Soilless Agriculture Integrated With Agrivoltaics: A Pathway To Sustainable Food And Energy Security In India

Carthikswami Thoniparambil

Independent Researcher, USA

1. Introduction

Feeding a global population expected to reach 9.8 billion by 2050 requires transformative strategies that align productivity with sustainability [1]. Per-capita arable land availability is projected to be just one-third of its 1970 level, exacerbated by climate change, water scarcity, and shifting dietary demands [2]. India's agricultural landscape exemplifies these strains: more than 70% of its farms which measure under one hectare, depend on monsoon-fed cropping, and have limited irrigation, energy access, and post-harvest infrastructure [3]. Such conditions constrain yields, farmer livelihoods, and resilience. Without strategic interventions, these structural bottlenecks risk undermining India's ability to meet future food needs and adapt to environmental volatility.

2. Agriculture and Agrivoltaics Integration

Soilless cultivation offers a paradigm shift, saving up to 90% water, eliminating soil-borne diseases, and boosting yields by up to 30% [4], [5]. Yet, these gains hinge on clean, affordable energy for lighting, nutrient delivery, and climate control. Without renewable sources, environmental benefits may be offset by carbon-intensive grids and volatile costs [5]. Agrivoltaics—integrating photovoltaic (PV) panels directly into agricultural settings—promises a complementary solution. By co-locating solar arrays, farms can generate on-site renewable electricity, stabilize their energy supply, reduce greenhouse gas emissions, and lower operational expenses [6]. Partial shading from PV structures can moderate extreme temperatures and reduce evapotranspiration, further improving resource efficiency [7], [8]. Together, soilless systems and agrivoltaics create a synergy that aligns sustainable intensification with environmental stewardship and rural prosperity.

3. Integrating Agrivoltaics with Soilless Systems

Global case studies affirm these synergistic effects. Research indicates that agrivoltaics can enhance crop yields, diversify rural employment, and strengthen resilience in vulnerable regions [8]. India-specific analyses show that coupling solar energy with advanced cultivation methods can align with initiatives like PM-KUSUM, helping smallholders stabilize incomes and reduce dependence on erratic power supplies [6], [9]. Further International water resource assessments underscore the importance of these integrated solutions, especially in water-scarce contexts [10].
Emerging innovations, such as advanced PV panels designed for greenhouses and controlled environments, further boost productivity and efficiency [11].

4. Policy, Institutional Frameworks, and Technology Adoption

Realizing the full potential of soilless-agrivoltaic systems in India requires deliberate policy support and robust institutional frameworks. Region-specific guidelines, soft loans for solar infrastructure, feed-in tariffs, and streamlined approval processes can catalyze widespread adoption [3], [13]. Ensuring a “Just Transition” ensures that marginalized communities and smallholders benefit, rather than being displaced or left behind.
Policy-driven transitions in other sectors highlight the transformative potential of strategic

governance: China's policy-driven transitions demonstrate how economic incentives and sound frameworks can steer entire sectors toward resilience and higher value-add activities [12]. While the focus differs, the lesson stands: well-designed policies and institutional support can scale integrated agricultural-energy solutions rapidly and equitably.
Concurrently, advanced digital technologies—IoT sensors, machine learning, big data analytics—can optimize nutrient delivery, predict stress factors, and refine best practices through simulations and digital twins [4], [5], [8], [14]. Such intelligent, data-driven farming systems promise not only greater resource use efficiency but also the adaptability to weather market and environmental uncertainties.

5. Conclusion

Integrating soilless cultivation with agrivoltaics, informed by global insights and supported by inclusive policies and digital innovations, charts a compelling trajectory for Indian agriculture. This holistic approach harmonizes resource efficiency, renewable energy generation, socio-economic upliftment, and climate resilience. Building on existing policy frameworks, investing in research, and ensuring equitable benefit distribution can enable India to exemplify a sustainable, inclusive model that meets the dual imperatives of food security and environmental stewardship. It stands as a replicable blueprint for other regions striving to balance productivity, sustainability, and social justice in a rapidly changing world.

6. References

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