



Harvesting Energy, Growing Food: The Promise of Agrivoltaics

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The agriculture sector is currently at a pivotal moment, with demands to produce food for a burgeoning world population and a shift towards renewable energy. The global population is expected to reach over 9 billion by 2050, leading to a growing need for food. Meanwhile, farming is becoming more sensitive to the effects of climate change - unpredictable precipitation, rising temperatures, soil erosion and water stress - which affect crop yields and livelihoods. At the same time, the world is facing a pressing need to move away from fossil fuels and accelerate the transition to renewable energy sources to curb greenhouse gas emissions and climate change. Agriculture and energy production have historically been in competition for land. Solar farms, needed for renewable energy production, are often constructed on expanses of land that might be suitable for farming. This poses a challenge, especially in densely populated and farming countries such as India, where land is scarce and valuable. In such situations, strategies that help maximise land use while not affecting food or energy production are crucial. Agrivoltaics offers a potential solution to this dilemma by co-locating solar photovoltaics and agriculture on the same land. Instead of seeing solar panels as a competing land use, agrivoltaics integrates them as an added element within agriculture. Elevated or variously spaced solar panels can be installed over or between crops to produce renewable energy while simultaneously harvesting crops. This approach not only enables higher land productivity but also facilitates a symbiotic relationship between renewable energy and farming.

Agrivoltaics: Where Sunlight Fuels Both Food and Power

Agrivoltaics is an innovative land-management approach that combines solar photovoltaic (PV) power generation with crop production on the same land area, allowing farmers to produce both energy and food. Rather than solar farms, where land is solely dedicated to electricity production, in agrivoltaics, solar panels are strategically installed at a height above crops, allowing them to grow with minimal yield loss. Here, solar panels are positioned at the right elevation and spacing to ensure sufficient sunlight, ventilation and access for agricultural activities. The solar panels alter the microclimate, offering partial shading, which can mitigate extreme temperatures, minimise water evaporation and shield crops from adverse weather (extreme sunlight or hail). This can be advantageous for shade-tolerant and horticultural crops that thrive in less extreme conditions. Agrivoltaics also brings economic benefits to farmers. The generation of renewable energy allows farmers to offset their electricity demands (irrigation, refrigeration, etc.) and potentially even generate revenue by feeding-in excess electricity. This income diversification increases the resilience and stability of farms, particularly in climatically vulnerable areas. Furthermore, agrivoltaics is beneficial for the environment by encouraging the use of renewable energy, cutting greenhouse gas emissions, and increasing land productivity. It transforms land use from a mono-functional to a poly-functional, sustainable system, in line with the concept of climate-smart agriculture. In this way, agrivoltaics is not only a technological breakthrough but also a paradigm shift in

agriculture - where the same sunlight is used twice, to produce crops and electricity, and ultimately create a more sustainable and efficient future for agriculture.

