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A SUSTAINABLE ENERGY APPLICATION IN AGRICULTURE-AGRI VOLTAICS

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Abstract - Renewable Energy Systems are driving toward ac- complishing our Energy demands more sustainably. Due to its plentiful source, Solar Energy has gained attention on a global scale. Yet, it requires significant amount of land for energy production. Agrivoltaics, a concept of simultaneous energy generation under selective agricultural adaptation, is a niche concept in India. Currently, very few Indian states are foraying into the Agrivoltaic domain. This is a creative project that combines food production and energy production to reduce the amount of land needed for two separate uses. This system can also harvest biomass as well as rainwater from the installed solar panels to enhance production. India ranks 2nd globally in agricultural products. Hence there is a need to shift from conventional Photovoltaic Systems to smart Agrivoltaic systems at a greater rate than today. In this paper, the authors have showcased a review of Agrivoltaic infrastructure in India, and its future scope, as well as providing information on an ongoing case study in Gujarat.

Keyword - Agrivoltaic, Agriculture, Photovoltaic, Farming, Joint production, Solar farm

I. INTRODUCTION

Solar photovoltaic generation requires a lot of land. Glob- ally, ground-mounted photo voltaics have emerged as the least expensive means of generating electricity. Yet, there has scarcely ever been any discussion of the spatial component of the deployment of Ground mounted projects and the loss of cropland.

Fresh water, food, and many other biological resources are mostly sourced from the land. Cropland areas are expected to decline globally by 50 to 650 million hectares by 2100 as a result of the socioeconomic society's uplift brought on by soil degradation. [1].

The amount of land needed will be roughly 1200 square km for India to generate 60 GW of PV-based power as mentioned in the Jawaharlal Nehru National Solar Mission (JNNSM) targets set for the year 2022. The combined usage of agricultural land by calling this technology agro photovoltaic (APV), initially suggested by Zastrow and Goetzberger in 1981, is one way to reduce land grabbing. [3].

An innovative method of capturing solar energy for food and electricity in a specific land area is called agrivoltaic systems (AVS). AVS aims for maximum land productivity along with advantages including increased crop productivity, reduction in water requirement for irrigation, and reduction in agricultural land degradation along with other socio-economic benefits pertaining to farmers.

Agrivoltaics is described as an application-based land-use configuration where sunlight-dependent agricultural activities and solar energy generation are directly integrated. Within the boundaries of the solar infrastructure, there is a layer of farm productivity in this arrangement. A defining feature of Agri- voltaics is when sunlight is shared between photosynthesis and photovoltaics, the two prominent energy conversion processes. Several nations, including France, China, the United States, Japan, and Malaysia, have made announcements regarding their support for AVS developments and deployments by 2015. The APV installations are regarded by the Government of India (GoI) as the most dependable energy production for water, food, and energy on an appropriate plot. Several nations, including France, China, the United States, Japan, and Malaysia, have made announcements regarding their support for AVS developments and deployments by 2015. The APV installations are regarded by the Government of India (GoI) as the most dependable energy production for water, food, and energy on an appropriate plot.

As shown in Fig. 1, there exist three basic forms of agrivoltaics structure for energy generation. They are slanted solar array installation overlain crops land, solar arrays with the provision of space for crops underneath, and solar array enclosed within greenhouse environment.

Agrivoltaic applications include

1) Cultivation of food and crop,
2) Provide ecosystem services by managing vegetation,
3) Livestock production, and
4) Formation of solar green- houses

