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NATIONAL SOLAR ENERGY FEDERATION OF INDIA
NSEFI
MAKING SOLAR ENERGY AFFORDABLE

Agrivoltaics in India

Overview of projects and relevant policies

Imprint

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Introduction

The report offers a thorough analysis of agrivoltaics in India, providing a comprehensive overview of 22 operational projects and 3 upcoming pilot projects. It delves into the technical, financial, and agricultural aspects of these initiatives, offering detailed insights. Additionally, the book assesses relevant Indian policies related to agrivoltaics, serving as a foundation for discussing the immense potential of agrivoltaics in India. Its findings highlight the significance of agrivoltaics in the country's ongoing energy transition.

As an emerging economy, India's demand for electricity has increased rapidly in recent years and is expected to grow further at an annual rate of +6% [1]. With no sign of this momentum slowing in the near future, India is poised to rapidly expand its generation capacity. The focus increasingly has shifted towards solar power capacity additions which undercut thermal generators in terms of price per unit of electricity (Levelized cost of electricity, LCOE). Additionally, in response to international efforts to decarbonise the economy, the Indian government has set an ambitious target of 500GW of installed renewable energy capacity by 2030, with around 300GW coming from solar energy alone [1].

From April 2022 to January 2023, the increase of solar capacity was +9.8 GW [2]. As of 31st January 2023, India's solar capacity reached 63 GW [2], already making it the 5th largest country in the world in terms of installed solar capacity.

However, in order to achieve the necessary growth rates to reach the 2030 ojective, the Government of India amongst other schemes introduced Kisan Urja Suraksha evam Uthaan Mahabhiyaan (KUSUM) translating to Farmer Energy Security and Guarantee Scheme. The scheme consists of three components aiming to boost the erection of decentralised solar generation capacities.

Component-A facilitates the implementation of decentralized ground-mounted grid-connected solar power plants with a combined capacity of 10 GW. These solar plants, ranging from 500 kW to 2 MW in size, can be installed on both agricultural and barren land. The strategic selection of agricultural land for solar plant development is primarily driven by its proximity to infrastructure and demand centres, as well as the availability of bureaucratic incentives and farmers' willingness to set up the project on their land. However, it is important to acknowledge that this approach may give rise to land use challenges between energy generation and crop cultivation.

As a result, the co-location of crop cultivation and solar power generation on the same area, commonly known as agrivoltaics, is gaining interest in Indian academia, industry, and politics. Through this report, agrivoltaics facilities across the country were examined to understand their operations, workings, and best practises to ultimately prescribe the way forward for agrivoltaics in India.

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Acronyms and Abbreviations

APV	Agrivoltaics
APVRT	Roof Top Agrivoltaics
CAZRI	Central Arid Zone Research Institute
DISCOM	Distribution Company
GIPCL	Gujarat Industries Power Company Ltd.
GSECL	Gujarat State Electricity Corporation Limited
GUVNL	Gujarat Urja Vikas Limited
GoI	Government of India
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
FiT	Feed-in-Tariff
FPO	Farmer Producer Organisation
IGEF	Indo-German Energy Forum
IGEF-SO	Indo-German Energy Forum Support Office
JAU	Junagadh Agriculture University
JISL	Jain Irrigation Systems Limited
KUSUM	Kisan Urja Suraksha evam Uthaan Mahabhiyaan
MNRE	Ministry of New and Renewable Energy
MoP	Ministry of Power
NHPC	National Hydroelectric Power Corporation
NHRDF	National Horticultural Research and Development Foundation
NISE	National Institute of Solar Energy
NSEFI	National Solar Energy Federation of India
NTPC	National Thermal Power Corporation
PBI	Performance-based Incentive
PPA	Power Purchase Agreement
REPP	Renewable Energy Power Project
SECI	Solar Energy Corporation of India
STP	Sewage Treatment Plant
TNERC	Tamil Nadu Electricity Regulatory Commission
WUA	Water User Associations

Key Findings

1. The co-location of solar panels and commercial crops, known as Agrivoltaics, is a beneficial concept for India that has the potential to: solve the problem of clean energy production; enable rural farmers to participate in India's growth and progress; and save valuable and fertile farmland from increasing land pressure.

2. Currently operating agrivoltaic pilots range from a few kW to several MW of installed capacity, and there are no utility-scale pilots yet. Instead, the pilots are focused on further exploration and gathering experience and research.

3. Throughout the report it can be seen that there is a trend towards the development of 3 main types of plant layouts for agrivolatic installations.

    a. Ground-mounted panels, which allow interspace farming. The Agrivoltiac site at Cochin airport is currently the most advanced and largest example of this type in India.

    b. Slightly elevated panels, that allow crops to be grown partially under the panels and in the space between the panels. By raising the structures slightly, the space under the panels can be used for shade-loving crops, allowing a slightly higher land use. For example, at the CAZRI research site in Jodhpur and at the GIPCL plant near Amrol these systems are installed.

    c. Fully elevated panels, that allow farming and cultivation with small machinery under all parts of the site. Depending on the number of panels installed and the use of additional irrigation, a whole new microclimate can be developed. This allows farmers to grow new or higher value crops and diversify their income. This type of system is also installed at the Agrivoltics site near Parbhani.

    d. Other notable layouts include: vertically mounted systems or single and multi-axis trackers.

4. Despite a slightly higher panel cost, there is a trend towards increased use of bifacial panels. Due to the higher mounting structures in agrivoltaic installations, reflections to the back of the panels increase, which only bifacial panels can take advantage of.

5. In most reviewed cases, operation of the solar plant and farming activities are conducted by two different parties. By fostering strong collaboration and communication among all involved parties, the potential for miscoordination can be minimized, leading to enhanced operational efficiency and productivity.

6. In existing installations across the country, there is an ongoing effort to accurately assess the balance between the additional costs of accommodating agriculture under solar panels and the corresponding revenue generated from cultivation. Developers have identified the cost of building higher structures and effectively cleaning solar panels at greater heights as key considerations. This provides an opportunity for further analysis and innovation to optimise these aspects and increase the positive impact of agrivoltaics.

Way Forward

In order to accelerate the adoption of agrivoltaics in India, a policy framework is needed to create the right conditions. Based on the experience of existing pilot projects and input from roundtable discussions on agrivoltaics, renewable energy conferences and bilateral exchanges with local research and development institutions, the following appropriate measures have been identified. Some of these are further elaborated in the chapter on Policy Recommendations.

- **Define Agrivoltaics with minimal Requirements to be met**
- **Initiate a National Level Research Program on Agrivoltaics**
- **Integrate Agrivoltaics into India's Land Use Classification**
- **Establish a Multi-Ministerial Committee for Coordinated Action**
- **Introduce Financial Incentives for Agrivoltaics in India**
- **Define National Deployment Targets for Agrivoltaics**
- **Innovative Tenders for Agriphotovoltaic Demonstration Projects**
- **Establish a Single Window Clearance and Nodal Agency for Agrivoltaics**
- **Introduce Agrivoltaics Award of the Year**
- **Establish dedicated Skill Development and Capacity Building Programs**

Policy Recommendations

1. Define Agriphotovoltaics
    - Indian standard or other definition may be proposed by assessing and analyzing the standardisation DIN SPEC 91434:2021-05 [17], ADEME – Characterising Solar PV Projects on Agricultural Land and Agrivoltaism in France or the Guidelines for the Design, Construction and Operation of Agrivoltaic Plants from Italy
    - Allow projects to be developed on agricultural land
    - Min. of 80% of the total surface may have to be guaranteed to be available and used for agricultural purposes
    - Crop cultivation plan, cleaning concept and periodic reports may be made mandatory
    - Foresee further adaptations based on continuous feedback from farmers and developers for design improvement
    - Consultation with Ministry for Agriculture & Farmers Welfare to ensure a clear ownership structure from onset

2. Define deployment targets for Agriphotovoltaics for the next 10 years
    - Start with annual targets in MW towards potential GW targets until 2030
    - Involve states with a request to submit state wise targets to ensure ownership
    - Involve the Ministry of Agriculture & Farmers Welfare to improve collaborative efforts of the agricultural and energy sector

3. Initiate special "innovation tenders" for Agriphotovoltaic projects
    - Through SECI, NTPC, NHPC and other nodal agencies
    - Draft a federal tender guideline supporting states to easily adjust and adapt to regional conditions
    - Consider different cost structures of various agrivoltaic concepts by defining sub groups within agrivoltaics tender guideline (distinguish between tenders for vertical and horizontal agrivoltaics)
    - Explore large utility scale >10 MWp agrivoltaic farms
    - Consider offering around 25% viability gap funding for a pre-defined amount of initial capacity
    - Create bank financing products specific to AgriPV projects through IREDA, NABARD and others
    - In consultation with the Ministry of Agriculture & Farmers Welfare explore opportunities for synergies in the horticulture sector e.g. for grapes or other fruits or vegetables that require protection from sun scorching or other extreme weather events

4. Introduce the 10th category of "agriphotovoltaic land" to the current classification of land in India
    - Based on Ministry of Statistics and Programme Implementation [18]
    - Provide legal certainty to farmers by certifying their land holdings especially regarding agricultural land productivity and clearly defined rights in a potential lease agreement
    - Category to assure developers to get all construction permits if in line with the definition of Agriphotovoltaics

    - Provide guidelines for supporting states to elaborate common approval procedures in their region

5. Establish a multi ministerial committee to coordinate action
   - With members from MNRE, Ministry of Agriculture & Farmers Welfare and Ministry of Science and Technology
   - With the involvement of interest groups from Industry and Agriculture and states

6. Introduce Agriphotovoltaics Award of the Year
   - Together with NISE on a national level

7. Establish a dedicated national research program on Agriphotovoltaics
   - Create a compendium of suitable Agri and Horti crops and the extent of increase in productivity based on climatic zones which will aid in project design and development
   - Involve the Ministry of Agriculture & Farmers Welfare

8. Establish dedicated skill development and capacity building programs
   - E.g. in cooperation with the Skill Council for Green Jobs [19]

Overview of Agrivoltaic Projects in India

In order to compile this report, experts of NSEFI and IGEF-SO visited agrivoltaic projects across the country. This section gives a detailed insight into findings regarding capacity of the power plants, cultivated crops, operational principles as well as techno-economic aspects. Figure 1 shows the location of operational agrivoltaic projects in India.[1]

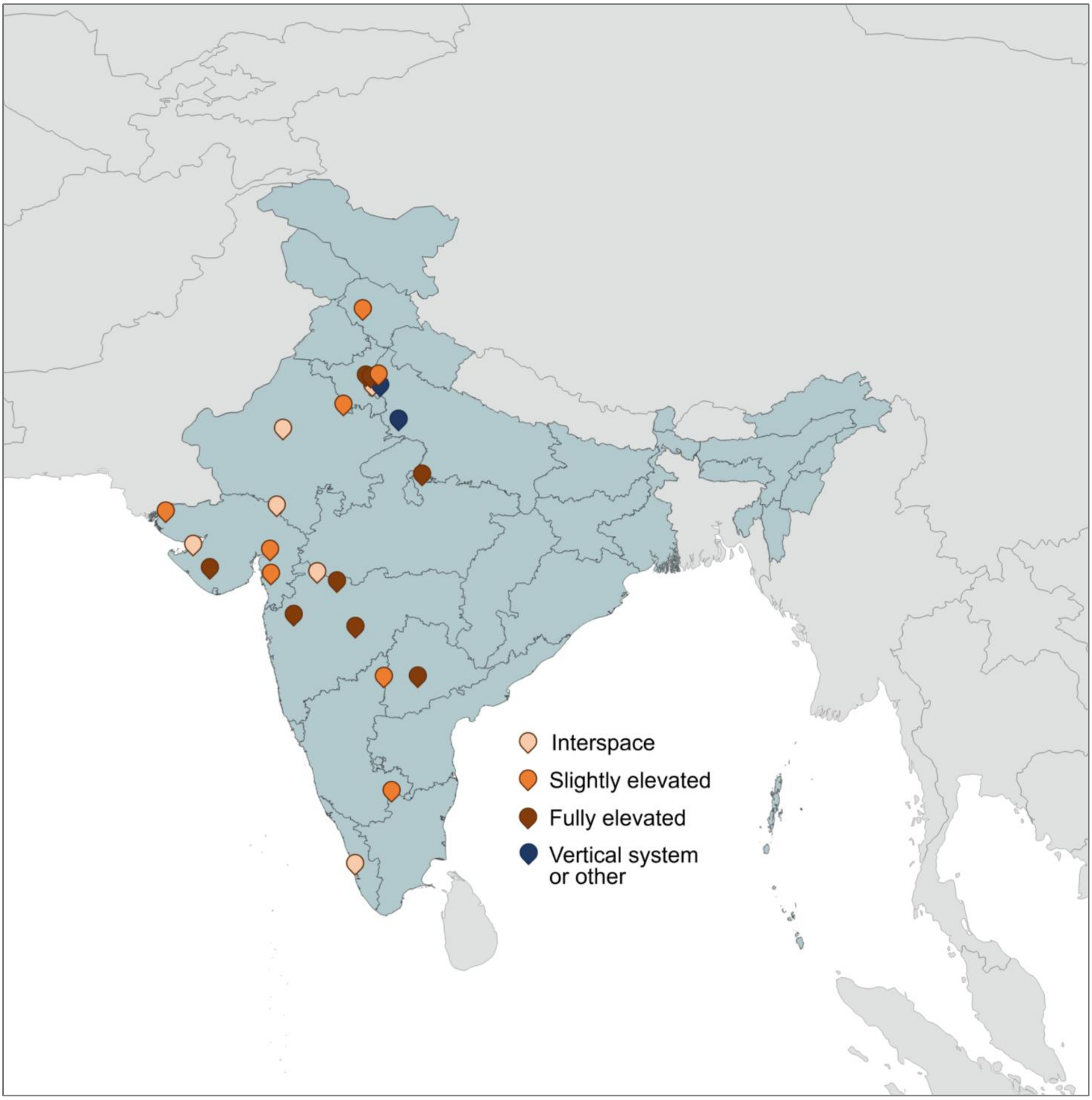

Figure 1: Agrivoltaics projects in India by type of agrivoltaics system

[1] Interactive map with location of all plants covered in this report can be found here. Any plants to be added or any information to be modified kindly get in touch with agropv@energyforum.in or admin@nsefi.in.

