Agrivoltaics in India

Overview of operational Projects and relevant Policies

Imprint

Commissioned on behalf of
Ministry of New and Renewable Energy (MNRE), Govt. of India
Federal Ministry for Economic Affairs and Energy (BMWi), Govt. of Germany

Commissioned by
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Version: v2.4, May 2021, New Delhi

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Key Findings

1. The co-location of solar panels and commercial crops appears to be a feasible solution in the Indian context however it has not yet been fully explored.

2. The capacity of the agrivoltaic installations in India ranges between 3kWp and 3MWp. Utility-scale agrivoltaic projects of more than 3MWp have not yet been deployed. As a result, there are no experiences of respective technical, economic and agricultural viability.

3. The co-location of solar power generation and agriculture, commonly known as Agrivoltaics, is realised in three distinct types of first pilot plants in India:

    a. Cultivation of crops between the space of two rows of ground-mounted photovoltaic panels (interspace farming).

       Cochin airport project has the largest interspace farming activity in India. Abellon Energy has the longest experience with this technique. Mahindra Susten just entered into this practice in large scale.

    b. Farming between and below ground-mounted panels installed at fixed tilt angle allowing for manual cultivation only.

       Research institute CAZRI has the most experience with such systems in the country.

    c. Farming below panels mounted on an elevated structure. Given sufficient elevation, the use of agricultural machinery is possible.

       At the Amrol project this type of farming is successfully practiced at the largest scale in India. The best scientific data is available from the Junagadh and Amity pilots. Jain Irrigation has the longest experience with 3 different pilots running. Dayalbagh Agriculture University plant and Krishi Vigyan Kendra in Ujwa, Delhi have just comissioned the newest promising pilots.

4. In the existing installations throughout the country, the trade-off between the extra cost incurred for facilitating agriculture below the solar panels and the resulting revenue from the cultivation is yet to be thoroughly quantified. Cost involved in a higher structure and costs for effectively cleaning solar panels at greater height have been identified as the major constraints for developers.

5. In most reviewed cases, operation of the solar plant and farming activities are conducted by two different parties. Miscoordination between stakeholders frequently compromises the efficiency in Agrivoltaic plants.

6. There is a lack of data investigating potential influence of different solar panel technologies and solar panel spacings on crop growth. There is no bifacial panels tested so far except in solar greenhouses by Jain Irrigation. No known research has been conducted to measure the influence of the vegegation on the performance of the solar panel.

Policy Recommendations

1. Definition of deployment targets: Define a specific national target for agrivoltaic plants in India with a year wise trajectory for the next 10 years.

2. Tenders and pilot projects: Central and State Government tenders for projects specific to Agrivoltaics while also encouraging pilot projects to sensitise stakeholders.

3. National Level Research Program: Government in coordination with the Ministry of Agriculture & Farmers Welfare, Department of Science and Technology and leading research institutions should constitute a national level research program to understand, analyse and present the impact of Agrivoltaics on farmers, their income as well as PV performance.

4. Land Use Classification: The explicit mention of agrivoltaics is necessary in any law, scheme or policy when cultivable land is used with PV and an agrivoltaic system could be designated in the land use plan as a "special area for agrivoltaics". A prerequisite shall be that a minimum of 80% of the total surface is available and used for agricultural purposes so that the farmer or landowner continues to receive the agricultural subsidy allocated to the area in which case statistically the area does not count as sealed.

5. Technical Norms and Quality Standards: As of now there are no regulations on land use with solar PV under the Indian legal framework. To ensure dual use of land through Agrivoltaics, and to avoid solar energy yield at the cost of agricultural purpose, criteria need to be set to avoid the installation of improper agrivoltaic installation that neglect agricultural purposes.

6. Financial Incentives for Agrivoltaics in India: The improvement of livelihoods of the partnering farmers must be prioritised and if possible, annual incomes doubled for farmers with less than 2 hectares. To consider Agrivoltaics in future feed-in-tariff calculations and ceiling price setting for tender, the figures stated in the recommendations chapter of this report should be considered.

Acronyms and Abbreviations

CAZRI	Central Arid Zone Research Institute
DISCOM	Distribution Company
GIPCL	Gujarat Industries Power Company Ltd.
FiT	Feed-in-Tariff
FPO	Farmer Producer Organisation
GoI	Government of India
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
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
TNERC	Tamil Nadu Electricity Regulatory Commission
WUA	Water User Associations

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Introduction

As an emerging economy, India’s demand for power has increased by almost 40% over the last five years [2, 3]. With no signs of this dynamic development slowing down any time soon, India is poised to rapidly scale up its generation capacity. The focus increasingly has shifted towards solar power capacities additions which now undercut thermal generators in terms of price per unit of energy (Levelized cost of energy, LCOE). Moreover, the Indian Government has set itself an ambitious goal of achieving 100GW of installed capacity of solar photovoltaics by 2022 in response to international efforts to decarbonise the economy.

As of 31st October 2020, India's official solar generation fleet added up to approximately 36 GW of capacity [12], already making it the 5th largest country in the world in terms of installed solar capacity after China, US, Japan and Germany. However, in order to achieve the necessary growth rates to reach the 2022 objective, the Government of India 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.

Under Component-A, a total of 10GW of decentralised ground mounted grid connected solar power plants are planned with an individual plant size ranging from 500kW to 2 MW. These decentralised plants can be installed on both barren and agricultural land. Due to proximity to infrastructure and demand centres, bureaucratic incentives as well as willingness of farmers to sell their land, mostly agricultural land is being procured and converted for solar plant development. This reinforces existing conflicts between energy generation as opposed to 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, agrivoltaic plants across the country were examined to understand their operations, working and best practices to ultimately prescribe the way forward for Agrivoltaics in India.

This report provides a comprehensive overview of the current situation of Agrivoltaics In India. This includes a summary of 16 operational pilot projects as well as a detailed examination of their technical, economical and agricultural properties. Furthermore, the paper presents a preliminary review of Indian policies relevant to Agrivoltaics as a concept. This way the report presents a basis for discussion of the potentials of Agrivoltaics In India and its role in the country's ongoing energy transition.

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.

Figure 1: Map of agrivoltaic projects in India[1]

[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.