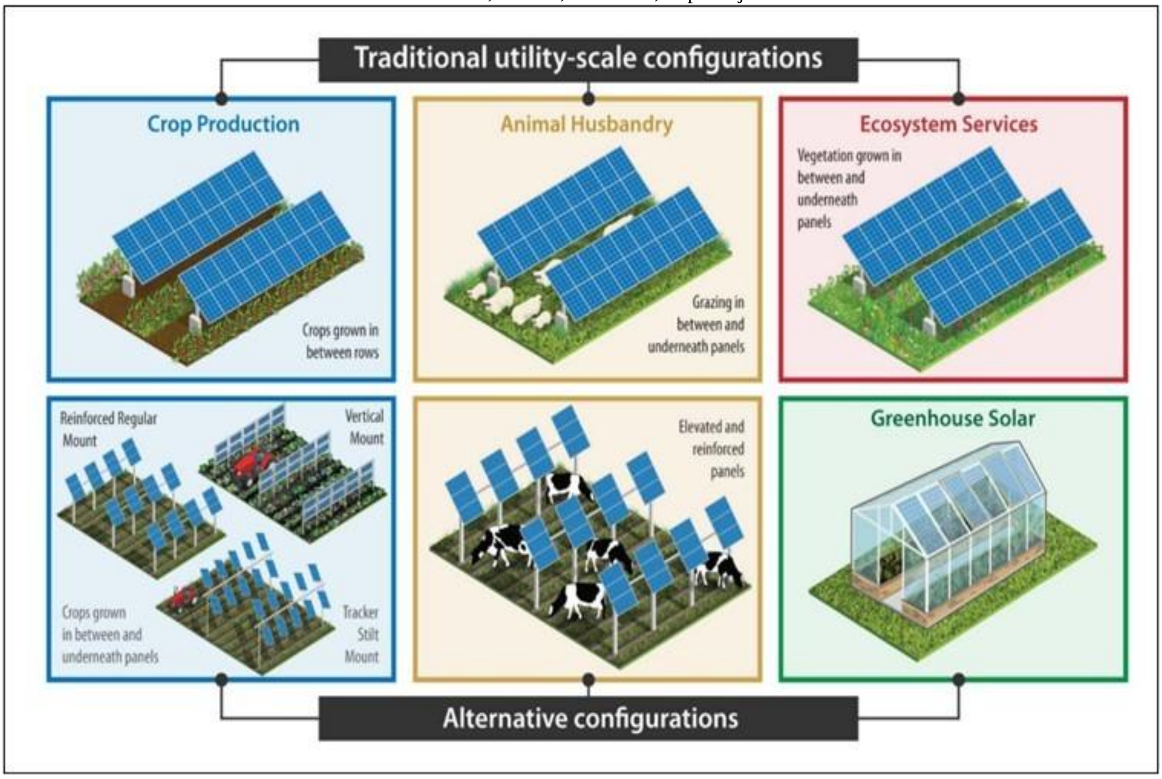
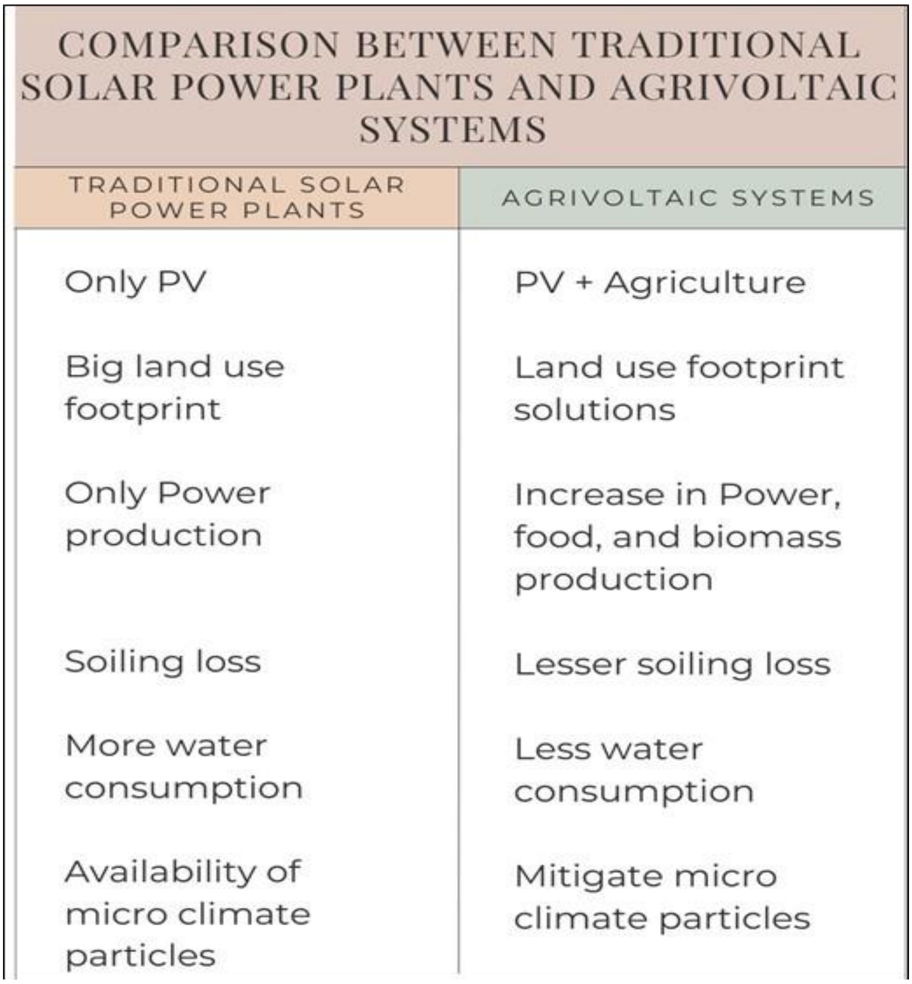