Existing Projects

GIPCL plant near Amrol, Gujarat - 1 MW

Table 1: Properties of GIPCL plant near Amrol, Gujarat

Project name	**Amrol Distributed Solar Power Project**
Date of commission	28.04.2016
Installed capacity DC	1 MWp
State, city	Gujarat, Amrol
GPS location	22.37903, 73.05033
Type of project	Commercial
Project developer	Gujarat Industries Power Company Ltd. (GIPCL)
EPC	GIPCL & local companies
Ownership structure	GIPCL
Operation & Maintenance	GIPCL
Scientific partner	Anand Agricultural University (AAU), Dr. Mevada
Financing structure	3.44 Rs./kWh in 2019 Generated power is directly fed into rural grid (11kV rural feeder in 12km distance) Minimum T&D losses: Down from 8 - 10% to about 1% Investment: 6 Crore INR/MWp; 60,000 INR/kWp
Type of agrivoltaic plant	Interspace / Overhead stilted hybrid
Module technology	Monofacial, polycrystalline (310Wp)
Mounting structure	- 1-3m horizontal mounting height - Different configuration of PV arrays with gaps between panels of 0 / 100 / 250mm - Cables were put around agricultural fields, resulting in higher costs due to longer lines, partly put under the ground up to 2.5m deep
Tracking	- 5-28° manual tilting due to season every 2 months
Cleaning & water management	- Manual cleaning with telescope cloth - Cleaning period: Each 10 days / module - Water consumption approx. 3 l / module, own borewell to get water for cleaning - Total water consumption: 200,000 litre/MWp/yr. - No rain-gutter and no rain water harvesting - Water management system installed by the company Jain Irrigation
Agricultural aspects	- Loamy sand type soil, irrigation required, tractor can go between panels and partially below panels (which may need to be tilted to low angle)
Crops	- Kharif: Groundnut, soybean, pearl millet, cotton, green gram, pigeon pea, maize, cluster bean - Rabi: chickpea, wheat, mustard, lucerne, vegetables - Summer: additionally, sesame, fodder, black gram
Crop cultivation	- More than 40 crops tested, but results not yet published

	- Conventional agriculture, non-organic with use of fertilizers
Further aspects	- Cooperation also with Mahatma Gandhi Institute of Renewable Energy - Challenge: Not all tractors used able to work below the structure.

The project was commissioned by Gujarat Industries Power Company Ltd. (GIPCL). Anand Agriculture University, a university renowned in Asia for cutting-edge research, is in charge of the plant's agricultural components. The panels are installed at a height of 3m on a mounting structure. Seasonal inclination can be adjusted manually. The plant has varying inter-module and inter-array gaps to investigate the effect of different shade patterns on crop growth.

Figure 2: GIPCL's Amrol plant (Credit: NSEFI)

Figure 3: Aerial view of GIPCL's Amrol plant (Credit: GIPCL)

GIPCL built and operates this plant with assistance from Navsari Agricultural University. It is a scale model of the GIPCL factory at Amrol, Anand. It is located at [21.41111, 73.12264](#).

Figure 4: View of GIPCL's Vastan plant (Credit: GIPCL)

Figure 5: Harvesting at GIPCL's Vastan plant (Credit: GIPCL).

GSECL Harsha Abakus plant near Sikka, Gujarat - 1 MW

Table 2: Properties of Harsha Abakus plant near Sikka, Gujarat

Project name	**1MW GSECL STPS Solar**
Date of commission	02.05.2016
Installed capacity DC	1054 kWp
State, city	Gujarat, District Jamnagar, Sikka
GPS location	[22.42277, 69.84348]
Type of project	Commercial
Project developer	GSECL
EPC	Harsha Abakus
Ownership structure	Gujarat State Electricity Company Limited (GSECL) (Govt.)
Operation & Maintenance	Harsha Abakus
Scientific partner	Gantar NGO
Financing structure	- PPA with Gujarat Urja Vikas Nigam Limited (GUVNL) at Rs. 3.22/kWh (20 yrs.), progressively raise by 0.05 INR/kWh - Investment: 5.75 Cr. INR/MWp; 57,500 INR/kWp - OPEX: Approx. 700 INR/kWp/yr
Type of agrivoltaic plant	Interspace / Overhead Hybrid
Module technology	Monofacial, polycrystalline (310Wp)
Mounting structure	- Elevation height 3m - Cabling underground below tillage depth - 4.5 acre/MWp, 549 kWp/ha - Testing of different gaps between modules: 25 / 150 / 250mm
Tracking	- Manual single axis tracking with seasonal tilt: 0,10° & 25° - Tilting angle possible above 85°
Cleaning & water management	- Proximity to a cement-producing industry (sticky sediment) - Manually cleaning with stand, dry cleaning not an option - 2-5 litre water needed per module (every 7-8 days) - Rainwater harvesting found not cost efficient
Agricultural aspects	- Gritty, sandy soil - Plough / harrow must be lifted where AC cables are relocated (only once a season) - Pipes for drip irrigation - $5m^3$ & $22m^3$ tank for cleaning & drip irrigation
Crops	- Lady fingers, bottle gourd, coriander, cluster beans - Winter: Tomato, cucumber, ladyfingers, zucchini, chili - Summer: Moong dal
Crop cultivation	- No research done on shading effects of APV setup on different crops and respective yields - Agriculture between rows, not below panels - Crops higher than 5-6ft cannot be grown

Further aspects	Challenges:
	- Cleaning
	  - Structure too high for efficient cleaning.
	  - Water falling on the crops with force and stand used for cleaning may damage flowers and crops

	- Water comes from public network grid pipeline. - Tilting on segment of 20 panels each requires ~10 people - Proper maintenance of drip irrigation system

The project is situated near Sikka in the Jamnagar district of Gujarat. The region experiences fluctuating seasonal temperatures ranging from $21^{o}C$ and $35^{o}C$, with an average annual rainfall of 744mm. Although the sandy and gritty soil is suitable for certain crops, the site has never been utilized for agricultural purposes before.The project has been developed on land owned by Gujarat State Electricity Company Limited (GSECL), a state-owned utility.

The modules are mounted on a 3m steel structure, allowing for limited cultivation of crops through manual farming practices. Farming can be carried out between the module rows and directly below the PV modules. In the past 2.5 years, the project managed to successfully grow crops such as lady fingers, calabash (bottle gourd), coriander, and cluster beans in the summer season. Winter crops included tomatoes, cucumbers, zucchinis, and chillies. The responsibility for maintaining and planning the crops was assigned to an undisclosed private agriculture research organisation.

The cabling system within the plant is fully underground, enabling regular ploughing of the field. Pipes are laid throughout the field for irrigation purposes, employing a drip irrigation-like system with pores for efficient watering of the crops. These pipes are connected to a central water tank with a volume of $22m^3$. During ploughing and seed sowing, the network of micro-irrigation pipes needs to be lifted, causing disruptions.

Due to the close proximity to a cement-producing industry, frequent cleaning of the modules is necessary. Dry cleaning has proven ineffective, thus a separate pipe connected to a $5m^3$ water tank on-site is used for manual cleaning of each array every 7- 8 days. According to data provided by Harsha Abakus, each cleaning consumes 2- 5 litres of water [14].

The power generated by the project is sold to Gujarat Urja Vikas Nigam Limited through a PPA with an incremental tariff structure spanning 20 years.

Figure 6: Harsha Abakus 1MW Sikka plant (Credit: NSEFI)

GSECL Harsha Abakus plant near Pandhro, Gujarat - 1 MW

Table 3: Properties of Harsha Abakus plant near Panandharo, Gujarat

Project name	**1 MW Agri Base Solar Power Plant**
Date of commission	02.05.2016
Installed capacity DC	1054 kWp
State, city	Gujarat, District Kutch, Pandhro
GPS location	23.66482, 68.77906
Type of project	Commercial
Project developer	Harsha Abakus
EPC	Harsha Abakus
Ownership structure	Governmental owned: Gujarat State Electricity Company Limited (GSECL)
Operation & Maintenance	Harsha Abakus
Scientific partner	Gantar NGO
Financing structure	PPA with Paschim Gujarat Vij Company Limited (PGVCL) at Rs. 3.22/kWh (20 yrs.)
Type of agrivoltaic plant	Interspace / Overhead hybrid
Module technology	Monofacial, polycrystalline (310Wp)
Mounting structure	Sister plant to Sikka
Tracking	Sister plant to Sikka
Cleaning & water management	Netafim drip irrigation
Agricultural aspects	Rocky land without sufficient nutrients
Crops	- Vegetable: Brinjal, cluster beans, coriander, ladyfinger, bottle gourd - Pulses: Green gram, sesame, split black gram, zucchini, peas
Crop cultivation	- Average crop height of 3-6ft. - Crops grown in summer and winter
Further aspects	- Challenges include cleaning through network grid pipeline, theft of solar panels, structure height too high for easy cleaning

Pandhro, a village situated in the mining-dominated Kutch district, grapples with an arid climate characterised by temperatures ranging from 15°C to 27°C. The region receives meager annual rainfall, with precipitation levels averaging between355 -375mm per annum. The project at Pandhro mirrors the' 1MW Sikka plant developed by Harsha Abakus. In this instance, the PPA has been established with Paschim Gujarat Vidyut Company Limited (PGVCL). The mounting structure, PV design, operational attributes, and crop patterns remain consistent with the Sikka project.

Figure 7: Harsha Abakus 1MW Panandharo plant (Credit: Hasha Abakus)

CAZRI plants in Jodhpur, Rajasthan - 100 kW

Table 4: Properties of CAZRI plants in Jodhpur

Project name	**CAZRI plants in Jodhpur**
Date of Commission	12.08.2017
Installed capacity DC	105 kWp
State, City	Rajasthan, Jodhpur
GPS Location	26.25793, 72.99297
Type of Project	Research
Project Developer	Central Arid Zone Research Institute (CAZRI)
EPC	n.A.
Ownership structure	Governmental owned, CAZRI Institute
Operation & Maintenance	CAZRI Institute
Scientific partner	CAZRI Institute
Financing Structure	Economic assumptions (2019): - 500 kWp/ha - Capex of 2.25 Cr. INR (50,000 INR/kWp) - Net income crops: 80,000 INR/ha/yr - FiT of 4 INR/kWh
Type of Agrivoltaic Plant	Interspace
Module technology	Monofacial (260Wp), 1.64m to 0.992m

Mounting structure	- Latitude angle considered as tilt angle in this project (26° at Jodhpur)
	- Height:
	  - Array 1: 1.22m
	  - Array 2: 1.94m
	  - Array 3: 2.66m
	- Interspace:
	  - Arrays of 1-row PV module and 3m interspace
	  - Arrays of 2-row PV modules and 6m interspace
	  - Arrays of 3-row PV modules and 9m interspace
	- Ploughing can be easily possible in 2 cases, while in one case it has to be done manually
	- Total system cost of (105 kW/INR 60 lakh) -> 57,142 INR/kWp

Tracking	Fixed with no tracking as well as single axis tracking
Cleaning & Water Management	- Rainwater harvesting system from surface of PV-modules - Harvest rainwater annually approx. 1.5 lakh litres, stored in a 100 m3 water tank - Efficiency rainwater harvesting system 70 - 80%
Agricultural aspects	Sandy and loamy
Crops	- Mungbean, mothbean, clusterbean, isabgol, cumin, chickpea - Aloe vera, sonamukhi, sankhpuspi, chili, cabbage, onion, garlic
Crop Cultivation	49% land area can be used for agriculture, Land Equivalent Ratio (LER) of about 1.41

Situated in Jodhpur, this agrivoltaics plant finds itself in an arid climate with meager prospects. The region experiences an average irradiance on horizontal surface of 6.11 $kWh/m^2/day$, the region has cloud-free skies for nearly 300 days each year. The temperature range spans from a chilling 9.6ºC to a scorching 41.4ºC.

The plant's layout boasts three different patterns, featuring PV arrays with varying rows and significant interspaces of 3m, 6m, and 9m, allowing the use of heavy machinery. The plant's design includes a rainwater harvesting system based on duct pipes attached to the PV-modules bottom edge. This facilitates the harvesting of up 1.5 lakh litres of rainwater annually. The collected water serves the dual purpose of cleansing the module surfaces and serving as irrigation. A storage tank of 100m^3 is present, for holding water during the rabi season. This project effectively utilizes 49% of available land that would otherwise remain unused, transforming it into productive agricultural land. The project demonstrates a remarkable land equivalent ratio of 1.41, indicating efficient use of the cultivated area.

Table 5: Effects on yield of different crops as examined in interspacing area at CAZRI Jodhpur plants

Crop category	Interspacing (crops)	Yield affection by
Kharif	Mungbean (*Vigna radiata*), moth bean (*Vigna aconitifolia*), clusterbean (*Cyamopsis tetragonoloba*)	Growth and yield of mungbean (vigna radiata) was not affected by the shade of PV module, whereas rest two are affected
Rabi	Isabgol (*Plantago ovato*), cumin (*Cuminum cyminum*), chickpea (*Cicer arietinum*)	Growth and yield of isabgol (plantago ovata) and Cumin (cuminum cyminum) are significantly affected by shade of PV module
Medicinal plants	Aloevera (*Aloe vera)*, sonamukhi (*Cassia angustifolia*), sankhpuspi (*Convolvulus pluricaulis*)	Performance of medicinal crops were superior in the interspace area than over control.
Vegetables	Chilli (*Capasicum annum*), cabbage (*Brassica oleracea var. capitat*), onion (*Allium cepa*), garlic (*Allium sativum*)	Growth and yield of solanum melongena was significantly affected by shade of PV module.

When examining the economics aspects of the project, it is evident that revenue generated from electricity generation surpasses that from agricultural production. databased on available data, mung beans during the kharif season generate INR 8,235 in income, while isabgol in rabi season yields revenues of INR 23,339 [15].

Figure 8: Agrivoltaics at CAZRI (Credit: CAZRI)

Figure 9: Agrivoltaic system with rain gutter at CAZRI (Credit: CAZRI)

Amity University plant in Noida, Uttar Pradesh - 10 kW

Table 6: Properties of Agrivoltaic project at Amity University

Project name	**Agrivoltaic project at Amity University**
Date of commission	2017
Installed capacity DC	10 kWp
State, city	Uttar Pradesh, Gautam Buddh Nagar District, Noida
GPS location	28.54162, 77.33241
Type of project	Research
Project developer	Amity University, in-house development
EPC	n.A.
Ownership structure	Amity University Funding agency; Department of Science and Technology, Govt of India
Operation & Maintenance	Amity University
Scientific partner	Amity University
Financing structure	Project cost 24.9 lakh INR Electricity used for self consumption
Type of agrivoltaic plant	Single column
Module technology	Monofacial, polycrystalline (330Wp), Canadian
Mounting structure	- Optimum tilt angle - Approximately 15 ft (4.6m) height of the mounting pole - Area: 630m²; 159 kWp/ha
Tracking	None
Cleaning & water management	- Automatic piping system for sprinkler module cleaning - Drainage system implemented - No storage of harvested water, but water harvested dropping directly on the field resulting in reduction of irrigation needs
Agricultural aspects	- Sandy loam soil - Farmer friendly cabling above the ground attached to cleaning water pipes
Crops	Maize, potato, brinjal, mustard
Crop cultivation	- Nearly 90% land can be utilized for cultivation - Height of crops practically not limited, at present up to 1m - Minimal shading impact, crop yield unchanged
Further aspects	n.A.

Noida, a well-planned city in Uttar Pradesh, boasts a steppe climate that offers favorable conditions for various activities. This region experiences minimum and maximum temperatures of of 16ºC and 45ºC respectively, along with an average annual rainfall of approximately 714mm. The location benefits from sandy loam soil, rich in nutrients, moisture, and humus. The project implemented on the land of Amity University showcases an innovative approach to water management. Each mounting structure is equipped with a piping system featuring cork valves, facilitating automatic cleaning of the modules. The water used for cleaning is efficiently captured and redirected to irrigate crops, reducing overall water consumption.

