Agrivoltaics in India

Challenges and opportunities for scale-up

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Agrivoltaics in India: Challenges and opportunities for scale-up

May 2023

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Executive Summary

In the future, many countries, including India, may witness growing competition for land resources between agriculture and renewable energy. Agrivoltaics—the simultaneous use of land for both agriculture and photovoltaic (PV) power generation—offers a potential solution. Studies show potential for increasing crop yield and panel efficiency, making agrivoltaics an attractive option for farmers and solar developers. Agrivoltaics has grown swiftly across the world in recent years, and India is taking the first steps in its adoption, with more than a dozen pilot projects already deployed across the country.

This background paper assesses the current state of development and identifies the challenges and opportunities for the commercialization of agrivoltaics in India. We reviewed existing literature on agrivoltaics and interviewed 11 experts from power distribution companies, research institutions, and commercial firms who have implemented pilot projects. These pilots were limited to the co-location of horticulture crops and grid-connected solar PV, and hence this is the focus of our interviews (not co-location with livestock or other agriproducts). This background paper is supplementary to a comprehensive guidebook on PM-KUSUM[1] Components A & C that is being published separately.

We identify seven key findings for India:

1. **Agrivoltaics did not negatively impact—and in some cases even increased—crop yields, according to implementers.** But pilots in India have only tested agrivoltaics with a limited variety of crops and agricultural settings. Better-designed pilots with rigorous testing methods are required to build a strong knowledge base. The experience of pilot implementers suggests the technical feasibility of agrivoltaics with no change (or even an increase) in the yield of some crops like leafy vegetables, millet, and medicinal plants under shading conditions. However, better-designed pilots with rich data collection on the crop microenvironment are required before these results can be generalized. Moreover, the crop choices trialled in the pilot projects are still limited, and mainstream crops like paddy and wheat have yet to be tried successfully. Established value chains and price support mechanisms for these crops make it challenging to encourage farmers to shift to crops that are most suitable for agrivoltaics.
2. **The key to the commercialization of agrivoltaics lies in increasing its attractiveness through technological innovations and testing business models most viable in the Indian context.** Agrivoltaics pilots in India have focused on technical analysis, including crop suitability, crop yields, and cost competitiveness. States can encourage the testing of new business models and new technologies. We identified three potential business models and conditions for deploying agrivoltaics: i) agrivoltaics jointly owned by farmer and developer, ii) agrivoltaics solely owned by either the farmer or the developer, and iii) developer as the primary promoter and

[1] PM-KUSUM refers to the "Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan Yojana" program, a flagship solar irrigation scheme launched in 2019 by the Government of India to support the deployment of solar pumps to farmers and the installation of decentralized solar plants to solarize rural and agricultural feeders.

farmer as a partner. Their commercial viability needs to be tested before widespread application. Technological innovations like bifacial panels and sun tracking have shown some promising results in agrivoltaics and can be encouraged through state-sponsored pilots.

3. **Arid and semi-arid regions, as well as peri-urban areas, are likely to be favourable locations for agrivoltaics in India.** The pilot projects in India and abroad indicate that arid and semi-arid regions may provide conditions that enable maximum synergy between agriculture and energy generation. A couple of studies show that the lower temperature and humid microclimate below the panel enabled by the shading could stimulate crop growth. However, there is a shortage of research and pilots in arid and semi-arid climates, and this impedes the growth of agrivoltaics. India can take the lead on establishing the necessary evidence base. Interviewees indicated that it would also be valuable to explore the agrivoltaics at peri-urban sites close to cities and towns with proximity to markets for high-value horticultural products. Access to technical and financial resources makes these areas ideal for the next set of pilots.
4. **State governments need to reform land-use and tax regulations to support agrivoltaics, as well as develop consistent standards and definitions for agrivoltaics.** Land-use and tax laws currently distinguish between agricultural and non-agricultural activities with associated restrictions on their use and tax benefits. Existing laws need to be amended to recognize and encourage businesses that may conduct both activities concurrently. Clear definitions and standards for agrivoltaics are needed to ensure project developers, governments, and lending institutions have a shared understanding of the criteria that define such projects. This is particularly important to determine the eligibility for any subsidies or concessional financing in the future. However, there should be adequate safeguards and enforcement mechanisms to prevent developers from misusing the provision to circumvent land-use laws.
5. **States need to think beyond the uniform ceiling tariff regime if agrivoltaics is going to be commercialized at scale.** Market mechanisms can be explored for supporting agrivoltaics through innovative tariff structures. A single ceiling tariff across a state negates the locational advantage of agrivoltaics in areas with high land rent. States should consider alternative tariff-setting approaches, including substation or zone-specific tariffs, or support the open-access route (through which developers can sell the power directly to electricity consumers at a mutually decided rate) for promoting agrivoltaics.
6. **Capacity building would be critical in scaling up agrivoltaics.** Scientific design of an agrivoltaics system to ensure optimal sunlight distribution is a skill-intensive process. Similarly, crop management under shading conditions requires advanced skills among farmers. Co-management of resources can introduce managerial challenges. States have a role in ensuring farmers and developers have access to information through training, professional networks and centres of excellence.
7. **Continuous innovation and peer learning are critical to overcoming operational challenges.** On the agriculture side, farmers' safety concerns due to proximity to high-voltage cabling, as well as constraints on the mobility of farm

equipment, are the main challenges. The major concerns for power production included the increased maintenance cost due to elevated structures, structural decay due to the humid microenvironment, and challenges in coordinating water management with farmers. There are some promising solutions, like the integration of rainwater harvesting structures with agrivoltaics. However, scaling up these solutions requires further research and peer learning.

The study finds promising results in pilot projects and identifies key areas of opportunity for agrivoltaics, justifying future research and investment. State and central governments can support further pilots and facilitate innovations by forging partnerships with key stakeholders, co-creating legal and technical frameworks, and creating appropriate incentives. Lessons from this research could also be applicable to the testing and commercialization of other agrivoltaics models in India, such as solar panels in association with broadscale crops or livestock.

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Abbreviations

ADEME	French Agency for Ecological Transition (Agence de l'environnement et de la maîtrise de l'énergie)
CAZRI	Central Arid Zone Research Institute
DIN	German Institute for Standardization (Deutsches Institut für Normung)
DISCOM	distribution company
ENEA	Italian National Agency for New Technologies, Energy and Sustainable Economic Development (Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile)
LER	land equivalent ratio
PV	photovoltaic

1.0 Introduction

In the future, many countries, including India, may witness growing competition for land resources between agriculture and renewable energy. Agrivoltaics—the simultaneous use of land for both agriculture and photovoltaic (PV) power generation—offers a potential solution. Studies show potential for increasing crop yield and panel efficiency, making agrivoltaics an attractive option for farmers and solar developers. Agrivoltaics has grown swiftly across the world in recent years, and India is taking the first steps in its adoption, with more than a dozen pilot projects having been deployed across the country.

This paper reports the experiences of stakeholders (power distribution companies [DISCOMs], agricultural universities, private solar PV developers, and farmers) who have implemented agrivoltaics pilots across India. The objective is to bring together evidence from research studies and learnings from pilot projects through interviews with relevant stakeholders to summarize the current status, implementation challenges, and opportunities for commercialization and scale-up of agrivoltaics. The paper aims to inform future policy actions and studies by bringing out key guiding observations and addressing key research questions.

