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# Agrivoltaics in India: Fertile Ground?

*Multiple Social and Economic Benefits of Farmland Solar Are Possible – But Not Without New Policy Settings*

## Executive Summary

The rapidly developing field of agrivoltaics – combining farming with solar power generation in ways that maintain agricultural productivity – holds special promise for India. A number of research and demonstration projects are already in progress and it has the potential to become an important new player in the country's renewable energy sector.

This report reviews several features of agrivoltaics that make it especially relevant for India, as well as policy challenges that must be addressed if it is to reach its full potential.

The factors that make the sector well suited to Indian conditions include:

- The outlook for energy needs and distributed renewable energy infrastructure
- Geographical characteristics of the solar resource, farmland coverage and land use patterns
- The capacity to address some of the socioeconomic challenges facing India's rural sector
- The advantages of particular agrivoltaic panel configurations for local needs.

In order for the agrivoltaics sector to move from the pilot project stage to more widespread adoption, several policy and regulatory obstacles must be removed. A benefit of having not been amongst the earliest adopter countries is that India can make good use of the policy and legislative responses these countries have already made to help resolve various legal, financial and regulatory challenges.

Lessons learned elsewhere and issues raised by Indian proponents of agrivoltaics form the basis for several recommendations about governance, research and knowledge dissemination, legal issues, incentives for adoption, and the protection of farmers' interests, farmland and food production.

## Table of Contents

## Agrivoltaics Is of Particular Relevance to India

The idea that with suitable crops and conditions, farming output can be maintained at high levels on land that also hosts solar energy generation first arose in Europe, where, together with Japan and China, agrivoltaic methods have also been most extensively tested.

Although some crops cannot tolerate excessive shade, others, including tomatoes, peppers, some leafy vegetables, various berries, and root crops such as potatoes have been shown to grow well with appropriate panel spacing and configurations. Some have even been shown to benefit from reduced exposure to excessive heat and better soil moisture retention in hotter seasons.[1] Yet others can be grown with relatively minor yield decreases under certain panel layouts. In addition, fodder production and/or grazing can be very compatible with appropriate panel spacings and panel support structures.

Globally, it is estimated that agrivoltaic installed capacity has grown from about 5 megawatts (MW) in 2012 to approximately 2.9 gigawatts (GW) today,[2] led mostly by Germany, France, and Italy (whose COVID recovery plan devotes over 1 billion Euros to establishing 2GW of agrivoltaic projects).[3] There has been a rapid accumulation of research and empirical experience, evidenced by the 2021 Agrivoltaics Conference attracting 84 abstracts and delegates from 39 countries in only its second year.[4]

In India, a joint German-Indian report has listed 16 existing installations with details of their location, type, size, crops and panel configurations,[5] and has also developed a publicly accessible online map of these projects.[6] Subsequently an additional 7MW solar project for Gro Solar Energy in Maharashtra has been announced, with low-height crops between modules, and others are in various stages of development.

Though at a very early stage, and comprising mostly small-scale research and demonstration projects, agrivoltaics is of special relevance to India for three distinct reasons.

The first concerns the scale and scope of electricity system growth. India is on course for significant energy demand growth over coming decades at just the time when calls to accelerate the clean energy transition are intensifying and Prime Minster Narendra Modi has committed to a key 2030 goal of 50% renewable

[1] Weselek, A et al. Agrivoltaic system impacts on microclimate and yield of different crops within an organic crop rotation in a temperate climate. Agron. Sustain. Dev. 4, 2021.
[2] Fraunhofer ISE. Agrivoltaics. Company website.
[3] PV Magazine. Italy devotes €1.1bn to agrivoltaics, €2bn to energy communities and storage. 28 Apr 2021.
[4] Agrivoltaics 2021 Conference and Exhibition website.
[5] National Solar Energy Federation of India (NSEFI). Agrivoltaics in India: Overview of operational projects and relevant policies. Commissioned by Indo-German Energy Forum Support Office on behalf of Ministry of New and Renewable Energy (MNRE), Govt. of India Federal Ministry for Economic Affairs and Energy (BMWi), Govt. of Germany, v.2.4, May 2021.
[6] Agrivoltaic Pilots in India (online map).

energy.[7] Unlike Europe, where demand is static or falling and sectors such as transmission and distribution are fully mature, India will see far more extensive power infrastructure growth of all types and strong incentives to build a geographically diverse and robust network, at speed. This will favour forms of generation that can be built quickly and at a range of scales, across the country, which could favour growth of agrivoltaics.