The strategic height of the structures allows for the use of tractors for ploughing, streamlining agricultural operations. Moreover, manual work on the crops is not limited, ensuring flexibility in cultivation practices. The photovoltaic panels play a crucial role in the project, as they eliminate the need for grid power supply to operate the pump set. Consequently, the water requirements remain similar while reducing reliance on external energy sources. In this setup, over 95% of the land can be utilised for crop cultivation due to the limited PV capacity installed and the overhead cabling system. This efficient design maximizes the productive potential of the area while maintaining a sustainable approach to energy and water usage.

Figure 10: Plant at Amity University (Credit: NSEFI)

Figure 11: Plant at Amity University (Credit: NSEFI)

Dayalbagh Agriculture University plant in Agra, Uttar Pradesh - 200 kW

Table 7: Properties of plant at Dayalbagh Agriculture University

Project name	**n.A.**
Date of commission	26.01.2020
Installed capacity DC	200 kWp
State, city	Uttar Pradesh, Agra
GPS location	27.22671, 78.01072
Type of project	Research
Project developer	Dayalbagh Educational Institute (DIE), Faculty of Engineering
EPC	Dayalbagh Educational Institute
Ownership structure	Dayalbagh Educational Institute Research & Development project sponsored by Department of Science and Technology (DST) Mission Innovation
Operation & Maintenance	Dayalbagh Educational Institute
Scientific partner	Dayalbagh Educational Institute (Deemed University)
Financing structure	- No power purchase agreement with any DISCOM, electricity has been utilized in the institute premises and nearby facilities (self consumption) - Project investment: 3 cr. INR (150,000 INR/kWp), payback time of 7 years is claimed
Type of agrivoltaic plant	Single column
Module technology	- Semi-transparent glass modules, monocrystalline - 50% of modules with transparent tedlar sheet, 50% regular - Towers with monofacial panels only, towers with transparent panels only, towers with mixed panels in checkerboard pattern - Space between modules helps mitigate storms
Mounting structure	- 18ft elevation height - 19 towers each with 50 modules - Current weight: about 3.5 tons per column. Research ongoing to significantly reduce weight
Tracking	- Single axis tracking, azimuth tracking claimed to increase yield by up to 20% - Storms used to damage gearboxes, which could successfully be mitigated by additional mechanical locks
Cleaning & water management	- R&D in progress - variable pressure sprinkler system - Before that, manual cleaning with a ladder, every 15 days
Agricultural aspects	- Deep loamy soils - Ploughing can be easily done in this plant with tractor
Crops	- Grams, brinjal, tomato, wheat, spinach, cauliflower, carrot, gourds - Crop sizes should not exceed 8ft
Crop cultivation	- Drip irrigation for all vegetables, STP water for grams (roughly 50-50%) - Crop yields reported to be unchanged - Tillage of 1 - 2ft, cables laid below 3ft - Sheets and mulching is applied for further water savings

Further aspects	Additional battery storage system implemented

Agra, situated on the banks of river Yamuna in Uttar Pradesh, is globally renowned for the Taj Mahal monument. The region experiences a semi-arid climate with temperatures ranging from 18.6ºC to 44.6ºC. It receives an average annual rainfall of 736.3mm, contributing to the fertile deep loamy soil.

Dayalbagh University is an esteemed agricultural technical university with a thriving cow breeding economy. The university manages over 1100 cattle, primarily for milk and manure production. Grazing provides their sustenance, and the dung is dried and used as fertilizer on the fields. Covering an extensive area of 1200 acres, the university conducts innovative research and development activities. Their cow-based fertilizer has proven to enhance soil health and biodiversity, creating a favourable environment for earthworms.

Within the university's premises, a research facility is dedicated to agrivoltaics, located on previously utilized fodder land. Students engage in agricultural activities regularly, either as part of their coursework or through voluntary participation. The mounting structure of 18ft height, along with ample spacing between the poles, allows for ploughing using heavy machinery..

In addition to agrivoltaics, the university excels in research on mobile photovoltaic systems, which have practical applications in disaster-stricken areas. The Mitsubishi Innovation Prize was awarded to the researchers for their contributions in this field. Furthermore, the university focuses on developing electrified downstream processing machines, such as press-drying and threshing equipment, as an eco-friendly alternative to diesel-powered machinery commonly associated with tractor engines.

Figure 12: Dayalbagh Agriculture University APV plant (Credit: DAU)

Figure 13: Dayalbagh Agriculture University APV plant (Credit: DAU)

Figure 14: Dayalbagh Agriculture University APV plant with different arrangement (Credit: DAU)

Junagadh Agriculture University plant in Junagadh, Gujarat - 7 kW

Table 8: Properties of Junagadh Agriculture University plant

Project name	**Junagadh Agriculture University plant**
Date of commission	2017
Installed capacity DC	7.2 kWp
State, city	Gujarat, Junagadh
GPS location	21.50109, 70.44758
Type of Project	Research
Project developer	Junagadh Agriculture University
EPC	n.A.
Ownership structure	Junagadh Agriculture University
Operation & Maintenance	Junagadh Agriculture University
Scientific partner	Junagadh Agriculture University
Financing structure	Research funding
Type of agrivoltaic plant	Overhead tilted
Module technology	- 150 Watt (0.67m X 1.47m) Poly crystalline
Mounting structure	- Elevation height: 3m - Chequered module arrangement - 7.6, 11.4m plot
Tracking	None
Cleaning & water management	Manual cleaning
Agricultural aspects	- Black soils - No use of tractor as per land use and as per crop cultivation methods - Experiments with shade/insect protection nets are conducted
Crops	Tomato, capsicum, cotton
Crop cultivation	n.A.
Further aspects	- Experiments with water pipe based cleaning system with water harvesting by raingutters - Local data comparing crop yield in open field with agrivoltaics for tomato and capsicum

A 7.52kWp capacity plant was installed at the Junagadh Agriculture University for research and development purposes. The university is located in a tropical wet and dry climate region, characterized by minimum and maximum temperatures of approximately 16ºC and 38ºC. The annual average rainfall in the area is about 827mm. The soil type prevalent in this region is black soil, which is highly suitable for vegetable cultivation. The crops grown in this project can be cultivated without the need for heavy machinery such as tractors for ploughing. Junagadh Agriculture University, a leader in the field of overhead stilted agrivoltaics systems, has recommended this model to farmers in Gujarat, offering promising benefits.

Figure 15: Junagadh agrivoltaic system (Credit: Prof. P.M. Chauhan, JAU)

Figure 16: Aerial view of Junagadh agrivoltaic system (Credit: College of Agricultural Engineering and Technology, JAU)

Figure 17: Irrigation system at Junagadh Agriculture University site (Credit: JAU)

Figure 18: Installed pipe system to collect cleaning water (Credit: JAU)

Abellon Energy plant in Aravalli District, Gujarat - 1 MW

Table 9: Properties of Abellon Energy plant

Project name	Solar-Agri Electric Model Project
Date of commission	28.01.2012
Installed capacity DC	3000 kWp (~1000 kWp with agriculture)
State, city	Gujarat, District Aravali, Sardoi, Modasa Taluka
GPS location	23.55983, 73.28684
Type of project	Commercial
Project developer	Abellon Clean Energy Ltd, Ahmedabad
EPC	n.A.
Ownership structure	n.A.
Operation & Maintenance	n.A.
Scientific partner	n.A.
Financing structure	FiT (2015, 2016, 2017) of 0.23 USD/kWp, Gujarat Solar Policy
Type of agrivoltaic plant	Interspace
Module technology	Poly crystalline 230W, 240W, 280W
Mounting structure	- 7.08 ha; 423 kWp/ha. - Conventional ground mounted PV design
Tracking	None
Cleaning & water management	- Manual cleaning - Water used for cleaning modules irrigating the plants - Cotton fibre is used to keep moisture on the ground
Agricultural aspects	Rocky soil, porous, less retention capacity
Crops	- Vegetables: bottle gourd, lady finger - Fruits: watermelon - Spices: turmeric, ginger, chili
Crop cultivation	n.A.
Further aspects	- Henna plants encircling the solar plant as secondary wind braking barrier

Located in the semi-arid climate of the Aravalli mountain range foothills, this plant benefits from its position in the tropic of cancer, enjoying ample sunlight. The temperature ranges from 15°C to 45°C. With an average annual rainfall of 690mm in Modasa taluka, Aravalli district, the region receives a sufficient amount of precipitation. The soil, though rocky and porous with low retention capacity, is not well-suited for cereal crop cultivation. In this plant, module cleaning is carried out manually, with the water used for cleansing directly irrigating the interspace cropping area. As an additional measure, henna plants surround the solar plant, acting as a secondary wind braking barrier.

Figure 19: Interspace farming at Abellon Energy plant (Credit: Abellon Energy)

Figure 20: Cleaning and irrigation at Abellon Energy plant (Credit: Abellon Energy)

Mahindra Susten plant at Tandur, Telangana - 400 kW

Table 10: Properties of Mahindra Susten plant

Project name	**Clean Solar Private Limited, Tandur**
Date of commission	2016
Installed capacity DC	36.6 MWp (~400kW with agrivoltaics)
State, city	Telangana, District Tandur, Gingurthy Village
GPS location	17.36825, 77.54105
Type of project	Commercial, partly research
Project developer	Mahindra Susten, in-house development
EPC	Private PPA
Ownership structure	Mahindra Teqo
Operation & Maintenance	Kancor Mane, Indo-French Spice producing company, CII
Scientific partner	n.A.
Financing structure	Economic assumptions: - 18,000 INR/MWp/yr weeding costs - 1.5 to 2 lakh INR/ha gross income through lemon gras oil
Type of agrivoltaic plant	interspace
Module technology	Thin film (170Wp) Mono-/ Polcy-crystalline (310Wp; 315Wp) SAT & Fixed Tilt Combined
Mounting structure	Conventional ground mounted PV design
Tracking	None
Cleaning & water management	- Manual cleaning - 2.5 Ltr/Panel - FortnightlyWet Cleaning - Rain gutter/ drainage system possible as the area is having lots of natural drains - Water harvesting of cleaning water possible, but not a lot of rain
Agricultural aspects	- Loamy soil, sandy loam, sandy clay loams - Tractor way free between rows
Crops	- Main crop: lemon grass - Other crops: annatto dye, brinjals, lady finger, green chilies, onions
Crop cultivation	- 2 to 3 ft - Round the year harvest - 60 to 70 litres of lemon grass crude oil - Less soil erosion - 1 acre cultivated - Lemon grass requires minimal water, suitable for rainfed conditions
Further aspects	n.A.

Figure 21: Mahindra Susten plant at Tandur with seedlings planted (Credit: Mahindra Susten)

Figure 22: Mahindra Susten plant at Tandur with lemon grass (Credit: Mahindra Susten)

Jain Irrigation plants at Jalgaon, Maharashtra – 290 kW

Table 11: Properties of Jain Irrigation Banana Pilot

Project name	**Jain Irrigation Banana Pilot**
Date of commission	2014
Installed capacity DC	14.4 kWp
State, city	Jalgaon, Maharashtra
GPS location	20.99146, 75.50704
Type of project	Research
Project developer	Jain Irrigation, in-house development
EPC	n.A.
Ownership structure	Jain Irrigation
Operation & Maintenance	Jain Irrigation
Scientific partner	Jain Irrigation
Financing structure	Internal funding
Type of agrivoltaic plant	Overhead stilted
Module technology	- In-house production - 240W panel, polycrystalline
Mounting structure	- Mounting structure design nearly allows 95% use of land area below panels - >5m height, 500m²; 288 kWp/ha - Machinery operated below modules
Tracking	- Single axis
Cleaning & water management	- Manual
Agricultural aspects	- Black fertile soil
Crops	- Banana - Experimentation with maize in 2014
Crop cultivation	- Reported yield impacts: 14-34.5 ton/acre (+140%) bananas; water use (-) 55% - Crop height: 4 – 5m

Figure 23: 14.4 kW agrivoltaic structure with banana (Credit: Jain Irrigation)

Table 12: Properties of Jain Irrigation Rice Pilot

Project name	**Jain Irrigation Rice Pilot**
Date of commission	2014
Installed capacity DC	9.6 kWp
State, city	Jalgaon, Maharashtra
GPS location	20.99146, 75.50727
Type of project	Research
Project developer	Jain Irrigation, in-house development
EPC	n.A.
Ownership structure	Jain Irrigation
Operation & Maintenance	Jain Irrigation
Scientific partner	Jain Irrigation
Financing structure	Internal funding
Type of agrivoltaic plant	Overhead stilted
Module technology	- In-house production - 240W panel, polycrystalline
Mounting structure	- 3m height, 105m2 area; 533 kWp/ha - Machinery operated below modules
Tracking	- Fixed tilt
Cleaning & water management	- Drip irrigation installed - Manual cleaning of panels
Agricultural aspects	- Black fertile soil
Crops	- Rice
Crop cultivation	- 3.1 – 3.8 ton/acre (+22.5%) rice; water use (-) 33.7% - Crop height: 1 – 1.8m
Further aspects	n.A.

Figure 24: 9.6 kW agrivoltaics system with rice (Credit: Jain Irrigation)

Table 13: Properties of Jain Irrigation Okra/Cotton Pilot

Project name	**Jain Irrigation Okra/Cotton Pilot**
Date of commission	2014
Installed capacity DC	50.4 kWp
State, city	Jalgaon, Maharashtra
GPS location	20.99245, 75.510641
Type of project	Research
Project developer	Jain Irrigation, in-house development
EPC	n.A.
Ownership structure	Jain Irrigation
Operation & Maintenance	Jain Irrigation
Scientific partner	Jain Irrigation
Financing structure	Internal funding
Type of agrivoltaic plant	Overhead stilted
Module technology	- In-house production - 240W panel, polycrystalline
Mounting structure	Single column
Tracking	- Dual axis
Cleaning & water management	- Manual - Drip irrigation
Agricultural aspects	- Black fertile soil - Tractor to be operated below panels
Crops	- Cotton and okra
Crop cultivation	n.A.
Further aspects	n.A.

Figure 25: Agrivoltaics with 2-axis tracking and drip irrigation (Credit: Jain Irrigation)

Table 14: Properties of Jain Irrigation Tumeric/Ginger/Mint Pilot

Project name	Jain Irrigation – Tumeric/Ginger/Mint Pilot
Installed capacity DC	19.3 kWp 482.5 kWp/ha
GPS location	[20.93792, 75.56204]
Type of agrivoltaic plant	Stilted 1.7 – 2.5m
Module technology	semi-transparent glass-glass modules
Mounting structure	- Stilted 1.7 – 2.5m - Almost full shade on area of 400m²
Tracking	Fixed
Cleaning & water management	- Cleaning done by sprinkler system - Cleaning water is descaled to prevent chalk stains on panels
Crops	Turmeric, ginger, mint

Figure 26: 13.9 kW agrivoltaics system with turmeric (Credit: Jain Irrigation)

Table 15: Properties of Jain Irrigation Greenhouse PV Pilot

Project name	**Jain Irrigation Greenhouse-PV Pilot**
Date of commission	n.A.
Installed capacity DC	200 kWp
State, city	Jalgaon, Maharashtra
GPS location	20.99105, 75.50709
Type of project	Research
Project developer	Jain Irrigation, in-house development
EPC	n.A.
Ownership structure	Jain Irrigation
Operation & Maintenance	Jain Irrigation
Scientific partner	Jain Irrigation
Financing structure	n.A.
Type of agrivoltaic plant	Greenhouse
Module technology	Transparent Building Integrated Photovoltaic Modules (BIPV), 260Wp per Panel
Mounting structure	- 1100m² Greenhouse - Rooftop fully covered by PV modules
Tracking	- Fixed
Cleaning & water management	Irrigation system
Agricultural aspects	Additional LED lighting
Crops	Banana
Crop cultivation	Suitable for raising seedlings
Further aspects	n.A.

