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

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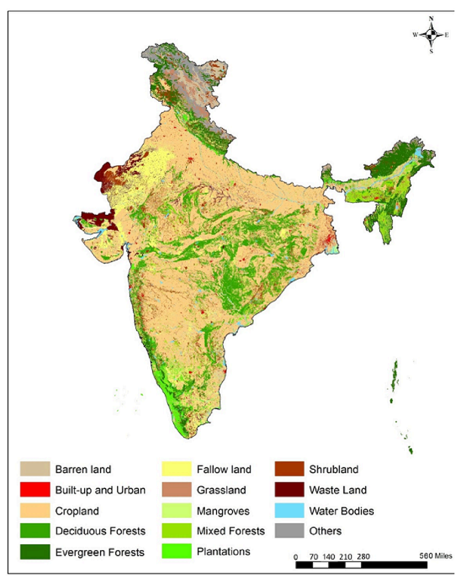
India's Current Agricultural Realities[1,2,3]

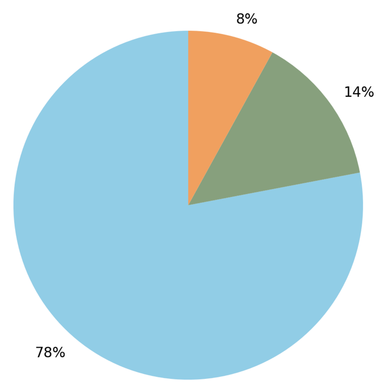
Land Fragmentation & Monsoon Dependency



- India allocates the highest proportion of its land to agriculture, about 179.8 Mha.
- 55-60% of India's land is already cultivated, but 70% of farms are <1 ha, limiting scale & efficiency.
- Monsoon dependence leaves farming vulnerable to floods, droughts, and seasonal shifts.
- Rising urbanization and shrinking land per capita intensify pressure on smallholders.