How Agrivoltaics Systems Work: A Synergy of Sunlight, Crops, and Clean Energy

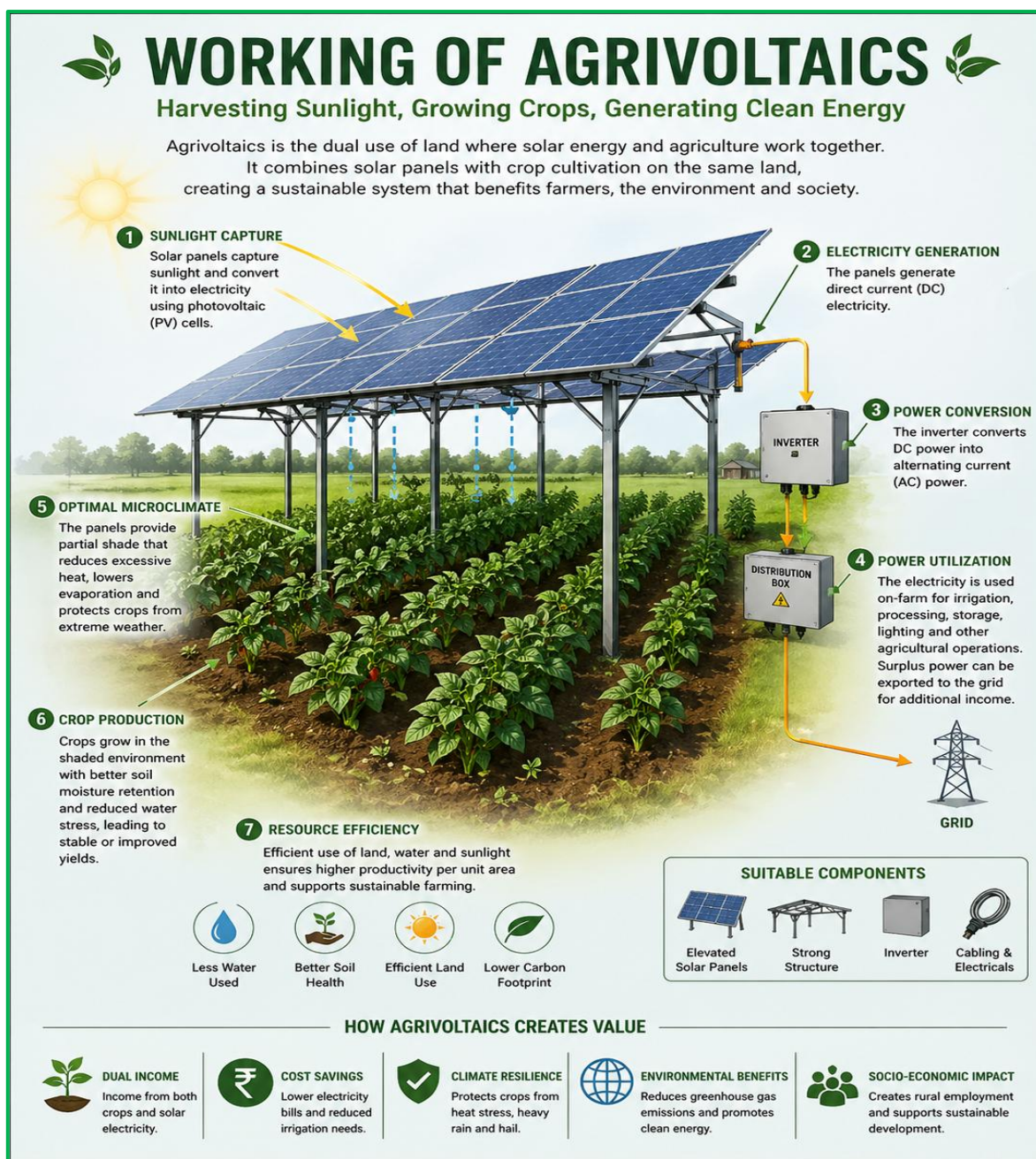
Agrivoltaics systems aim to optimise solar energy production and crop cultivation by effectively allocating sunlight between solar cells and crops. The technology is a combination of design, engineering and farming.

- 1) **Solar Panel Design and Positioning:** Agrivoltaic systems start with the careful placement of solar panels at a higher elevation or in rows with sufficient distances in farmlands. This allows for the sun's light to be partially blocked but still reach the underlying crops. The inclination, direction, and arrangement of the panels are optimised according to the climate of the region and the light needs of the crops to balance energy production and crop yield.
- 2) **Simultaneous Crop Cultivation:** Like traditional farming, crops are grown under and around the solar panels. The shading effect of the panels can be advantageous for many horticultural and shade-tolerant crops. This can reduce heat stress, scorch and improve physiological conditions for crop production, particularly during hot summer
- 3) **Creating the Right Microclimate for Crop Growth:** Microclimate change is one of the main modes of operation of agrivoltaics. The shading provided by solar panels slightly reduces soil and air temperatures and reduces the intensity of sunlight. This, in turn, reduces evapotranspiration, enhances water retention in the soil and creates a more stable microclimate. This is especially beneficial in water-scarce areas.
- 4) **Sustainable Water and Resource Use:** Many agrivoltaics systems also use advanced irrigation methods like drip and sprinkler irrigation, further improving water efficiency. Shading helps to retain water, so crops need less watering more sophisticated setups, water runoff from the panels can be recycled, further recovering a precious resourcing.
- 5) **Two for One: Crops and Energy:** As crops are grown, the solar panels absorb sunlight and generate electricity via photovoltaic cells. This can be used for various agricultural processes such as pumping water, refrigeration or processing, with any surplus electricity fed back into the grid. In this way, we produce a two-product system where we can generate both crops and electricity.
- 6) **Smart and Adaptive Technologies:** In more sophisticated agrivoltaics systems, smart technologies like solar tracking, sensors and control systems are applied. Solar panels could tilt to capture more sunlight during the day and allow enough light to reach the crops. Such intelligent technologies improve efficiency and showcase the integration of precision agriculture with renewable energy.
- 7) **Overall Functioning Concept:** Ultimately, agrivoltaics work by balancing light, crops, and energy. By turning agricultural areas into a multifunctional system, they increase land efficiency, reduce resource waste and build a sustainable farming model for the future.

