality: 0.85

Figure 24: Vertical Agrivoltaics Site

3. HOW TO INSTALL AGRIVOLTAICS SYSTEMS

3.1. Site Identification and Assessment

The initial step is to identify suitable site for the installation of agrivoltaics systems. Factors such as crops grown, solar irradiance, land availability, soil quality, and proximity to water sources, distance from grid are the essential element while considering best site to install system.

3.2. Designing of the site

When the selection of the potential site is done then the designing phase begins. This step includes determining the optimal height and orientation of panel placement to maximize sunlight exposure for both electricity generation and significant shade required for the growth of plants to be cultivated.

3.3. Permits and Approvals

Approval and permits from the DISCOMs, and government are while installing the site based of electricity laws, land-use guidelines issued by the government. To facilitate the clearance of solar projects, the Ministry of New and Renewable Energy (MNRE) in India has streamlined procedures. For example, the Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) initiative facilitates the installation of solar panels and pumps on farms by offering subsidies and streamlining the licencing procedure.

3.4. Installation

At the installation stage the structure on which solar panels will be placed are installed. The structures may vary in the form of design and material used depending on soil type, water level, sunlight availability, and weather conditions of the location. When the structure of the site is installed then the solar panels are placed. The panels' position and spacing are carefully considered in this step to maximise the generation of electricity and maintaining shading for the crops grown below the structure.

Figure 25: Operations and Maintenance of Agrivoltaics Site

Figure 26: 3MW, Abellon Energy, Gujarat

3.5. Integration with Agricultural Activities

After the installation of the site cultivation of crops is the main component. This step involves the crops to be grown under the solar panels. Crops are selected carefully for the systems installed on the land. In India, numerous research has been conducted to provide in-depth detail about the suitable crops that can be considered for various agrivoltaics systems.

3.6. Maintenance and Monitoring

Once the agrivoltaics site is operational, ongoing operation and maintenance are necessary for the optimal performance of the site. This step covers regular inspection of the site, cleaning of the solar panels, and cultivation of crops on regular basis.

4. POTENTIAL CROPS

On the basis of extensive research conducted by various institutions and organizations across the globe on the specific set of crops are feasible and best suited for various agrivoltaics systems nationally and internationally. Certain crops like leafy vegetables, fruits, herb, and root vegetable as well as those with a high shade tolerant capacity, are among the best suited crops for various agrivoltaics systems. The crops grown under the partial or complete shade provided by the solar panels have showed improvement in the yield of the crops. Even agrivoltaics systems are also useful for the crops that need shade at specific periods of growth.

A matrix for the feasible crops experimented with agrivoltaics across the globe can be referred in the annexure.

Feasible Crops Experimented Under Various Agrivoltaics Systems Across India

***Experimented out of India**

A. Leafy Vegetables

Elevated Agrivoltaics System

- Cauliflower
- Coriander
- Lettuce
- Spinach
- Amaranthus
- Betel Leaves
- Broccoli
- Mint

Ground-Mounted or Non-Elevated Agrivoltaics System

- Cabbage
- Cauliflower
- Coriander
- Curry Leaves
- Spinach

Greenhouse Agrivoltaics System

- Cabbage
- Basil
- Chard*
- Lettuce*
- Red Leaf Lettuce*
- Spinach*

Vertical Agrivoltaics System

- Lettuce*

B. Fruits, Flowers and Nuts

Elevated Agrivoltaics System

- Banana
- Chrysanthemum
- Citrus Plants
- Grapes
- Groundnut
- Hibiscus
- Alfalfa
- Muskmelon
- Marigold
- Mango (Hybrid)
- Oranges
- Pomegranate
- Rose
- Raspberries
- Strawberry
- Tuberose
- Watermelon
- Cherry Tomato
- Tomato

Ground-Mounted or Non-Elevated Agrivoltaics System

- Allamanda
- Eugenia
- Geranium
- Muskmelon
- Marigold
- Pumpkin
- Watermelon
- Tomato