Fig. 1. Three basic forms of agrivoltaics [8]



COMPARISON BETWEEN TRADITIONAL SOLAR POWER PLANTS AND AGRIVOLTAIC SYSTEMS

TRADITIONAL SOLAR POWER PLANTS	AGRIVOLTAIC SYSTEMS
Only PV	PV + Agriculture
Big land use footprint	Land use footprint solutions
Only Power production	Increase in Power, food, and biomass production
Soiling loss	Lesser soiling loss
More water consumption	Less water consumption
Availability of micro climate particles	Mitigate micro climate particles

Fig.2.Agri PVV SN on AgriPV

The remainder of this paper is structured as follows: A brief overview of AgriPV in India along with technologies used is discussed, followed by a case study from an established AgriPV project at Anand, Gujarat. Later, the paper discusses challenges in agrivoltaic systems, proposing ideas for further research and development.

A. Current Studies of Agrivoltaic Systems

Prannay R.Malu et al. [2] have accessed the agrivoltaic potential of grape farms in India by performing a technoe- conomic analysis at a grape farm at Nashik, India. When compared to conventional ground mounted systems, the pro- posed agrivoltaic system generates more than 15 times the crop income, for the same grape production.

Surendra Poonia et al. [1] have performed a techno-economic analysis of an existing 105 kWp AgriPV plant at ICAR-Central Arid Zone Research Institute, Jodhpur, by considering five possible agrivoltaic designs with varied crop selections. Out of the five designs, the one-row full-density photovoltaic array with irrigated brinjal recorded the highest combined net returns of PV and well as crop components.

Harshwardhan Dinesh et. al. [3] developed a coupled simu- lation model for both PV production (PVSyst) and agricultural production (Simulateur mulTI disciplinaire les Cultures Stan- dard (STICS) crop model), to gauge the technical potential of scaling agrivoltaic systems. PV power increased between 40 and 70 GW for lettuce cultivation in the US. C. Dupraz et. al. [5] has used the concept of Land Equivalent Ratio (LER) to compare conventional PV system with agrivoltaic system with different density of PV modules, in Montpellier, France. The results show that the proposed system is highly productive with increase in land productivity as high as 70% These promising developments in photovoltaic cumulative installation capacity motivate users to expand agrivoltaic en- ergy production and efficient land use. Investments in renew- able energy have grown, with a particular emphasis on photo- voltaics, as carbon dioxide emissions and energy demand have risen. Research on the effects of massive solar installations is required as PV system costs are falling and PV capacity is rising. Agrivoltaics may be the best strategy for achieving sustainable development in agricultural areas since they are integrated photovoltaic systems that address both the energy and food shortages.