The second reason is geographic. Sixty percent of India's land area is farmed, a much higher share than the world average of 39%.[8] Agrivoltaics in India is better placed than in most countries to relieve pressure on other land and ecosystems, as suggested in IEEFA's recent report on mid-century land-use.[9] Coupled with this is the widely spread nature of India's solar resource. Although areas such as Rajasthan offer especially high levels of generation potential, large tracts of the country are capable of producing solar power in higher quantities and more reliably than almost any European countries except Spain and Portugal.

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Moreover, solar generation potential is determined not only by insolation but factors such as the prevailing microclimate. In a comparison of 17 land cover types, a 2019 study found that, globally, croplands provided the highest generation potential at about 28 $W/m^2$ reflecting favourable combinations of wind, temperature, solar radiation and humidity, leading the authors to conclude that *"dual-use, agrivoltaic systems may alleviate land competition or other spatial constraints for solar power development",* [10] an important requirement for India's energy transition.

The third reason has to do with the socio-economic opportunities agrivoltaics could offer to India's rural sector, a case that has been argued for both developed and developing countries.[11] [12] Despite Indian agriculture's regional diversity, some common and persistent challenges confront the rural sector in large parts of the country. These include low and unreliable farm incomes, lack of alternative income sources, dependence on rain-fed farming, and inadequate infrastructure for

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[7] The Wire. COP26: Modi Announces 2070 Net-Zero Target in Expanded Bouquet of Climate Pledges. 2 Oct 2021.
[8] World Bank. Agricultural land (% of land area).
[9] Worringham C. Renewable Energy and Land Use in India by Mid-Century. IEEFA. Sept 2021.
[10] Adeh, EH et al. Solar PV Power Potential is Greatest Over Croplands. Sci Rep 9, 2019.
[11] Proctor AW. Agrivoltaics Align with Green New Deal Goals While Supporting Investment in the US Rural Economy. Sustainability, 13, 2021.
[12] Abidin MAZ. Solar Photovoltaic Architecture and Agronomic Management in Agrivoltaic System: A Review. Sustainability, 13, 2021.

retaining value from agriculture in communities (through cleaning, drying and processing crops, storage and cold-chain facilities, etc.).[13] Wastage in agricultural product storage and distribution is widespread,[14] and the absence of effective cold-chains has been implicated as a major problem.[15] Many farmers live at the periphery of India's grid, and a reliable power supply still eludes many even if tariff cross-subsidies generally flow in the direction of rural consumers.

A related and pressing socio-economic issue is the additional growth stress on cities brought about by large-scale seasonal migration, which sees millions of rural Indians seek work in cities for part of the year, given the increasing difficulty in living securely off the land year-round. In the face of declining farm-size (over 70% of rural households own less than one hectare of land),[16] unreliable weather, variable access to markets[17] and price instability, any innovations that could strengthen the rural economy, stabilise agricultural employment and grow non-agriculture work could contribute to relieving the pressures of rapid growth on India's cities.

## *Several Agrivoltaic Technology Developments May Suit Indian Conditions*

India's initial batch of projects represents the full range of equipment types and configurations. These vary from simple ground-mounted rows of panels with larger than normal spacing to allow crops between panels, to single-axis and biaxial tilting arrays, with multiple types of support structures to raise panels above crops.

Indian conditions may favour particular types of agrivoltaic technology. For example, new panel designs suited for this application are starting to be developed, including transparent panels and those with spectral sensitivity tuned to particular locations[18,19] as well as the use of Fresnel lenses to preferentially direct sunlight onto crops (or into greenhouses) in winter and to panels in summer, an approach that has been evaluated in Spain and Italy.[20] These would increase the cost, but potentially enhance the productivity of agrivoltaic projects.

