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AGRIVOLTAICS: PIONEERING THE FUTURE OF SUSTAINABLE AGRICULTURE

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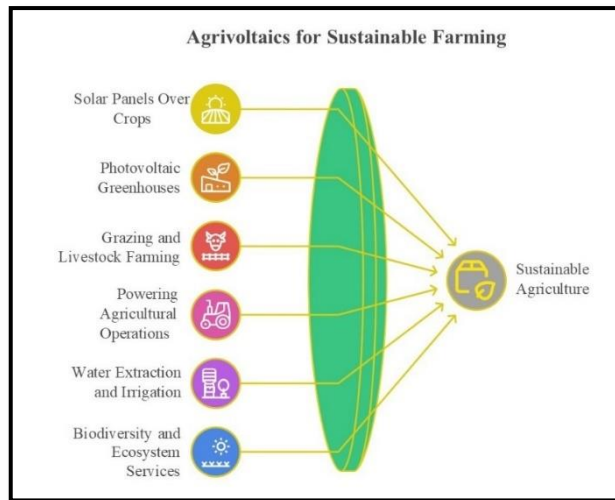
Agrivoltaics is a new way to use land for both farming and solar power. It is also called agrisolar or dual-use solar. This method lets farmers grow crops and produce solar energy on the same land. Solar panels are placed above or between crops or on grazing land. This helps make the most of the land, gives shade to crops, and provides farmers with extra income. It allows food and clean energy to be produced together. By putting solar panels on farmland, it not only creates clean energy but also supports sustainable farming. As climate change becomes a bigger issue and the need for renewable energy grows, agrivoltaics is becoming popular worldwide.



Architecture of Agrivoltaic System

Agrivoltaics, first introduced in the 1980s, is increasingly recognized globally as an innovative approach to cultivate food and generate renewable energy simultaneously. This

method is particularly significant for nations such as India, which face constraints in land availability and have substantial energy demands. Agrivoltaics involves the installation of solar panels above crops or grazing areas, where the panels harness sunlight to produce electricity, while the land beneath continues to support plant cultivation or livestock rearing.



- **Raised solar panels:** Instead of being installed directly on the ground, solar panels are installed on structures that are high enough to allow sunlight and rain to reach the crops below. These raised solar panels in agriculture also enable farmers to easily move their equipment underneath.
- **Partial shading:** The panels offer shade that protects crops from intense heat and minimizes water loss from the soil and provides a cooler, more stable environment for plant growth, particularly in hot or arid areas.
- **Dual land use:** With solar panels producing electricity and crops or livestock flourishing below, farmers benefit from both food and clean energy on the same land.
- **Electricity for the farm and beyond:** The solar power generated on an agrivoltaic farm can supply energy for farm operations, lowering electricity expenses. Any surplus power can be fed back into the grid, providing extra income.

By balancing the demands of agriculture and energy production, agrivoltaics transforms farmland into a multifunctional space that supports sustainable farming and clean energy generation simultaneously.

Applications of Agrivoltaics Farming

Agrivoltaics has the following applications for sustainable farming.

1. **Solar panels over crops:** A prevalent method of agrivoltaics involves placing solar panels above agricultural fields. This arrangement offers partial shading to the crops, enhancing water retention and minimizing heat stress, which is particularly advantageous for dry farming with limited irrigation.

- 2. Photovoltaic greenhouses:** Another innovative application of agrivoltaics is the use of photovoltaic greenhouses, where solar panels are installed on the roof or exterior of the greenhouse. These panels function as a canopy, helping to regulate temperature and humidity inside, thereby reducing energy consumption for climate control. The electricity generated is used to power greenhouse operations, lowering costs and enhancing sustainability.
- 3. Grazing and livestock farming:** Agrivoltaics extends beyond crop cultivation. Solar installations can be set up over grazing areas, allowing animals like sheep or goats to find shelter beneath the panels. This dual-purpose land use benefits animal welfare by providing shade and decreases the costs associated with vegetation maintenance.
- 4. Powering agricultural operations:** Solar energy can be directly utilized on farms to power essential equipment such as irrigation pumps, lighting and fencing. Employing solar energy in agriculture decreases reliance on fossil fuels and reduces energy expenses, enabling farmers to save money and lessen their carbon footprint.
- 5. Water extraction and irrigation:** In numerous rural regions, water access is a significant challenge. Agrivoltaic solar power can operate pumps that draw water from wells, facilitating more efficient irrigation systems and supporting crop growth in dry areas. This integration of solar energy with water management is transformative for sustainable agriculture.
- 6. Supporting biodiversity and ecosystem services:** Some agrivoltaic farms create pollinator-friendly environments beneath and around solar panels, boosting biodiversity and promoting ecosystem health. This strategy benefits crops dependent on pollination and fosters environmental sustainability.