Greenhouse Agrivoltaics System

- Coleus*
- Petunia*

Vertical Agrivoltaics System

- Berries*

C. Spices and Medicinal Crops

Elevated Agrivoltaics System

- Fenugreek
- Ginger
- Turmeric

Ground-Mounted or Non-Elevated Agrivoltaics System

- Aloevera
- Fenugreek
- Ginger
- Turmeric
- Sankhpuspi
- Sonamukhi

D. Cereals, Pulses, And Oils

Elevated Agrivoltaics System

- Bajra
- Beans
- Black Gram
- Chickpea
- Cluster Bean
- Grams
- Sorghum
- Green Gram
- Millets
- Mustard
- Maize
- Pearl Millet
- Pigeon Pea
- Peas
- Rice
- Soybean
- Sesame
- Split Black Gram
- Wheat

Ground-Mounted or Non-Elevated Agrivoltaics System

- Chickpea
- Cluster Bean
- Green Gram
- Mungbean
- Mothbean

Greenhouse Agrivoltaics System

- Lentils
- Green Gram
- Red Gram
- Wheat

E. Other Crops

Elevated Agrivoltaics System

- Bottle Gourd
- Brinjal
- Capsicum
- Cotton
- Cucumber
- Mushroom
- Okra
- Zucchini

Ground-Mounted or Non-Elevated Agrivoltaics System

- Annatto Dye
- Ash Gourd
- Bitter Gourd
- Blonde Cucumber
- Bottle Gourd
- Brinjal
- Drumstick
- Lemon Grass
- Long Yard Bean
- Okra
- Snake Gourd

Greenhouse Agrivoltaics System

- Cucumber*
- Okra*
- Orchid*
- Tomato*
- Zucchini*

Vertical Agrivoltaics System

- Bottle Gourd*
- Okra*

F. Rooted Vegetables

Elevated Agrivoltaics System

- Carrot
- Onion
- Potato
- Sugarbeet

Ground-Mounted or Non-Elevated Agrivoltaics System

- Onion
- Yam

Greenhouse Agrivoltaics System

- Potato*
- Turnips*

Vertical Agrivoltaics System

- Potato*
- Sugarbeet*

5. HOW CAN FARMERS INSTALL AGRIVOLTAICS THROUGH SCHEMES?

5.1. Pradhan Mantri Kisan Urja Suraksha Evam Utthaan Mahabhiyan Yojana (PM-KUSUM)

Overview of the scheme

The Pradhan Mantri Kisan Urja Suraksha Evam Utthaan Mahabhiyan Yojana (PM-KUSUM) was launched by the government of India in 2019. The scheme aims to promote farmers' income, de-dieselisation the farming sector, provide energy and water security to the farmers and mitigate environmental pollution. The scheme is divided into three components targets to achieve solar energy generation capacity and add 34.8 GW by 2026 with the financial support of Rs. 34,422 Cr. (GoI, 2023)

How Agrivoltaics can be integrated with the existing schemes

The PM-KUSUM Scheme was launched by the Government of India in the year 2019, can play a crucial role in promoting solar installation by the farmers in the country. One of the major component of the PM-KUSUM Scheme is the "Farmer's Sector Renewable Energy Component" i.e. farmers can install solar panels on their agricultural land. This component provides a significant momentum for the implementation and promotion of agrivoltaics in the country, as it encourages farmers to install solar PV systems on their land. Under the scheme, a farmer can install a solar PV system of up to the capacity of 2 MW, by either decentralized mode (i.e. individual farmers or groups of farmers) or by grid-connected mode. The agrivoltaics systems can come under the PM-KUSUM scheme as these systems not only generate electricity through solar energy but also promote agricultural production under the panels, even provide shade and protection to the crops sensitive of sunlight and protect the crops from extreme weather conditions which lead to improved crop yields, water conservation, and increased land-use efficiency. The PM-KUSUM Scheme can accelerate the broad adoption of agrivoltaics systems in India by offering various financial incentives, technical assistance.

5.2. Mission for Integrated Development of Horticulture (MIDH)

Overview of the scheme

MIDH scheme aims to promote the growth of horticulture sector by encouraging the aggregation of farmers into cohesive farmer groups like Farmer Interest Groups (FIGs), Farmer Producer Organizations (FPOs), and Farmer Producer Companies (FPCs). This approach facilitates economies of scale and scope, bolstering agricultural productivity and enhancing farmers' incomes while fortifying nutritional security. Moreover, the mission endeavors to boost horticulture production, augment farmers' income, and strengthen nutritional security by promoting quality germplasm, improved planting material, and enhancing water use efficiency through measures such as Micro Irrigation.The primary goal of the Mission for Integrated Development of Horticulture (MIDH) Centrally Sponsored Scheme is to promote all-around growth in the horticulture industry, which includes a wide range of crops like fruits, vegetables, root and tuber crops, mushrooms, spices, flowers, aromatic plants, coconut, cashew, cocoa, and bamboo. In most states, the Government of India (GOI) bears 85% of the overall expenditure for developmental efforts under this plan, with the State Governments in charge of the remaining 15%.