Figure 27: Jain Irrigation Greenhouse PV with Building Integrated Photovoltaic Modules (Credit: Jain Irrigation)

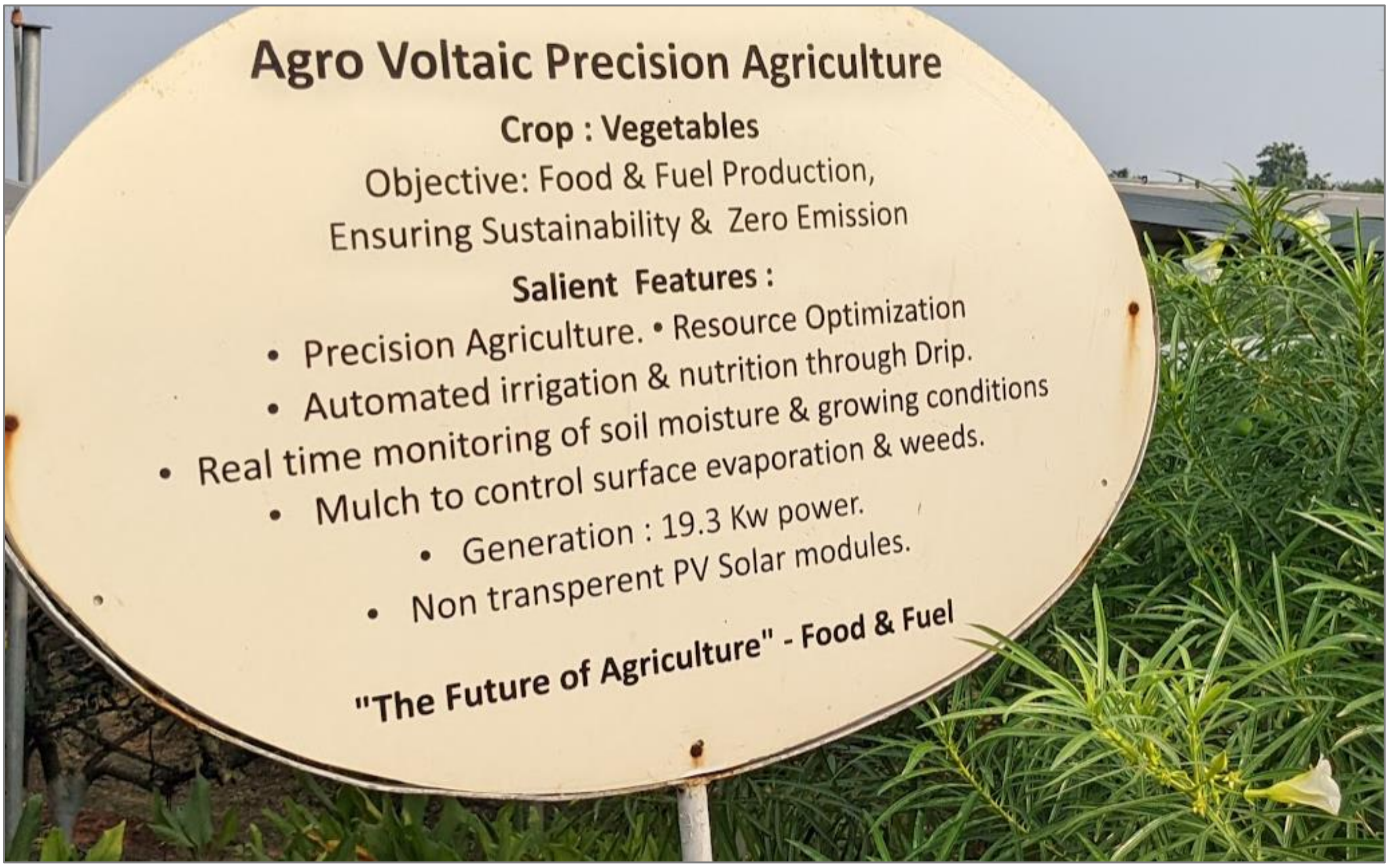

Figure 28: Information board at Jain Irrigation (Credit: Jain Irrigation)

Jain Irrigation Systems Limited (JISL) is an innovative water management company based in Jalgaon, India with a strong focus on farmers. Since 2012 [8], JISL has been actively exploring agrivoltaics, a technique that combines agriculture and solar power. Dr. Bhavarlal Jain, founder of JISL, pioneered agrivoltaic installations at their R&D farm, Tissue Culture Park, primarily to power agriculture pumps.

One of their successful experiments involved a 14.4kW agrivoltaic structure covering a 600m2 area, where bananas were cultivated. In 2018, JISL expanded their research to include maize cultivation under the same structure. Another impressive initiative combined solar photovoltaics, drip irrigation, and low greenhouse gas-emission rice cultivation in a neighboring plant. A third agrivoltaic plant, equipped with drip irrigation, located 400m away, focused on cotton and okra production.

In addition to agrivoltaics, JISL is actively working on a cutting-edge PV greenhouse concept. This concept involves fully covering the rooftop with PV modules while providing supplementary LED lighting. The goal of this innovative approach is to significantly reduce the hardening time of banana seedlings, optimizing their growth process. NISE plant near Gurgaon, Haryana - 100kW

Table 16: Properties of NISE plant near Gurgaon, Haryana

Project name	**n.A.**
Date of commission	n.A.
Installed capacity DC	100 kWp
State, city	Gurugram, India
GPS location	28.42754, 77.16071
Type of project	Research
Project developer	National Institute of Solar Energy (NISE)
EPC	n.A.
Ownership structure	National Institute of Solar Energy (NISE)
Operation & Maintenance	n.A.
Scientific partner	n.A.
Financing structure	n.A.
Type of agrivoltaic plant	Interspace
Module technology	n.A.
Mounting structure	n.A.
Tracking	fixed
Cleaning & water management	n.A.
Agricultural aspects	Loamy sand
Crops	Tomato, chili, flowers, Kufri Lima potato
Crop cultivation	n.A.

NISE has conducted successful experiments in cultivating tomatoes, chilies, and flowers in the space between and beneath solar arrays at ground mounted PV plant. Additionally, NISE has procured and overseen the construction of a vertical PV pilot plant featuring bifacial modules, in collaboration with Adani Solar (see below).

Figure 29: Experimental agriculture at NISE (Credit: NSEFI)

NISE Vertical Agrivoltaics Pilot, near Gurgaon, Haryana - 5 kW

Table 17: Properties of vetcial APV plant NISE near Gurgaon, Haryana

Project name	**Vertically Installed Bifacial PV Modules Pilot**
Date of commission	n.A.
Installed capacity DC	5 kWp
State, city	Haryana, Gwal Pahari, near Gurgaon
GPS location	28.42679, 77.15838
Type of project	Research
Project developer	National Institute of Solar Energy (NISE)
EPC	Adani Solar
Ownership structure	National Institute of Solar Energy (NISE)
Operation & Maintenance	n.A.
Scientific partner	National Institute of Solar Energy (NISE)
Financing structure	n.A.
Type of agrivoltaic plant	Vertical Installation
Module technology	Bifacial (mono-PERC), Module Bifaciality: 0.85
Mounting structure	n.A.
Tracking	no
Cleaning & water management	n.A.
Agricultural aspects	Loamy sand
Crops	n.A.
Crop cultivation	n.A.
Further aspects	Energy generated is fed into the grid

The vertical APV plant, operational since June 2021, was installed in 2020.

The site features a 5kWp vertical bifacial PV module array installation. Adjacent to this installation, individual modules are being tested outdoors, exploring variations in module orientation (i.e., deviation from E-W) and different type of ground surface. Alongside the vertical APV system, NISE has also implemented a 5kWp bifacial PV system and a 10kWp monofacial PV system, both set at latitude tilt.

This pilot project aims to evaluate the performance of vertical PV installations using bifacial PV modules, providing a comparison to both mono- and bifacial modules at latitudinal tilt. By examining the effects of surface albedo, environmental factors, and installation conditions on bifacial and vertically mounted modules, researchers can gain insights into the impact of these variables.. The experimental findings will contribute to the development of a bifacial module gain simulation for various locations across India.

Figure 30: Vertical PV installation with bifacial modules at NISE (Credit: NSEFI)

Cochin Airport plant in Kerala - 4 MW

Table 18: Properties of project at Cochin Airport

Project name	**Cochin International Airport Limited (CIAL)**
Date of commission	18.08.2015
Installed capacity DC	Total capacity of solar plants in Feb. 2020 of 42 MWp 20 acres co-located with agrivoltaics agrivoltaics electricity generation capacity not provided
State, city	Kerala, Cochin
GPS location	10.15667, 76.38253
Type of project	Commercial
Project developer	Bosch Ltd.
EPC	Bosch Ltd.
Ownership structure	Cochin International Airport Limited (CIAL)
Operation & Maintenance	Sun Ray Products Pvt Ltd.
Scientific partner	n.A.
Financing structure	PPA with Kerala State Electricity Board. Debt financed by Deutsche Bank
Type of agrivoltaic plant	Interspace
Module technology	265Wp Renesola polycrystalline, centralised inverters 1MW by ABB India with MPPT (refers to only one part of the plant)
Mounting structure	Conventional ground mounted PV design
Tracking	None
Cleaning & water management	- Manual cleaning with water - Water used for crop irrigation - Cleaning is required about two times per month
Agricultural aspects	n.A.
Crops	- Over 20 different vegetables, among them: yam, long yard bean, drumstick, mountain ginger, turmeric, cabbage, cauliflower, snake gourd, bitter gourd, bottle gourd, ash gourd, blonde cucumber, eggplant, tomato, pumpkin and okra - The edges of the area are also further beautified by curry leaf trees, drumstick trees, buddha bamboo, small mango trees as well as euginia and alamanda flowers
Crop cultivation	- Formerly barren land has been improved by applying natural fertilizers like cow manure - 60-80 tons per year cumulative production reported - Fully organic cultivation
Further aspects	n.A.

The Cochin Airport boasts an impressive array of eight solar plants situated within its premises. Among these, the largest solar plant spans a vast area of 45 acres, with approximately 20 acres dedicated to agrivoltaics practices as of December 2021.

While detailed information on the agrivoltaics project at Cochin Airport was limited during the time of this report, the project has reported a cumulative annual production of approximately 60-80 tons through completely organic cultivation. Moreover, the airport has established strong market connections and directly sell its agricultural produce to regular consumers and passengers, generating additional revenue. This agricultural endeavor predominantly involves interspace cultivation, contributing to its success.

Figure 31: Agrivoltaic plant at Cochin Airport (Credit: CIAL)

Figure 32: Agrivoltaic plant with elephant foot yam at Cochin Airport (Credit: CIAL)

Krishi Vigyan Kendra (NHRDF) Ujwa, Delhi – 110 kW

Table 19: Properties of project at Krishi Vigyan Kendra (NHRDF) Ujwa

Project name	**Krishi Vigyan Kendra Ujwa Solar Farm**
Date of commission	February, 2021
Installed capacity DC	110 kWp
State, city	Ujwa, Delhi
GPS location	28.57134, 76.89579
Type of project	Research
Project developer	Krishi Vigyan Kendra (KVK) under National Horticultural Research and Development Foundation (NHRDF), Ujwa, New Delhi
EPC	Oakridge Energy Pvt. Ltd. Noida
Ownership structure	Land and farming by Krishi Vigyan Kendra, Ujwa, New Delhi Agrivoltaic plant owned by Oakridge Rooftops Pvt Ltd.
Operation & Maintenance	Oakridge Rooftops Pvt Ltd.
Scientific partner	Solar Department, Department of Power, Govt of NCT Delhi and ICAR- ATARI, Zone-II, Jodhpur
Financing structure	30% equity and 70% debt financing through IREDA rooftop credit line backed by German Development Bank KFW
Type of agrivoltaic plant	Elevated structure with provision for limited agriculture underneath
Module technology	335 Wp poly crystalline solar panels
Mounting structure	- Hot dipped galvanized steel structure - 3.5m elevation height at 15° tilt
Tracking	Fixed tilt
Cleaning & water management	- Local water tank made available for cleaning water supply. Rainwater gutters ensure that the cleaning water drains to an underground tank for reutilisation of water. - Every 10 days the modules are cleaned with a 1600 W, 90 to 130 bar pressure water washer. - A drip irrigation system for the entire agrivoltaic plant has been implemented. - Soil moisture was observed to be much better with significant irrigation water savings
Distribution of power	- The facility is connected to the public grid of BSES Delhi with group metering - Power utilised by National Agricultural Co-operative Marketing Federation of India Ltd. (NAFED), National Horticultural Research and Development Foundation (NHRDF), Krishi Vigyan Kendra (KVK) at ratio of 70:20:10 at a tariff of INR 3.13 / kWh.
Agricultural aspects	- Located in agroclimatic zone VI trans-gangatic plains region with annual rainfall of 420-780mm. - Temperature variation from 2°C-47°C. Soil with PH of 8.5 and above
Crops	Okra, tomato, brinjal, capsicum, leafy vegetables, root vegetables and cole crops planned
Crop cultivation	- Mulching and sheets are applied.

	- Final crop yields were not yet determined but are likely to be close to standard, plant canopies seem a little better in open field reference areas. - Crop maturity is expected to be prolonged. - Cultivated crops are not necessarily shade loving but rather what local farmers usually plant.
Further aspects	- Demonstration established as pilot project - Further expansion in NCT region foreseen under Mukhyamantri Kisan Aay Badhotri Solar Yojana scheme - Apart, more than 720 further Krishi Vigyan Kendra established throughout India may promote agrivoltaics in the future

A 110kWp agrivoltaic solar farm demonstration unit has been successfully installed on a 2000m² area in Krishi Vigyan Kendra (NHRDF), Ujwa, New Delhi. This pilot project is part of the Mukhyamantri Kisan Aay Badhotri Solar Yojana scheme of GNCT, Delhi. Under this scheme, entities are allowed to set up photovoltaic power plants on agricultural land, utilizing up to one third of the farmland, which can be rented out to the solar power plant owner. The minimum structure height of 3.5m ensures convenient passage for tractors and other farming equipment. The funding for this unit has been fully provided by Delhi Transco Limited, Delhi, as part of their Corporate Social Responsibility (CSR), a long with support from the NABARD fund, Regional office, Delhi. The primary objective of this demonstration unit is to preserve and enhance the green belt surrounding Delhi by cultivating horticultural crops and encouraging the retention of agricultural land.

