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Agrivoltaics in India – A Review

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ABSTRACT

In response to the growing demand for photovoltaic's as a key component in the energy transition strategy of many countries, which involves land use issues as well as concerns about landscape transformation, biodiversity, ecosystems, and human well-being, new strategies and market segments that take into account interdisciplinary viewpoints have emerged. One of them is agrivoltaics, which has a lot of potential for allowing benefits in the food-energy (and water) nexus. All throughout the world, demonstrative projects are being produced, and information regarding various design solutions suited for scales up to commercial size is being obtained largely focused on efficiency considerations. It is unavoidable, however, that as the scale grows, from the demonstration to the commercial scale, consideration must be given to the ecological effects connected with certain design decisions, especially those connected to concerns involving landscape alteration. Using a comprehensive analysis based on the most recent scientific research, this study investigates and assesses the technical and spatial design used in Agrivoltaics plants in India. On the basis of design and performance metrics, it also gives a complete methodological proposal that enables us to describe the essential system features from a multidisciplinary perspective.

Keywords: Agrivoltaics, Elevated Structure, Farming, Landscape, Mounting Structure, Solar

INTRODUCTION

In order to meet societal demands, 6000 TWh, or roughly 16% of all energy produced, will be produced as PV energy in 2050, according to the International Energy Agency. India's demand for power has surged by more than 40% in the preceding five years despite the fact that it is a developing country [1].India is prepared to quickly boost its generation capacity because there are no signs that this fast expansion would soon slow down. Since solar energy is now more affordable per unit of energy than thermal generators, the emphasis has switched more and more in favour of expanding solar power capacity[2]. In addition, the Indian government initially established a goal of putting in 100 GW of solar PV by 2022 as a response to global efforts to decarbonise the economy [3].The entire goal for renewable energy generation capacity, which includes 280 GW of solar power generation, has been set at 500 GW by 2030. As of October 2020 [4], the official solar power fleet in India had a combined capacity of around 36 GW. However, in only 2 years, this number increased to almost 70 GW by the end of November 2022, demonstrating progress towards achieving a target for solar power generation. India is a developing market, and as a result, its need for energy has lately increased significantly. This requirement is expected to increase at a rate of 6% years [1]. There are no indications that this momentum will slow down soon; therefore India is in a position to quickly grow its generation capacity. Expanding solar power capacity now prioritised more than thermal generator capacity since it provides cheaper energy per unit than thermal generators (Levelized cost of electricity, LCOE). In response to international efforts to decarbonise the economy, the Indian government has likewise set a high goal of adding 500GW of renewable energy capacity by 2030, with over 300GW coming from solar PV alone [5]. From April 2022 to January 2023, solar capacity increased by 9.8 GW [6]. With 63 GW [6] of solar capacity built as of the end of 2023, India had the fourth-place position in the globe The Indian government created a variety of programmes, notably the Kisan Urja Suraksha evam Uthaan Mahabhiyaan (KUSUM), or Farmer Energy Security and Guarantee Scheme, to attain the required growth rates to reach the 2030 aim. The three elements of the strategy work together to encourage the growth of distributed solar power capacity.

The Indian government created the Kisan Urja Suraksha evam Uthaan Mahabhiyaan (KUSUM) Scheme, in order to attain the required growth rates to actualize the 2030ojective. The plan is made up of three parts, and they all work together to encourage the development of distributed solar power capacity. Although it has not yet been properly studied, agrivoltaics, or the co-location of solar panels and industrial crops, looks to be a workable option in the context of India. 3kWp to 3MWp of power may be produced by agrivoltaics plants in India. More than 3MWp of utility-scale agrivoltaics plants have not yet been implemented. There hasn't been much experience with the respective technological, economic, and agricultural viability up to this point. In India, there are three main kinds of first pilot plants where agrivoltaics—also known as the co-location of solar power generation and agriculture—is used:

1 Interspaced farming is the practise of growing crops between two rows of ground-mounted solar panels.

2 Manual cultivation only between and below ground-mounted panels that are tilted at a predetermined degree.

3 Farming beneath solar-panel installations on tall structures. A high enough elevation makes it feasible to operate agricultural equipment.