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 [kWp]	1000
State, city	Gujarat, Amrol
GPS location	22.37903, 73.05033
Type of project	Commercial
Project developer	Gujarat Industries Power Company Ltd. (GIPCL), in-house development
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 to 3 m horizontal mounting height - Different configuration of PV arrays with gaps between panels of 0 / 100 / 250 mm - Cable were put around agricultural fields, resulting in higher costs due to longer lines, partly put under the ground up to 2.5 m deep
Tracking	- 5-28-degree 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.

This project has been commissioned by Gujarat Industries Power Company Ltd. (GIPCL). The agricultural aspects of the plant are handled by Anand Agriculture University, a university well-known in Asia for cutting-edge research. The panels are installed on a mounting structure at a height of 3 meters. Seasonal tilt is manually adjustable. This plant features differing inter-module and inter-array gaps in order to study the impact of different shading patterns on crop growth.

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

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

GIPCL plant near Vastan, Gujarat - 1 MW

This plant is built and operated by GIPCL with the support by Navsari Agricultural University. This is a replica of the plant maintained by GIPCL in 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 [kWp]	1054
State, city	Gujarat, District Jamnagar, Sikka
GPS location	22.42277, 69.84348
Type of project	Commercial
Project developer	GSECL
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 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 3 m - Cabling underground below tillage depth - 4.5 acre/MWp, 549 kWp/ha - Testing of different gaps between modules: 25 / 150 / 250 mm
Tracking	- Manual single axis tracking - Seasonal tilt: 0,10- & 25-degree - Tilting angle possible above 85 degree - Tilting of panels manually, requires approx. 10 people
Cleaning & water management	- Very close to a cement-producing industry (sticky sediment) - Manually cleaning with stand, dry cleaning not an option - 2-5 litre water needed per module - Cleaning 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 - 5m3 & 22m3 tank for cleaning & drip irrigation
Crops	Lady fingers, calabash (bottle gourd), coriander, cluster beans. Winter: Tomato, cucumber, ladyfingers, zucchini, chili Summer: Mug, tal
Crop cultivation	- No research done so far in terms of interaction of different panel configurations (shading) with different plants and respective yields - Agriculture between rows, not below panels - Crops higher than 5-6 feet cannot be grown

Further aspects	- Challenges include cleaning, tilting on segment of 20 panels each requires approx. 10 people, proper maintenance of drip irrigation system and theft - Specific cleaning challenges: Structure height too high for efficient cleaning. Water falls on the crops with force and sometimes damages the flowers. The stand used for cleaning the modules sometimes damages crops as well. Water comes from public network grid pipeline. - No further agrivoltaic plant planned so far

The project is located near Sikka in the Jamnagar district in Gujarat. Seasonal temperatures vary between 21°C and 35°C. Average annual rainfall per annum is 744mm. Albeit sandy and gritty, soil in the region is suitable for cultivation of a number of crops. However, the site is located in hilly terrain not ideal for agricultural use and has not been utilised for the purpose 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 steel structure 3 meters above the ground, a height that allows for the cultivation of a variety of crops and all manual cultivation practises. Farming can be performed in between the module rows as well as directly below the PV modules. At the time of visit no plants were grown below the modules. However, over the prior 2.5 years of operation, crops including lady fingers, calabash (bottle gourd), coriander, cluster bean were successfully grown in the summer season. Additionally, tomato, cucumber, zucchini and chillies were grown during winter season. An unknown private agriculture research organisation was entrusted with maintaining and planning the crops for the project.

The cabling in this plant is completely underground at a depth that doesn't restrict regular ploughing of the field. For irrigation purposes, pipes are laid throughout the field. Similar to a drip irrigation system, the pipes feature pores that allow for even and efficient irrigation of the crops. Through a network, they are connected to a central water tank with a volume of 22 m^3. The network of pipes for micro-irrigation must be lifted during the process of ploughing and seed sowing.

As this plant is situated very close to a cement-producing industry, regular cleaning of the modules is necessary; Dry cleaning of the PV modules was found not to be an appropriate solution. A separate stand-alone pipe is connected to a different water tank of 5 m^3 volume in the premises of the solar plant through which every array in the plant is cleaned manually every 7- 8 days. As per the data provided by Harsha Abakus, each cleaning consumes 2- 5 litres of water [14].

The power generated is sold to Gujarat Urja Vikas Nigam Limited through a PPA at an incremental tariff until 20 years.

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

GSECL Harsha Abakus plant near Panandharo, Gujarat - 1 MW

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

Project name	1MW Agri Base Solar Power Plant
Date of commission	02.05.2016
Installed capacity DC [kWp]	1054
State, city	Gujarat, District Kutch, Panandhro
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	n.A.
Agricultural aspects	Rocky land without sufficient nutrients Netafim drip irrigation
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- 6 ft - 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

Panandhro is a village located in Kutch district, an area dominated by mining industry. The region features an arid climate with temperatures between 15ºC and 27 Cº. Rainfall in this region amounts to only 355 -375 mm per annum. The project Is a replica of Harsha Abakus' 1 MW Sikka plant. In this case the PPA is signed with Paschim Gujarat Vidyut Company Limited (PGVCL). Mounting structure, PV design, operational properties and crop pattern are similar to the project in Sikka.

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

CAZRI plants in Jodhpur, Rajasthan - 100 kW

Table 1: Properties of CAZRI project in Jodhpur

Project name	n.A.
Date of Commission	12.08.2017
Installed capacity DC [kWp]	105
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 (260 Wp), 1.64 m to 0.992 m
Mounting structure	Latitude angle considered as tilt angle in this project (26° at Jodhpur) Height: - Array 1: 1.22 meters - Array 2: 1.94 meters - Array 3: 2.66 meters - Arrays of one-row PV module and 3 m interspace - Arrays of two-row PV modules and 6 m interspace - Arrays of three-row PV modules and 9 m interspaces - 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
Further aspects	n.A.

This Agrivoltaics plant is located in Jodhpur which has an arid climate with an average irradiance on horizontal surface of 6.11 kWh/m2/day. The region is cloud-free almost 300 days per year and has minimum and maximum temperatures ranging from 9.6 ⁰C to 41.4 ⁰C.

The layout of the plant features three different patterns: PV arrays of one-row PV module and 3 m interspaces between arrays; PV arrays of two row PV modules and 6 m interspaces between arrays and PV arrays of three-row PV modules and 9 m interspaces between arrays. All cases allow for the use of heavy machinery. The plant's design includes a rainwater harvesting system based on duct pipes attached to the bottom edge of the PV-modules. This facilitates the harvesting of up 1.5 lakh litres of rainwater annually. The water is utilized for cleaning the modules' surfaces and irrigation purposes. The design includes a storage tank of 100 m^3 that can hold water for rabi season. 49% of the available land can be used to cultivate crops in this project which would otherwise be left as fallow land. The project achieves a land equivalent ration of 1.41.