Schemes and Initiatives Supporting Agrivoltaics in India

National schemes promote agrivoltaics by supporting solar adoption in agriculture and enabling stakeholder collaboration. They aim to boost clean energy while enhancing farm incomes:

- 1. India Agrivoltaics Alliance (IAA):** Established by the National Solar Energy Federation of India (NSEFI), it aims to harmonize agriculture and solar energy.
- 2. PM-KUSUM (Pradhan Mantri Kisan Urja Suraksha Evam Utthan Mahabhiyan):** Launched in 2019, PM-KUSUM supports farmers in installing solar-powered pumps

and grid-connected solar power plants in different states like Telangana, Maharashtra, Gujarat, Haryana, Karnataka and Delhi.

3. **Mukhyamantri Saur Krushi Vahini Yojana (MSKVY):** Maharashtra aims to solarize 1,600 MW of agricultural feeders by 2026 under MSKVY. The state has already installed 500,000 solar pumps, surpassing the rest of India combined. The scheme offers a fixed tariff of ₹3.10 per kWh for solar power projects, with the Maharashtra State Electricity Distribution Company Ltd. (MSEDCL) facilitating implementation.
4. **Suryashakti Kisan Yojana (SKY):** In Gujarat, SKY provides farmers with subsidies and loans to install solar panels on their fields. Farmers can sell surplus electricity to the grid, earning additional income. The scheme offers a feed-in tariff of ₹7 per unit for the first 7 years and ₹3.50 per unit for the next 18 years. The government covers 60% of the installation cost, with the remaining 40% financed through loans.
5. **Surya Raitha Scheme:** This scheme focuses on solarizing agricultural pumps to reduce farmers' dependency on grid electricity and diesel in Karnataka state. It offers financial assistance for installing solar pump sets and encourages farmers to sell excess power back to the grid, providing an additional income stream. The initiative aims to promote renewable energy use in agriculture and enhance sustainability.
6. **Mukhyamantri Kisan Aay Badhotri Solar Yojana:** Under this scheme, Delhi farmers lease their land to developers who install solar panels, generating electricity. This initiative provides farmers with an additional revenue source while promoting solar energy adoption.
7. **The National Solar Energy Federation of India (NSEFI)** is working with local, state, and agricultural institutions to align agrivoltaics with AP's diverse agro-climatic zones. AP is recognized as a leader in solar adoption and is exploring agrivoltaics to strengthen the rural economy.
8. **PM-KUSUM:** The Government of Telangana is actively implementing the PM-KUSUM Component A scheme, which encourages farmers to set up 500 kW to 2 MW solar plants on their land to foster combined agricultural and energy production. The Telangana Renewable Energy Development Corporation Limited (TGREDCO) oversees the deployment of these projects, aligning them with state-level agricultural support, such as the *Rythu Bharosa* initiative and Telangana is also a key focus state for the India Agrivoltaics Alliance (IAA), which is working on establishing pilot projects to validate business models.

Few Agrivoltaics Projects in India

- India's largest agrivoltaics farms in Sagar, Madhya Pradesh. Spanning 16 acres farm grows crops like strawberries and lettuce beneath elevated solar panels, producing about 25,000 units of clean electricity daily.
- In Nashik, Maharashtra, Sahyadri Farms, the largest Farmer Producer Organization in India, runs a pilot agrivoltaics project pairing solar power with grape cultivation to boost farmer earnings and eco-friendly practices.
- The Central Arid Zone Research Institute (CAZRI) in Jodhpur tested a 105 kWp system that improved land productivity and water use in arid regions.
- The Muradpur lift irrigation scheme in Nagpur uses floating solar panels to support irrigation over 465 acres, enabling up to three crops annually while reducing energy costs. These projects showcase agrivoltaics' potential to enhance land use, promote sustainable agriculture, and deliver clean energy to farmers across India.