OVERVIEW OF AGRIVOLTAIC PROJECTS IN INDIA

The list below includes the name of each agrivoltaics project that has been put in place in India, together with a map in Figure 1 that shows where each project is situated. According to the research, academic, commercial, and government plants that are shown in figs. 2, 3, and 4, there are three categories into which agricultural photovoltaic projects can be classified..

Fig1: Map Of Agrivoltaics Projects In India[7]

Research and 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 .)
- (NISE vertical PV plant near Gurgaon, Hayana : 5kW.)
- (Jain Irrigation plants at Jalgaon, Maharashtra: 290kW).
- (APV at Telangana State Agricultural University, Telangana: 10kW)

Fig2 : Research And Academic Agrivoltaics Plants [7]

Commercial Pilots

- (Sunseed - GIZ plant near Parbhani, Maharashtra :1.4MW .)
- (Abellon Energy plant in Aravalli District, Gujarat : 3MW)
- (Cochin Airport plant, Kerala : 4MW)
- (Mahindra Susten plant at Tandur, Telangana : 400kW.)
- (Hinren Agri-PV Rooftop (APVRT), Bangalore : 3kW .)
- (Farmer-Owned Agrivoltaics plant at Jahu, Himachal Pradesh : 250kW .)
- (GroSolar Agrivoltaics plant near Dhule, Maharashtra : 1MW.)
- (Sun Master Agri-PV System, Delhi : 2MW)

Fig3 : Commercial Pilots Agrivoltaics[7]

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.)

Fig4 : Government Supported Agrivoltaics[7]

CURRENT DESIGN SOLUTION AND TECHNOLOGIES

Agrivoltaics systems have been the focus of several investigations in recent years because of their promise in the food-energy nexus. Demonstrative efforts using novel conceptual PV module-based designs for covering open fields have produced encouraging results by maximising light availability while minimising the requirement for irrigation and safeguarding against adverse weather events. Since APV refers to sharing sunshine for the co-production of food and electricity on the same plot of land, designs must, to the extent possible, overcome physical obstacles to covering crops with solar modules in order to reduce the drop in agricultural profitability. In India following design methodologies are used to install the agrivoltaics system to mitigate the problem of Minimizing shadows on crops (biomass yield), maximizing electricity generation and the social acceptance of the project. Below is all the detail mentioning the all the designing and technical details of the installed agrivoltaics project in India.

Table 1: Detail description of designed structure Agrivoltaics installed in India .[7]

Project Name : GIPCL plant near Amrol, Gujarat *Installed capacity* : 1000 kWp Type of agrivoltaics plant : Interspaced/ Overhead stilted hybrid Mounting structure : 1 to 3 horizontal metres , different PV array arrangements with panel spacing's of 0, 100, and 250mm.The installation of cables in agricultural regions resulted in greater costs because of the longer lines and partial burial of the wires up to 2.5 metres below the surface. Due to the season, there is a 5 to 28° manual tilt every two months.
Project Name : GSECL Harsha Abakus plant near Sikka, Gujarat and GSECL Harsha Abakus plant near Pandhro, Gujarat *Installed capacity* : 10504kWp *Type of agrivoltaics plant* : Interspaced/ Overhead stilted hybrid *Mounting structure* : 3 m is the elevation height, below-tillage depth cabling,549 kWp/ha, or 4.5 acres per megawatt,