Table 2: 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, 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. capitata), onion (allium cepa), garlic (allium sativum)	Growth and yield of solanum melongena was significantly affected by shade of PV module.

Assessing the economics of the project, it was found that the revenue from agricultural production lags that of electricity generation. As per the data available, the source of income from mung bean during kharif season amounts to INR 8,235, while isabgol in rabi season creates revenues of INR 23,339 [15].

Figure 2: Agrivoltaics at CAZRI (Credit: CAZRI)

Figure 3: Agrivoltaic system with rain gutter at CAZRI (Credit: CAZRI)

Amity University plant in Noida, Uttar Pradesh - 10 kW

Table 3: Properties of Agrivoltaic project at Amity University

Project name	n.A.
Date of commission	2017
Installed capacity DC [kWp]	10
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 (330 Wp), Canadian
Mounting structure	- Optimum tilt angle - Approximately 15 ft (4.6 m) height of the mounting pole - Area: 630 m2; 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 1 m - Minimal shading impact, crop yield unchanged
Further aspects	n.A.

Noida is a planned city in the northern state of Uttar Pradesh having a steppe climate. The project has been constructed on land of Amity University. Minimum and maximum temperatures in this region is of 16 °C and 45 °C. The average rainfall per annum is approximately 714 millimetres. Sandy loam soil is available in this location containing more nutrients, moisture and humus. A piping system on each mounting structure with cork valves enables automatic cleaning of the modules. The water used for cleaning is captured and then directly falls on the ground below in order to irrigate the crops. This reduces the overall water consumption of the project.

The height of the structure allows for tractors to be used on the field for ploughing. Manual work on the crops is not restricted either which is crucial for the type of crop cultivated. Without the photovoltaic panels, water requirement would be similar, but grid power supply would be required in order to operate the pump set. In the given setup, more than 95% of the land can be utilised for crop cultivation due to the limited PV capacity installed and cabling above the ground.

Figure 4: Plant at Amity University (Credit: NSEFI)

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

Table 4: Properties of plant at Dayalbagh Agriculture University

Project name	n.A.
Date of commission	26.01.2020
Installed capacity DC [kWp]	200
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)
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
Mounting structure	- 18' feet elevation height - 19 towers each with 50 modules
Tracking	Single axis tracking
Cleaning & water management	R&D in progress - variable pressure sprinkler system
Agricultural aspects	Deep loamy soil Ploughing can be easily done in this plant with tractor
Crops	Grams, brinjal, tomato, wheat, spinach, cauliflower, carrot
Crop cultivation	Drip for all vegetables, STP water for grams (roughly 50-50%)
Further aspects	Additional battery storage system planned

Agra is a city on the banks of river Yamuna in Uttar Pradesh district with a semi-arid climate and globally renowned for the Taj Mahal monument. Minimum and maximum temperature occurrence in this location is of 18.6°C and 44.6°C. This region receives an average moderate annual rainfall of 736.3mm. The soil is of deep loamy soil. The plant is installed on the Dayalbagh Agriculture University's land to conduct research and development activities regarding Agrivoltaics. Ploughing in this field can be conducted with heavy machinery due to the mounting structure of 18 feet height and sufficient interspacing between the poles.

Figure 5: Dayalbagh Agriculture University agrivoltaic plant (Credit: DAU)

Figure 6: Dayalbagh Agriculture University agrivoltaic plant (Credit: DAU)

Junagadh Agriculture University plant in Junagadh, Gujarat - 7 kW

Table 5: Properties of agrivoltaic plant at JAU

Project name	n.A.
Date of commission	2017
Installed capacity DC [kWp]	7.2
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 (0.67 m X 1.47m) Poly crystalline
Mounting structure	- Elevation height: 3m - Chequered module arrangement. - 7.6, 11.4 m 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
Crops	Tomato, capsicum
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

This plant of 7.2kWp capacity was installed at the Junagadh Agriculture University (21.50109, 70.44758) to carry out research and development. Junagadh climate region is of tropical wet and dry climate with having minimum and maximum temperatures of around 16°C and 38°C. The average rainfall per annum is about 827 mm. Soil in this region is of black soil that is ideal to grown vegetables. The cultivated crops in this project do not require the use of heavy machinery (e.g. tractors for ploughing).

Figure 7: Junagadh agrivoltaic system (Credit: Prof. P.M. Chauhan, JAU)

Figure 8: Aerial view of Junagadh agrivoltaic system (Credit: College of Agricultural Engineering and Technology, JAU)

Abellon Energy plant in Aravalli District, Gujarat - 1 MW

Table 6: Properties of Abellon Energy plant

Project name	Solar-Agri Electric Model Project
Date of commission	28.01.2012
Installed capacity DC [kWp]	3000 (~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

This plant is located in the foothills of Aravalli mountain range where the climate is semi-arid. Lying in the tropic of cancer, the area receives abundant sunlight. The minimum and maximum temperature range between 15°C and 45°C. The average rainfall per annum in the Modasa taluka, Aravalli district is 690 mm. Soil is rocky, porous and has less retention capacity which makes it less suitable for cultivation of cereal crops. Module cleaning in this plant is done manually. Water used to cleanse directly falls on the ground irrigating the interspace cropping area. Henna plants encircle the solar pant as secondary wind braking barrier.