The findings in this paper are designed to support state agencies, developers, and other stakeholders in the faster adoption of agrivoltaics by providing policy recommendations, proposing business models, as well as financial and technical transition mechanisms.

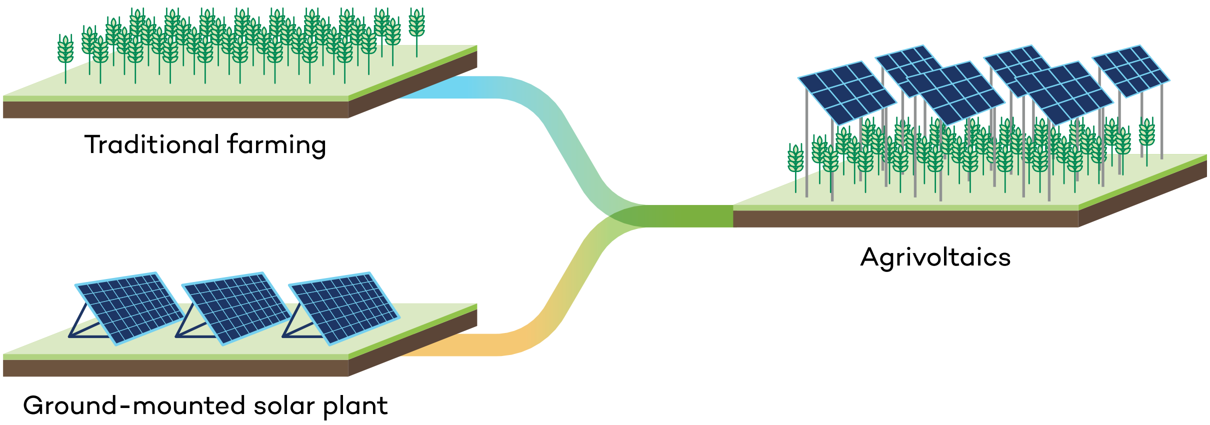
This paper is a supplementary companion to a comprehensive guidebook (referred to throughout this document as the "guidebook") on how to deploy small-scale decentralized solar power plants under India's Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan (PM-KUSUM) scheme. The guidebook provides practical guidance to states on how they can begin to pilot agrivoltaics in their first phases of deployment under PM-KUSUM, which explicitly states that it can be used to support agrivoltaics.

2.0 Context: The what, why, and where of agrivoltaics

Food security and the rapid rollout of large-scale renewable energy production are critical for sustainable development. But both require significant areas of land and, without adequate planning, may compete for finite land resources (Nonhebel, 2005). In the coming years, increased food demand due to India's rising population and improving living standards may put pressure on agricultural land resources (Kumar & Sharma, 2020). According to estimates by Worringham (2021), the amount of solar and onshore wind power required to reach net-zero in India by 2050 would require between 55,500 and 77,000 km2 of land (Worringham, 2021). In addition, in the very short term, governments have accelerated the push for localizing both food and energy production following Russia's invasion of Ukraine and the subsequent food and energy crises. This underscores the importance of early planning by policy-makers on the links between food, energy, and land.

Agrivoltaics is one of the solutions proposed to address this potential conflict. Agrivoltaics refers to the simultaneous use of land for agriculture and photovoltaic power generation. As illustrated in Figure 1, this is achieved by designing a solar power plant to enable farming between or below the panels on land that would otherwise remain unused. Figure 2 demonstrates the central premise of agrivoltaics: to improve land-use efficiency and sustainably enhance energy and food security.

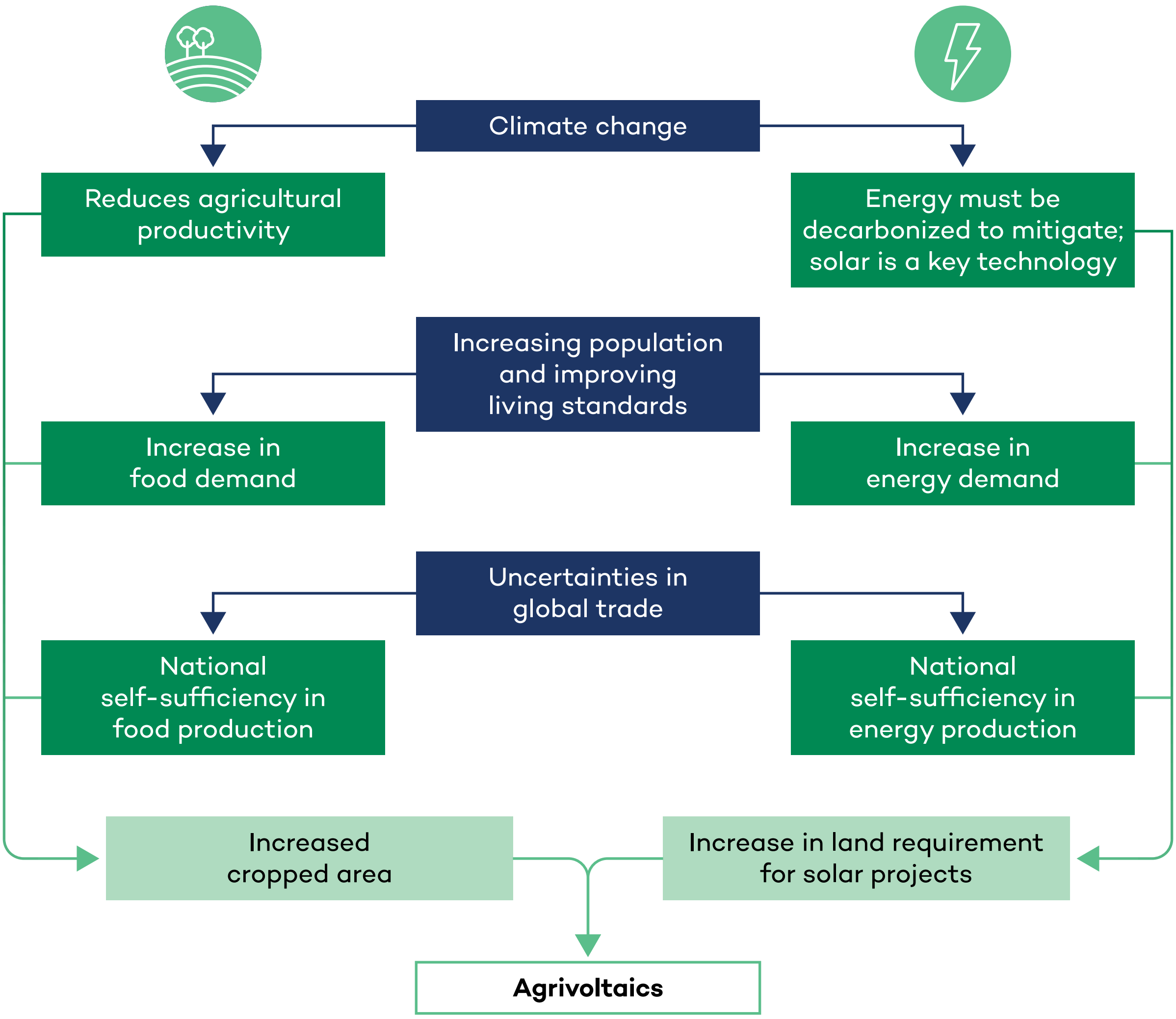
Figure 1. Illustration of a typical agrivoltaics system



Source: Authors' diagram.