Figure 33: Aerial view on Krishi Vigyan Kendra pilot with water gutter before cultivation (Credit: KVK Ujwa)

Figure 34: Krishi Vigyan Kendra pilot after cultivation (Credit: KVK Ujwa)

Figure 35: Krishi Vigyan Kendra pilot after cultivation (Credit: KVK Ujwa)

Agrivoltaics plant near Parbhani, Maharashtra – 1.4 MW

Table 20: Properties of agrivoltaics Site near Parbhani, Maharashtra

Project name	**Agrivoltaics plant near Parbhani**
Date of commission	12.11.2022
Installed capacity DC	1.4 MW
State, city	Manwath, Maharashtra
GPS location	19.31373, 76.45862
Type of project	Research project
Project developer	- Agriculture: SunSeed APV Pvt. Ltd. and GIZ - Solar: n.A.
EPC	Kanoda Energy Systems Pvt. Ltd., SunSeed APV Pvt. Ltd.
Ownership structure	n.A.
Operation & Maintenance	n.A.
Scientific partner	SunSeed APV Pvt. Ltd.
Financing structure	n.A.
Type of Agrivoltaic plant	Test field for different types: see tables below
Water management	Land graded for water harvesting and drip irrigation system
Agricultural aspects	Jai Hind Agro Farm Management
Crop cultivation	Rotational cropping, residue-free crop cultivation
Further aspects	Crop cultivation commenced in January 2023

The plant is divided into 4 sections to investigate the benefits of various APV designs.

Table 21: Properties of Agrivoltaics plant near Parbhani, Section I

APV Parbhani Section I	
Type of Agrivoltaic plant	Elevated structure with shadehouse
Area	1.6 acres
Module technology	- Polycrystalline
Mounting structure	- Overhead 3.75m - Fixed tilt 11° - Pitch 5.64m
Cleaning & water management	- Robotic dry cleaning - Fogger system & Drip irrigation system
Crops	Cherry Tomato, Capsicum, Cucumber, Betel Leaves, Turmeric, Ginger, Basil, Spinach, Methi, Coriander, Mint, Rose, Chrysanthemum, Tuberose, Hibiscus, Marigold, Watermelon, Muskmelon

Table 22: Properties of Agrivoltaics plant near Parbhani, Section II + III

APV Parbhani Section II + III	
Type of Agrivoltaic plant	Below and interspace
Area	0.8 acres and 0.8 acres
Module technology	- Mono PERC
Mounting structure	- Height: 1,75m - Fixed tilt: 11° - Test field with two pich distances: 10m (II) and 7.5m (III)
Cleaning & water management	- occassional wet cleaning - Drip irrigation system
Crops	Section II: musk melon, coriander, spinach, fenugreek Section III: marigold, basil

Table 23: Properties of Agrivoltaics plant near Parbhani, Section IV

APV Parbhani Section IV	
Type of Agrivoltaic plant	Interspace
Area	0.8 acres and 0.8 acres
Module technology	- Bifacial PERC
Mounting structure	- Height: 1,25m - Fixed tilt: 11° - Pich distance: 10m
Cleaning & water management	- occassional wet cleaning - Drip irrigation system
Crops	Water melon

Located in the Marathwada region of Maharashtra, Western India, the agrivoltaics farm spans over 5 acres of land and boasts a remarkable capacity of 1.4 MW. Developed as a part of the larger 50 MW solar project, this innovative facility is a collaboration between SunSeed APV, Kanoda Energy, and GIZ German Development Cooperation. The primary aim of the project is to establish a harmonious relationship between solar energy generation and agriculture while showcasing the economic viability and bankability of APV systems.

The project encompasses four distinct APV configurations, alongside an open farming area that serves as a control environment for research purposes. Notably, a standout feature of the project is a 6000m² elevated system integrated with a shade net house, where trellising vegetables thrive. The use of highly reflective shade nets not only enhances PV generation but also promotes the albedo effect. Moreover, three of the APV setups, situated at lower elevations (1.25m and 1.75m), require only slightly higher capital costs compared to conventional solar projects.

To optimize water usage, the project has implemented an advanced water management system, complete with a drip irrigation network and soil moisture sensors in each crop section. Additionally, the shading effect of the PV panels and the application of mulch contribute to reduced evapotranspiration, resulting in further water conservation.

Furthermore, the project features extensive instrumentation, serving as a platform for research and development in both crop cultivation and solar energy generation. The research conducted here will pave the way for scientific approaches to designing and adapting agrivoltaics projects, as well as the development of cultivation strategies specific to agrivoltaics.

Figure 36: Overview of agrivoltaics plant near Parbhani. (Credit: GIZ)

Figure 37: Section IV (Interspace) at Agrivoltaics plant near Parbhani (Credit: GIZ)

Figure 38: Soil preparation at section III (below and interspace) at agrivoltaics plant near Parbhani (Credit: GIZ)

Figure 39: Marigold growing at section II (below and interspace) at agrivoltaics plant near Parbhani (Credit: GIZ)

Figure 40: Soil preparation at section I (fully elevated) at agrivoltaics plant near Parbhani (Credit: GIZ)

Figure 41: Visitors examine green capsicum at elevated section I at agrivoltaics plant near Parbhani (Credit: GIZ)

Hinren Agri - PV Rooftop (APVRT) System, Bangalore - 3 kW

Table 24: Properties of Hinren Agri-PV Rooftop (APVRT) System

Project name	**Residential Agri-PV Rooftop**
Date of commission	31 October, 2019
Installed capacity DC	3 kWp
State, city	Bangalore, Karnataka
GPS location	12.90890, 77.59428
Type of project	Commercial product for residential customers
Project developer	Hinren Engineering Pvt. Ltd.
EPC	Hinren Engineering Pvt. Ltd.
Ownership structure	Private
Operation & Maintenance	By system owner, Enphase Enlighten monitoring tool
Financing structure	100% equity
Type of agrivoltaic plant	Elevated structure with provision for home gardening
Module technology	- 380Wp mono-crystalline twin peak PERC solar panels from REC Solar Make with Enphase IQ7+ micro inverters.
Mounting structure	- Galvanized steel, 2.3m elevation height with walkway to permit manual cleaning of the system - White heat seal paint was applied to cool the roof and increase albedo effect
Tracking	- Fixed tilt
Cleaning & water management	- Automatic solar panel cleaning with water with harvested rainwater going back into a wastewater tank for filtration and reutilisation
Distribution of Power	- Net-meetering with local distribution company BESCOM
Agricultural aspects	- Albedo effect from white heat seal paint applied on the floor of the roof provides extra light for the plants grown - Leaf and kitchen composters complete the nutrition cycle providing soil for the rooftop garden
Crops	- Good experience with cowliflowr and tomato but also ladies finger, chily, pomgrade, lemmon, spinach, rosemary, bitter gourd, brinjal, beans, basil, coreander, papaya and lettuce amongst others - Ragi and rice did not grow successfully so far
Crop cultivation	To improve sunlight availability some crops must be shifted two to three times per year.
Further aspects	Considerations are made for urban agrivoltaics e.g. as part of public parks or urban gardening.

The APVRT system offers a dual benefit of clean electricity and pesticide-free vegetables. Over the course of a year, it generated approximately 4,500 kWh of emission-free power. Out of this, 2,200 kWh were consumed by the residents, while the remaining 2,300 kWh were sold to the local DISCOM. This not only provided green electricity for nearby houses but also contributed to a sustainable energy ecosystem.

Figure 42: Hinren Agri-PV rooftop system (Credit: Hinren Engineering Pvt. Ltd.)

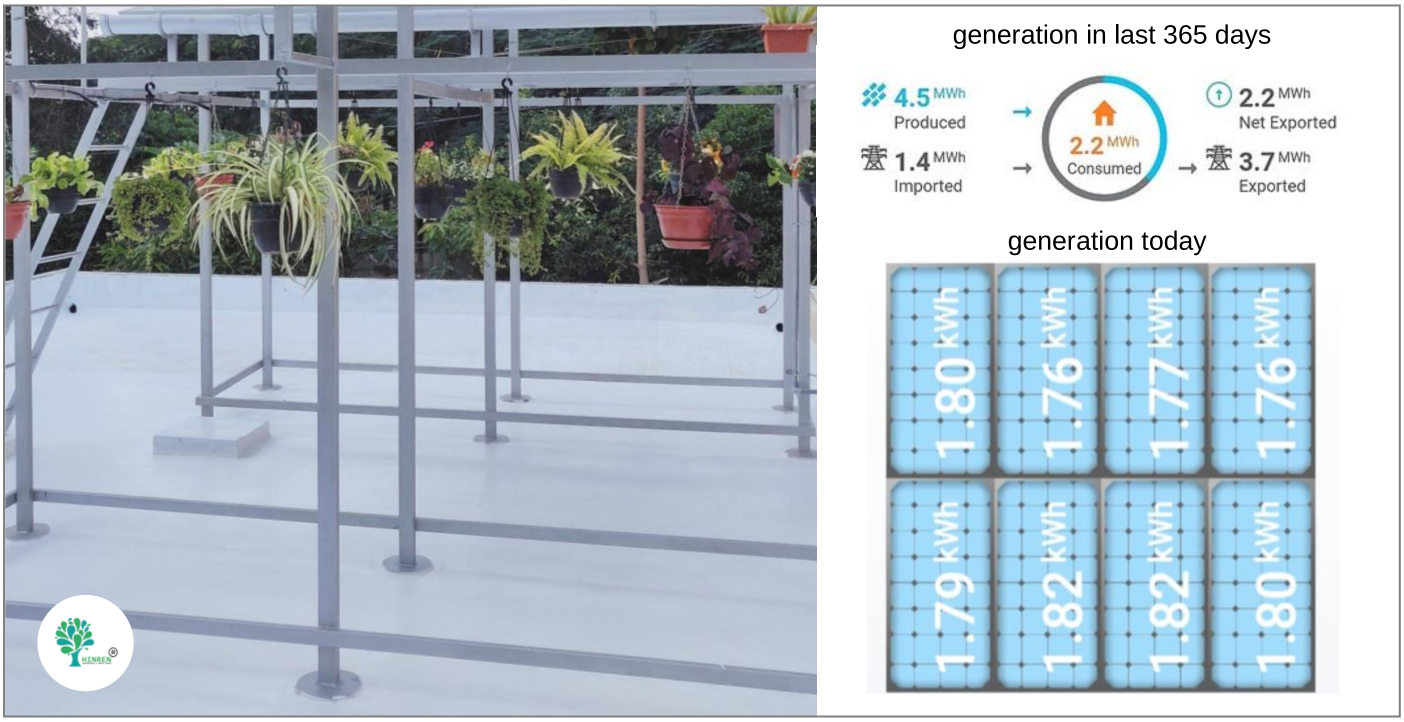

Figure 43: Hinren APVRT structure and white heat seal paint (l), generation profile (r) (Credit: Hinren/Enphase)

Farmer owned Agrivoltaics plant at Jahu, Himachal Pradesh – 250 kW

Table 25: Properties of agrivoltaics plant at Jahu, Himachal Pradesh

Project name	**Sandhwani Solar Power Plant**
Date of commission	n.A.
Installed capacity DC	250 kWp
State, city	Jahu, Himachal Pradesh
GPS location	31.57869, 76.73662
Type of project	Commercial
Project developer	Farmer himself
EPC	n.A.
Ownership structure	Individal Farmer
Operation & Maintenance	Voltaics Agro Pvt Ltd.
Scientific partner	none
Financing structure	PPA with Himurja at rate of 3.75 INR-/ for 25 years Total cost of PV structure: 1.1 crore including non-AC store room
Type of agrivoltaic plant	- Interspace (primarily) - Some cultivation underneath panels
Module technology	- Monofacial / polycrystalline
Mounting structure	- 2.2m Elevation of panels - Panel rows with 2m interspace, 4m between structure base - Cable underground for tillage purpose
Tracking	- Seasonal tilt (manual), following summer and winter solstices
Cleaning & water management	- Manual - Profitable climate: air generally clean and pollution free
Agricultural aspects	- Sandy loam - Low acidity
Crops	- Eggplant, cabbage, onion, chilly and ladyfinger (for seed)
Crop cultivation	- Cultivation of most crops as interspace agrivoltaics - Some crops (incl. turmeric) cultivated underneath PV modules
Further aspects	- Agrivoltaics plant across a total of 1.5 acres land

Nestled beneath the majestic Dhauladhar range, the agrivoltaics site enjoys a picturesque location. With an average annual rainfall of approximately 1,411mm, the area experiences abundant precipitation. To ensure the protection of the fields and crops, meticulous attention must be given to the design and implementation of structures and effective water management strategies.

Figure 44: 2.2m elevated Agrivoltaics system near Jahu, Himachal Pradesh (Credit: Gramin Vikas Trust)

GroSolar Agri-PV Interspace System, Dhule, Maharashtra - 1 MW

Table 26: Properties of GroSolar Agri-PV interspace system

Project name	**GroSolar APV**
Date of commission	n.A.
Installed capacity DC	7 MWp with approximately 1 MW under agrivoltaics use
State, city	Sindakhede, Dhule, Maharashtra
GPS location	21.17731, 74.56914
Type of project	Research
Project developer	Mr. Gulabsing Girase
EPC	Panasonic Life Solutions
Ownership structure	Gro Solar Energy
Operation & Maintenance	GroSolar Energy
Scientific partner	n.A.
Financing structure	EPC Basis
Type of agrivoltaic plant	Interspace
Module technology	30,300 Panasonic Anchor 72 Cell 330W PV Polycrystalline Modules made in India
Mounting structure	n.A.
Tracking	Fixed tilt
Cleaning & water management	n.A.
Agricultural aspects	Loamy sand
Crops	Geranium, Guava, Lemongrass
Crop cultivation	n.A.
Further aspects	- Rearing of sheep is one main aspect of this Agrivoltaic plant and the low mounting structure allows for low heighted crops - PPA with MAHAGENCO - Electricity produced is also used to power homes in nearby villages and farmer's agricultural activities

Figure 45: Geranium plants in interspace farming of GroSolar APV site (Credit: GroSolar)

Figure 46: Grazing sheep enjoying gras below the panels. Because of their light weight and calm behaviour, they do not harm the solar panels (Credit: GroSolar)

SunMasterAgri-PV System, Delhi, India- 2 MW

Table 27: Properties of SunMaster Agri-PV System

Project name	**SunMaster APV**
Date of commission	26.03.2021
Installed capacity DC	2 MW
State, city	Delhi, India
GPS location	28.58209, 76.86706
Type of project	Research
Project developer	SunMaster
EPC	SunMaster
Ownership structure	Private
Operation & Maintenance	SunMaster & dedicated cleaning company
Scientific partner	n.A.
Financing structure	n.A.
Type of agrivoltaic plant	Overhead, 4.3m elevation
Module technology	SunPower
Mounting structure	Hot Dip Galv
Tracking	Fixed Tilt
Cleaning & water management	Telescopic water brush and manual dry cleaning
Agricultural aspects	Research field
Crops	Brinjals, Lettuce, Spinach, Lady Finger, Potatoes, Tomatoes, Bottle Guard, Fenugreek, Coriander, Cucumber
Crop cultivation	Mango, tumeric, pomegranate
Further aspects	Massive steel structure and foundations