Figure 9: Interspace farming at Abellon Energy plant in Aravalli District (Credit: Abellon Energy)

Figure 10: Cleaning and irrigation at Abellon Energy plant (Credit: Abellon Energy)

Mahindra Susten plant at Tandur, Telangana - 400 kW

Table 7: Properties of Mahindra Susten plant

Project name	Clean Solar Private Limited, Tandur
Date of commission	2016
Installed capacity DC [kWp]	36.6 MW (~400 kW 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 feet - 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 11: Mahindra Susten plant at Tandur with seedlings planted (Credit: Mahindra Susten)

Figure 12: Mahindra Susten plant at Tandur with lemon grass (Credit: Mahindra Susten)

Jain Irrigation plants at Jalgaon, Maharashtra - 14.4 kW, 9.6 kW and 50.4 kW

Table 8: Properties of Jain agrivoltaics plants

Project name	AgroPV Model Plants by Jain Irrigation
Date of commission	2014 (first pilots date back to 2012)
Installed capacity DC [kWp]	14.4 (banana pilot), others are 9.6 (rice pilot), 50.4 (okra/cotton pilot)
State, city	Maharashtra, Jalgaon
GPS location	20.99144, 75.5073
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., internal funding
Type of agrivoltaic plant	Overhead stilted
Module technology	240 W panel
Mounting structure	Mounting structure design nearly allows 95% use of land area below panels (banana pilot) Area: 600 m2; 240 kWp/ha
Tracking	single axis (banana pilot), fixed (rice pilot), dual-axis (cotton pilot)
Cleaning & water management	Manual
Agricultural aspects	Black fertile soil Tractor to be operated below panels
Crops	Banana, rice, maize, cotton, lady finger
Crop cultivation	- Banana plant height: 4 to 5 meters - Rice crop height: 1 to 1.8 meters - Reported yield impacts: Banana: 14 to 34.5 ton/acre (+140%); water use (-) 55% Rice 3.1 to 3.8 ton/acre (+22.5%); water use (-) 33.7%
Further aspects	n/a

Jain Irrigation Systems Limited (JISL), a multinational conglomerate organisation based in Jalgaon, India, is experimenting with Agrivoltaics since 2012 [8]. Dr. Bhavarlal Jain, founder of JISL, had initiated several agrivoltaic installations mainly to power agriculture pumps at his R&D farm called Tissue Culture Park. Jain's Tissue Culture Park started in 1995 for propagation and supply of tissue culture planting material for banana, pomegranate and strawberry. A 14.4kW agrivoltaic structure covers a 600 m2 area with banana production. In 2018 the company also experimented with maize under the same structure. A second plant right beside is combining solar photovoltaic with drip irrigation and rice cultivation low in greenhouse gas emissions. A third agrivoltaic plant also equipped with drip irrigation is situated 400m away from the other two plants. Here cotton and okra has been grown.

Figure 13: 14.4kW agrivoltaic structure with banana (Credit: Jain Irrigation)

Figure 14: Aerial view of 14.4kW agrivoltaic structure with banana (Credit: Jain Irrigation)

Figure 15: Agrivoltaics with tracking and drip irrigation (Credit: Jain Irrigation)

Figure 16: Agrivoltaics with rice (Credit: Jain Irrigation)

NISE plant near Gurgaon, Haryana - 100kW

Table 9: Properties of NISE plant near Gurgaon, Haryana

Project name	n.A.
Date of commission	n.A.
Installed capacity DC [kWp]	100
State, city	Haryana, Gwal Pahari, near Gurgaon
GPS location	28.42754, 77.16071
Type of project	Research
Project developer	National Institute of Solar Energy (NISE)
EPC	Tata Solar
Ownership structure	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	no
Cleaning & water management	n.A.
Agricultural aspects	Loamy sand
Crops	Tomato, chili, flowers, Kufri Lima potato
Crop cultivation	n.A.
Further aspects	An additional vertical pilot power plant has been installed by Adani Solar in 2020

NISE has been experimenting with growing of tomato, chili and flowers between and below solar arrays in one part of an existing ground mounted PV plant. Official results are expected in 2021. NISE has also successfully tendered a vertical PV pilot plant with bifacial modules, which was constructed by Adani Solar.

Figure 17: Experimental agriculture at NISE (Credit: NSEFI)

Cochin Airport plant in Kerala - 12 MW

Table 10: Properties of project at Cochin Airport

Project name	Cochin International Airport Limited (CIAL)
Date of commission	18.08.2015
Installed capacity DC [kWp]	12,000 (partly co-located with agriculture) Total capacity in 2020 above 26,000
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	n.A.
Scientific partner	n.A.
Financing structure	PPA with Kerala State Electricity Board. Project cost estimate 10.74 Mio. USD debt financed by Deutsche Bank
Type of agrivoltaic plant	Interspace
Module technology	265 Wp Renesola, inverters 1 MW by ABB India
Mounting structure	Conventional ground mounted PV design
Tracking	None
Cleaning & water management	Manual cleaning with water
Agricultural aspects	n.A.
Crops	- Tomato - Ginger, turmeric, green chilli - Snake gourd, bitter gourd, bottle gourd, ash gourd, blonde cucumber, eggplant - Pumpkin - Ladies finger - Long beans
Crop cultivation	60-80 tons per year cumulative production reported. Completely organic cultivation. There is strong market linkage and direct selling to regular consumers and passengers which helps the unit to earn revenue from agriculture part. Most of it is interspace cultivation.
Further aspects	PV capacity has been extended to above 26 MW until 2020.

There was little detailed information available on the Agrivoltaics project at Cochin airport at the time of writing of this report. 60-80 tons per year cumulative production reported. Completely organic cultivation. There is strong market linkage and direct selling to regular consumers and passengers which helps the unit to earn revenue from agriculture part. Most of it is interspace cultivation.

Figure 18: Agrivoltaic plant at Cochin Airport (Credit: CIAL)

Figure 19: Agrivoltaic plant with pumpkin at Cochin Airport (Credit: CIAL)

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

Table 11: 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 [kWp]	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 with 3.5 m elevation height at 15 degree 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. A drip irrigation system for the entire agrivoltaic plant has been implemented.
Distribution of power	Connected to public grid of BSES Delhi with group metering and power utilised by National Agricultural Co-operative Marketing Federation of India Ltd. (NAFED), National Horticultural Research and Development Foundation (NHRDF), Krishi Vigyan Kendra (KVK) and ratio of 70:20:10 at tariff of INR 3.13 / kWh.
Agricultural aspects	Located in agroclimatic zone VI trans-gangatic plains region with annual rainfall of 420-780 mm. Temperature variation from 2-47 degree centigrade. Soil with PH of 8.5 and above.
Crops	Okra, tomato, brinjal, capsicum, leafy vegetables, root vegetables and cole crops planned
Crop cultivation	Start in may 2021
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.