India's Water Use

- 78% → Agriculture
- 8% → Domestic
- 14% → Industry



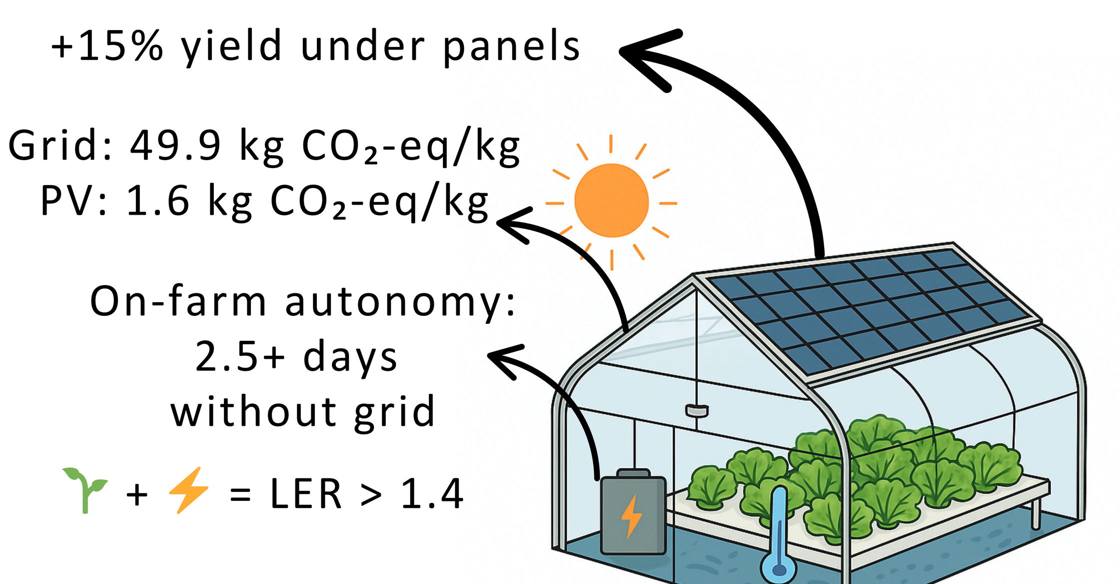
Climate Projections

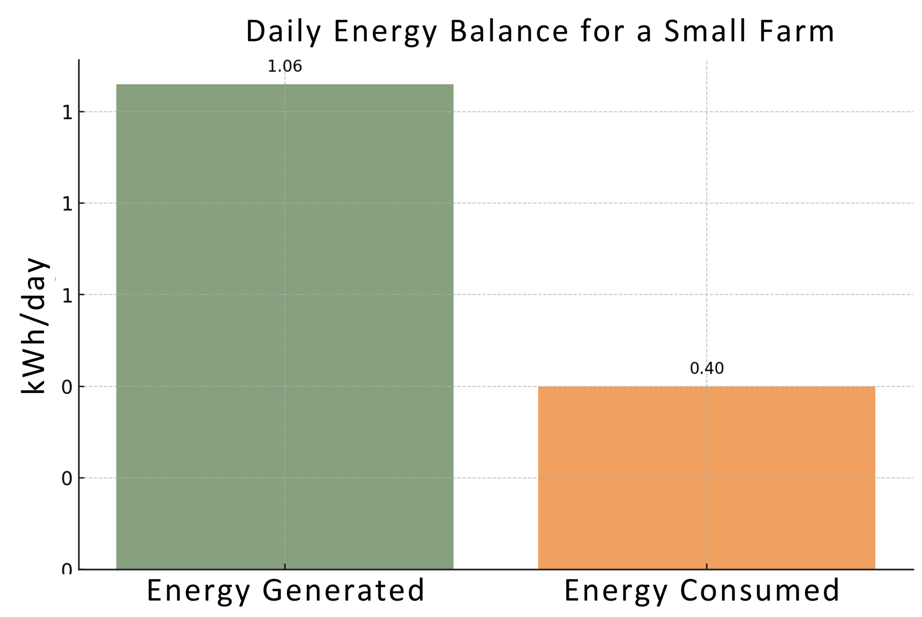
Variable	SSP1-2.6 (Low Emissions)	SSP5-8.5 (High Emissions)
Monsoon Rainfall	+15% increase	+25% increase
Post-Monsoon Temp	+5% increase	+12% increase
Rice Yield Impact	−3% yield	−22% yield

- Rain-fed fields face flooding, root rot, and nutrient leaching from heavier downpours.
- Hotter, more erratic weather compounds crop stress.
- Every Indian district is projected to register some rice-yield decline.

Integrating Renewable Energy: Agrivoltaics as a Sustainable Solution[5,6,7]