Several countries, especially industrialized nations, have achieved a significant scale in agrivoltaics through national support programs. The globally installed agrivoltaics capacity stood at 2.8 GW in 2020, up from a mere 5 MW in 2014 (Trommsdorff, Gruber et al., 2022). China leads in installed capacity, with 1.9 GW deployed as of 2020 (Trommsdorff, Gruber et al., 2022). Figure 3 summarizes the growth of agrivoltaics in these countries.

Figure 2. Agrivoltaics as a food–energy nexus approach to resource use



Source: Authors' diagram.

Agrivoltaics is still a nascent practice with evolving technology, designs, and standards. In India, agrivoltaics is still limited to a handful of pilots and has not yet reached a commercial scale. However, existing schemes could facilitate the widespread adoption of the practice. The PM-KUSUM scheme promotes the "solarization" of agriculture. Among other strategies, the scheme promotes the setting up of small-scale decentralized grid-connected solar power plants on farmers' land. Although the scheme primarily targets barren and uncultivable land, setting up plants on agricultural land is also allowed with the condition that the solar panels are installed on raised stilts and adequate spacing between panels, allowing cultivation to continue. This provision enables the adoption of agrivoltaics under the scheme.

Figure 3. Major developments in agrivoltaics in some first-mover countries[2]

China[1]	• Installed capacity of agrivoltaics: 1,900 MW (as of 2020). Promotion through PV poverty alleviation and power generation front-runner base schemes. • Baofeng Group is developing a 1 GW agrivoltaic project in Ningxia province.
Japan	• Installed capacity of agrivoltaics: 500-600 MW.[2] • Promotion through feed-in tariff scheme with preferential treatment to agrivoltaics. • New Energy and Industrial Technology Development Organization published new guidelines.[3]
Germany	• Installed capacity of agrivoltaics: 15 MW. • German regulator BnetzA invited bids for allocating 403 MW agrivoltaics capacity in 2022.[4] • Fraunhofer Institute for Solar Energy Systems published new guidelines on agrivoltaics.
Italy	• Italy is investing EUR 1.1 billion for the development of 2 GW in agrivoltaics capacity.[5] • The Italian National Agency for New Technologies, Energy and Sustainable Economic Development (Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibil) launched a "National Network for Sustainable Agrivoltaics" to develop a regulatory framework for agrivoltaics in the country.
France	• France Agrivoltaisme, world's first trade association of agrivoltaics, was formed in 2021. • The French Agency for Ecological Transition (Agence de l'environnement et de la maîtrise de l'énergie, or ADEME) defined standard for agrivoltaics in 2022. • Implemented several tender rounds, with more than 100 MW capacity already allocated.[6]

Sources: 1. ADEME et al., 2021; Bellini, 2021; Italian National Agency for New Technologies, Energy and Sustainable Economic Development, 2021; EnerData, 2022; Khattar, 2020; Matalucci, 2021; Tajima & Iida, 2021; Trommsdorff et al., 2021 2022; Vorast, 2022.

[2] The standards for agrivoltaics installations is not uniform across these countries. Hence, we have used the respective country definitions for agrivoltaics.

3.0 Understanding Agrivoltaics

Beyond the broad definition of "simultaneous use of land for agriculture and solar PV power generation," there are no standards and definitions for agrivoltaics in India. Countries like Germany, France, and Japan pioneered the adoption of agrivoltaics and are constantly evolving and updating their standards and definitions.

Deutsches Institut für Normung (German Institute for Standardization, or DIN), a prominent independent association for standardization in Germany, uses the following definition: "Agricultural photovoltaics (agrivoltaics) is the combined use of one and the same area of land for agricultural production as the primary use, and for electricity production by means of a PV system as a secondary use" (DIN, 2021).

Similarly, France's definition of agrivoltaics mandates that the PV system in agrivoltaics should not cause "a significant qualitative and quantitative degradation of the agricultural yield, as well as a reduction of the revenue generated from the agricultural activity" while bringing beneficial services to agriculture production (Bellini, 2022).

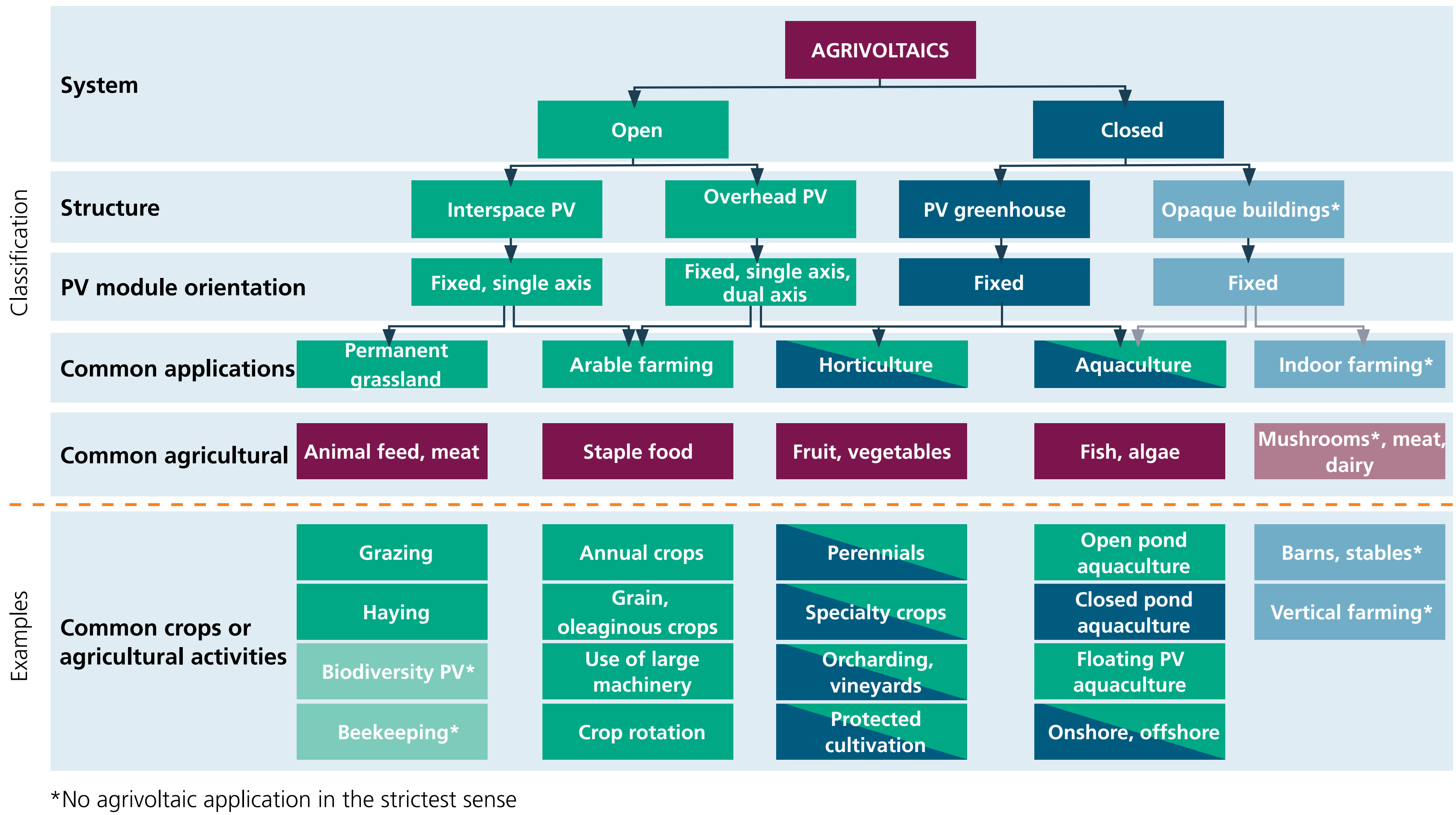
Japan differentiates agrivoltaics from other solar power plants as those solar power plants where optimal crop production is the central design criteria (Bellini, 2021). Thus, the primacy of agricultural activities is a cornerstone for agrivoltaics in these countries.