Figure 47: Below Panel View of SunMaster APV plant, Delhi (Credit: SunMaster)

Fish Pond Agri-PV System, Bhaloji, Rajasthan – 30 kW

Table 28: Properties of Fish-pond agrivoltaics system

Project name	**Fish Pond Agrivoltaics**
Date of commission	n.A.
Installed capacity DC	30kW installed with interspace fish pond Total site capacity of 1MW
State, city	Bhaloji, Rajasthan
GPS location	27.64157, 76.15659
Type of project	Commercial
Project developer	Independent Farmer
EPC	n.A.
Ownership structure	Private
Operation & Maintenance	n.A.
Scientific partner	n.A.
Financing structure	n.A.
Type of agrivoltaic plant	n.A.
Module technology	n.A.
Mounting structure	n.A.
Tracking	Fixed tilt
Cleaning & water management	Manual cleaning
Agricultural aspects	Fish farming, no further known agricultural activities
Crops	n.A.
Crop cultivation	n.A.
Further aspects	Maintainence challenges and irregular power supply

Figure 48: Fish Pond set-up underneath PV-modules (Credit: Down to Earth)

Agrivoltaics plant at Telangana Agricultural University, Telangana- 10 kW

Table 29: Properties of APV at Seed Research and Technology Centre

Project name	**Agritech Innovation Pilot 2.0**
Date of commission	16.11.2022
Installed capacity DC	10 kW
State, city	Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad
GPS location	17.33065, 78.41036
Type of project	Research
Project developer	Renkube Private Limited, Bangalore
EPC	n.A.
Ownership structure	n.A.
Operation & Maintenance	n.A.
Scientific partner	Seed Research and Technology Centre, Telangana State Agricultural University
Financing structure	n.A.
Type of agrivoltaic plant	Elevated structure
Module technology	n.A.
Mounting structure	Steel structure Approx. 3.5 m Elevation of panels Approx. 3 m Pitch distance
Tracking	Fixed tilt
Cleaning & water management	n.A.
Agricultural aspects	Research field for University
Crops	Multiple, high growing crops possible
Crop cultivation	n.A.
Further aspects	Drip irrigation system Suitable for cultivation with a tractor

Figure 49: Agrivoltaics site before cultivation (Credit: Renkube)

Figure 50: Agrivoltaics site after cultivation (Credit: Renkube)

Indra Solar Farm at Khargapur, Madhya Pradesh – 400 kW

Table 30: Properties of APV at Indra Solar Farm

Project name	**Indra Solar Farm**
Date of commission	Polyhouse 2016, retrofitted with PV panels in 2023
Installed capacity DC	2 Polyhouses with 0.7 acres and 0.8 acres under PM KUSUM-A Scheme
State, city	Indra Solar Farm, Khargapur, Tikamgarh, Madhya Pradesh - 472115
GPS location	24.818603, 79.161423
Type of project	Research
Project developer	Navin Khare, Ward-08, V.P. – Khargapur, Tikamgarh Madhya Pradesh - 472115
EPC	Khare Energy Pvt Ltd. Indore
Ownership structure	Capex
Operation & Maintenance	Khare Energy Pvt Ltd. Indore
Scientific partner	No
Financing structure	Loan – 70% (State Bank Of India, Tikamgarh), Equity -30%
Type of agrivoltaic plant	Elevated structure combined with polyhouse
Module technology	Polycrystalline
Mounting structure	Lightweight polyhouse steel structure
Tracking	Fixed tilt
Cleaning & water management	Overhead pipeline Manual cleaning using long wiper every 2-3 weeks
Agricultural aspects	Research field
Crops	Rabi: wheat Zaid: lentils, green and red gram Kharif: peanuts
Crop cultivation	All seasons

The solar panels are installed with offsets and gaps on the polyhouse to ensure an even and decent light distribution throughout the day for the plants.

Figure 51: Areal view of Indra solar farm (Credit: Khare Energy Pvt Ltd.)

Figure 52: Lightweight polyhouse structure used to mount solar panels at Indra solar farm (Credit: Khare Energy Pvt Ltd.)

Figure 53: Polyhouse structure at Indra solar farm (Credit: Khare Energy Pvt Ltd.)

Upcoming Projects

Agrivoltaics plant near Nashik, Maharashtra – 500 kW

Table 31: Properties of Agrivoltaics plant near Nashik

Project name	**Agrivoltaics plant near Nashik**
Date of commission	Expected: August 2023
Installed capacity DC	250 kWp (later 500kWp)
State, city	Sahyadri Farms, Nashik, Maharashtra
GPS location	[20.16144, 73.8791]
Type of project	Research
Project developer	Sunseed APV, Kanoda Energy and GIZ
EPC	WRS
Ownership structure	Sahyadri Farms
Operation & Maintenance	Farming operations: Sahyadri Farms Technical O&M: WRS
Scientific partner	SunSeed APV and GIZ
Financing structure	n.A.
Type of agrivoltaic plant	Fully elevated single axis tracking
Module technology	Bifacial
Mounting structure	Scorpius & SunSeed APV single axis tracker
Tracking	Yes
Cleaning & water management	Robotic
Agricultural aspects	Research field
Crops	Grapes, oranges, raspberry, tomato, strawberry
Crop cultivation	Orchards
Further aspects	n.A.

Figure 54: In the front, columns that will soon be mounted during the construction of the agrivoltaics plant near Nashik
(Credit: GIZ)

Indra Solar Farm 2 near Khargapur, Madhya Pradesh – 1 MW

Table 32: Properties of Indra Solar Farm 2

Project name	**Indra Solar Farm 2**
Date of commission	Expected: 2023
Installed capacity DC	1 MWp
State, city	Indra Solar Farm, Khargapur, Tikamgarh, Madhya Pradesh - 472115
GPS location	24.818603, 79.161423
Type of project	Research
Project developer	Navin Khare, Ward-08, V.P. – Khargapur, Tikamgarh Madhya Pradesh - 472115
EPC	Khare Energy Pvt Ltd. Indore
Ownership structure	Capex
Operation & Maintenance	Khare Energy Pvt Ltd. Indore
Scientific partner	No
Financing structure	Loan – 70% (State Bank Of India, Tikamgarh), Equity -30%
Type of agrivoltaic plant	Elevated
Module technology	Monocrystalline Bifacial panels
Mounting structure	4 meter high RCC columns 7 meter inter-row and 5 meter inter-column distance for easy movement of farm equipment such as tractor
Tracking	10-degree fixed tilt
Agricultural aspects	Research field

Figure 55: Indra Solar Farm 2 during construction (Credit: Khare Energy Pvt Ltd.)

SunMasterAgri 2 near Issapur, Delhi – 2.5 MW

Table 33: Properties of SunMasterAgri 2 near Issapur

Project name	**Solar Power Plant 2.5 MWp**
Date of commission	Ready from 31.03.2023, (Not yet Commissioned)
Installed capacity DC	2490 kWp
State, city	Issapur, New Delhi
GPS location	28.5714767, 76.8567175
Type of project	n.A.
Project developer	SAEV P Ltd. (Sunmaster)
EPC	Sunmaster
Ownership structure	Raj Kumar & Anju Kumar (50%)
Operation & Maintenance	Sunmaster
Scientific partner	n.A.
Financing structure	Self funding
Type of agrivoltaic plant	4.5m height
Module technology	Monocrystalline Bifacial panels
Mounting structure	Hot dip, galvanised
Tracking	No tracking light transparency 22 %
Cleaning & water management	Walkway installed
Agricultural aspects	Growing different vegetables
Crops	Millet, jawar , bazra, leafy vegetables
Crop cultivation	Mushroom croping
Further aspects	n.A.

Figure 56: SunMasterAgri 2 near Issapur before cultivation (Credit: SunMaster)

Analysis of Characteristics

On a closer inspection, the existing agrivoltaics plants in India can be categorised along several criteria. This section explores these criteria in order to present a structured analysis of the Indian agrivoltaics sector.

Project types

Almost half of the plants are in the state of Gujarat, which can be credited as the first state in the country to examine agrivoltaics as a concept on a broader scale. The oldest of these sites was commissioned by Abellon Energy in 2012 (see above). Together with the company Jain Irrigation Systems Limited (JISL) from the state of Maharashtra, both can be credited as the pioneers of Agrivoltaics in India. JISL has given agriculture even priority with the first pilots being started in 2012 (see above) and crops being grown also below the solar structures.

Since then, India's agrivoltaics sector has seen development from different players. Today, three different plant types are operational in India, namely projects with a focus on R&D, governmental supported projects and commercial projects developed by private entities. The below figure groups the operational projects into these categories.

R&D / Academic Plants	CAZRI plant in Jodhpur, Rajasthan – 100 kW Amity University plant in Noida, Uttar Pradesh – 10 kW Dayalbagh Agriculture University plant in Agra, Uttar Pradesh – 200 kW Junagadh Agriculture University plant in Junagadh, Gujarat – 7 kW NISE plant near Gurgaon, Haryana – 100 kW NISE vertical PV plant near Gurgaon, Hayana – 5 kW Jain Irrigation plants at Jalgaon, Maharashtra – 290 kW APV at Telangana State Agricultural University, Telangana- 10 kW
Government supported / Tendered as Agrivoltaics	GSECL Harsha Abakus plant near Sikka, Gujarat – 1 MW GSECL Harsha Abakus plant near Panandharo, Gujarat – 1 MW GIPCL plant near Amrol, Gujarat – 1 MW GIPCL plant near Vastan, Gujarat – 1 MW Krishi Vigyan Kendra (NHRDF) Ujwa, Delhi – 110 kW
Commercial Pilots	AgriPV plant near Parbhani (Sunseed, GIZ), MH – 1.4 MW AgriPV plant near Nashik, (Sahyadri Farms, Sunseed, GIZ), MH – 250 kW Abellon Energy plant in Aravalli District, Gujarat – 3 MW Cochin Airport plant, Kerala – 4 MW Mahindra Susten plant at Tandur, Telangana – 400 kW Hinren Agri-PV Rooftop (APVRT), Bangalore – 3 kW Farmer-Owned Agrivoltaics plant at Jahu, Himachal Pradesh – 250 kW GroSolar Agrivoltaics plant near Dhule, Maharashtra – 1 MW SunMaster Agri-PV System, Delhi – 2 MW Indra Solar Farm at Khargapur – 400 kW

Figure 57: Project types found in India

R&D / Academic Plants

Research and Development institutions or academic institutions like CAZRI, NISE, Amity and Junagadh University set up projects to study several aspects of agrivoltaics. As a result, all four projects are distinctive. CAZRI focuses mainly on arid zone crops and water use optimization while the others set different focuses. There is no convergence in terms of system design.

Government supported / Tendered as Agrivoltaics

The four 1MW plants in Gujarat by GIPCL and GSECL were tendered as agrivoltaic plants at an early stage of technology maturity. This underpins the interest and commitment of the Government of India related to the development of agrivoltaics. The four projects falling into this category should be considered as pilot projects implemented to understand the functionality of agrivoltaics. By integrating agricultural universities in the design and operations of the plants, the projects demonstrate the significance of industry-academia-cooperation in the conceptualisation of agrivoltaics as a concept.

GIPCL's plant in Amrol features a streamlined mechanism of coordination between solar power generation operations and cultivation of crops. It can be considered an example in terms of effective stakeholder coordination. The learnings made should be made available to upcoming projects under the Mukhyamantri Kisan Aay Badhotri Solar Yojana scheme of GNCT, Delhi.

As important as it is to have dedicated personnel taking care of cultivation and solar plant operation separately, it is also important to have a cohesive relation and coordination between these stakeholders. Miscoordination was observed in some of the plants, resulting in compromised cultivation. However, the projects do not examine the financial implications of switching the type of cultivated crops (e.g. from fruits and vegetables to commercial crops).

Commercial Projects

In a few cases, the development of agrivoltaics has been driven by private corporations. These projects provide an insight into what commercially viable solutions might already look like. Abellon was the first mover in inculcating cultivation between panel arrays and has achieved 0.866 tons/acre production of ginger with net profit of 75,361 INR/acre and for bottle gourd the productivity under solar panel was around 1.16 tons/acre with net profit of 5051 INR/acre. The company also analysed the revenues from various crops if cultivated below the solar panels.

From the perspective of sector development, it is encouraging to see private independent power producers (IPPs) testing this concept for its economic feasibility. A large-scale deployment of agrivoltaics will only be possible with the private sector taking up on the concept.

Plant Layout

The arrangement of solar modules and agricultural area, or the layout of an agrivoltaics plant, dictates its effectiveness in terms of both electricity generation and crop cultivation. As illustrated in figure 19, three different layouts were observed among the visited Indian plants. While an elevated plant structure may permit the usage of tractors and other heavy machinery, it also makes required cleaning more difficult.

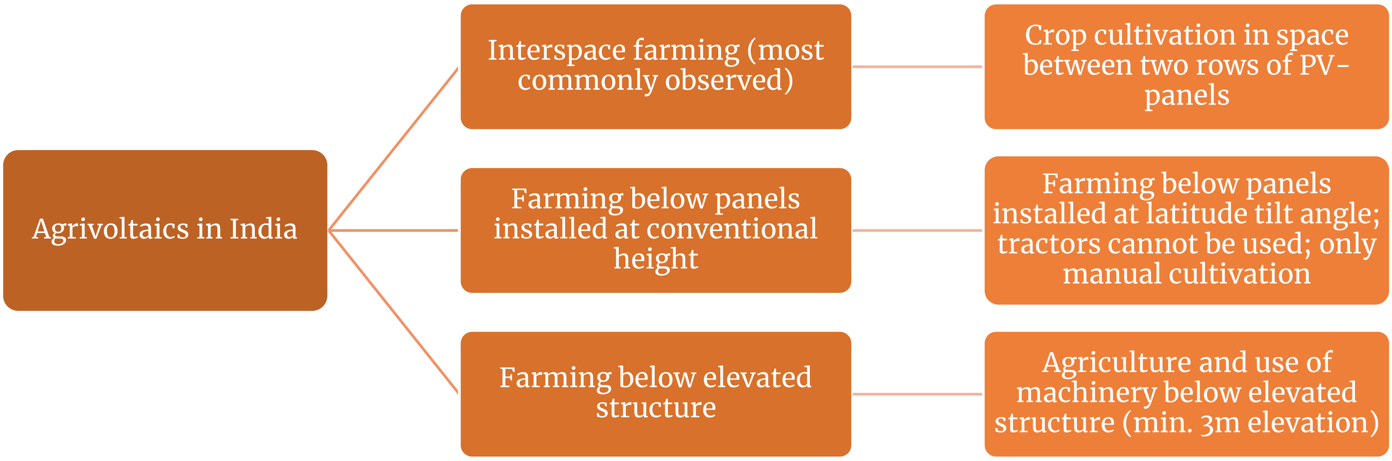

Figure 58: Layouts of agrivoltaic plants

Agronomic Aspects

In order to identify feasible agrivoltaic plant models, it is important to keep the price conscious Indian electricity market in view. In this respect it may be viable to cultivate commercial crops and horticulture crops, which have a higher value in the Indian market and account for higher export. This can help to raise the financial viability of an agrivoltaic project. In most cases, vegetables, medicinal plants, spices and sometimes flowers have been cultivated below the panels, due to their comparably high commercial value. As bifacial solar panels with transparent backsheet will become more common in India too, this should allow a wider crop variety to be grown below the elevated structure.