Economic and Environmental Impact of Agrivoltaics

Agrivoltaics harnesses a symbiotic relationship between farming and renewable energy, with economic and environmental benefits. From an economic standpoint, it converts traditional agriculture into a double-income farming system, with farmers benefiting from both crop yields and energy production. The generated power can be used for farm operations, including irrigation, storage, and processing, thus lowering costs. Excess electricity can also be fed into the grid, offering farmers a reliable income stream. This helps farmers become more financially resilient, mitigate risks from crop failure or market uncertainty, and increase land values. Agrivoltaics optimises production per land unit, enhancing the efficiency of the land without increasing its size. Environmentally, agrivoltaics is a key component of sustainable and climate-smart farming. Solar energy generation helps to shift away from fossil-fuel-based energy sources and decreases greenhouse gas emissions, contributing to climate change mitigation efforts. On the other hand, the shading effect of the panels

enhances the efficiency of resource use, especially water and soil. The shading effect increases moisture in the ground, reduces evaporation and irrigation needs, which is particularly valuable for arid zones. Moreover, because of the reduced temperature, crops are shielded from extreme weather events such as heatwaves and precipitation, enhancing climate resilience. Through its efficient land use and environmental protection, agrivoltaics offers a sustainable approach that benefits both farmers and the environment.



Choosing the Right Plants Under Solar Panels

Type of Crop	Crop Name	Remarks
Leafy Vegetables	Spinach, Lettuce, Amaranthus	Thrive well under partial shade; improved leaf quality and reduced heat stress
Root & Tuber Crops	Carrot, Beetroot, Radish, Potato	Less dependent on direct sunlight; benefit from cooler soil conditions
Vegetable Crops	Tomato, Chilli, Brinjal, Cabbage	Moderate shade tolerance; reduced evapotranspiration improves yield stability
Fodder Crops	Napier grass, Alfalfa, Clover	Highly adaptable; suitable for livestock-based integrated systems

Medicinal Crops	Turmeric, Ginger	Prefer partial shade; improved rhizome development and moisture retention
Aromatic Crops	Mint, Coriander, Basil	Grow well in diffused light; maintain quality and essential oil content
Fruit Crops (Short Stature)	Strawberry, Papaya (young stage)	Can be grown with proper spacing and light management
Flower Crops	Marigold, Chrysanthemum	Tolerate partial shade; useful for commercial floriculture
Spice Crops	Coriander, Fenugreek	Suitable for low to moderate light conditions
Crops to Avoid (High Light Demand)	Maize, Sugarcane, Wheat	Require full sunlight; not ideal under dense panel shading

Challenges in Implementation of Agrivoltaics

While agrivoltaics has potential advantages, it also presents some challenges to large-scale deployment. A major obstacle is the upfront capital cost of deploying solar panels, support structures, and other infrastructure. This can be particularly prohibitive for small and marginal farmers, particularly without the support of financial incentives, subsidies or credit. Moreover, agrivoltaics systems need to be carefully designed and installed by technical experts to achieve satisfactory energy generation and crop production, taking into account factors such as panel height, tilt, spacing and crop type.

A further challenge is the trade-off between light exposure for crops. Although some plants thrive with partial shading, too much shading or poor panel placement can result in reduced photosynthesis, stunted growth and reduced yield, especially for light-loving crops. This makes the choice of crop and design of the system very site-specific and demand extensive research and experimentation.

Operational and maintenance issues also pose difficulties. Solar panels on farms are vulnerable to dust, dirt, bird excreta, and weather exposure, which may lead to decreased efficiency and the need for cleaning and maintenance. In turn, conventional farm activities like ploughing, irrigation and harvesting could be limited due to the presence of the panels, requiring modifications to farm equipment and practices. Additionally, there are policy and institutional barriers, such as a lack of guidelines, farmer awareness, and extension support for agrivoltaics uptake. Access to the grid, tariffs for feeding-in excess power and permit acquisitions may also impact the viability of these systems. Cultural and socio-economic factors, such as resistance to change, particularly in rural communities, may also play a role.

Conclusion

Agrivoltaics is an innovative approach that combines farming and clean energy generation on the same plot, boosting productivity, sustainability and resilience for farmers. This approach allows the co-generation of crops and renewable energy, maximising resource efficiency, minimising environmental footprint and adding value to agricultural operations. While there are drawbacks, including high upfront costs and technical challenges, if adequately supported, researched and supported through policy changes, agrivoltaics can contribute to the development of climate-smart and sustainable farming.