The main challenge for developing a standard is that there is no one all-encompassing agrivoltaics model. There is a wide range of designs and configurations piloted and demonstrated in different countries. A diversity of parameters like panel height, orientation, and spacing can be tinkered with to optimize for specific requirements. The agricultural and power output will vary with these design factors, making it challenging to propose uniform standards and definitions for all models. Trommsdorff, Gruber, et al. (2022) classified agrivoltaics based on agricultural production activities and PV system structure and design, as summarized in Figure 4. This indicates how agrivoltaics can be integrated with closed farming systems like greenhouses and conventional open farming systems.

Pilot projects in India (see Table 2)—all of them open farming systems with crop cultivation—are mainly differentiated by their structure. There are two types:

1. **Overhead PV:** PV panels are mounted on an elevated structure, and the area beneath is used for cropping. The panels' height is based on crop choices, ground-level light requirements, and operational requirements like moving agricultural equipment. Aquaculture, like shrimp farming, is also possible underneath the panels when it is set up over small water bodies. Livestock grazing requires large amounts of land, and overhead PV in large areas is prohibitively expensive.
2. **Interspace PV:** The PV panel is ground-mounted or close to the ground, and the gaps between adjoining rows of panels are primarily used for cultivation. Livestock grazing and aquaculture are also possible in this model. Extending agriculture to the area below the panel is also possible, but the crop choice is extremely limited in this case due to the height and shading constraints.

Figure 4. Classification of agrivoltaics systems



Source: Trommsdorff, Gruber, et al, 2022. Published with permission © Fraunhofer ISE.

Note: Tilt management refers to the degree of freedom for movement of the solar PV panels to track the sun. It can be fixed (no movement), 1-Axis (movement in one direction, typically for tracking the seasonal movement of the sun), and 2-Axis (movement in two directions allowing daily and seasonal movement of the sun).

Although livestock rearing and aquaculture are possible, no pilots in India have experimented with them. Further, the characteristics of both these sectors in India are very different from industrialized countries, where most international pilot projects have taken place. For example, the bulk of the Indian dairy industry is based on small-scale cultivators using backyards for livestock rearing, while in industrialized countries, it is through integrated dairy farms (Sharma et al., 2009). Hence, assessing the suitability of these agrivoltaics models to Indian conditions is beyond the scope of this paper. Rooftop agrivoltaics is also an emerging area of interest. While some of this document's learnings apply to rooftop agrivoltaics, in this paper, we haven't explored issues specific to rooftop agrivoltaics.

3.1 Potential Benefits and Risks of Agrivoltaics

The benefits and risks of agrivoltaics are highly contextual, depending on various factors like crop choices, agroclimatic conditions, and the design and configuration of the system. Further, due to the nascency of agrivoltaics, not all aspects are fully studied, leaving many of the impacts theoretical or contested without concrete scientific evidence. Table 1 summarizes the intended benefits and potential risks of agrivoltaics based on the available evidence.

Photo: Akash Sharma/CUTS.

Table 1. Potential benefits and risks of agrivoltaics

Potential benefits	Associated risks
Increased land productivity	
The primary benefit of agrivoltaics is an increase in land-use efficiency, leading to higher total output from a given piece of land compared to farming or energy production in isolation. For instance, Fraunhofer ISE achieved a land equivalent ratio (LER) of 1.86 in its Heggelbach research project (Trommsdorff, Gruber, et al., 2022), implying that if the crop and power were produced separately, ~1.86 times the total land would be required.	Multiple studies show LER values greater than one, indicating better land-use efficiency (Guerin, 2019; Kostik et al., 2020; Trommsdorff, Gruber et al., 2022). But LER assigns equal value to agriculture and power production yields. An increase in one may compensate for a reduction in the other. For instance, setting up agrivoltaics on fertile land may significantly reduce crop yield, but the LER can exceed one through optimized power production. Productivity benefits need to be assessed relative to the bigger-picture needs for food and energy production, prioritizing food above energy as essential for human survival.
Symbiotic relationship It is theorized that the two systems—agriculture and power production—can have mutual benefits.	
Shading can improve the yields of some crops.	Studies on yield impact show wide variations in results. Leafy vegetables and legumes increase yield, while crops like rice and wheat show a significant drop in yields, and most other crops show mixed results (Gonocruz et al., 2021; Homma et al., 2016; Trommsdorff, 2021; Weselek et al., 2019). The key takeaway from the literature review is that the impact on yield is dependent on factors like crop choices, agroclimatic conditions, and panel density. Hence, further context-specific research and pilots are needed to understand the shading impact on crop yields better.
The cooler microenvironment created by crops may improve the panel efficiency.	The impact on the PV panel operating temperature and efficiency is not well studied. Barron-Gafford et al. (2019) have reported a drop in panel temperature in test projects in Arizona, United States. Still, it may not apply to all climatic regions and needs further investigation. Simulation studies (Johansson et al., 2022; Williams et al., 2023) also show potential gains from panel efficiency.
Agricultural activities can help in reducing the cost of land maintenance.	Although there may be benefits from land maintenance, some reports have also expressed concerns about farmers' safety from electric wiring and the impact on day-to-day operations in agriculture (SolarPower Europe, 2021). These have not been well studied.

Potential benefits	Associated risks
Crop protection from weather hazards like hailstorms and a decrease in dust erosion and deposits on the panel.	
Other benefits associated with decentralized solar power plants	
Land availability is one of the main constraints facing developers in the PM-KUSUM scheme (under Component-A and Component C[feeder level solarization]) and other similar schemes (*Guidebook Placeholder*, n.d.). Agrivoltaics could help address this challenge in some contexts, helping to unlock the benefits of decentralized solar power plants, including a reduction in power purchase cost and transmission losses, improvement in local power supply quality, and the creation of local employment opportunities (Guidebook Chapter 1).	Interviewees noted that grid-connected agrivoltaics systems are likely to be more scalable than off-grid systems because the power produced from agrivoltaics is typically much higher than the demand within the system. However, grid-connected renewable energy also requires adequate evacuation capacity and to be situated near substations to reduce losses. There could also be an impact of intermittent generation on power systems. These topics have been further elaborated on in the guidebook accompanying this paper (*Guidebook Placeholder,* n.d.). The alternative of battery storage to use the stored energy for other internal energy demands is not yet well tested.

3.2 Costs

The main barrier to the wide-scale adoption of agrivoltaics is its capital cost. The mounting structure of an agrivoltaics system is costlier for several reasons.

1. The elevated design and lower panel density increase the materials that go into the mounting structure.
2. The increase in height also raises the risk of higher wind velocity, requiring better-quality materials.
3. The cost of land preparation and installation is correspondingly high.