The agrivoltaic solar farm demonstration unit of 110 kWp capacity is installed on a total area of 2000 m2 in Krishi Vigyan Kendra (National Horticultural Research and Development Foundation), Ujwa, New Delhi as a pilot project. This project was established under Mukhyamantri Kisan Aay Badhotri Solar Yojana scheme of GNCT, Delhi. This scheme permits any entity to install photovoltaic power plants on agricultural land. Up to one-third of the farmland can be occupied by the structure and rented out by the farmer to the solar power plant owner. Minimum structure height is 3.5 meters to allow passage for tractors and other farming equipments. The unit is fully financed by Delhi Transco Limited, Delhi under Corporate Social Responsibility (CSR) and NABARD fund, Regional office, Delhi. The main objective of this demonstration unit is to keep the green city belt around Delhi green by cultivating horticultural crop. In addition farmers can substantially enhance their income through land lease and increased crop yield. This paves the way for the vision of Hon'ble Prime minister of India to double farmer income by 2022.

Figure 20: Krishi Vigyan Kendra Solar Farm Pilot (Credit: KVK Ujwa)

Figure 21: Aerial view on Krishi Vigyan Kendra Solar Farm Pilot with water gutter (Credit: KVK Ujwa)

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

Table 12: Properties of Hinren Agri-PV Rooftop (APVRT) System

Project name	Residential Agri-PV Rooftop
Date of commission	31 October, 2019
Installed capacity DC [kWp]	3 KWp
State, city	Bangalore, Delhi
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	380 Wp 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 waste water tank for 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.

This APVRT system provides emission free electricity and fresh and pesticide-free vegetables. In one year the system generated around 4,500 kWh with 2,200 kWh consumed by the residents and 2,300 emission free unites sold to the local DISCOM providing green electricity for neighbouring houses.

Figure 22: Hinren Agri-PV rooftop system (Credit: Hinren Engineering Pvt. Ltd.)

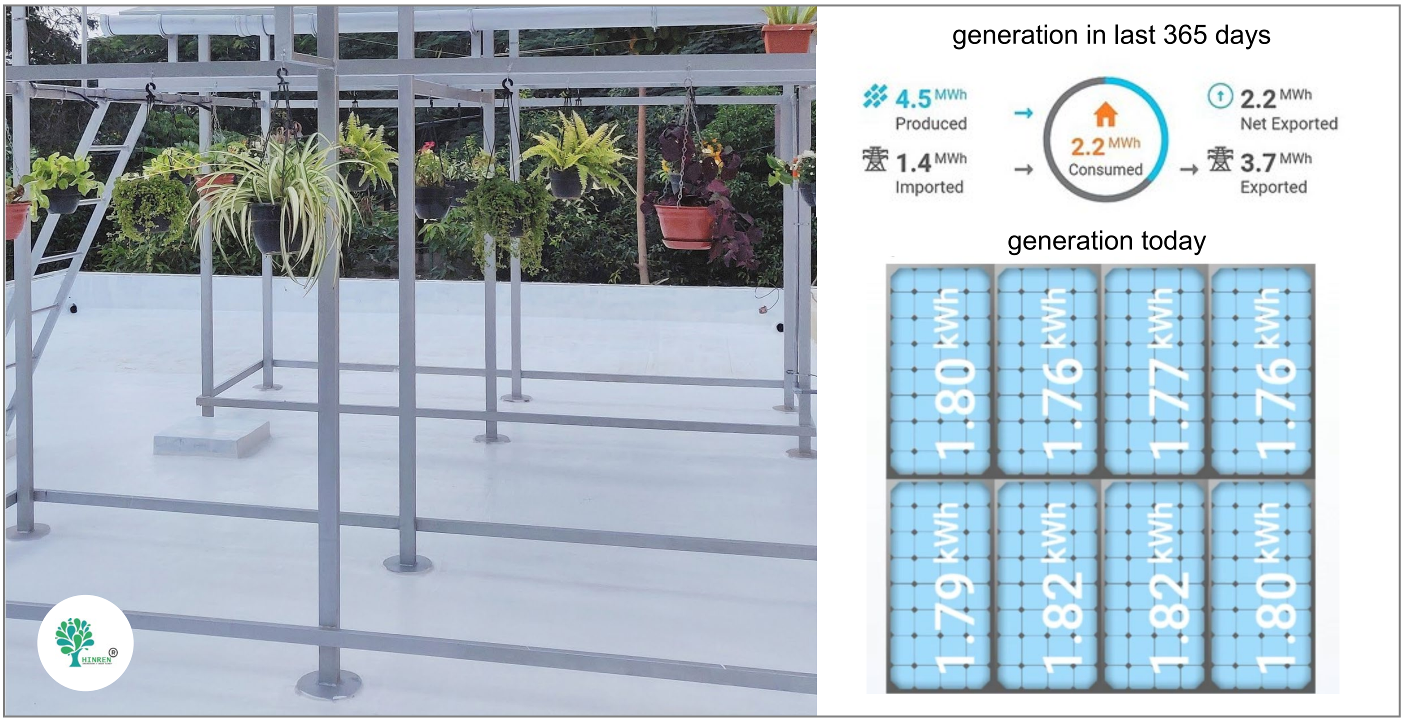

Figure 23: Hinren APVRT structure and white heat seal paint (l), generation profile (r) (Credit: Hinren/Enphase)

Analysis of Characteristics

On a closer inspection, the existing agrivoltaic 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 plants in Jodhpur, Rajasthan - 100kW Amity University plant in Noida, Uttar Pradesh - 10kW Dayalbagh Agriculture University plant in Agra, Uttar Pradesh - 200kW Junagadh Agriculture University plant in Junagadh, Gujarat - 7kW NISE plant near Gurgaon, Haryana - 100kW Jain Irrigation plants at Jalgaon, Maharashtra - 14.4kW
Government Supported / Tendered as Agrivoltaics	GSECL Harsha Abakus plant near Sikka, Gujarat - 1MW GSECL Harsha Abakus plant near Panandharo, Gujarat - 1MW GIPCL plant near Amrol, Gujarat - 1MW GIPCL plant near Vastan, Gujarat - 1MW Krishi Vigyan Kendra (NHRDF) Ujwa, Delhi - 110kW
Commercial Projects	Abellon Energy plant in Aravalli District, Gujarat - 3MW Cochin Airport plant, Kerala - 40MW Mahindra Susten plant at Tandur, Telangana - 400kW Hinren Agri-PV Rooftop (APVRT), Bangalore - 3kW

Figure 24: 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 focusses mainly on arid zone crops and water use optimisation 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 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.