Yield Boost & Net-Positive Energy

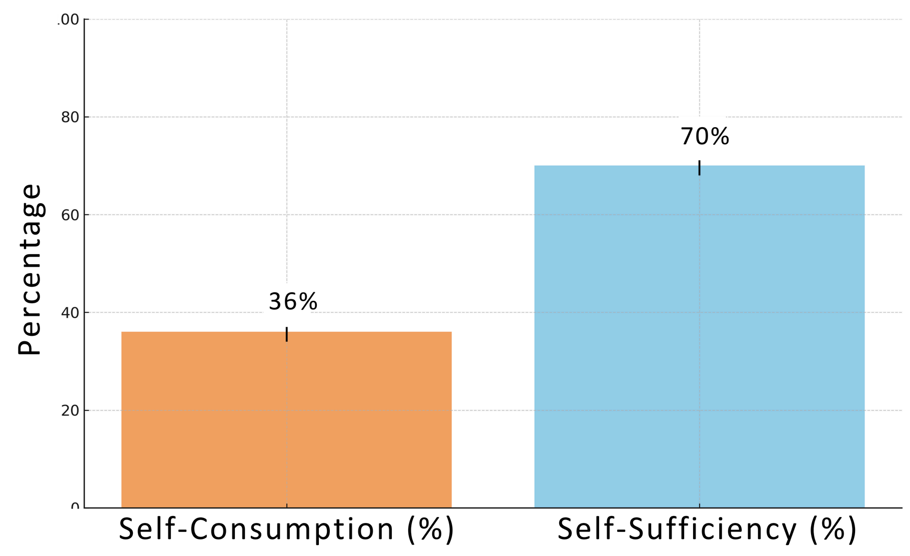




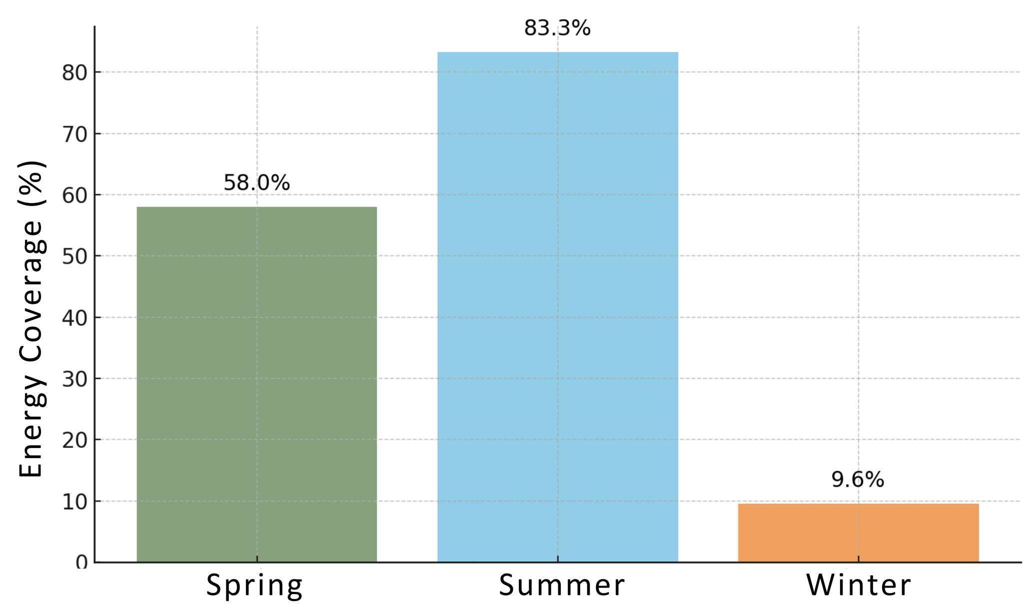
- Sell surplus PV → extra cash, faster payback.
- Solar micro-climate cuts evapotranspiration.
- Spectrum-selective PV transmits PAR while harvesting the rest.

- Generates 1.06 kWh/day, consumes only 0.40 kWh/day.
- Surplus energy enables storage or additional loads.
- Entire system powered by renewables (PV + Wind).
- Ensures autonomy in remote or underserved areas.
- AI-based control + efficient hardware = low power draw.

Renewable Self-Sufficiency Across Seasons



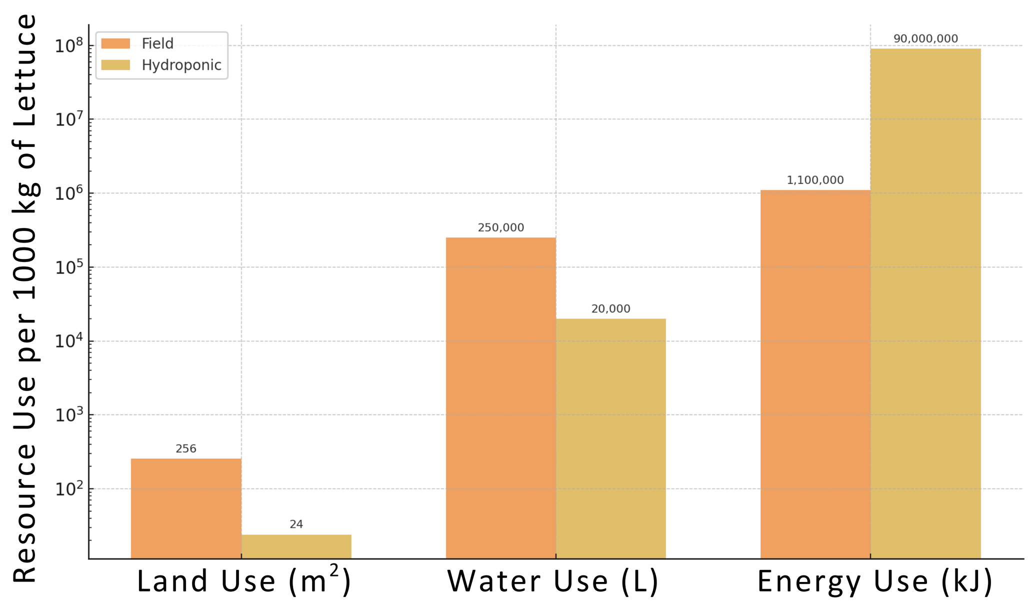
- 36% of electricity is used directly on-site (self-consumption).
- 70% of total energy needs are met by on-farm renewables (self-sufficiency).
- Optimized scheduling + storage boost off-grid potential.



- 83% PV coverage for root heating in summer.
- 58% covered in spring supports seasonal self-reliance.
- Winter coverage (~10%) signals need for backup.