II. AGRIVOLTAICS IN INDIA

It is estimated that India receives 0.2 GW/km of solar radiation on average. India's land area is 3.287 million square kms, and it generates 0.6574 million MW of electricity. As de- picted in Fig. 3, the majority of India experiences intense sun radiation on a daily average of 5 kWh/m. According to a report from National Solar Energy Federation of India (NSFEI), to date, most agrivoltaics facilities in India are research pilots. Real farmer exposure to Agri photovoltaics remains limited, making it difficult to enhance widespread public acceptance of this innovative approach. Fig. 4 showcases existing agrivoltiac projects in India.

S.No.	Project Name	Type of Project	Module Used	Characteristics
1	CAZRI 105 kW Agri-voltaic plant in Jodh-pur, Rajasthan [1]	Research and Develop-ment	Monofacial (260 Wp)	• Commissioned in: 2017 • Tilt angle 26 degree • 3 configurations: 1) Array 1: 4 feet 2) Array 2: 6.3 feet 3) Array 3: 8.5 feet • Arrays of one-row PV module and 9.8 feet gap • Arrays of two-row PV modules and 19.6 feet gap • Arrays of three-row PV modules and 29.5 feet gap • Harvest rainwater annually approx. 1.5 lakh liters, stored in a water tank of volume $100m^3$ • $70-80$ % efficient rainwater harvesting system • Crops Grown: Mungbean. Aloe vera, sonamukhi, sankh-puspi, mothbean, clusterbean, isabgol, cumin, chickpea chili, cabbage, onion, garlic
2	Abellon Energy 1 MW Agrivoltaic plant at Ar-avalli District, Gujarat [9]	Commercial	Polycrystalline (230 Wp, 240 Wp, 280 Wp)	• Commissioned in: 2012 • Fibre made from cotton is used to keep moisture on the ground • Crops Grown: 1) Vegetables: Bottle gourd, lady finger 2) Fruits: Citrullus lanatus (watermelon) 3) Spices: Turmeric, ginger, chili

3	GIPCL 1 MW Distributed Solar Power Project at Amrol, Anand, Gujarat [9]	Govt. Supported / Ten- dered	Monofacial, polycrys- talline (310 Wp)	• Commissioned in: 2016 • Tilt angle is between 5-20-degree manual changing in every 60 days of the year. • More than 40 crops tested; Crops currently grown include: 1) Kharif: Groundnut, Soyabean, pearl millet, cotton, greengram, pigeon pea, maize, cluster bean 2) Rabi: Chickpea, wheat, mustard, Lucerne, vegetables 3) Summer: Sesame, fodder crops, black gram • Manual cleaning with telescope brush and cloth • Cleaning time: 15 days/panel • Water consumption approx. 3l/panel, own vertically drilled wells to get water for panel cleaning • Total water consumption 2L litres/MWp/year • No rain gutter and no rainwater harvesting

Table I Some of the Major Agrivoltaic Projects in India

III. 1MW AGRIVOLTAIC PROJECT AT AMROL, ANAND, GUJARAT: A CASE STUDY

A. Field of Study

Site location and Geographical conditions

An Agri Voltaic system has been set up on a private farmland of 'Mahatma Gandhi Institute for Integrated Rural Energy', (22.381N, 73.052E) in Amrol district of Anand City in the state of Gujarat. The land type of the present Agri Voltaic system is almost flat, and the soil contents correspond to the loamy sand. Anand city witnesses wind speeds averag- ing to 7 − 11 km/hr, average temperatures vary in the range of 28deg − 35degC.