How Agrivoltaics can be integrated with the existing schemes

The MIDH scheme can play a vital role in promoting agrivoltaics in the country especially through horticulture crops best suited to be grown under the panels. The scheme provides financial assistance and technical support for various interventions for the horticulture crop. The major elements of the scheme are the establishment of horticulture clusters, which involves the creation of infrastructure and facilities for pre and post-harvest, and marketing activities. Within these clusters, agrivoltaics systems can also be integrated, where solar panels are installed above the agricultural land, provide shade to the crops. Similarly, scheme can also provide financial assistance for the installation of agrivoltaics systems, covering a proportion of the costs associated with the solar panels, structure, and other related components. Various programmes under the scheme can be beneficial to educate farmers and other stakeholders about the potential benefits of implementing these systems specifically for the horticulture crops.

5.3. Pradhan Mantri Krishi Sinchayee Yojana: Per Drop More Crop

Overview of the scheme

Government of India launched the "Pradhan Mantri Krishi Sinchayee Yojana: Per Drop More Crop" on July 1, 2015. The main goal of the programme is to improve farm-level water use efficiency by implementing Micro Irrigation, which includes both Drip and Sprinkler Irrigation Systems. To complement the construction of sources for Micro Irrigation, the project also extends its support towards micro-level water storage and water conservation/management initiatives, which together are referred to as Other Interventions. The scheme's multiple goals include increasing the nation's adoption of microirrigation technologies to improve water use efficiency, which will raise crop output and increase farmers' revenue through precision water management. In water-intensive or water-consuming crops like sugarcane, bananas, cotton, etc., special attention is paid to promoting micro-irrigation technologies, with a focus on expanding the coverage of field crops under these technologies. In addition, the plan aims to develop microirrigation systems in water-scarce, water-stressed, and key groundwater blocks/ districts in order to maximise their potential for fertigation. Additionally, it seeks to integrate micro irrigation technology with tube-well and river-lift irrigation systems to maximise energy efficiency for pressurised and lifting irrigation whenever possible. Another important component of the plan is creating convergence and synergy with current programmes and schemes, especially those concerning the development of water resources and the integration of solar energy for pressurised irrigation.

How Agrivoltaics can be integrated with the existing schemes

The scheme's primary objective is to improve use of water effectively and efficiently in the agricultural activities through various interventions, and agrivoltaics can be incorporated with the scheme to achieve multiple benefits of energy generation, improvement in crop yield and water conservation. One of the major advantage of installing agrivoltaics systems is their ability to conserve water and reduce wastage of water in the agricultural activities sue to the solar panels installed reduce the evaporation process and makes micro climate under the panels leading towards declined the water requirements for irrigation. The scheme can help make it easier to combine micro-irrigation methods such as sprinkler or drip irrigation integrated with agrivoltaics systems. Farmers can save water and produce energy from the solar panels at the same time to operate the micro-irrigation systems by combining them with agrivoltaics. This combination has the potential to significantly increase the overall effectiveness of water use while also saving a substantial amount of money. The scheme offers financial support, capacity building and other incentives to encourage the use of water-saving measures. Agrivoltaics system installation can be included in these incentives, increasing their affordability and accessibility for the farmers.

5.4. Agriculture Infrastructure Fund

Overview of the Scheme

The scheme launched by the central government to support and provide medium to long-term debt financing for the investment in viable projects or value-added projects for the post-harvesting management infrastructure and community farming capital is known as Agriculture Infrastructure Fund (AIF). The scheme is launched by the central government in 2020. The primary aim of the scheme is to create and enlarge agricultural facilities through improving the value-addition or value-chain to ensure the better returns for the farmers. The scheme benefits through providing subsidies and credit guarantees for supporting the development of numerous agricultural infrastructure and value-addition projects, inclusively focussing on primary food processing units, marketing infrastructure, cold storage units, packaging and upgrading units and logistics facilities etc. The scheme aims to create the investment of approximately ₹1 lakh crore (around $13 billion) for the creation of modern agricultural infrastructure and assets. (PIB, 2020) the scheme was implemented through a combination of interest subvention and credit guarantee in which the government will provide 3% interest subvention and up to ₹2 crores a credit guarantees for each project. The scheme is accessible for the farmers, agri-entrepreneurs, farmer producer organizations (FPOs), and other stakeholders involved and promoting agricultural sector in the country.