testing different spacing. Manual single axis tracking with seasonal tilts of 0, 10 and 25 degrees. Possible tilting angle between modules is more than 85: 25 / 150 / 250mm
Project Name : CAZRI plants in Jodhpur, Rajasthan - 100 kW *Installed capacity* : 105 kWp *Type of agrivoltaics plant* : Interspaced *Mounting structure :* This project uses the latitude angle (26° at Jodhpur) as the tilt angle. Height: 1.22 metres, 1.94 metres, and 2.66 metres for each of the first two arrays. Interspaced: - Arrays with 1 row and 3 m of interspaced - PV module arrays with two rows and a 6 m interspaced - Arrays of 3-row solar panel modules with a 9-meter interspaced. With a total system cost of (105 kW/INR 60 lakh), ploughing is easily doable in two cases, but it must be done manually in the third. • Fixed with single axis tracking as well as without tracking
Project Name : Amity University plant in Noida, Uttar Pradesh - 10 kW *Installed capacity :* 10kWp *Type of agrivoltaics plant* : Single column *Mounting structure :* Optimum tilt angle - Approximately 15 ft (4.6m) height of the mounting pole . Area: 630m2 ; 159 kWp/ha degree & 25 degree. Tilting angle possible above 85 between modules: 25 / 150 / 250mm. No tracking
Project Name : Dayalbagh Agriculture University plant in Agra, Uttar Pradesh - 200 kW *Installed capacity* : 200kWp *Type of agrivoltaics plant :* one column *Mounting structure* : A height of 18 feet. Nineteen towers with fifty modules each. Tracking on one axis.
Project Name Junagadh Agriculture University plant in Junagadh, Gujarat - 7 kW *Installed capacity* : 7.2kWp *Type of agrivoltaics plant* : Overhead tilted *Mounting structure :* 3 metres of elevation 7.6 and 11.4 metres of plotted modules in a chequered configuration no tracking.
Project Name Abellon Energy plant in Aravalli District, Gujarat - 1 MW *Installed capacity* : 3000kWp *Type of agrivoltaics plant* : Interspaced *Mounting structure :* 7.08 hectares at a 423 kWp/ha rate. Standard ground-mounted PV design; No tracking.
Project Name Mahindra Susten plant at Tandur, Telangana - 400 kW *Installed capacity* : 36.6 MW *Type of agrivoltaics plant* : Interspaced *Mounting structure :* Traditional design for ground-mounted PV No tracking.
Project Name Jain Irrigation plants at Jalgaon, Maharashtra – 290 kW *Installed capacity* : 36.6 MW *Type of agrivoltaics plant* : Overhead stilted Mounting structure : Nearly 95% of the land area beneath the panels may be used thanks to the mounting structure design. A height of 5 metres. Equipment used below modules. Single axis tracking.

Project Name Jain Irrigation Rice Pilot *Installed capacity* : 9.6 kW *Type of agrivoltaics plant* : Overhead stilted *Mounting structure :* 3 m tall, 105 m^2. 533 kWp/ha for the area. Equipment ran below modules. Static tilt
Project Name Jain Irrigation Okra/Cotton Pilot *Installed capacity* : 50.4 kWp *Type of agrivoltaics plant* : Overhead stilted Mounting structure : Single column . Double tracking .
Project Name Jain Irrigation – Tumeric/Ginger/Mint Pilot *Installed capacity* : 19.3 kWp *Type of agrivoltaics plant* : Overhead stilted *Mounting structure :* Stilted between 1.7 and 2.5 m. Almost complete shade across 400 m$^{2.}$ No tracking.
Project Name Jain Irrigation Greenhouse-PV Pilot *Installed capacity* : 19.3 kWp *Type of agrivoltaics plant* : Greenhouse Mounting structure : 1100 m^2 greenhouse. totally covered roof with photovoltaic panels. no tracking.
Project Name NISE plant near Gurgaon, Haryana - 100kW *Installed capacity* : 100kWp *Type of agrivoltaics plant* : Interspaced *Mounting structure* : There is no tracking and a vertical PV pilot.
Project Name NISE Vertical Agrivoltaics Pilot, near Gurgaon, Haryana - 5 kW *Installed capacity :* 5kWp *Type of agrivoltaics plant* : Interspaced *Mounting structure* : There is no tracking and a vertical PV pilot.
Project Name Cochin Airport plant in Kerala - 4 MW. *Installed capacity* : 4 MWp *Type of agrivoltaics plant* : Interspaced *Mounting structure :* Standard ground-mounted PV design. There is no tracking.
Project Name Krishi Vigyan Kendra (NHRDF) Ujwa, Delhi – 110 kW *Installed capacity* : 110kWp *Type of agrivoltaics plant* : Structure that is elevated and has space for small-scale agricultural below it. Mounting structure : Structure made of hot-dipped galvanised steel, with a 15° tilt and 3.5m elevation height. No tracking.
Project Name Agrivoltaics plant near Parbhani, Maharashtra – 1.4 MW *Installed capacity* : 1.4 MWp *Type of agrivoltaics plant :* Elevated building with a shade house and interspaced. *Mounting structure :*