Potential of Solar Energy of Amrol, Anand

The average radiation on a horizontal surface in India is 5.6 kWh/m2/day. Anand is located in the western part of India and receives approximately 5.5 − 6 kWh/m2/day. Total sunirradiation is approximately 2500 hours in a year, which is ideal for photovoltaic applications. Because of these reasons, the Amrol region of India has a notable solar energy potential with respect to total sunshine duration to generate electricity using Solar Energy.

Basic Requirement of Solar PV based electricity gener- ation

To deliver the required electricity at the required voltage and current, solar panels are organised to form an array. Vertical alignment is used to arrange the various rows of 310 Wp polycrystalline silicon solar PV modules. DC to AC conversion is accomplished using 0.5 Megawatt inverters. The length of PV arrays is dependent on number of PV modules in series. Typically, 6 −12 m of spacing between two rows of PV arrays is maintained in typical ground-mounted solar power plants in order to prevent shadow on the next row.

Parameters	1MW with AgriPV	1MW without AgriPV
Project Land area used out of total land area	65%	60%
Project Structure Weight (MT/MW)	75%	22.1%
Module Rating (Wp)	310	335
Inverter Rating (MW)	2×0.5	4 ×0.25
PV Modules in 1 array	18	15
Total Arrays	180	199
Gap between two arrays (m)	1	4.9
Distance between two rows (m)	11	5.5
Crops can be grown	Y	N
Project Cost (PV Mounting cost)	6Cr.	4Cr.
Crop Cultivation Cost	25 Lacs	N/A
Presence of Agri Feeder	Y	N
Payback Period (years)	3	4

Table II Comparison Between Agripv as Well as Non Agripv

Fig. 3. India's Solar irradiance Map: Irradiance is defined as the rate at which solar energy falls onto a surface