The final cost of the agrivoltaics system will depend on the system design. In Western countries, it ranges between 1.3 to 2 times that of a conventional ground-mounted solar power plant on a per kW basis (Horowitz et al., 2020; Trommsdorff, Dhal, et al., 2022). The higher cost impacts the competitiveness of agrivoltaics compared to conventional solar plants and raises financial sustainability concerns.

4.0 Agrivoltaics Projects in India

Agrivoltaics are in the technology demonstration phase in India. Based on conversations with implementers, many projects are set up on a pilot basis. Table 2 summarizes the major pilot projects across the country. It suggests there has been an uptake in interest in agrivoltaics over the last decade. The National Solar Energy Federation of India and the Indo-German Energy Forum have prepared an interactive webpage, including a map of agrivoltaics pilots in India, accessible here.

Photo: Akash Sharma/CUTS.

Table 2. List of pilot projects on agrivoltaics in India

Sl. No.	Project name	Developer	Capacity (kW)	Type of agrivoltaic	Type of crops	Commissioning year	Additional remarks
1	GSECL STPS solar Jamnagar, Gujarat	Gujarat State Electricity Corporation	1,000	Interspace/ Overhead	Lady fingers, bottle gourd, coriander, cluster beans, tomato, cucumber, chilli, mung dal	2016	Adopts drip irrigation
2	Agri-based solar power plant Kutch, Gujarat	Gujarat State Electricity Corporation	1,000	Interspace/ Overhead	Brinjal, cluster beans, coriander, lady finder, bottle gourd, pulses	2016	Adopts drip irrigation
3	Amrol distributed solar power project Amrol, Gujarat	Gujarat Industries Power Corporation	1,000	Interspace/ Overhead	Groundnut, soybean, pearl millet, cotton, green gram, pigeon pea, maize, cluster bean	2016	In collaboration with Anand Agriculture University
4	GIPCL plant in Vastan Surat, Gujarat	GIPCL	1,000	Interspace/ Overhead	Groundnut, soybean, pearl millet, cotton, green gram, pigeon pea, maize, cluster bean	2016	In collaboration with Anand Agriculture University
5	Central Arid Zone Research Institute (CAZRI) plant Jodhpur, Rajasthan	CAZRI Institute	105	Interspace/ below the panel	Brinjal, aloe vera, mung bean, moth bean, cluster bean, cumin, chickpea, cabbage, onion	2017	Equipped with a rainwater harvesting system for cleaning panels & irrigation
6	Amity University plant Noida, Uttar Pradesh	Amity University	10	Overhead	Maize, potato brinjal, mustard	2017	Automated sprinkler system for panel cleaning

Sl. No.	Project name	Developer	Capacity (kW)	Type of agrivoltaic	Type of crops	Commissioning year	Additional remarks
7	Dayalbagh project Agra, Uttar Pradesh	Dayalbagh Educational Institute	200	Overhead	Grams, brinjal, tomato, wheat, spinach, cauliflower, carrot	2020	Panel mounted on towers at 18' feet height provide enough space for machinery use
8	Junagarh Agriculture University Junagarh, Gujarat	Junagarh Agriculture University	7.2	Overhead	Tomato	2017	No requirement for agricultural machines
9	Solar-Agri electric model Ahmedabad, Gujarat	Abellon Clean Energy	3,000	Interspace	Bottle gourd, lady finger, watermelon, turmeric, ginger, chilli	2012	A project set up under Gujarat Solar Policy
10	Clean Solar Tandur, Telangana	Mahindra Susten	200	Interspace	lemongrass, brinjals, lady finger, onions, green chillies	2016	The project is part of a 36.6 MW ground-mounted project
11	Agro PV model plants Jalgaon, Maharashtra	Jain Irrigation	14.4	Overhead	Banana, rice	2014	Heightened stills allow the movement of agricultural machinery

Sl. No.	Project name	Developer	Capacity (kW)	Type of agrivoltaic	Type of crops	Commissioning year	Additional remarks
12	National Institute for Solar Energy plant Gurgaon, Haryana	National Institute of Solar Energy	100	Interspace/ below the panel	Tomato, chilli, flowers	NA.	The institute is also planning to develop a vertical PV plant with bifacial modules
13	Cochin International Airport Project Cochin, Kerala	Cochin International Airport	NA	Interspace	Vegetables, cucumber, pumpkin	2015	The project is part of a 40 MW ground-mounted solar project
14	Grosolar agrivoltaic Dhule, Maharashtra	Grosolar	7,000	Interspace/ below the panels	Geranium, onion, vegetables	2021	The project was set up under Mukhyamantri Saur Krishi Vahini Yojana

Source: Compiled from Pulipaka & Peparthy, 2021.

5.0 Insights From Stakeholder Consultations

We interviewed stakeholders involved in several of the pilot projects mentioned in Table 2 to understand their perspectives on challenges and opportunities for agrivoltaics in India. The main findings are below.

1. Agrivoltaics did not negatively impact—and in some cases even increased—crop yields, according to implementers. But pilots in India have only tested agrivoltaics with a limited variety of crops and agricultural settings. Better-designed pilots with rigorous testing methods are required to build a strong knowledge base.

The primary concern from farmers regarding agrivoltaics is the reduction in crop yield due to shading. However, the implementers of pilot projects claimed an increase in yield for medicinal crops and leafy vegetables in their pilots. Their experience suggests that shade-loving crops like pepper, coffee, and cardamom are also good candidates for adoption, while other crops like millet and vegetables do not show any significant reduction in yield.[3] However, the variety of crops that can be grown in an agrivoltaics project is limited based on factors like the height of the crop, shading effect, and irrigation requirements. So far, pilot projects in India have focused on horticulture farming with crops ranging from vegetables (such as brinjal, cabbage, tomato, potato and beans) to lentils (such as moong), flowers (such as geranium) and spices and medicinal plants (such as chilli, cumin, aloe vera, lemon grass, and coriander).

Furthermore, the results from many of these pilots cannot be generalized as they are not controlled for other environmental variables. The lack of adequate data on crop growth factors like temperature, light flux, and humidity in the proximity of crops makes it challenging to identify the precise contribution of agrivoltaics design in crop growth and apply the learnings to a wider geography. Hence, the results so far can only be taken as suggestive of future designs. Further pilots with rigorous testing methods are needed to build a strong knowledge base for scaling up agrivoltaics.

Traditional broadscale crops like paddy, wheat, or sugarcane pose integration challenges with agrivoltaics, primarily because of reduced sunlight. According to the interviewed stakeholders, flood-irrigated crops such as paddy are unviable in the agrivoltaics system. Experiences from other countries on such crops show similar results. Either the crop yield is significantly lower than conventional farming (Gonocruz et al., 2021; Trommsdorff, Gruber, et al., 2022) or the PV panels layout should be of sufficiently low density to reduce shading (Sekiyama, 2019), which significantly increases the cost. Paddy, wheat, and sugarcane account for more than 40% of India's gross cropped area (Ministry of Agriculture & Farmers Welfare, 2022). Cultural and agroeconomic factors strongly influence these crop choices. Their production is subsidized through regulated minimum procurement prices in some states, and they have well-established value chains. Encouraging farmers to shift from such crops would be challenging

[3] We note here that we could not get access to data or peer-reviewed studies establishing these results from any of the projects and hence rely solely on the implementers' claims.

and perhaps inadvisable from a food security perspective. As a result, large swathes of croplands are likely to remain outside the purview of current agrivoltaics practices.

2. The key to commercializing agrivoltaics is technological innovation and testing business models that will be most viable in the Indian context.