Conclusions

It can be observed that India's APV ecosystem is slowly maturing from a R&D stage into the commercial market. Nevertheless, there are still hindrances on the way to a broad uptake of the concept in India as this report unveils. Decisive action from policy makers is required if the concept is to be taken up on a broader scale.

Firstly, as there is no convergence towards one dominant type of agrivoltaic plant design, further R&D efforts are required. Exploring best practices across the world (namely from Germany, Italy, France, China, South Korea and Japan) appear worthwhile in order to define standards for technical properties and plant layout. More Indian specific requirements such as those related to required cleaning need to be incorporated. This would function as a reference point for project developers and installers.

Secondly, questions on financial viability need to be addressed. It remains unclear what a viable business plans might look like, particularly if the project is set up by a stakeholder consortium (farmers and solar project developer). A deeper investigation into the crops chosen is required in order to assess optimisation potentials in the financial planning.

Analysis of Relevant Policies

Land Use Policies

In India, land is classified into nine different categories as illustrated in the figure below.

Forests

- Includes all lands classed as forest under any legal enactment dealing with forests or administered as forests, whether state-owned or private, and whether wooded or maintained as potential forest land. The area of crops raised in the forest and grazing lands or areas open for grazing within the forests should remain included under the forest area

Area under non-agricultural use

- Includes all lands occupied by buildings, roads and railways or under water, e.g. rivers and canals and other lands put to uses other than agriculture.

Barren and uncultivable land

- Includes all barren and unculturable land like mountains, deserts, etc. Land which cannot be brought under cultivation except at an exorbitant cost, should be classed as unculturable whether such land is in isolated blocks or within cultivated holdings.

Permanent pastures & other grazing land

- Includes all grazing lands whether they are permanent pastures and meadows or not. Village common grazing land is included under this head

Land under miscellaneous tree crops

- Includes all cultivable land which is not included in 'Net area sown' but is put to some agricultural uses. Lands under Casurina trees, thatching grasses, bamboo bushes and other groves for fuel, etc. which are not included under 'Orchards' should be classed under this category.

Culturable waste land

- Includes lands available for cultivation, whether not taken up for cultivation or taken up for cultivation once but not cultivated during the current year and the last five years or more in succession for one reason or other. Such lands may be either fallow or covered with shrubs and jungles, which are not put to any use.

Current Fallows

- Represents cropped area, which are kept fallow during the current year. For example, if any seeding area is not cropped against the same year it may be treated as current fallow.

Fallow land other than Current Fallows

- Includes all lands, which were taken up for cultivation but are temporarily out of cultivation for a period of not less than one year and not more than five years.

Net area sown

- Represents the total area sown with crops and orchards. Area sown more than once in the same year is counted only once.

Figure 59: Land use category classification in India

Figure 42 shows the distribution of area covered per category.

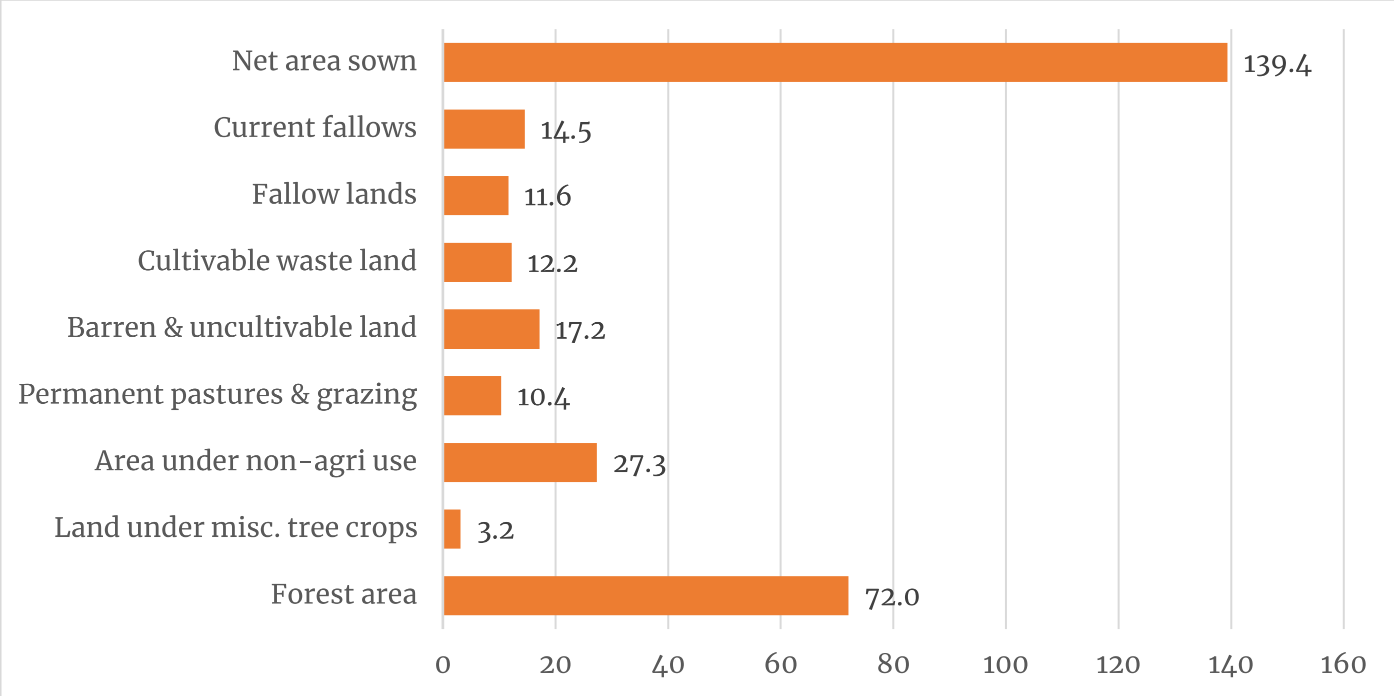

Figure 60: Area (in mio. hectares) per land use category (2018-2019)

On the basis of a thorough Trans India Law Associates' state-wise analysis of Land Acts, such as Land Revenue Code and Land Reforms Act and regulations under electricity laws, it is clearly regulated that on "agricultural" land (see categorisation of land above) only the use for agricultural purposes is allowed. As the law stands now, agricultural land would need to be converted to non-agricultural land for agrivoltaic plants to be constructed.

Generally, solar or any renewable energy development is considered as non-agricultural activity. There is a procedure laid down under each state for land conversion, which needs to be requested from the responsible district administration. Conduction of non-agricultural activities on agricultural land without proper conversion results in potential penalties being imposed on the owner or tenant of the land.

However, there are sections under the law which allow for flexibility within agricultural purposes. These exceptions facilitate constructions that benefit agriculture but are not agricultural purposes in and of itself. For instance, this includes greenhouses. Whether agrivoltaic plants might fall under the same regulatory exemption is yet to be assessed. There is no clear regulation for this case at the time of writing of this report.

In addition to these, the Land Ceiling Acts as legislated by the state governments impose certain upper limits to land acquisition. Some states have provided relaxation in a "Land Ceiling Act" to accommodate projects of larger capacity but it can still pose a barrier to large-scale project development.

Furthermore, land ownership structures are often granular. In order to secure large areas hanging together contracting of local land aggregators who can convince the landowners to sell or rent their land is often required.

PM-KUSUM

Pradhan Mantri Kisan Urja Suraksha evam Uthaan Mahabhiyaan (PM-KUSUM) is the core regulation in place to guide the development of Solar-PV assets in rural areas [11]. The Scheme consists of three components (A, B, C). While components B and C focus on the deployment of PV-powered water pumps, component A is relevant for larger grid-connected projects. It intends to enclose farmers in the development of PV assets. The legislation aims to achieve the deployment of:

- 10GW of Decentralised Ground Mounted Grid Connected Renewable Power Plants of individual plant size up to 2MW.
- Renewable Electric Power Projects (REPP) of 500kW and 2MW will be set up by individual farmers or group of farmers or cooperatives or FPO by utilising their barren and uncultivable land.

Agrivoltaics are not directly in the scope of KUSUM, particularly because the scheme focuses on project development on barren and uncultivable land. Albeit the document's preface states that "cultivable land may also be used if the solar plants are set up on stilts where crops can be grown below the stilts and sell renewable energy power to DISCOMs", there are no incentives in place that would effectively support the development of agrivoltaics. The enticements given to the DISCOMs through the Performance-Based Incentives (PBI) are currently likely not enough to cover the higher cost of agrivoltaics that are caused by its low technological maturity. As a result, the generators (i.e. individuals or groups of farmers, cooperatives, panchayats, Farmer Producer Organisations (FPO), Water User Associations (WUA) or independent power producers), are unlikely to invest. Generally, if the ceiling tariff for the proposed competitive bidding is considered high enough to cover costs, DISCOMs could benefit from investments under KUSUM A. Farmers can benefit through the income of land leasing if they possess land near a substation.

According to a cost-benefit analysis undertaken by Auroville Consulting in Tamil Nadu [3], the scheme primarily benefits the DISCOM and farmers with available non-agricultural land to lease next to a substation in its current form. Auroville calculated that with an investment under Component A over a period of 25 years, DISCOM would save 43% per kW solar capacity and farmers even 100% per kW for the leasing of land. However, a generator would make 20% loss per kW. The calculations are based on assumptions found in the Solar Tariff order 2019 by Tamil Nadu Electricity Regulatory Commission (TNERC). The cost benefit for the DISCOM depends on the solar feed-in-tariff, which was INR 3.04 per KW in the case of Tamil Nadu. The effect on crops of farmers have not been accounted for in the analysis as only the use of non-agricultural land has been taken into consideration.

Summary of State-Specific Laws

Table 34: State-specific policies

State	Policy	Description
Delhi	Agriculture-cum-Solar Farm Scheme	The officially called Mukhyamantri Kisan Aay Badhotri Solar Yojana scheme states the modules "shall be placed on raised structures and spaced enough to allow unhindered farming and aims to provide a source of additional earning to farmers starting from Rs.8333/- per month per acre, with increment @ 6% p.a. The policy prescribes the "Renewable Energy Service Companies" (RESCO) model. A developer leases land from the farmer and establish a PPA with a governmental institution. A maximum of 2.5 MWp per plant was agreed upon [6].
Gujarat	SKY scheme	Total duration of the scheme is 25 years which split between 7-year period and 18-year period. As per the scheme, the farmers will get per unit rate of Rs 7 (Rs 3.5 by GUVNL + Rs 3.5 by State Govt.) for the first 7 years and succeeding 18 years, Farmers will get the rate of Rs 3.5 for each unit sold [5].
Haryana	KUSUM	The Commission determined a tariff at 3.11 INR/kWh. A minimal CUF of 15% must be achieved and DISCOMS shall allocate 135 MWp to set up a pilot basis. The normative O&M expenses shall escalate at 5.72 % annually [4].
Karnataka	Surya Raitha Scheme	Government of Karnataka had launched Surya Raitha Scheme for solarization of agricultural pumps. Under the Scheme, old inefficient pumps are replaced with new energy efficient pumps. Two-third of the electricity generated through solar panels is to be mandatorily used by farmers and the balance energy can be sold to the Discom at a proposed rate of Rs. 7.50 / kWh [13].
Maharashtra	KUSUM	The Maharashtra Electricity Regulatory Commission (MERC) has approved the tariff of ₹3.11/kWh for 100 MW of solar power on a long-term basis for 25 years. The project is being developed by Energy Efficiency Services Limited (EESL) at various locations in Western and North Maharashtra under the Mukhyamantri Saur Krushi Vahini Yojana (MSKVY) [9].
	Mission 2025	Mukhyamantri Saur Krushi Vahini Yojana - 2.0 with a set objective of 30% feeder solarization by 2025 as a "Mission 2025" by implementing 7000MW decentralized solar projects on fast-track mode, wherein decentralized solar projects within the 5 - 10 kM radius from agriculture load dominated distribution sub-station will be installed with the capacity from 0.5 MW to 25 MW for giving day time power to farmers. [www.mahadiscom.in/solar-mskvy]
Odisha	KUSUM	The solar-agricultural development is also underway to be implemented in Odisha as SECI and local DISCOM OREDA agreed to develop several projects under an "Annual Lease Model" over 25 years, in which the participating farmer receives 20,000 INR per acre (49,600 INR/ha) annually in addition to cultivating the land.
Rajasthan	KUSUM	The Rajasthan Electricity Regulatory Commission (RERC) approved ₹3.14/kWh as the pre-fixed levelised tariff for the Component A of the KUSUM program for capacities of up to 725 MW [7].

Uttarakhand	KUSUM	Approved Generic Tariffs for Grid Connected Rooftop & Small Solar PV Plants for FY 2022-2023 (Rs./kWh) [16]

Particulars	**Approved Generic Tariff (Rs. /kWh) with 80% subsidy**
For project having capacity up to 10kW	
Gross Tariff	4.00
Less: Acc Dep Benefit	0.13
Net Tariff	3.87
For Projects having capacity above 10kW and up to 100kW	
Gross Tariff	3.63
Less: Acc Dep Benefit	0.12
Net Tariff	3.51
For Projects having capacity above 100kW and up to 500kW	
Gross Tariff	3.37
Less: Acc Dep Benefit	0.11
Net Tariff	3.26
For Projects having capacity above 500kW and up to 1MW	
Gross Tariff	3.21
Less: Acc Dep Benefit	0.11
Net Tariff	3.10

Policy Recommendations

To expedite the adoption of agrivoltaics in India, the policy framework needs to establish favourable conditions. Through extensive discussions in roundtable events, participation in renewable energy conferences, and collaborations with local research and development institutions, numerous effective strategies have been identified. The subsequent section presents a comprehensive outline of these measures..

Define Agrivoltaics and Minimal Requirements

A key step for enabling the deployment of agrivoltaics in India is establishing an official definition as well as minimal requirements for plants to be categorized as agrivoltaic systems. An Indian norm may be drafted by assessing existent national standards, including such already provided by Germany (DIN SPEC 91434:2021-05), France (ADEME – Characterising Solar PV Projects on Agricultural Land and Agrivoltaism) and Italy (Guidelines for the Design, Construction and Operation of Agrivoltaic Plants). To safeguard agricultural and arable lands, minimum criteria and specifications must be formulated. Such criteria may include:

- Minimum percentage of total surface to remain available and used for agricultural purposes
- Maximum yield loss permitted compared to non-agrivoltaic reference projects
- Requirement for the structure to be removable after the end of life of the installation
- The requirement to provide a crop cultivation plan, cleaning concept and periodic reports

Based on input from farmers and developers, norms and laws should proactively foresee the need for change. Given the creative character of agrivoltaics, it is essential to generate information and work together to promote technological and normative adjustments.