How Agrivoltaics can be integrated with the existing schemes

The scheme can be leveraged to promote various value addition services such as organic inputs production, bio stimulant production units, nursery and tissue culture, seed processing, warehouses, bulk chilling and cold storage etc. with the adoption of agrivoltaics and sustainable agricultural practices. The AIF scheme provides financial assistance in the form of interest subvention and credit guarantees for the setup a post-harvest system and various community farming value-addition infrastructures. Agrivoltaics systems can be considered as part of the community farming asset especially in case of small and marginal farmers, as it provides the community level integration of solar PV with agricultural activities. In the scheme farmers, FPOs, and agri-entrepreneurs can avail the 3% interest subvention and credit guarantee of up to ₹2 crores for the project, which can significantly reduce the initial capital investment required for setting up a agrivoltaics system. Also the scheme supports the development of primary facilities such as processing units, bulk chilling, cold storage and logistic, which are also essential components of value addition chain as a business models for agrivoltaics system. This can help farmers and producers who have installed agrivoltaics systems on their farmland to sell their agricultural produce directly in the market or use the yield as an intermediate good with the value additions provided in the scheme and potentially leverage premium prices for goods.

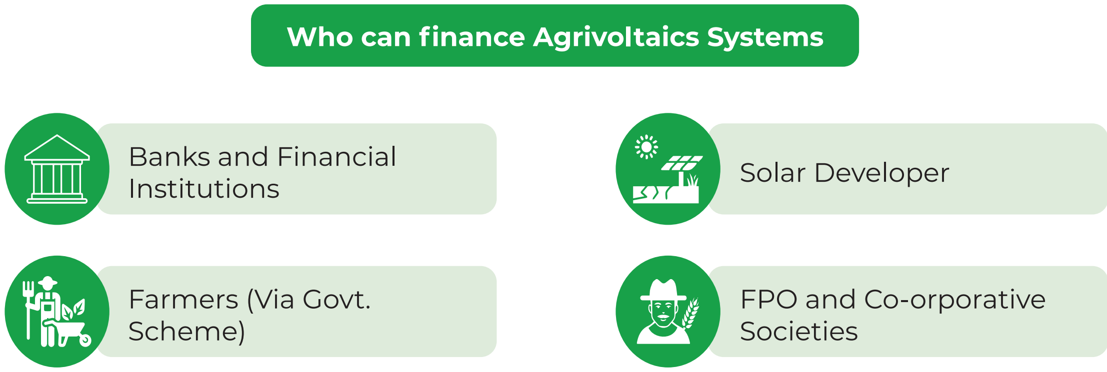


Figure 27: Ownership of Agrivoltaics System

A. Banks and Financial Institutions

Banks or banking sector can be a potential source to finance and promote agrivoltaics systems in India economy through various mechanisms like by providing loans, credit facility and other financial support to farmers for installation, operations and maintenance of agrivoltaics systems. The funding may make it possible to install and run agrivoltaics systems, assisting in the agricultural sector’s shift to sustainable energy methods. Financial institutions may also be very helpful in promoting the development of these cutting-edge energy solutions in India by providing specialised financial products, investment possibilities, and funding mechanisms. These can help in the adoption and scale-up of agrivoltaics.