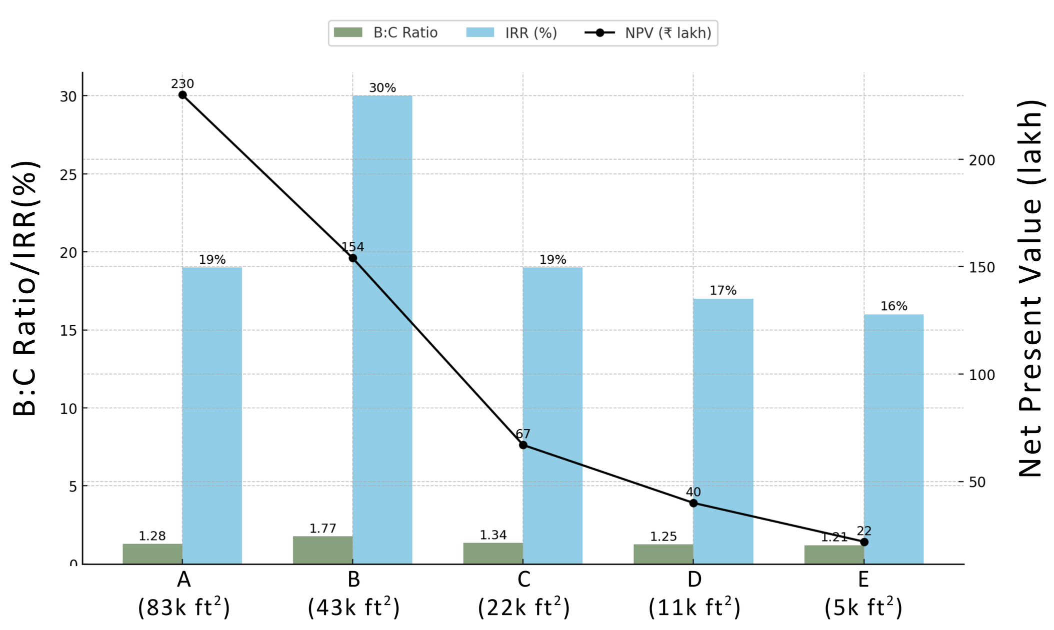
Unlocking the Potential of Soilless Cultivation[4]