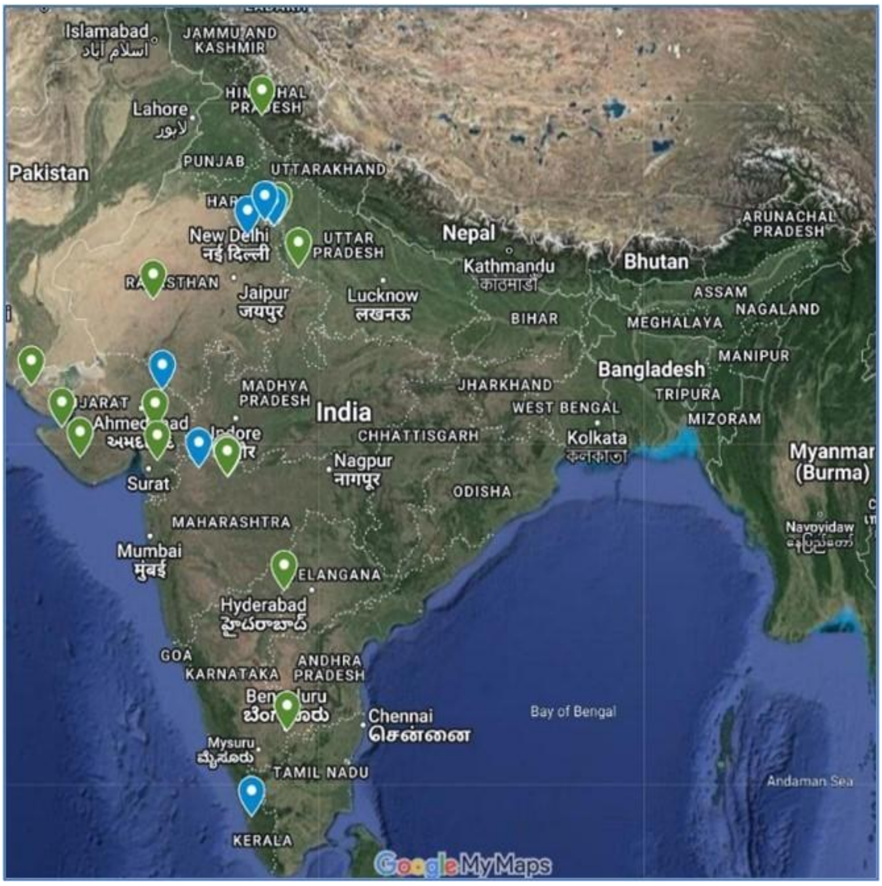


Fig. 4. Agrivoltaic projects in India: In a nutshell

B. Design of AgriPV System

1) Agri Voltaic design: The agrivoltaic system with a 1MW capacity installed in Amrol, Anand, was employed for evaluation in this study [11]. The AVS system had a ground- mounted as well as seasonal tilt and covered a 21000 m2 area. The panels are mounted at a height of three meters on a mounting structure.

The seasonal tilt can be manually changed. To investigate the effects of various shade patterns on crop growth, this plant has various inter-module and inter-array gaps.

The site has a Direct connection with 11 kV Jyoti Gram Yojna (JGY) feeder to reduce Transmission and Distribution (T&D) losses [10]. It also features design of single water pumping and distribution network for panel cleaning and drip irrigation to reduce cost.

Fig. 5. An aerial view of 1 MW Agrivoltaic plant located at Amrol, Anand

The 1 MW Distributed Solar PV Pilot Project was divided into four variants:

- Variant 1: Open plot (Control plot) – 870 sq. m
- Variant 2: 25 mm gap between two panels- 7 rows
- Variant 3: 150 mm gap between two panels- 6 rows
- 250 mm gap between two panels- 4 rows

Using a net metering system, the installed AgriPV system was linked to the regional electrical grid. As a result, the gen- erated electricity is sold directly to the local power distribution business at a fixed rate that differs between Indian states.

2) Crop Design: The PV array interspaces in the current AVS system were used to grow the relevant crops. Crops with small heights (less than 0.5m), a marginal tolerance for shade, and a moderate water requirement were chosen for the AVS.

- Fertilizers used: Diammonium Phosphate (DAP) and Urea
- Crop Summary: Refer Fig, 6

Year	2016-17	2017-18	2018-19	2019-20	2020-21
Season			Crops		
Kharif	Groundnut	Groundnut	Turmeric	Brinjal	Turmeric
	Soybean	Maize	Okra	Tomato	Cotton
	Pearl millet	Chilli	Forage Maize		Castor
	Greengram	Cotton	Castor		
	Pigeon pea				
	Cluster bean (As Green Manure) + Castor				
Rabi	Wheat	Wheat	Wheat	Potato	Wheat
	Mustard	Amaranths	Potato		
			Chickpea		
Summer	Pearl millet	Pearl millet	-	Forage Sorghum	
	Greengram	Greengram	-		
	Fodder Jowar				

Fig. 6. Crop Cycle for 1 MW Amrol Agrivoltaic plant

IV. CHALLENGES AND FUTURE SCOPE

Agrivoltaic systems have some key benefits as compared to standard Ground mounted systems. These include, pro- viding rural electrification, increasing revenue, reduction in water usage for irrigation, lowering Green House Gas (GHG) emissions, temperature and weather protection, increase in soil moisture and reduction in evaporation, ecosystem improve- ment, and maximum electricity production. However, Agrivoltaics pose a few challenges in the Indian agricultural scenario.

Agrivoltaics isn't popular in India thereare high capital and installation costs for setting up a ground-mounted solar power plant. Local production of Solar panels can be one of the solutions. Manufacturers and end users of solar systems are given loans with fairly high-interest rates. In India, utility costs for manufacturing facilities are also relatively expensive, which drives up the cost of production. So, it will be challenging to persuade farmers to implement the concept of AgriPV on their agricultural land and benefit from it unless the cost of the solar panels is reduced. There are no incentives targeted towards agrivoltaics in India.