Scaling up agrivoltaics requires establishing business cases for it. Agrivoltaics pilots in India have focused on technical analysis, including crop suitability, crop yields, and cost competitiveness. This is likely a result of being studied by DISCOMs or knowledge institutions. However, our interviews revealed there is a significant challenge in aligning the incentives of the two key stakeholders—farmers and developers. It is crucial for states to test new business models in different agroeconomic contexts, integrating farmer perspectives and needs.

Based on our consultations with different stakeholders, we could identify three potential business models. Table 3 summarizes the characteristics of these models.

Models I & II (partnership and sole operation by the PV producer) are prevalent in early-adopter countries like China, Japan, and Europe. Interviewees highlighted the potential for farmer–developer conflict could be a major impediment to scaling up Model I.

Model III (developer as the primary business operator, farmer as a partner) does not fall under those countries' scope of agrivoltaics, given the primacy of agricultural production in their definitions. Most large-scale pilots in India fall into this category (Pulipaka & Peparthy, 2021). Many stakeholders were very positive about the prospects of this model. A significant share of solar power capacity installed in India is concentrated in arid and semi-arid regions with high PV potential and a benefit from shading for agricultural production. The interviewees suggested that Model III can be implemented in many of these projects.

Table 3. Business models of agrivoltaics

	Model I: Partnership between farmer and developer	Model II: System wholly owned and operated by one entity	Model III: Developer as a primary promoter, farmer as a partner

Farmer's role and incentives	• Farmers co-design the system to ensure its suitability for prospective crops. The farmer continues cultivation and manages the agricultural side of agrivoltaics.
	• Farmers' interest lies in increasing income from the land, which can be derived in two ways:
	  ◦ Additional income through land rent may potentially offset any decrease in the agricultural income.
	  ◦ The "services" provided by the PV system—in the form of shading, microclimate, or weather protection—enhance crop productivity and enable a shift to high-value crops.
		• An individual farmer, a group of farmers, or a developer owns and operates the entire system, including agriculture.
		  ◦ Revenue maximization from the available land is the main incentive for the implementer.
		  ◦ For the developer-owned system, the farmer receives land rent.
			• Farmers manage the agricultural side of the system.
			• Farmer gains from access to land that would have otherwise not been cultivated.

Developer's role and incentives	• Developers co-design the project and manage the power generation side of the system. • Developers' interest in participating is through the reduced cost of land and in response to policy incentives encouraging agrivoltaics.		• Developers design the project with modifications to allow cultivation. • Developer benefits from lower site maintenance costs and social goodwill.

	Model I: Partnership between farmer and developer	Model II: System wholly owned and operated by one entity	Model III: Developer as a primary promoter, farmer as a partner
Desirable criteria for stakeholders	• Farmers willing to experiment with new technologies and high-value crops. • Developers willing to experiment with different deployment models.	• Entrepreneurial developers or farmers willing to explore business opportunities beyond agriculture.	• Landless farmers or farmer groups can benefit from this model. • Developers should be willing to accommodate some design modifications, including increasing the panel elevation or space between the panels.
Suitable conditions	• Areas with a high land rent and ready markets available for high-value crops (e.g., peri-urban areas of large cities). • Areas where precision farming and advanced technologies like greenhouses have good adoption rates. • Specific government incentives for agrivoltaics that are shared with the farmer (this is the case in many European countries).	• Areas with a high degree of early technology adoption and ready markets available for high-value crops (e.g., peri-urban areas of large cities). • Areas where shading services improve crop growth (e.g., semi-arid areas).	• It can be implemented in many regions. It has great potential in arid and semi-arid conditions where shading improves the conditions for cultivation.
Design considerations	• Agricultural productivity is a primary design consideration. • Features like raised structure, bifacial panels, and customized orientation allow maximum flux and airflow.	• Increasing net revenue from a given land is the primary design criterion. • Flexibility in crop management, including customized shading management etc., is desirable.	• Revenue generation from power is the primary design consideration. • However, minor changes in structure height and orientation can drastically improve the scope of cultivation.

	Model I: Partnership between farmer and developer	Model II: System wholly owned and operated by one entity	Model III: Developer as a primary promoter, farmer as a partner
Advantages	• Competing interests ensure a balance between agricultural and power production imperatives.	• Opportunity to extract maximum synergy between the two systems.	• Lower capital cost.
Risks	• Convincing farmers to participate may be challenging in the absence of sufficient incentives. • Competition for resources may lead to conflict among stakeholders. • Farmers are locked into a cropping system that must always remain compatible with the agrivoltaics structure, likely resulting in conflicts.	• As maximizing revenue becomes a primary interest for the system owner, agricultural production may lose priority if revenues from power generation are significantly higher. This could potentially create food security concerns.	• Uncertainty for farmers as the developers has a minimal stake in cultivation. • Security risks for the developer as the site will be open to farmers. • See Box 1.

Box 1. Safeguarding against greenwashing and misuse of Model III

The merits of the third model—"Developer as a primary promoter, farmer as a partner"—lie in the additional value it can generate from a land parcel that has very low prospects for cultivation and is therefore already considered appropriate for upcoming ground-mounted solar plants. This is likely to be especially relevant in arid and semi-arid areas, where much land may be barren or have very low productivity. Any application of the model outside this scope could result in unintended negative impacts. For example, if there is an additional incentive for agrivoltaics under Model III, such as monetary benefits or relaxed land-use regulations, developers might try to take up farmer land that is well cultivable and claim that it is barren in order to give a reduced role to farmers. Equally, developers could try to pass off a regular solar power plant as an agrivoltaics system while no agricultural activity is, in fact, taking place. Hence it is important to create necessary safeguards if this model is being adopted by creating standards and definitions for agrivoltaics (see next subsection).

Model III should only be recognized for areas that are

- Barren/not cultivated either due to poor land productivity or state ownership of the land
- Designated for setting up solar power plants through the completion of all modalities related to land-use change.

Overcoming the technological constraints of agrivoltaics systems requires innovation. Based on interviews with experts, innovative technologies, like bifacial PV panels and sun-tracking systems, are finding greater acceptance in agrivoltaics projects compared to ground-mounted power plants. Bifacial panels reduce shading effects, increase power generation, and expand crop choices. The increased height and space between panel rows in agrivoltaics increase power output. Sun-tracking systems are not typically included in conventional solar plants in India due to their high cost. But an entrepreneur who has implemented an agrivoltaics system suggested that the cost escalation from the tracking system is proportionally lower in agrivoltaics. Customized tracking responsive to sunlight requirements during various crop growth stages helps enhance both crop and power output.

The CAZRI pilot has pioneered an integrated rainwater harvesting structure with PV panels in its agrivoltaics system. The project promoters mentioned that water scarcity is a significant concern in drylands, and groundwater is unsuitable for PV plant maintenance. The integrated rainwater harvesting structure significantly improved water availability for irrigation and power plant maintenance. Such innovation adds value and compensates for the cost disadvantage faced by agrivoltaics.

Business models and technology models are closely connected. There is no one-size-fits-all model for agrivoltaics. States can encourage experiments on technology and business models in close collaboration with developers and farmers. States must also identify the relevance of different models based on their agroeconomic context and provide policy support for these business models.