B. Developers

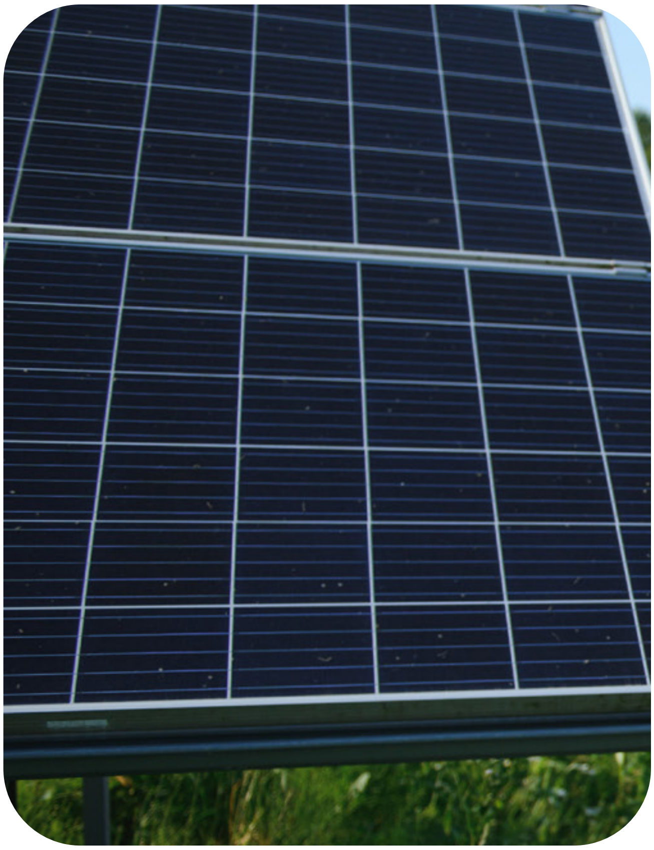
Agrivoltaics system developers in India can have access to a number of financing options that are suited to the unique requirements and difficulties faced by the agricultural industry. Getting loans and subsidies under carious schemes developers can make financial arrangement. Also, solar developers can look at cutting-edge financing options including leasing agreements and power purchase agreements (PPAs), in which farmers lease their property to developers so that they can place solar panels on it while continuing to conduct agricultural activities. Through the utilisation of various financing alternatives solar developers may expedite the adoption of agrivoltaics in India, therefore propelling the deployment of renewable energy and sustainable farming practices.

C. Farmers (Via Govt. schemes)

Financing agrivoltaics systems for farmers is a possible due to various schemes and incentives Agrivoltaics systems may be installed more easily and affordably for farmers with the help of a variety of financing alternatives. The Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) programme, which offers financial support for the installation of solar pumps and solar power plants on agricultural fields, is one popular method that uses government plans and subsidies. Farmers might also take loans and various credit programmes under consideration that banks and other financial institutions offers to promote agriculture and renewable energy in the country. Farmers can also have collective ownership of agrivoltaics systems with developers, FPO, Co-orporative societies through lease agreements and community-based financing programmes might be investigated. Farmers may take advantage of the initial investment barrier associated with agrivoltaics and reap its benefits, such as increased crop yields, lower power costs, and environmental sustainability, by using these financing alternatives.

D. FPOs/Co-orporative Societies

Farmer Producer Organizations (FPOs) and cooperatives plays an important role in the implementation of agrivoltaics on ground especially for small, marginal and medium farmers. Farmer Producer Organizations (FPOs) and cooperatives can provide support to farmers by leveraging various financing opportunities to support farmers in installing agrivoltaics systems across the country. A possible approach will be the use of government incentives and subsidies designed to encourage the use of renewable energy in agriculture. Examples of these include the Pradhan Mantri Kisan Urja Suraksha Evam Utthan Mahabhiyan (PM-KUSUM) project. Also, FPOs and cooperatives can use the collaborative approach with the financial institutions to secure loans or grants.



6. OWNERSHIP OF AGRIVOLTAICS SYSTEM

Farmer	Solar Developer	FPO/Community
Individual Farmer Installs and owns the APV plant in his Land.	Farmer leases out his land to a solar developer for installation of the APV plant.	FPOs will install and own the APV plant and a number of intrested farmers will lend their land for the plant installation.
Solar Developer is limited to only EPC and O&M of the APV plant.	Developer will own the APV plant and will generate revenue from sale of electricity under PM-KUSUM scheme (A or C2)	Role of the developer is limited to EPC and O&M.
Revenue generation by sale of Electricity to grid under PM-KUSUM scheme (Under Component A or C2 FLS) and through the sale of agricultural produce.	Farmer will get the lease rent and will have the revenue through the sale of agricultural produce. (Land ownership will remain with farmers)	Sale of electricity will be shared among the farmers proportionately and the sale of agricultural produce will also be shared among the famers.

Note: (To study the extensive and diverse business models suitable for Agrivoltaics has been shared by India Agrivoltaics Alliance in the report on "Business Models for Agrivoltaics in India Analysis of Various Business Models and their Socio-Economic Impact")

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ANNEXURES

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INDIA AGRIVOLTAICS ALLIANCE

India Climate Collaborative