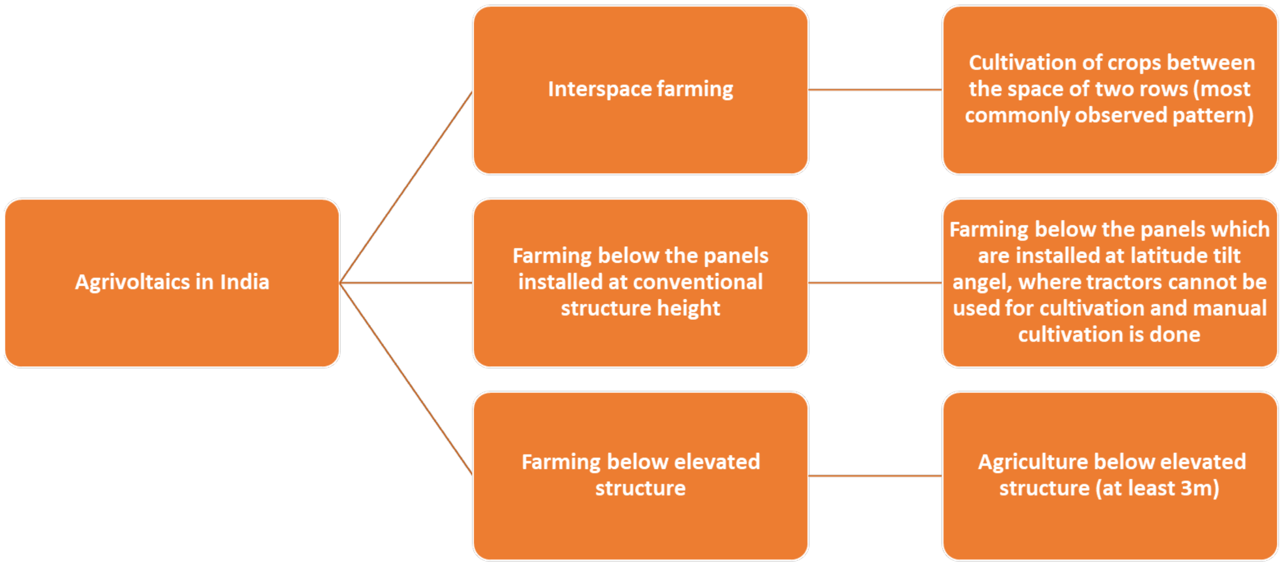

Figure 25: Layouts of agrivoltaic plants

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 26: Land use category classification in India

Figure 27 shows the distribution of area covered per category.

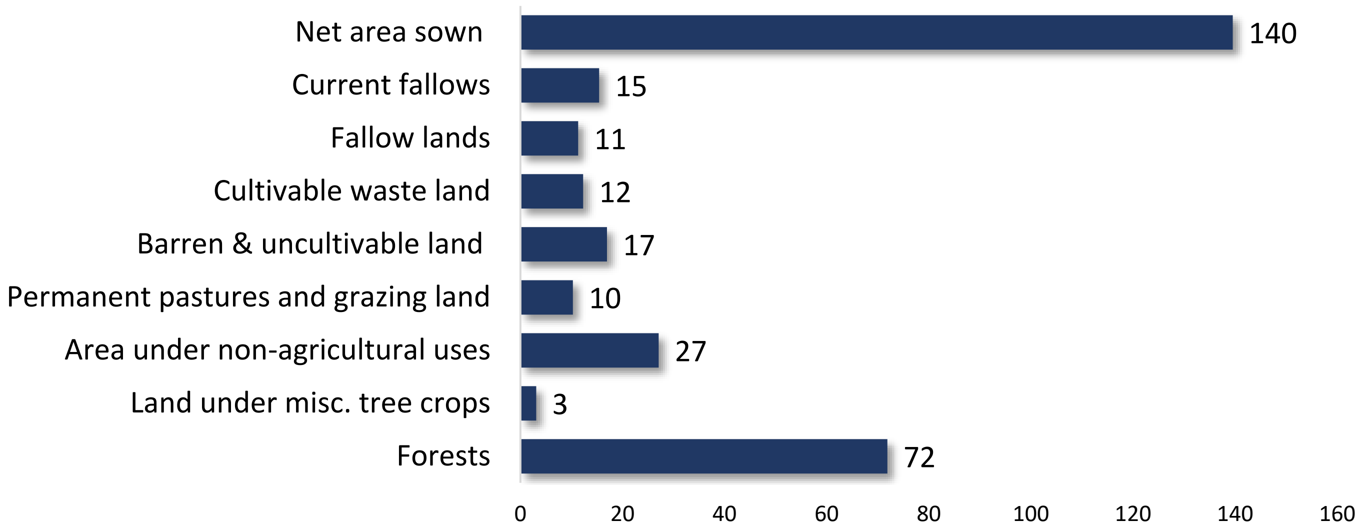

Figure 27: Area (in mio. hectares) per land use category (2015-2016)

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.

KUSUM

Kisan Urja Suraksha evam Uthaan Mahabhiyaan (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 RE 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 [1], 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 13: State-specific policies

State	Policy	Description
Andhra Pradesh	-	NA
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].
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.
Punjab	KUSUM	NA
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].
Tamil Nadu	-	NA

Uttarakhand	KUSUM	**Approved Generic Tariffs for Grid Connected Rooftop & Small Solar PV Plants for FY 2020-21 (Rs./kWh)** [16]	
		Particulars	**Approved Generic Tariff (Rs. /kWh) with 80% subsidy**
		For project having capacity up to 10kW	
		Gross Tariff	3.63
		Less: Acc Dep Benefit	0.15
		Net Tariff	3.48
		For Projects having capacity above 10kW and up to 100kW	
		Gross Tariff	3.27
		Less: Acc Dep Benefit	0.14
		Net Tariff	3.14
		For Projects having capacity above 100kW and up to 500kW	
		Gross Tariff	3.02
		Less: Acc Dep Benefit	0.13
		Net Tariff	2.9
		For Projects having capacity above 500kW and up to 1MW	
		Gross Tariff	2.97
		Less: Acc Dep Benefit	0.12
		Net Tariff	2.85

Policy Proposals

In order to accelerate the uptake of Agrivoltaics as a concept in India, the policy framework would have to arrange for suitable preconditions. The following section points out several viable measures.