Many countries such as the United States of America, Germany, Australia, France, China, Spain, and Canada, have provided incentives and are successful in implementing those. These incentives capture the attention of end-users to opt for Agrivoltaics and provided significant acceptance. Over the years, India has seen natural disasters like earth- quakes, floods, and cyclones. Indian and exotic crop damage is frequently caused by floods and cyclones. Such climatic conditions are going to worsen in the future due to climate change. Along with the crops, solar panels will also get affected due to worsening climate conditions. So, it's important to have suitable insurance plans so that farmers can recoup their investment in case their crops are harmed by poor weather. There is a lack of information about agrivoltaics in the Indian farming community. The operation and maintenance of any solar power plant need intensive training.

As agrivoltaics is not implemented due to illiteracy, the potential advantages that this technology might provide are lost. So, the Indian government should take proactive measures to inform the farming community on how to deploy agrivoltaics correctly. Moreover, the fear of failure prevents the agrivoltaics strategy from being widely adopted. To help farmers overcome their fear of failure, the Indian government should host training sessions to teach them how to make informed judgments.

Total Number of 310Wp Modules	3240
Number of Solar Modules in one Array	18
Total Arrays	180
Distance between two arrays(m)	10

Table III A Brief Summary of Module Sizing in 1MW Amrol Agrivoltaic Project

On the other hand, if this technology is implemented correctly, Agrivoltaics can provide immense scope for reshap- ing the future of Renewable Energy in the Indian farming ecosystem. Agrivoltaics' adoption and success will raise public awareness of the advantages of transitioning to renewable energy sources, especially in rural areas where local villagers feel no need to switch to solar since their daily energy consumption is relatively low. Agrivoltaics can create more electricity, which will lessen the need for coal-fired power plants. India being the third coun- try contributing to greenhouse emissions, Agriculture produces GHGs as a result of methane gas produced by cows, buffalos, and many other animals. Also, farmers rely on animals for both their use on farms and as a secondary source of income. 1 Litre of milk produces 3 kg of GHG. The concept of agrivoltaics as a source of secondary income generation will decrease livestock dependency and reduce GHG emissions.

V. CONCLUSION

The implementation of agrivoltaics offers many advantages such as rural electrification, sustainable income generation, water conservation, and agriculture yield improvement. The population of India will be able to effectively utilise its enor- mous landmass to produce green energy, food, and a consistent income through the widespread installation of agrivoltaics. Financial hardships are common among farmers and those working in the agriculture industry due to illiteracy about advancements in technology and dependence on unreliable farming techniques. People, environment, and economy consti- tute the three pillars of sustainability. Researchers and farmers can join hands and utilize these pillars in the agricultural sector to contribute to the world of Sustainable farming in a better way. The Indian Government (GOI) must implement the follow- ing policy-related measures in order for agrivoltaics to be more widely accepted:

- In addition to providing insurance coverage to cover unforeseeable incidents like thefts or damage, the GOImust develop plans utilize for financial support for buying and installing solar panels.
- Agrivoltaics is also a fantastic opportunity for the GOI to design novel policies like public-private partnerships where utility companies can work with farmers to achieve mutually advantageous results like boosting clean energy production, lowering GHG emissions, and providing rural areas with electricity, stable incomes, and sustainable farming.
- Offer instruction and training to the rural community on how to maintain solar farms and the best crops to grow depending on the season and location.
- Following the deployment of agrivoltaics on a large scale, there will be a large increase in the generation of solar e- waste towards its end of life. The GOI must be aware of the impending problem and create policies that allow the nation to turn the tide by optimizing waste management.

After the GOI begins focusing on its adoption, the broad adoption of agrivoltaics in India appears to be just a few years away thanks to a track record of successfully executing a wide range of policies.

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