

# ***Agrivoltaics: Powering the Future of Sustainable Agriculture***

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## **ABSTRACT**

In an era marked by climate variability, reducing land resources, increasing population and rising energy demands, agriculture stands at a critical crossroads. Feeding a growing population while ensuring environmental sustainability is one of the greatest challenges of the 21st century. At this intersection of food, energy and water lies an innovative solution- agrivoltaics is a system that harmonizes agriculture and solar energy on the same land.

## **INTRODUCTION**

**A**grivoltaics defines as the co-location of solar photovoltaic (PV) panels with agricultural activities which allows simultaneous production of crops and electricity. This dual-use approach optimizes land productivity and reduces competition between food and energy sectors (International Renewable Energy Agency [IRENA], 2020). On other side sustainable agriculture balances environmental health, economic profitability and social equity by using techniques that

protect resources, enhance soil health and minimize pollution.

Unlike conventional solar farms that grows crops on fertile land, agrivoltaic systems elevate or space solar panels in such a way that crops continue to grow underneath. The result is a synergistic system where sunlight is shared between energy generation and plant growth. This innovative approach is especially relevant for countries with limited land availability and high solar potential. By

optimizing land use and improving resource use efficiency, agrivoltaics emerges as a sustainable pathway for achieving both agricultural productivity and energy security.

### Need of Agrivoltaic system

Global demand for food and energy is rising rapidly, such as food demand is projected to rise 35%-56% by 2050, while energy demand continues to accelerate, growing by 2.2% in 2024, exceeding the 2013-2023 average (FAO, 2020). Countries like India need to significantly expand renewable energy capacity while also increasing agricultural output. Agrivoltaics offers a practical pathway to address this dual challenge by improving land-use efficiency and supporting climate-resilient farming systems.

Studies have shown that agrivoltaic systems can achieve a land equivalent ratio (LER) greater than 1, meaning that combined food and energy output exceeds that of separate systems (Jain *et al.*, 2021). This makes agrivoltaics not just an alternative, but a superior land-use strategy.

### Working of Agrivoltaic systems

Agrivoltaic system works on five-step process from sunlight capture to dual food and energy output.

- 1. Dual Land Use:** Systems are based on the simultaneous utilization of land for crop cultivation and solar energy generation.
- 2. PV Panel Placement:** Photovoltaic (PV) panels are installed at an optimized height above ground.
- 3. Solar Absorption:** Incoming solar radiation is partially absorbed by PV panels to generate electricity through the photovoltaic effect.

**4. Filtered Sunlight:** The remaining filtered sunlight reaches crops, enabling normal photosynthesis and plant growth.

**5. Co-Production:** The system ensures co-production of food and clean energy on the same land unit hence improving land-use efficiency.

Research indicates that such systems can:

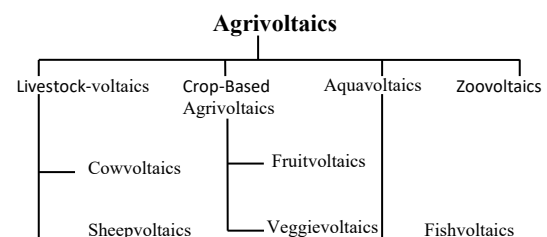
- Reduce soil and air temperatures by **2–4°C**
- Lower evapotranspiration by **20–30%**
- Improve soil moisture and water-use efficiency (Chopdar *et al.*, 2024)

This microclimatic regulation is especially valuable in water-scarce and heat-prone regions.

### Design Considerations

- Proper panel height to allow crop growth and machinery movement
- Adequate spacing between panels for sufficient sunlight to reach crops
- Correct tilt angle and orientation for maximum solar energy capture
- Selection of suitable crops based on light requirements
- Consideration of local climate and weather conditions
- Easy access for irrigation, maintenance, and harvesting

### Classification of Agrivoltaic System



## 1. Enhanced Water Use Efficiency

Agrivoltaics significantly reduces evaporation from soil, conserving water which is very crucial advantage in rainfed and dryland agriculture (Barron-Gafford *et al.*, 2019).

## 2. Climate Resilience

The shading effect protects crops from extreme heat, hail and heavy rainfall making farming more resilient to climate variability.

## 3. Improved Farmer Income

Farmers benefit from dual income streams i.e. crop production and electricity generation. Surplus energy can be sold to the grid, ensuring stable and diversified income.

## 4. Environmental Sustainability

By promoting renewable energy and reducing greenhouse gas emissions, agrivoltaics contributes to climate change mitigation and sustainable development.

### Crop Performance Under Agrivoltaics

Crop response to agrivoltaic systems varies depending on species and light requirements. Shade-tolerant crops such as vegetables and forage grasses often show stable or even improved yields. For instance, some studies report yield increases of up to **15%** under moderate shading conditions (Zahrawi & Aly, 2024).

However, light-demanding crops like wheat and maize may experience reduced yields if shading is excessive. Therefore, proper system design and crop selection are essential for maximizing benefits.

### Agrivoltaics in India: Opportunities and Challenges

India, with its high solar potential and vast agricultural base is well-positioned to adopt agrivoltaics. Government initiatives such as

the **PM-KUSUM scheme** are already promoting solar integration in agriculture, enabling farmers to access clean energy and reduce irrigation costs.

Despite its benefits, there are several challenges in its adaptation:

- High initial investment costs
- Limited awareness among farmers
- Technical complexity in system design
- Lack of standardized models

Addressing these barriers through policy support, research and capacity building is essential for large-scale adoption.

### Future thrust of Agrivoltaic System

The future of agrivoltaics lies in technological innovation and smart integration. Emerging developments such as **AI-based panel tracking, IoT-enabled monitoring systems and semi-transparent solar panels** are expected to enhance system efficiency and adaptability.

Moreover, agrivoltaics aligns strongly with global sustainability goals by linking food security, clean energy and climate action into a single solution. As research and investment grow, this approach has the potential to transform rural landscapes and livelihoods security.

## CONCLUSION

“Where sunlight meets soil, agrivoltaics creates a future where energy and agriculture thrive together.” Agrivoltaics represents a paradigm shift in how we use land and resources. By integrating agriculture with renewable energy, it offers a holistic solution to some of the most pressing challenges of our time. With proper planning, supportive policies and technological advancements,

agrivoltaics can play a pivotal role in building a resilient, sustainable and energy-secure future.

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