Definition of Deployment Targets

It is highly imperative for the Government to define a specific target for agrivoltaic plants in India with a year wise trajectory for the next 10 years. Estimating the potential of Agrivoltaics in the country, a safe place to begin with is what if 1% of each of the land under agriculture, barren land and other uncultivated land is used for Agrivoltaics with 5.5 acres of the land suitable for 1 MW of Agrivoltaics, a total potential of 629.69 GW alone is realised from net area sown (agricultural) lands. As figure 22 shows, the potential of Agrivoltaics is 49.50 GW and 56.6 GW for fallow lands and other uncultivated lands, respectively.

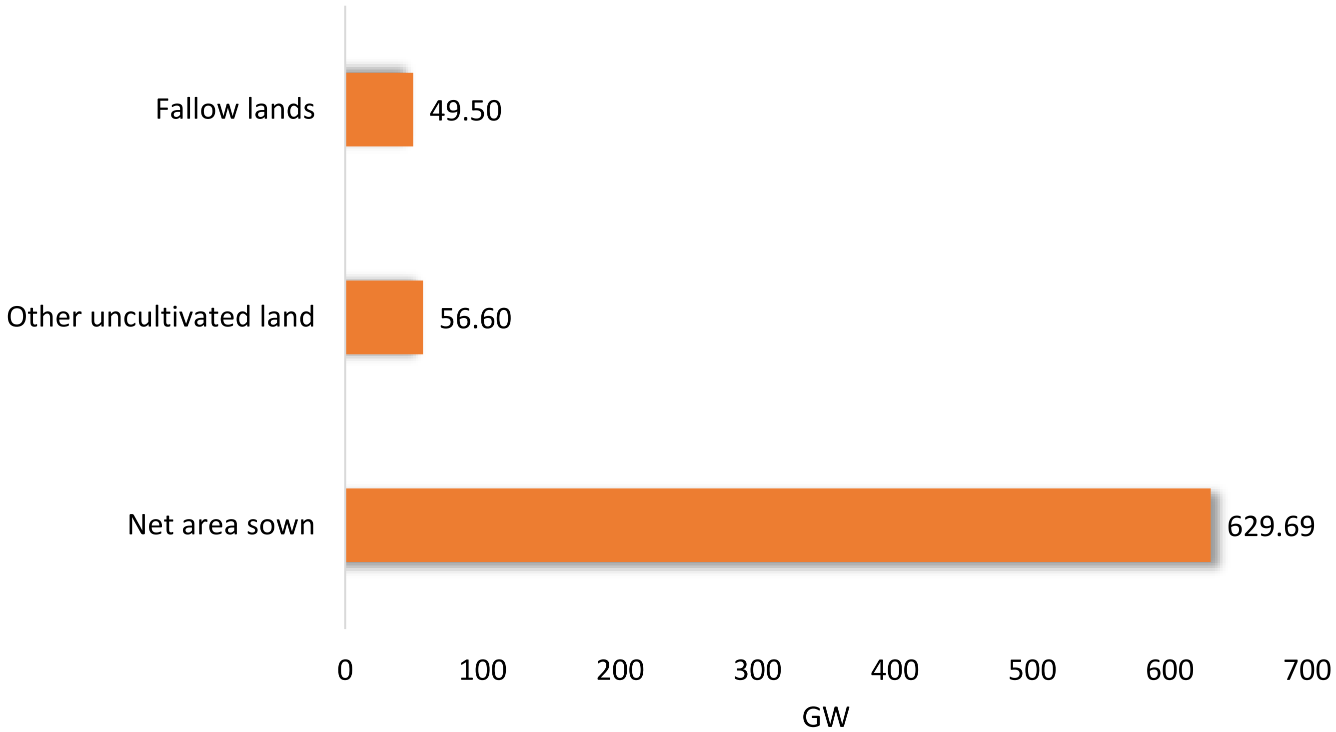

Figure 28: Potential for Agrivoltaics on different land categories assuming a coverage of 1% (in GW capacity)

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.

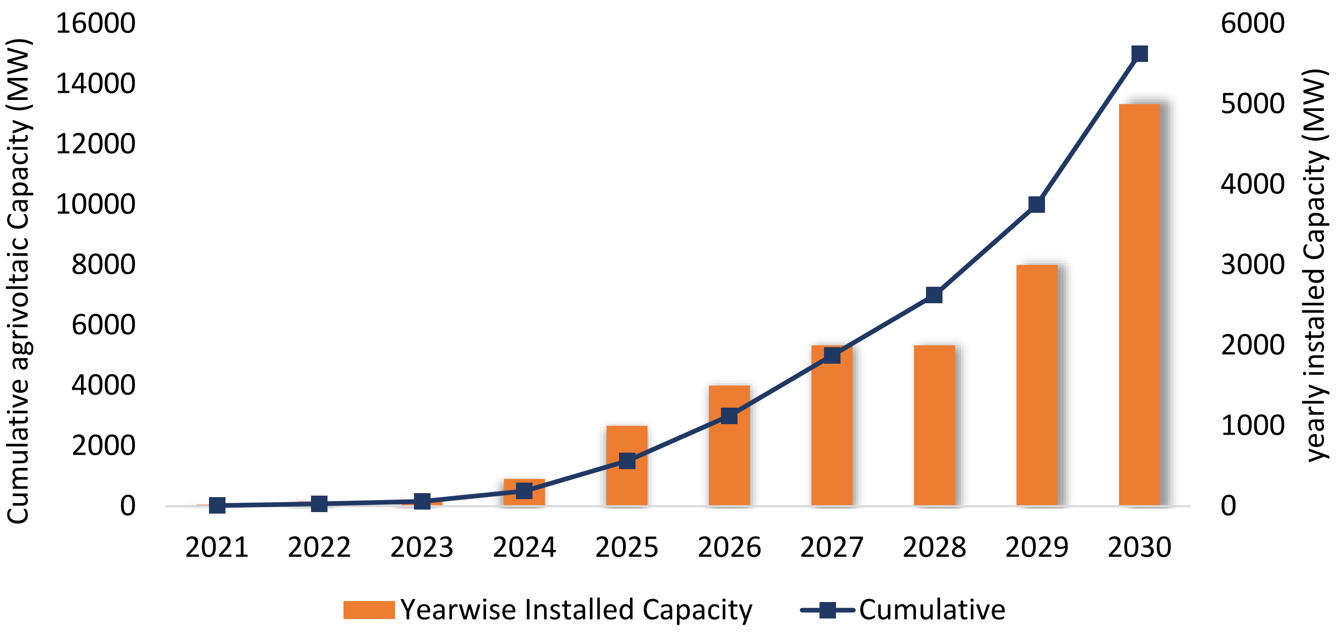

Figure 29: Suggested deployment targets for Agrivoltaic Capacity in India

Tenders and Pilot Projects

Government should consider tendering projects specific to Agrivoltaics while also encouraging pilot projects to sensitise stakeholders. SECI, NTPC, NHPC and other nodal agencies can issue agrivoltaic specific tenders to promote Agrivoltaics.