Resource Efficiency: Field vs Hydroponic



- Land: ~90% less
- Water: ~92% less
- Energy: ~80× more than field farming

Financial Feasibility of Hydroponics by Scale

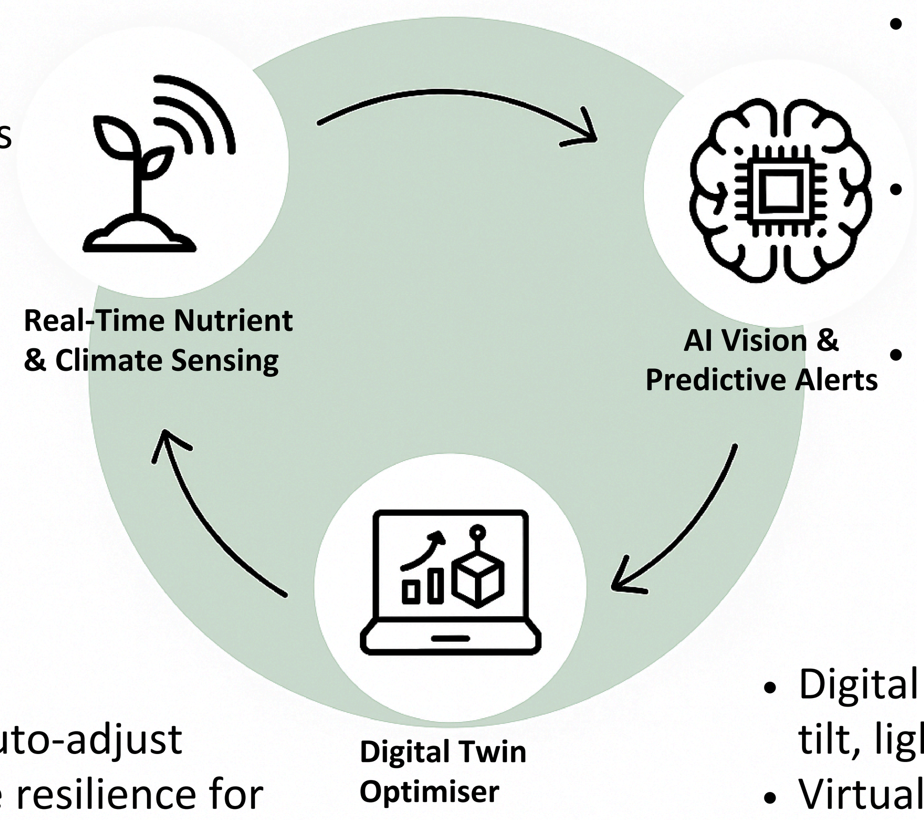


- 1-acre farms (B) strike the best return-to-investment balance.
- Large farms (A) earn more overall, but with lower efficiency.
- Small farms (D, E) stay profitable, though margins decline.
- All exceed the 10.5% IRR viability mark.

Closing the Loop: Emerging Digital Technologies

Precision Agriculture

- Sensors monitor nutrients and climate in real time.
- Automated dosing applies inputs only as needed.
- Closed-loop control improves consistency and cuts resource waste.

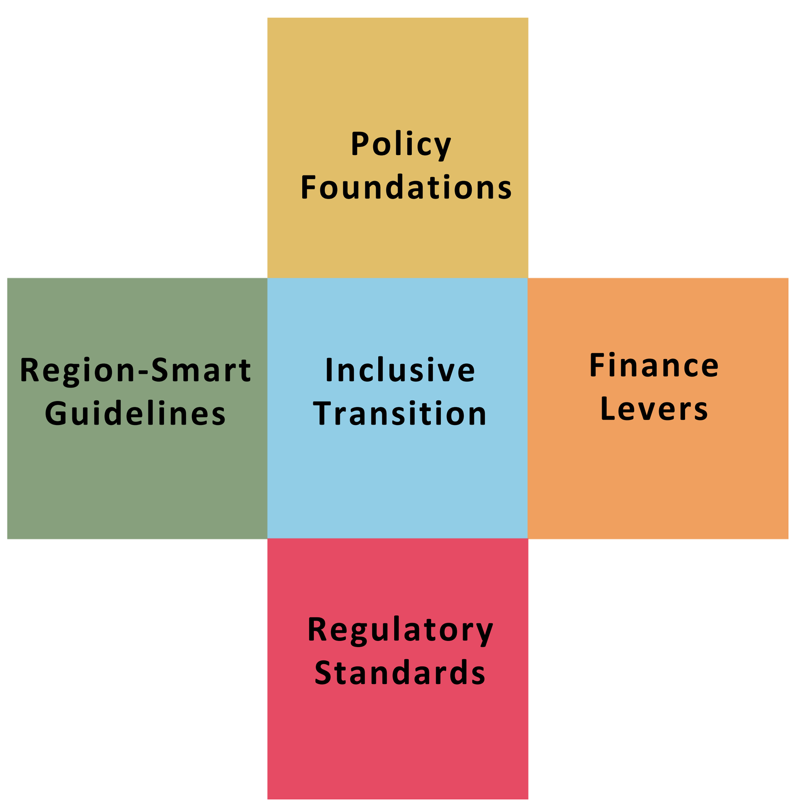


- RGB-D + AI estimate biomass, leaf area, and stress with 7.3 % error, no manual labelling.
- Growth dips flag early stress; models suggest fertigation tweaks from image data.
- Drone-based models enable real-time yield forecasts and input scheduling

- Linked to real sensors, twins auto-adjust schedules and improve climate resilience for smallholders.

- Digital twins simulate farm layouts, panel tilt, lighting to optimise yield vs. energy use.
- Virtual testing reduces trial-error and adapts design to local conditions before hardware deployment.

Empowering the Transition: Policy, Equity & Impact



Policy Pillars for Scalable, Inclusive Adoption

A comprehensive policy ecosystem anchored in region-specific design, financial support, regulatory clarity, and inclusive training can transform agrivoltaic-soilless systems from pilot concepts into mainstream rural infrastructure. By aligning incentives with local needs and embedding safeguards for food-energy balance, India can drive equitable adoption while ensuring long-term agricultural sustainability.

Conclusion

Integrating agrivoltaics with soilless farming offers smallholders a path to resource-efficient, climate-resilient agriculture. It enhances yields, water savings, and enables farmers to generate clean energy alongside crops.
With the right policy, financing, and training, this model can drive sustainable intensification and support India's goals for rural development and decarbonisation.

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