<table>
<tr><td></td><td>• Overhead 3.75m
• Fixed tilt 11° .
• Pitch 5.64m .
• None tracking.</td><td>• Height: 1,75m.
• Fixed tilt: 11° .
• Test field with two pitch distances: 10m (II) and 7.5m (III)</td><td>• Height: 1,25m.
• Fixed tilt: 11°.
• Pitch distance: 10m</td></tr>
<tr><td colspan="4">Project Name Hinren Agri - PV Rooftop (APVRT) System, Bangalore - 3 kW
Installed capacity : 3 kWp
Type of agrivoltaics plant :
An agrivoltaics plant is an elevated structure with room for indoor horticulture.
Mounting structure :
2.3-meter-high boardwalk made of galvanised steel that allows for manual system cleaning.
No tracking. The roof was painted with white heat seal paint to reduce heat build-up and boost albedo.</td></tr>
<tr><td colspan="4">Project Name Farmer owned Agrivoltaics plant at Jahu, Himachal Pradesh – 250 kW
Installed capacity : 250 kWp
Type of agrivoltaics plant : Mostly interspaced and some cultivation beneath panels
Mounting structure :
Panels are elevated by 2.2 m.
Panel rows with a 2 m interspaced and a 4 m base distance.
Cable installed underground for ploughing.
Seasonal tilt (manual), after the solstices of the summer and winter</td></tr>
<tr><td colspan="4">Project Name GroSolar Agri-PV Interspaced System, Dhule, Maharashtra - 1 MW
Installed capacity : 7 MW, including around 1 MW used for agrivoltaics
Type of agrivoltaic plant : Interspaced .
Mounting structure : Standrad ground mounted and and no tracking .</td></tr>
<tr><td colspan="4">Project Name SunMasterAgri-PV System, Delhi, India- 2 MW
Installed capacity : 2 MW of installed power and approximately 2527 kWp APV.
Type of agrivoltaic plant : overhead
Mounting structure : steel framework with a hot-dip galvanised elevation of 4.3 metres.</td></tr>
<tr><td colspan="4">Project Name Fish Pond Agri-PV System, Bhaloji, Rajasthan – 30 kW
Installed capacity : 30kW installed with a fish pond spread apart 1MW of site capacity overall.
Type of agrivoltaic plant : fishing farming only
Mounting structure : standard ground mounted.</td></tr>
<tr><td colspan="4">Project Name APV plant at Telangana State Agricultural University, Telangana- 10 kW
Installed capacity : 10 kWp
Type of agrivoltaic plant : fishing farming only
Mounting structure :
Steel construction.
elevation of the panels of 3.5 metres.
pitch distance of 3 metres.
No tracking.</td></tr>
</table>

CONCLUSION

The areas where current research is actively concentrating in Agrivoltaics systems include the optimisation of energy and engineering design, the development of new technologies, and the proper selection of plant species appropriate to the PV system. According to the findings of this study, various agrivoltaics farm and mounting structures like elevated , pole mounted and conventional ground mounted PV structures are created based on the needs and the land's accessibility. As can be observed, raised structures are utilised for agricultural operations such as crop cultivation and movement of agricultural machineries. Steel structures are typically employed in the building of elevated structures.

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