National Level Research Program

Government in coordination with 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, Jodhpur University or Amity University ventured into techno-economic studies of Agrivoltaics. Involving stakeholders from 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.

Land Use Classification

The explicit mention of Agrivoltaics is necessary in any law, scheme or policy when cultivable land is used with PV. Similar to the Japanese approach, a specific agrivoltaic temporary land conversion or another mechanism must be found to prevent agricultural land used for Agrivoltaics to be governed by non-agricultural land use regulations. This seems justifiable as the solar PV component of Agrivoltaics will be deinstalled after end of lifetime and the land remains agricultural thereafter. Therefore, an agrivoltaic system could be designated in the land use plan as a "Special area for Agrivoltaics". A prerequisite could be that a minimum of 80% of the total surface is available and used for agricultural purposes. The farmer or landowner continues to receive the agricultural subsidy allocated to the area in which case statistically the area does not count as sealed.

Technical Norms and Quality Standards

As of now there are no regulations on land use with solar PV under the Indian legal framework. In order to ensure dual use of land through Agrivoltaics, and to avoid solar energy yield at the cost of agricultural purpose, criteria need to be set to avoid the installation of improper agrivoltaic installation that neglect agricultural purposes. Ideally, norms on the implementation of agrivoltaic are required where specific criteria for land use and criteria for the geometry of the mounting of the panels are defined.

A crop cultivation plan and annual reports should accompany the operations to prevent negligence of agricultural activity. In case of potential non-compliance, the owner of the project must undergo an accredited audit. If non-compliant the owner of the project must become compliant within 6 months starting from the date the non-compliance has been proven by the audit. As an enforcing mechanism, the electricity feed-in allowance could be withdrawn or a fine could be imposed. Ultimately, if the regulation is not followed, the agrivoltaic installation can be ordered to be decommissioned. This case, however, from an international perspective is extremely rare and a well-designed policy should include provision to prevent potential malpractice on the project planning stage already.

Financial Incentives for Agrivoltaics in India

The improvement of livelihoods of the partnering farmers must be prioritised and if possible, annual incomes doubled for farmers with less than two hectares. To consider Agrivoltaics in future 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 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 lakh 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 cost. A decrease cost of debt from 8% to 3% can already reduce the 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.

A 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 poses a first overview of the current state of the Indian Agrivoltaics sector. The sector is still at an early stage of development. At the time of writing, there were 16 plants operational, most of which are used to experiment with the concept and its parameters. There is yet no convergence towards one dominant system design.

Albeit, the technology holds the potential to address some of the most pressing issues in India's electricity sector, a quick roll-out on a large scale is not to be expected. As this report has elaborated on, several conceptual and regulatory questions are yet to be answered. The report proposes a set of policy measures that could provide a starting point for a regulatory framework to simultaneously promote Agrivoltaics as a concept while ensuring the agricultural usability of the areas in question.

However, there are several factors to consider which were not in the scope of this report or only superficially touched upon. This includes technical questions of module suitability, module cleaning, design of mounting structures, as well as plant layout. Particularly the latter requires an alignment with agricultural requirements. Both strongly influence the financial viability of the concept for which reliable business plans are yet to be found. That is particularly the case when collaboration of stakeholders especially in between the farmer and the entity running the PV plant, is needed.

This plays into another central gap in research not only of this report, but in the Indian Agrivoltaics sector in general: The role of farmers in agrivoltaic power plants as well as their perception of this new concept. What would it need to make the concept appealing to farmers? How could they be empowered to drive projects themselves?

Bibliography

[1] Auroville Consulting. 2019. *Making Sense of KUSUM*. *Opportunities & Challenges in delivering water and energy security for agriculture in Tamil Nadu*.

[2] Central Electricity Authority. 2014. *Annual Generation Target 2014-15*.

[3] Central Electricity Authority. 2019. *ANNUAL GENERATION PROGRAMME 2019-20*.

[4] Department of New & Renewable Energy. 2020. *DISCOM KUSUM Tender for Installation of Decentralized Grid Connected Ground/ Stilt Mounted Solar Based Power Plants*.

[5] Government of Gujarat. 2019. *Suryashakti Kisan Yojana (SKY)*.

[6] Government of National Capital Territory of Delhi. 2018. *Agriculture-cum-Solar Farm Scheme in NCTof Delhi*.

[7] Government of Rajasthan. 2019. *Details of KUSUM Yojana*.

[8] Jain Irrigation. 2016. *Agro-Voltaic Farming*.

[9] Maha Vitaran. 2019. *MUKHYAMANTRI SAUR KRUSHI PUMP YOJANA*. https://www.mahadiscom.in/solar/index.html.

[10] Maximilian Vorast. 2020. *AGRIVOLTAICS SCOPING INDIA & INTERNATIONAL EXPERIENCES*. *Preliminary Report*. Fraunhofer Institute for Solar Energy Systems ISE.

[11] Ministry of New and Renewable Energy of India. 2019. *Guidelines for Implementation of Pradhan Mantri Kisan Urja Suraksha evem Utthan Mahabhiyan (PM KUSUM) Scheme*.

[12] Ministry of New and Renewable Energy of India. 2020. *Programme/Scheme wise Physical Progress in 2020-21 & Cumulative upto Oct, 2020*. https://mnre.gov.in/the-ministry/physical-progress.

[13] PM Modi Yojana. 2020. *Karnataka Surya Raitha Scheme*.

[14] Rangwala, M. 2019. *Large scale AgroPV: Experience in Gujarat*. REI Expo.

[15] Santra, R. K. Singh, H. M. Meena, R. N Kumawat, D. Mishra, D. Jain, O. P. Yadav. 2018. Agri-voltaic System. crop production and photovoltaic-based electricity generation from a single land unit. *Indian Farming* 68, 20–23.

[16] Uttarakhand Electricity Regulatory Commission. 07.06.19. *Suo-moto Order on the request of UPCL for determination of Tariff considering subsidy at the rate of 80% for the Solar Projects installed/to be installedunder PM-KusumYojana.*

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