3. Arid and semi-arid regions and peri-urban areas are likely to be favourable locations for agrivoltaics in India.

Agrivoltaics has significant potential in arid and semi-arid areas of India, where excessive thermal stress constrains crop growth. PV panels reduce the sunlight on the ground, reduce the ambient temperature, and create a relatively moist microclimate supporting crop growth (Barron-Gafford et al., 2019). The pilot project at CAZRI, Jodhpur, took place in an arid region and is India's most extensively studied pilot. It demonstrated improvements in yield for different bean varieties, vegetables, and medicinal crops (Santra et al., 2020). Experiences from drylands in other countries, such as the United States, also showed promising results for agrivoltaics with certain crops (Barron-Gafford et al., 2019; Reasoner & Ghosh, 2022). These studies also demonstrate significant improvement in irrigation efficiency under agrivoltaics due to reduced evapotranspiration. It is also theorized that agrivoltaics can mitigate the impact of climate change in vulnerable regions by stabilizing the agricultural yield (Trommsdorff, Dhal, et al., 2022).

About 53% of the total land area in India is categorized as arid or semi-arid (Ministry of Environment and Forests, 2001). Most of India's solar power capacity is installed in similar regions (Kiesecker et al., 2020). These regions have low levels of cropping intensity, indicating complete or partial land uncultivability (ICAR, 2016). Adopting agrivoltaics can improve the cropping intensity of this land and potentially transform the food–energy nexus relationship from competition to synergy. It may also contribute to future food security and climate resilience.

However, there is a shortage of research and pilots in dryland areas, as most pilots have been trialled in temperate regions of Europe, Japan, and Northeastern China (Mamun et al., 2022). Hence, there is a need for further research in structural design and crop selection in arid and semi-arid regions.

Interviewees also suggested that peri-urban areas could also be suitable for the expansion of agrivoltaics. Their proximity to markets for high-value crops and the intense competition for land use in these areas increase the cost competitiveness. In addition, these are areas where advanced agricultural technologies such as greenhouses are prevalent, signifying a willingness to adopt new technologies and potential viability. These areas also have the added advantage of proximity to technical expertise and financial resources to experiment with new technologies and crops. Easier access to media and communication channels also makes peri-urban areas ideal for building technology demonstration projects and raising awareness.

4. Governments need to reform land-use and tax regulations to support agrivoltaics, as well as develop consistent standards and definitions.

Multiple stakeholders emphasized the urgency of developing standards and definitions for agrivoltaics. Academic research and public sector utilities-promoted pilots have dominated agrivoltaics in India. However, commercial adoption of agrivoltaics is contingent on clarity on standards and regulations. Government support and concessional green financing are likely needed to encourage the wide-scale adoption of agrivoltaics. Such support would be contingent on projects meeting certain criteria (i.e., definitions and standards). Standards and definitions need to be developed to allow entrepreneurs to focus on projects that are likely to be eligible for government support and assistance.

There are two key questions that governments should consider in this regard:

What constitutes an agrivoltaics system?

Most early-adopter countries define agrivoltaics by prescribing limits to changes in vital agricultural parameters. The specific parameters selected for definitions vary between agencies and include the change in effective area under agriculture (DIN, 2021), change in total yield (PI-Berlin, 2021), or change in sunlight reaching the ground (Commonwealth of Massachusetts, 2018). The prescribed limits are also specific to the system design. For instance, the agrivoltaics standards by DIN Germany stipulate that the reduction in area under cultivation due to the solar PV system should not go beyond 5% and 10% of the arable lands in the overhead PV and interspace PV, respectively (DIN, 2021). France recently released a detailed set of guidelines to define and grade agrivoltaics along three critical criteria—services to agricultural production, impact on agricultural production, and impact on farm income (ADEME et al., 2021) (Box 2).

Box 2. France's definition of agrivoltaics

Note: The below definition is reproduced in full from ADEME et al. (2021) with slight modifications for clarity.

"A solar PV system can be considered agrivoltaic when the solar PV modules are located on the same area of plot as the agricultural production, and when they impact the agricultural production by providing, without any intermediary, one of the services listed below, without inducing any significant degradation of the agricultural production (both qualitatively and quantitatively), or any farm income loss.

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

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

Commonly used parameters for standards include "change in the effective area of cropping" and "change in crop yield." At present, there aren't enough projects in India to adequately develop these standards. If states wish to use this approach in formulating their definition, more pilots are needed to gather data on local contexts. The union government can coordinate these efforts from different states and collaborate with other first-mover countries in a coordinated manner to prepare a national definition and standards for agrivoltaics.

Creating standards is critical for lending targeted policy support for agrivoltaics. Incentives in the absence of standards may lead to "greenwashing," whereby developers implementing regular solar plants unduly receive the incentives provided to agrivoltaics systems. Policy support can range from loose regulations for agrivoltaics viz-à-viz regular solar plants to monetary support like a higher tariff.

Which regulations need revision to promote agrivoltaics systems?

Our interviews highlighted two principal regulations that need revision to scale up agrivoltaics.

1. **Land-use change regulations:** For solar projects on agricultural lands, legislation mandates a change in land-use status from "Agricultural" to "Non-Agricultural." Although the procedure for land-use diversion has been simplified in recent years, with many states adopting "deemed conversion" status for solar projects (Kumar & Thapar, 2017), it is still a critical step. States should create separate legal provisions for agrivoltaics under their land legislation and solar policies, removing the need for a land-use change and allowing mixed use of land, as recommended by interviewed developers. It may require amendments in the land-leasing laws, as the leasing of agricultural lands is highly restricted in many states. There should be adequate safeguards and enforcement mechanisms to prevent developers from misusing the provision to circumvent land-use laws.

   The land status also determines eligibility for agricultural subsidies, including subsidies for greenhouses (if it is a PV-greenhouse) and precision irrigation subsidies. The respective policies should be amended to clarify these aspects. Land use is a state subject under the Indian constitution, and the power is vested with states to govern this area.

2. **Classification of income from agricultural lands:** Agriculture income is exempt from taxation under India's income tax regulations (Income Tax Department, 2022). Interviewed stakeholders suggested there was a lack of clarity on whether the revenue accrued from agrivoltaics to the farmer—through either land rent or equity share—can be categorized as agricultural income. Other countries also have faced this issue. For example, in Japan, agrivoltaics lands are considered agricultural lands, and tax exemptions for farmlands are extended to revenue from power generation (Bellini, 2021).

5. States need to think beyond the uniform ceiling tariff regime to scale up agrivoltaics.

The viability of a wide-scale incentive program targeted at agrivoltaics is contingent on robust standards and definitions for agrivoltaics. In the short term, the government can provide incentives on a case-to-case basis for supporting new pilots. Another approach to promote pilots is to explore market mechanisms to help developers take inherent advantage of agrivoltaics.

Under the PM-KUSUM scheme, states must fix a pre-fixed levelized tariff for solar plants, and projects are allocated through reverse tariff bidding. Most state electricity regulatory commissions have notified a single tariff for their state, typically arrived at using the levelized cost calculation method. However, interviewees suggested that agrivoltaics cannot compete with a ground-mounted solar plant in commercial terms, except in limited contexts such as areas with high land rent. Land rent variations are not adequately factored in ceiling tariffs as solar power plants are typically installed in unproductive lands. For example, a single ceiling tariff regime puts agrivoltaics in a peri-urban area and a ground-mounted solar plant in a remote location in the same tariff category.