Benefits of Agrivoltaics Farming

Agrivoltaics farming offers a promising solution by enabling both farming and generation of solar energy simultaneously on the same piece of land, providing numerous environmental, economic, and social benefits. Here are some of the key advantages of agrivoltaics farming:

- Increases land-use efficiency by using agrivoltaics to generate renewable energy while carrying on with their agricultural operations.
- Agrivoltaics can lower electricity costs, supply clean energy to farm operations, and occasionally resell excess power to the grid, boosting the stability of farm income.
- Solar panels provide partial shade and keep soil moisture levels stable, lowers water evaporation and moderates' temperature extremes particularly in hot or arid areas, resulting in increase in yields and less need for irrigation.
- Diversifies income for farmers generate extra income by combining crop or livestock production with solar for agriculture.
- It enhances ecosystem services and biodiversity by preserving native vegetation and establishing habitats for pollinators like bees etc.,

- Agrivoltaics sites can also enhance the health of ecosystems by controlling water runoff and reducing the need for herbicides, these green areas lessen their negative effects on the environment and maintenance expenses.
- Provides grazing opportunities for sheep and chickens etc., that can graze beneath solar agriculture panels, naturally controlling vegetation while enjoying the shade and protection.
- Improves working conditions for farm workers by providing shade and improve comfort and safety by spending extended periods of time outside by shielding them from intense heat and damaging UV rays.
- Agrivoltaics can reduce greenhouse gas emissions and increase climate resilience in agriculture by producing clean, renewable energy and lowering dependency on fossil fuels.

Challenges to Agrivoltaics Farming

Besides its promising potential, agrivoltaics faces several challenges related to technical, economic, agronomic, and institutional that must be addressed for it to scale sustainably.

- 1. High capital costs:** Because of their higher structures, higher material requirements, and more complicated installations, agrivoltaics systems are substantially more expensive than ground-mounted solar. Prices per kw can increase by 1.3-2 times. Costs are further increased by lower panel density, wind resistance specifications, and higher panel heights. For small and marginal farmers, this makes Agri photovoltaics financially difficult unless financing options or subsidies are implemented.
- 2. Uncertain impact on crop yields:** The way that crops react to solar panel shading varies greatly. While some crops, like leafy greens, benefit yields of staple crops like wheat and rice are frequently lower. Although Land Equivalent Ratio (LER) values can conceal decreases in food production, they may indicate overall gains. Yield results are highly dependent on the panel. Crop type, spacing, orientation, and local agroclimatic conditions, all of which call for site-specific data and trials prior to scaling.
- 3. Design and compatibility issues:** Energy production and agricultural requirements must be balanced when designing agrivoltaics systems. For crop health, proper row spacing and enough room for farm equipment, particularly harvesters, are essential. Advanced technologies (like movable or transport panels) are still costly and uncommon in India, and many of the panels and mounting systems that are currently in use are not designed with agriculture in mind.

- 4. Operation, maintenance, and safety:** Most farmers lack the technical know-how and routine maintenance needed for Agri photovoltaics systems. Risks include exposed wiring or electrical infrastructure raising safety concerns and unintentional damage to solar equipment while farming. Reliance on outside technicians may result in higher operating expenses and downtime over time.
- 5. Soil and water impacts:** Compaction and erosion of the soil may result from the installation of solar structures, particularly if heavy equipment is used or topsoil is removed. The microclimate is changed by shading, which may lower evapotranspiration but also has an impact on water requirements and rainfall distribution. More research is required to determine how different crops will react to these changes.
- 6. Grid integration and storage constraints:** Although off-grid systems are less practical than grid-connected ones, many rural areas lack nearby substations or sufficient evacuation infrastructure. Without adequate planning, intermittent solar generation could put strain on the grid. In Indian Agri photovoltaics setups, battery storage is still costly and unproven.
- 7. Regulatory and policy barriers:** Clear national regulations pertaining to agrivoltaics are lacking. In some states, dual-use applications may be restricted by land use classifications and farmland protection laws. Solar installation approval procedures on agricultural land are complex and dispersed among several agencies.
- 8. Farmer awareness and adoption:** The potential advantages of Agri photovoltaics are unknown to most farmers. The threats to crop yields and disturbances to farming practices are the reasons for non-adoption of agri photovoltaics. Adoption is low due to absence of training, outreach and demonstration initiatives, particularly through Farmer Producer Organizations (FPOs).

Conclusion

Agrivoltaics represents a prime example of human ingenuity in tackling complex environmental and economic issues. By merging agriculture with renewable energy, it offers a promising path toward creating more resilient, sustainable, and economically sound futures in both the food and energy industries. To overcome current challenges and fully harness the transformative potential of agrivoltaics worldwide, ongoing research, supportive policy frameworks, and collaborative efforts are essential.

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