One substantial capital cost for agrivoltaic as opposed to standard solar projects is the additional expense of support structures to raise and secure panels. For larger

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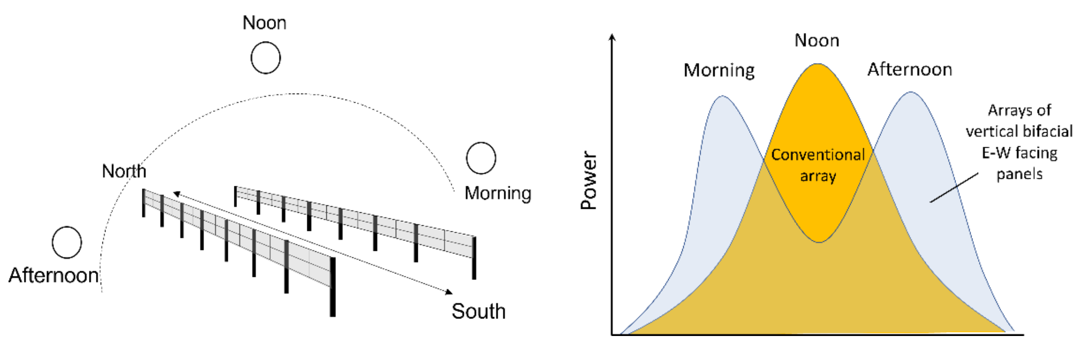
[13] Tongia, R. India's Biggest Challenge: The Future of Farming. The India Forum. 4 Oct 2019 (updated 28 May 2021).
[14] India Today. India grows more food, wastes more, while more go hungry. 22 Dec 2020, updated 21 Jan 2021.
[15] Economic Times. India in dire need to upgrade and expand its cold-chain capacity in food processing sector. 28 Jun 2021.
[16] Govt of India, Ministry of Statistics and Programme Implementation. Situation Assessment of Agricultural Households and Land and Holdings of Households in Rural India, 2019. BNSS 77th Round, Sep 2021.
[17] Chatterjee S et al. A Study of the Agricultural Markets of Bihar, Odisha and Punjab. Final Report. Center for the Advanced Study of India, University of Pennsylvania: Philadelphia. 2020.
[18] PV Magazine. Special solar panels for agrivoltaics. 23 Jul 2020.
[19] PV Magazine. Vietnamese manufacturer unveils PV module for agrivoltaics. 6 Oct 2021.
[20] Roccaforte G. Eclipse: A new photovoltaic panel designed for greenhouses and croplands. AIP Conference Proceedings 2361, 070002, 2021.

farms, at least, the need to control costs may drive the use of innovations including 'wide-span' tension support structures such as those developed by Germany's SBP Sonne, instead of conventional steel or truss supports. With arrays of horizontally distributed panels in a 'checker-board' pattern above crops, such systems could cut materials costs and give good access for farm equipment.[21]

Technological advances in agrivoltaics take in novel configurations as well as specific equipment. A variation of special interest to India is the use of bifacial panels arrayed in widely-spaced rows, which in addition to the different generation properties explained below, reduces dust accumulation, an important aspect of maintenance, especially in more arid regions.

One such layout is being trialled by India's National Institute of Solar Energy (NISE) as well as by Germany's Next2Sun GmbH[22] and Märladalen University in Sweden.[23] Vertical bifacial panel arrays have the property of generating maximum power in a morning and an afternoon peak, complementing the typical solar profile of midday peaking (Figure 1).

## Figure 1: Layout of Vertical Bifacial Panels and Generation Pattern Compared to Conventional Arrays




*Source: Author.*

The late afternoon generation this configuration allows could partly relieve evening peak demand to the extent that loads can be shifted earlier, as may be possible for some residential cooling, or by reducing the time between generation and discharge of batteries, enabling more flexible charging schedules. A research group at Lahore University of Management Sciences has undertaken extensive modelling of these layouts for

**Vertical bifacial arrays could be a particularly attractive option for agrivoltaics developers in India.**

[21] Frank, M. Low-Cost Long-Span AgriPV Solutions for Large-Scale Applications, Agrivoltaics 21.
[22] Next2Sun GmbH. Company website.
[23] Märladalen University. Double benefit when future solar cell systems combine agriculture and electricity production.

relevant latitudes, suggesting high levels of generation relative to conventional configurations.[24] If time-of-day pricing is introduced for feed-in tariffs as well as on the consumer side, vertical bifacial arrays could be a particularly attractive option for agrivoltaics developers in India.

## *Research and Demonstration Projects Are Crucial To Establish Agricultural and Financial Viability*

To be viable, let alone successful, an agrivoltaics project must meet some key requirements. First and foremost, it must complement, not replace the primary agricultural purpose of the land.