States could adopt alternative tariff determination approaches. One approach is the cost-saved approach, detailed in Chapter 3 of the guidebook, where the state decides the ceiling tariff based on the current cost of servicing power at a distribution substation. The cost of servicing power includes power purchase cost, transmission and distribution charges, and losses to wheel the power to the substation. Such a tariff becomes more viable for developers, especially in urban and peri-urban areas, without causing additional costs to the state. In this way, agrivoltaics can scale up purely on economic merit.

Another possible route is to promote agrivoltaics through an open-access route, as suggested by some stakeholders. Electricity consumers, by way of open-access approval, have the right to procure power from the supplier of their choice, that is, other than the DISCOM, which is authorized under the regulatory framework to operate and maintain a distribution system for supplying electricity to the consumer in their area of supply. DISCOM gets a service charge for wheeling the power. Typically, the tariff realized through the open-access route is comparatively higher. The interviewees also highlighted the attractiveness of agrivoltaics as a sustainability initiative to prospective open-access consumers like corporations. Ministry of New and Renewable Energy (2019) guidelines on setting up distributed solar power plants provide a framework for this.

6. Capacity building of farmers and developers is critical in deploying agrivoltaics.

Interviewed experts also highlighted the importance of training farmers and developers, as the agrivoltaics system design and crop management are skill-intensive processes. The structural design of a system is complex because it needs to consider the amount of sunlight on the ground, ventilation, water management, and safety concerns. Promoters of most pilots with overhead PV structures conducted an extensive simulation of sunlight distribution and design factors like structure height and panel orientation. Additionally, the construction may cause disturbance to topsoil, affecting agriculture and needing special care. Government agencies in other countries mandate a pre-approved plan that details these aspects before approval (Bellini, 2021; Commonwealth of Massachusetts, 2018; PI-Berlin, 2021).

Crop management also needs careful planning. The selection of crops requires knowledge of crop growth in different shading conditions. For the interspace PV, the optimum crop output is obtained if the arable area is properly zoned based on shade characteristics and appropriate crops are selected for each zone. Further, the co-management of the resources will be a significant challenge, as mentioned above.

States can facilitate training programs for farmers and support creating a network of skilled professionals for the developers. At the national level, institutes like CAZRI in Jodhpur are developing knowledge resources and capacities. Similarly, in other countries, knowledge institutions (like Fraunhofer ISE in Germany) and industry associations (like France Agrivoltaisme in France) are taking charge of capacity building. However, considering India's diversity in agroclimatic conditions, knowledge creation and testing should be further decentralized. States can identify local centres of excellence by partnering with knowledge institutions like Krishi Vigyan Kendras, universities etc., and industry partners. Apex institutes like the National Institute for Solar Energy can develop training courses for interested developers and knowledge institutions.

7. Continuous innovation and peer learning are critical to overcoming operational challenges.

Stakeholders also shared insights on the technical and operational challenges they faced in crop management and power production. These are listed below:

Challenges to the agriculture side:

1. **Safety concerns:** The cabling for most pilot projects was done overhead to prevent farmers from digging up the cables and exposing themselves to a safety threat. Still, the sagging of overhead cables can threaten farmers' safety. Some projects had underground cabling, with wires laid at a depth of 1 metre. However, this increases the cost and impacts the crop choices, as reported by some stakeholders.
2. **Mobility of agriculture equipment:** The mounting structure significantly restricts the movement of agricultural machinery, affecting crop production. Increasing manual labour can affect the cost competitiveness of agriculture.

Challenges to the power generation side:

1. **Maintenance:** Cleaning the panels installed at a height of 10–16 feet is a significant challenge for developers. Improper cleaning leads to the development of hotspots on panels, resulting in loss of power. Several solutions have been proposed and implemented, including sprinkler systems attached to panels and automated cleaning systems. However, these technologies need further testing before commercialization. Maintenance of such systems could, in itself, be a challenge.
2. **Structural decay:** Long-term exposure to a moist microclimate can weaken the mounting structures. A site visit to one agrivoltaics project in the arid areas of Rajasthan, installed in 2017, revealed the moisture effect of crop cultivation on

mounting structures. It was observed that the structure's base portion corroded much faster than the rest of the structure.

3. **Water management:** Proponents of agrivoltaics highlight the practice's potential to conserve overall water use—farmers can channel the water used for cleaning panels toward irrigation. However, interviewees shared practical challenges in this technique. Typically, solar plant developers install groundwater softeners on site or buy water in tankers, as hard water is unsuitable for cleaning panels. Solar PV developers indicated that coordinating with farmers to align the schedules of irrigation with cleaning activities is challenging because the water requirement varies during the lifetime of crops. The pilot in Jodhpur by CAZRI pioneered rainwater harvesting structures along with agrivoltaics, which could be a potential solution. It also reduces the runoff risks because of PV panels. But stakeholders pointed out that this could increase the capital cost.

6.0 Future Prospects

Agrivoltaics is rapidly growing globally as a potential solution to the food–energy competition for land. The pilot projects in India demonstrated promising initial results with some crops, addressing the core concern of yield reduction due to shading. There are also early indications that agrivoltaics can provide significant benefits in arid and semi-arid regions. Thus, there is a strong case for further investment and research in agrivoltaics to address India's energy and food security concerns. However, the technology is still nascent, and there are legal, technical, cultural, and political barriers that impede its adoption. The study proposes the following measures to support the scaling up of this technology:

1. Overcoming the multifaceted challenges in implementing agrivoltaics requires a coordinated approach from all stakeholders, which can be best facilitated by the union government through the creation of joint working groups with state officials, knowledge institutions, private developers, and farmer representatives.
2. The union government can support collaboration with first-mover countries such as Germany in developing standards and legal structures and testing new PV module technologies.
3. The union and state governments need to develop definitions and standards for agrivoltaics that are suitable for the Indian context. Agrivoltaics in arid and semi-arid regions has an excellent scope, and India can pioneer its development because it is not well studied in other countries.
4. State governments can support pilot practices that are currently not being tested, such as agrivoltaics with livestock grazing and aquaculture. The diverse agroecology in the country provides scope to experiment in agrivoltaics.
5. Future pilots should focus on business models to examine the commercial feasibility of the agrivoltaics system. Pilots are also needed to explore different crop choices and test the suitability of new designs and technologies of agrivoltaics in various settings.
6. States need to forge partnerships with several stakeholders, including private developers, farmers, financial agencies, and knowledge institutions, to integrate their perspectives into policies and regulations.
7. States need to provide incentives to promote the initial scale-up of agrivoltaics. Incentives can range from a higher tariff for power generation from agrivoltaics for developers and reduced taxes to express recognition of agrivoltaics in land legislation to simplify land-use conversion mandates.
8. State governments can support the establishment of centres of excellence at universities and technical colleges to facilitate capacity building through training programs for both farmers and private developers.

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Appendix. List of Stakeholder Consultations

1. Priyabrata Santra, Principal Scientist, CAZRI, Jodhpur
2. Sunil Purohit, AGM, GIPCL
3. Shravan Sampath, Founder & CEO, Oakridge Energy
4. Sunil Mysore, CEO, Hinren Energy
5. V. K. Jain, Distinguished Scientist and Professor, Amity University
6. Abhishek Verma, Associate Professor, Amity University
7. Barjeev Tyagi, Professor, IIT Roorkee
8. G. J. Girase, Director, Gro Solar Energy
9. Ajit Singh, Future Green Power Solutions
10. P. K. Gupta, Senior Scientist and Head, Krishi Vigyan Kendra Ujwa
11. Narayan R. Salve, Deputy Executive Engineer, Mahagenco

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