Integration of Agrivoltaics into India's Land Use Classification

As per the Indian Ministry of Statistics and Programme Implementation, land use statistics are currently collected and presented based on a "Nine-fold classification of Land Use" (see Figure 38). A highly enabling policy support would be the integration of agrivoltaics as a tenth land use class. Thereby, an agrivoltaic system could be designated in the land use plan as a "special area for agrivoltaics". Following the example of Japan, a specific agrivoltaic temporary land conversion or another mechanism would be advised. Such a land category would prevent agricultural land used for agrivoltaics to be governed by non-agricultural land use regulations. This would avoid negative implications on farmers, who may lose tax subsidies and continued access to agricultural support schemes. The introduction of "special areas for agrivoltaics" should be linked to previously mentioned minimum requirements, ensuring that the solar system will be fully decommissioned after the end of the lifetime and the land remains agricultural thereafter. Such an approach is crucial to ensure the farmer or land owner continues to receive the agricultural subsidy allocated to the area because statistically the area continues to be agricultural land and does not count as sealed.

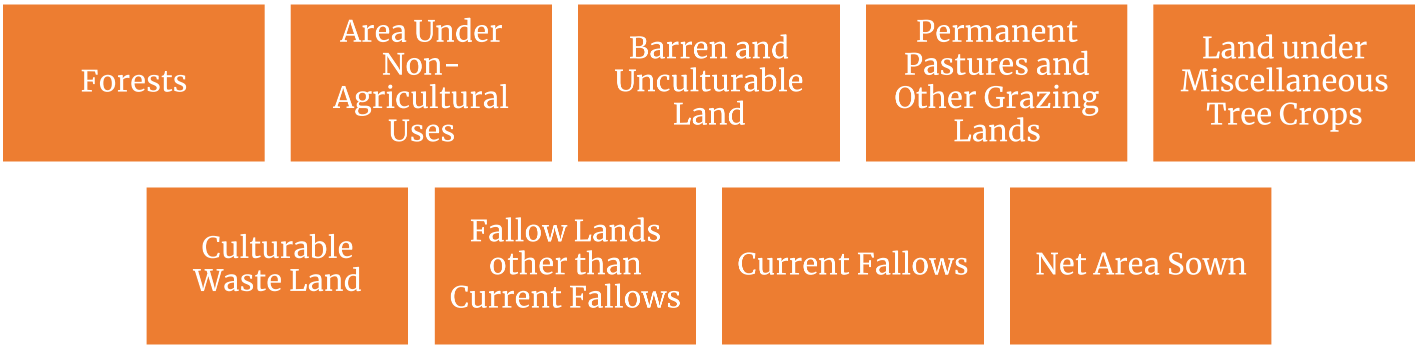

Figure 61: Nine-fold classification of Land Use according to Ministry of Statistics and Programme Implementation

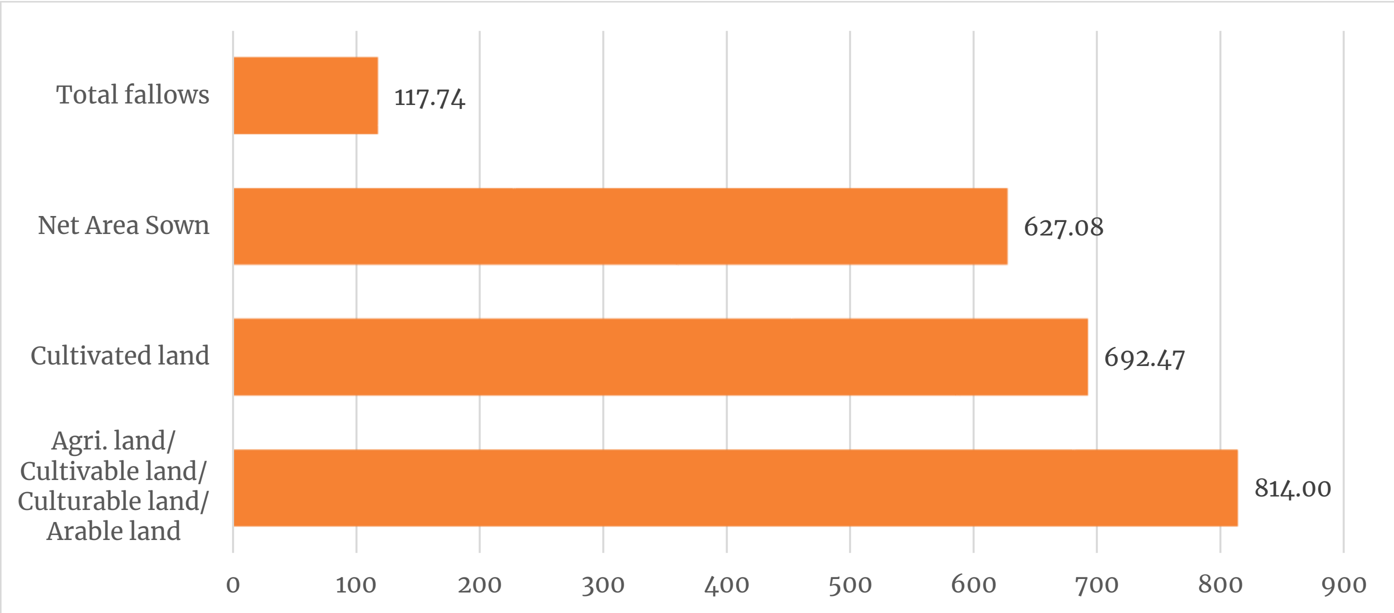

Figure 62: Potential for agrivoltaics on different land categories assuming coverage of 1% (in GW capacity) Calculations based on 2018-2019 land use data

Single Window Clearance and Nodal Agency for Agrivoltaics

In line with defining agrivoltaics and integrating its deployment in the land use classification, the introduction of a single window clearance and designation of a nodal agency for Agrivolatics is recommended. Uncertainties prevail on the required permits, processes and agencies to be approached for the development of an agrivoltaics system. Currently, land owners must undergo complex processes and approach multiple authorities to avoid any risk or liability. Furthermore, authorities and individual officials may have differing views and interpretations of existing non-specific regulations. A single window clearance and the designated nodal agency will allow streamlining planning and implementation, reducing transaction costs and accelerating the nation-wide expansion of agrivoltaics.

Define Deployment Targets for Agrivoltaics

The Government must define a specific target for agrivoltaic plants in India with a year wise trajectory for the next 10 years. In estimating the potential of agrivoltaics in the country, a safe and conservative estimate can be based on the assumption that 1% of each of the land under agriculture, barren land and other uncultivated land in India is used for agrivoltaics. Supposing that 5.5 acres of the land is suitable for 1 MW of agrivoltaics, a total potential of 629.69 GW alone is realised from net area is sown (agricultural) lands. As Figure 39 shows, the potential of agrivoltaics is 117.74 GW for fallow and other uncultivated lands alone (total fallows).

While these targets appear very ambitious, the Government may prefer to start with a modest target of 20-30 MW in the first year and accelerate it in the next 10 years. Indian Government may consider targeting around 15 GW of agrivoltaics in the next 10 years with the suggested trajectory illustrated in the below figure (Figure 44).

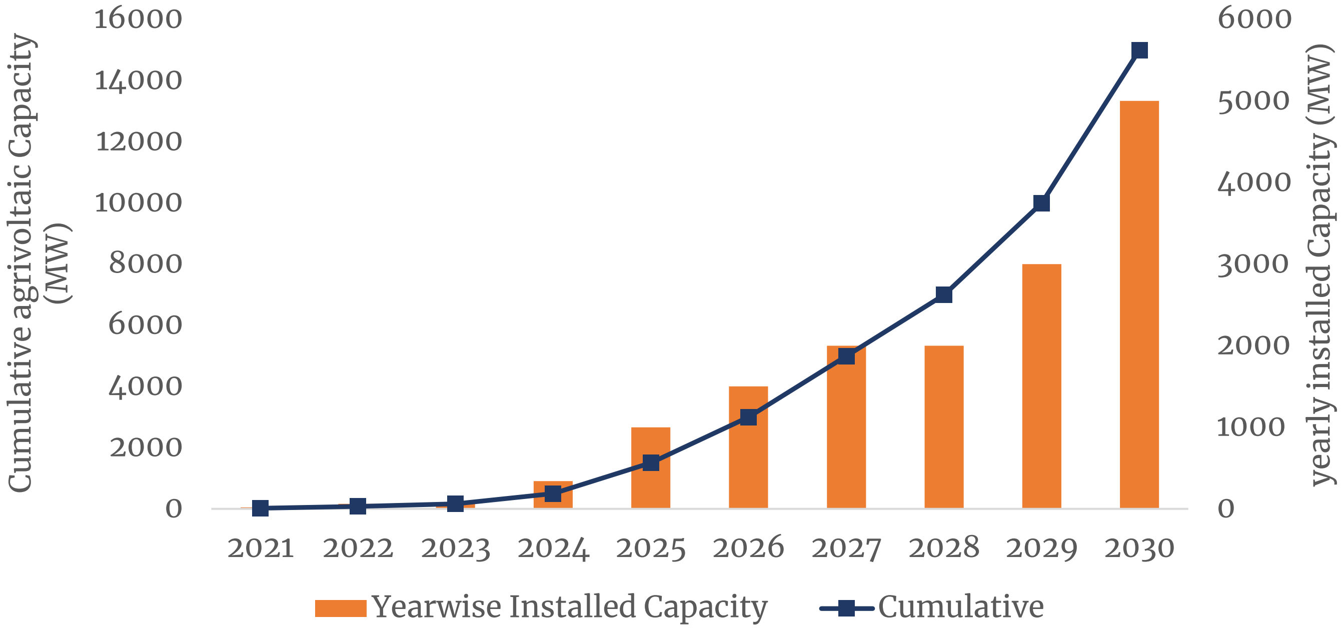

Figure 63: Suggested deployment targets for Agrivoltaic Capacity in India

In line with these national deployment targets, states may be integrated and requested to submit state-wise targets, thereby ensuring ownership and better integration of Agrivoltaics into state-level strategies and policies.

Multi-Ministerial Committee for Coordinated Action

Agrivoltaics, the integration of agriculture and renewable energy, requires improved coordination between stakeholders in both sectors. Specifically, farmers and solar developers need to collaborate effectively, especially when it comes to projects involving separate ownership of agricultural land and PV components. In addition, incentives should be aligned to benefit both farmers and solar developers. To facilitate the successful implementation of agrivoltaics and promote collaboration, the Ministry of Agriculture and Farmers Welfare (MoAFW) needs to play a more active role, while fostering stronger cooperation between the Ministry of New and Renewable Energy (MNRE) and MoAFW. One proposed solution is the establishment of a Multi-Ministerial Committee for Cooperation on Agrivoltaics, consisting of representatives from MNRE, MoAFW, and the Ministry of Science and Technology. Industry interest groups, agricultural stakeholders, and state-level ministries could also be involved in the committee.

National Level Research Program

Building enhanced cooperation between sectors and Ministries, the Government of India in coordination with the Ministry of Agriculture & Farmers Welfare and Department of Science and Technology as well as leading research institutions should constitute a national level research program to understand, analyse and present the impact of agrivoltaics on farmers, their income along with the PV performance. We have already seen the success achieved when research institutions like CAZRI in Jodhpur or Amity University ventured into techno-economic studies of agrivoltaics. Involving stakeholders from the solar industry and agriculture along with research institutions will go a long way to provide a strong scientific and economic case for agrivoltaics in India. Future research endeavours must address the ecologic and economic suitability of agricultural and horticultural crops under various agrivoltaics designs, and assess the potential for increasing productivity and yields across certain climate zones.

Innovation Tenders for Agriphotovoltaic Demonstration Projects

The novelty of agrivoltaics and its deployment in the geographic as well as socio-economic context of India create uncertainties for farmers, solar developers and potential investors. Accordingly, demonstration projects across regions in India, which consider different agricultural value chains and stakeholder models, and address key knowledge gaps are needed. The government of India may consider tendering projects specific to agrivoltaics while also encouraging pilot projects to sensitise stakeholders across sectors. SECI, NTPC, NHPC and other nodal agencies would be suited to issue agrivoltaic specific tenders which promote its deployment.

Financial Incentives for Agrivoltaics in India

The improvement of livelihoods of the partnering farmers must be prioritised and if possible, annual incomes doubled for marginal and small-holder farmers (< 2 hectares of land). To consider agrivoltaics in future Feed-in-Tariff (FiT) calculations and ceiling price setting for tender, the following figures should be taken into account:

- Overhead stilted systems are economical if a total FiT of 4 INR/kWh can be paid to the generator. Considering a baseline price of 3.2 INR/kWh, a subsidy leverage of only 25% would be required. In France for instance the price for awarded innovative agricultural co-location projects was 8.7 Cent/kWh compared to 5.9 Cent/kWh for conventional PV, an increase of 47.5% [10].
- Larger facilities can be tendered with a weighting system that sets the degree of innovation and LCOE on the same level. So not necessarily the lower cost project but also more experimental approaches can be allowed.
- Capital expenditure for KUSUM component. 364.54 lakh INR/MWp. Another suggestion of considering capital requirements as 377.5 lahks INR/MW has also been received. Cost benchmarks for overhead stilted systems estimate the CAPEX to be between 450 to 590 lakh INR/MWp (24% to 62 %increase) [10].
- As O&M expenses may also differ. The currently fixed benchmark at 4.5 lakh INR/MWp should also be raised to 6 to 7 lakh INR/MWp (33 to 56 % increase) [10].

Besides Government support, agrivoltaic projects can be leveraged by decreased capital costs. A decreased cost of debt from 8% to 3% can already reduce the levelized cost of energy (LCOE) by 25 % in case the share of debt is around 70% [10]. Soft loans or green climate bonds could further support the development of an agrivoltaic sector in India.

Potential leverage through carbon trade remains to be uncertain as agrivoltaic power plants have slightly higher life cycle carbon emissions. Carbon capture by crops and soil is likely to be not high enough to compensate for the additional steel or aluminium usage.

Conclusions

This report provides an overview of the current state of the agrivoltaics sector in India, highlighting its early stage of development. Currently, there are 22 operational and 3 upcoming plants, mainly dedicated to experimental purposes. A dominant system design has not yet emerged.

While agrivoltaics holds great potential for addressing significant challenges in India's electricity sector, it is important to acknowledge that achieving rapid and large-scale deployment may be challenging.. This report raises important conceptual and regulatory questions that need to be addressed. To promote agrivoltaics while ensuring agricultural usability, the report proposes a set of policy measures as a starting point for a regulatory framework.

Certain factors, such as module suitability, module cleaning, mounting structure design, and plant layout, were not extensively covered in this report but are crucial for the financial viability of the concept. Finding reliable business plans, particularly regarding collaboration between farmers and the entities operating PV plants, remains a challenge.

An area that requires further investigation in the Indian agrivoltaics sector is the active involvement and perception of farmers in agrivoltaic power plants. Understanding how to make this concept appealing and empowering farmers to drive projects themselves is crucial. Research should focus on identifying the factors that attract farmers to participate in agrivoltaic initiatives and exploring strategies to enable their active engagement in project development and implementation.

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