Although the ideal outcome is to see crop yields maintained (or in some special circumstances, even improved), minor yield declines (typically from additional shading) could be acceptable if the net benefits are clear. For example, a 5% drop in yield could be more than offset by additional income from selling the electricity, and/or using it to reduce wastage through refrigeration or adding value through additional processing, especially where power availability was previously limited or unreliable.

Several groups in India have already made a strong start in research to establish the circumstances in which agrivoltaics can be viable. There are multiple variables whose individual effects and interactions have to be considered, and these are best studied by specialised research organisations.

These factors include the effects of different panel layouts, because maximising power generation favours densely arrayed panels, while maximising yield requires dispersing the panels so as to prevent excessive shading. This involves studying how panel arrays with various combinations of spacing, height, orientation and support structures affect plant growth and farming practices as well as power output.[25]

Many other factors, especially appropriateness for different crops with varying levels of shade tolerance, interactions with soil and water conditions, maintenance tasks and costs (such as de-soiling panels) all influence viability. Establishing their effects goes beyond agricultural and technical research, because the financial outcomes require analysis of how optimising the various trade-offs affects farmers' incomes under different ownership and tariff regimes.

The Central Arid Zone Research Institute (CAZRI) is one group leading India's agrivoltaics research effort, with a track record of several years and important technical and economic studies, such as a report describing how different shading zones beneath and between panels affect photosynthesis.[26]

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[24] Younas, R. Agrivoltaic Farm Design: Vertical Bifacial vs. Tilted Monofacial Photovoltaic Panels arXiv:1910.01076v1 [physics.app-ph]. 2 Oct 2019.
[25] Parkinson S. Economic Potential for Rainfed Agrivoltaics in Groundwater-Stressed Regions Environmental Science and Technology 7. Jun 2020.
[26] Santra P. Spatial and temporal variation of photosynthetic photon flux density within agrivoltaic system in hot arid region of India. Biosystems Engineering. 209. Sep 2021.

Arid and semi-arid conditions predominate in large parts of the country and a special feature of agrivoltaics in these areas may be in soil moisture retention and water-harvesting. Both are being studied at CAZRI and since the majority of Indian farms are rain-fed, it is especially important to establish how the water regime can be improved. A recent US study on pasture land in Oregon showed substantial increases in soil moisture beneath panels, greater late season biomass, and much improved water efficiency. The study concluded that *"semi-arid pastures with wet winters may be ideal candidates for agrivoltaic systems as supported by the dramatic gains in productivity"*.[27] Although these specific soil and meteorological conditions may not be exactly replicated in India, the prospect of improving the use of available water as a co-benefit of agrivoltaics should be high on the list of research priorities. Scarce and unreliable water afflicts many farming regions, as outlined in two recent works on Maharashtra's Marathwada[28] and Vidarbha[29] districts.

CAZRI is joined by projects run by the National Institute of Solar Energy as well as Anand Agricultural University and Junagadh Agricultural University (Gujarat), Dayalbagh Educational Institute and Amity University (Uttar Pradesh). But commercial undertakings have also established research programs, such as that by Jain Irrigation Systems Pvt Ltd in Maharashtra. A recent German-Indian study has evaluated another Maharashtra project, finding that *"Depending on the institutional arrangement between the farming community and the investor, the social impact is expected to vary from high benefits to risk of severe poverty among affected farmers"*, emphasising the importance of regulatory and financial arrangements offering adequate protections.[30]

## Energy Security Must Not Compromise Food Security

Although lessons can be learned from the experience of other countries, the roll-out of agrivoltaics in India cannot proceed without taking account of the need to protect food production and food producers. Levels of food insecurity remain stubbornly high and, as Indian commentators have noted, India accounted for 22% of the global burden of food insecurity, the highest for any country, in 2017-19.[31] Median farm size is under one hectare, with high levels of self-consumption of produce, most farm labourers owning no land, and multiple

**The roll-out of agrivoltaics in India must take account of the need to protect food production and food producers.**

[27] Adeh E et al. Remarkable agrivoltaic influence on soil moisture, micrometeorology and water-use efficiency. PLoSONE. 1 Nov 2018.
[28] Iyer, K. Landscapes of Loss: The Story of an Indian Drought. Harper Collins India, 2021.
[29] Hardikar J. Ramrao: The Story of India's Farm Crisis. Harper Collins India, 2021.
[30] Trommsdorf M. Potential of agrivoltaics to contribute to socio-economic sustainability: A case study in Maharashtra/India. AIP Conference Proceedings 2361, 040001, 2021.
[31] The Hindu. More evidence of India's food insecurity. 24 Aug 2020.

structural and market access issues confronting the sector.[32] Any policies governing agrivoltaics must take account of these realities, as well as the needs of the 300 million additional citizens (still anticipated in coming decades despite recent falls in the total fertility rate),[33] and be designed in such a way that farming livelihoods, food quality and output are sustained.

Practical experience has already shown that inadequate regulation can result in a backlash against agrivoltaics. For example, over-development of projects in Taiwan, attributed to the higher profitability of energy generation compared to farming, led the Taiwanese Council of Agriculture to remove the right of local governments to approve projects over 2MW and centralising approvals.[34]

Similar actual or potential conflict between power generation and farming has resulted in some clear policies and regulations in several countries. These can address technical stipulations, such as requiring minimum panel heights (e.g. 2m above ground in Taiwan), and/or maximum shading ratios (e.g. 50% in Massachusetts, USA).

Other approaches can require agrivoltaics projects to have no more than a specified effect on yield compared to standard farming. For example, the Japanese Ministry of Agriculture, Forestry and Fisheries has instituted a guideline for agrivoltaics in rice farming that requires a minimum yield of 80% compared to standard conditions. (This has been reported to be achievable with shading at a maximum in the range of 27-39%. Applied to all Japan's rice farms, this ratio of coverage by solar panels has been estimated as having the potential to generate 29% of Japan's electricity demand.[35])

Taiwan has also adopted a minimum yield standard, choosing a value of 70% of the average yield for the three seasons preceding a project's inception.

The French Environment and Energy Management Agency (ADEME) has taken a definitional approach, stipulating that an agrivoltaic project is one that is *primarily* agricultural, and *secondarily* produces solar energy, and *creates synergies* between the two. They apply the principle that farming must not be diminished in quality or quantity by the presence of panels – a standard that some argue is too onerous on developers.

Balancing energy production and food production is an optimisation exercise. A quantity that has emerged in considering the economics and viability of agrivoltaics projects, which can be estimated for a given piece of land at the proposal stage and potentially used in the approval process, is the Land Equivalent Ratio (LER). This

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[32] Tongia, R. India's Biggest Challenge: The Future of Farming. The India Forum 4 October, 2019. Updated 28 May 2021.
[33] Washington Post. India says nationwide birthrates drop below key 'replacement rate'. 25 Nov 2021.
[34] PV Magazine. Restrictions for solar on agricultural land may slow PV growth in Taiwan. 29 Jul 2020.
[35] Gonocruz RA. Analysis of the Rice Yield under an Agrivoltaic System: A Case Study in Japan. Environments. 8, 2021.

compares the energy output of an agrivoltaics project to that of a pure solar farm, and the crop yield of the agrivoltaics project to that of farming only, all for the same piece of land:

$$LER = (Energy_{Agrivoltaics}) / Energy_{Solar\ Farm}) + (Crop\ Yield_{Agrivoltaics} / Crop\ Yield_{Farm\ only})$$

In theory, any value above one represents a more efficient use of land as an agrivoltaic project than as either purely agricultural land or a solar farm. But it is perfectly possible to weight the two components of the ratio, and or set thresholds, to reflect whatever balance is desirable.

However Indian policy-makers proceed, adopting a carefully considered set of standards and definitions, matched with an approval process that safeguards agriculture is essential. Without an agreed and clear process, many potential projects will wither on the vine.

Similar restrictions could be developed by India's states to suit regional circumstances, with the possibility that the Union Government might set "backstop" standards as a means of safeguarding agricultural production.

A second approach to the protection of farmers' interests would be to build on the existing prohibitions on using land designated for agriculture for other industrial purposes. Reforms of land-use classification could give farmers (and in most cases, farmers' groups) the right to own and operate agrivoltaics facilities, rather than energy developers, discoms or other intermediaries, perhaps by enabling them to apply for redesignation of land in a special agrivoltaic land category. This would not prevent them contracting with energy companies to install and operate facilities, but it would ensure that the control of land beneficial ownership be retained in farming communities.

# Recommendations

## *Governance*

Currently, the sector's growth is limited by uncertainties stemming from the separation of responsibilities between state ministries of agriculture and energy. This is reflected at the central level with its Ministries of New and Renewable Energy on the one hand, and Agriculture and Farmers' Welfare on the other. There are numerous precedents at both state and union levels for establishing Inter-Ministerial Committees or working groups, and the development of the sector may benefit from such arrangements, especially in its early stages when policy and regulatory uncertainty is greatest.

Regional variation in crops and conditions, farming practices and markets for produce suggest that states should have primary responsibility for agrivoltaics, with support from the Union government limited to items such as minimum standards and definitions, incentive schemes, and centrally funded research and agricultural extension.

## *Measures to Develop Agrivoltaics Knowledge and Expertise*

### Research Grant Schemes

Knowledge of agrivoltaic methods is accumulating quickly, but specific grant schemes could promote the evaluation of current practices in local conditions as well as nurturing a uniquely Indian research program that can take economic and social as well as technical factors into account.

### Agricultural Extension

Equally important is the dissemination of up-to-date and practical information to farming communities.

Funding for agrivoltaics programs within the Agriculture Ministry's Sub Mission on Agricultural Extension (SMAE) could give farming communities greater confidence in trialling agrivoltaics methods, as has been implemented elsewhere (e.g. the Farmer's Guide produced by the U.S. Department of Energy),[36] and state extension organisations should provide localised advice and support, despite reportedly inconsistent funding and performance of such services in different states.[37]

## *Measures to Accelerate and Promote Agrivoltaics Adoption*

### Designation of New Land Use Category

Most states forbid non-farming commercial activity on farmland unless it is reclassified as commercial land. This dichotomy between farming and other uses is a major barrier to agrivoltaics developments. By introducing a specific agrivoltaic land category, States could enable farm communities to establish income-generating agrivoltaic projects while retaining land ownership.

### Financial Incentives

At a time when many Indian farmers carry debts and struggle to afford seed and essential inputs, the uptake of agrivoltaics will be very limited unless the capital costs of installation can be met in whole or part, especially during the sector's early growth phase. Governments could provide early-stage support indirectly through loan guarantees via commercial lenders, or by direct support mechanisms, such as extensions to the Union government's PM-Kusum scheme. Direct support mechanisms would be the preferred option if small farmers are not to be frozen out of opportunities to adopt agrivoltaics, because additional loans would simply aggravate debt burdens for many.

The PM-Kusum scheme seeks to incentivise renewable generation in agriculture with three categories, two specifically directed towards solar irrigation, and one (Part A) for general purpose power generation, restricted, however, to 'barren' land. The PM-Kusum scheme or future variants should consider the addition of a new

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[36] U.S. Government Department of Energy, Office of Energy Efficiency & Renewable Energy. Farmer's Guide to Going Solar.

[37] Indian Express. The need of the hour: Bridging the gap between agri researches and farmers. 30 Nov 2021.

component to fund suitable agrivoltaics developments on productive farmland, without tying the uses to irrigation, as this would artificially restrict the range of potential projects.

Whichever mechanism is chosen, no policy to drive the development of an agrivoltaics sector is likely to be successful without a decision to provide an initial period of financial support.

## *Measures to Protect Farmers, Farmland, and Farm Production*

### Ownership and Development Rights

Grid-scale solar parks already have avenues to development through the designation of land for commercial purposes, and this will continue. There is merit in vesting ownership and development rights for agrivoltaics with farm communities rather than power companies, particularly through Farmer Producer Organisations (FPOs), as these bodies are best placed to determine the type of project that may be most suitable given crop and soil conditions, options for panel and support structure layouts, etc. They can aggregate smaller pieces of land and negotiate on behalf of smallholders, sharing any income from selling power, and determining the best use of electricity generated (self-consumption or sale). Such arrangements would not prevent FPOs contracting with power companies to undertake the project work on their behalf.

### Flexibility for Market Participation and Self-consumption Options

In areas where the grid is well developed and farmers have sufficient power access, selling all of the generated electricity to discoms may be the most attractive option. But flexible regulations allowing specified levels of self-consumption may be preferable for farmers who wish to firm their own electricity access, or direct it towards new economic activity, such as food processing or refrigeration.

### Standards and Oversight

To prevent loss of high productivity farmland to ‘sham’ agrivoltaics projects in which the intention is to sell power and discontinue farming, standards for continued agricultural production should be developed, along the lines of those in Japan, Taiwan or France described earlier. This will require independent audits before and after projects are develop. States could develop a system of incentives for successful co-production of power and crops, and retain the authority to discontinue projects if they consistently fall below the minimum established standards.

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