

REGENERATIVE AGRICULTURE AND AGRIVOLTAICS: THE SELF-SUSTAINING RURAL PATHWAY FOR VIKSIT BHARAT

Investigating the Economic Viability of Combining Solar Farming with Organic/Regenerative Cultivation to Create Low-External-Input, Climate-Resilient Rural Economies

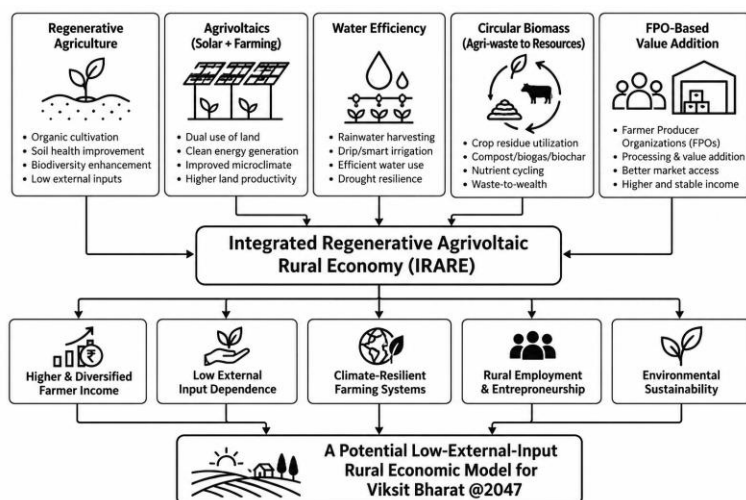
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Abstract

India's aspiration to become a developed nation by 2047 requires a rural development pathway that simultaneously addresses farm profitability, energy security, climate change, soil degradation, water scarcity and rural employment. This exploratory paper investigates the potential of integrating regenerative agriculture with agrivoltaics (Agri-PV)—the simultaneous use of land for agricultural production and photovoltaic electricity generation—as a model for self-sustaining rural economies. The central proposition is that biological nutrient cycling, organic/natural farming, solar energy, efficient irrigation and diversified farm enterprises can reduce dependence on purchased external inputs while creating multiple income streams. The term “zero-input” is treated as a strategic hypothesis rather than a literal claim: labour, knowledge, seeds, water, capital, infrastructure and maintenance remain necessary. The paper reviews Indian policy and research developments, develops an Integrated Regenerative Agrivoltaic Rural Economy (IRARE) model, proposes economic and sustainability indicators, identifies research hypotheses and outlines a field-validation methodology. Current Indian evidence suggests that natural farming can reduce input expenditure in some contexts, while agrivoltaic performance is highly dependent on crop, climate, panel configuration, water conditions, capital cost and electricity economics. The paper argues that the strongest development proposition is not “solar versus agriculture” but the coordinated production of food, renewable energy, biomass, employment and ecological services from rural landscapes. The proposed model merits multi-location pilot testing across India's agro-climatic regions.

Keywords: Regenerative Agriculture; Agrivoltaics; Agri-PV; Natural Farming; Organic Farming; Solar Farming; Viksit Bharat 2047; Rural Economy; Climate Resilience; Sustainable Agriculture; Farm Income; Renewable Energy; Circular Economy; Rural Entrepreneurship.

Core Research Proposition :



1. Introduction

Agriculture occupies a central position in India's economic, social and ecological structure. Yet the future of Indian agriculture cannot be secured simply by increasing agricultural output. The strategic question is increasingly how India can produce food, generate rural income and use fewer external resources while restoring soil, conserving water and reducing climate vulnerability.

Three structural transitions are converging. First, farmers face exposure to input-price

volatility and the recurring cost of fertilizers, pesticides, irrigation energy and other purchased inputs. Second,

climate variability—heat stress, irregular rainfall, droughts, floods and changing pest pressures—raises production risk. Third, India’s rapid renewable-energy expansion creates an opportunity to reconsider agriculture not merely as an energy consumer but also as an energy-producing activity [1–5].

Regenerative agriculture addresses the biological foundation of production through soil-cover maintenance, crop diversification, reduced disturbance, biological nutrient cycling, agroforestry and integration of livestock and biomass. Agrivoltaics addresses land and energy productivity by co-locating photovoltaic electricity generation with agricultural production. Their integration creates a research proposition in which the farm becomes a food system, energy system, water system, circular biological system and enterprise system simultaneously.

2. Conceptual Foundations

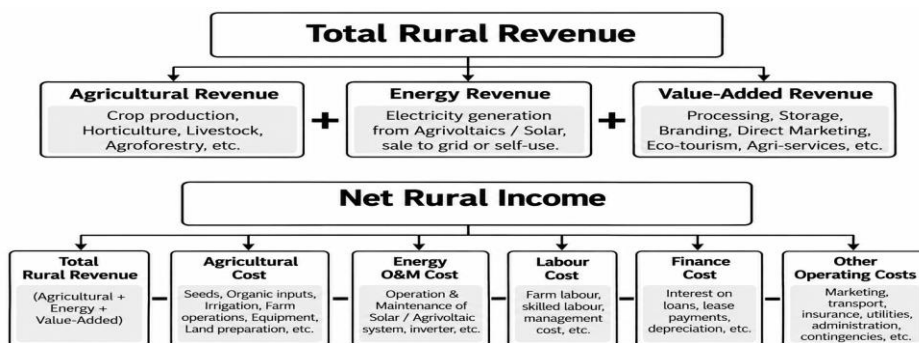
Regenerative agriculture is broader than a simple prohibition of synthetic inputs. It seeks to restore ecological functions and improve the condition of the production resource itself. Relevant practices include cover crops, crop rotation, minimum soil disturbance, organic amendments, agroforestry, livestock integration, mulching, biodiversity enhancement and improved water management [6,7].

Organic farming and natural farming overlap with regenerative agriculture but are not identical concepts. Organic standards generally specify permitted and prohibited inputs and certification requirements, whereas regenerative agriculture is more outcome-oriented, emphasizing soil health, biodiversity, resilience and ecological regeneration. India’s National Mission on Natural Farming provides an important policy platform for low-chemical, ecosystem-based and diversified farming [2,8].

Agrivoltaics refers to the simultaneous use of land for agriculture and photovoltaic electricity generation. The technical literature emphasizes that agrivoltaic performance depends on system design, crop selection, local climate, solar geometry, shading, water availability, electricity value and farm-management practices [3,9,10]. Thus, agrivoltaics should be treated as a location-specific production system rather than a universal technology.

3. Why Integration Matters

The economic value of integration lies in diversification. A conventional farm principally converts land, water, labour and purchased inputs into crop output. A solar farm principally converts sunlight and land into electricity. An integrated regenerative agrivoltaic farm can produce food and electricity from the same land while also improving resource-use efficiency and creating opportunities for biomass recycling, processing and rural enterprise.



The integrated production logic can be expressed as:

This framework shifts attention from yield alone to net income, resource productivity and resilience. Natural-farming evidence from selected Indian states shows why this distinction

matters: lower input expenditure can improve profitability even when yield gains are not universal [1].

4. The Integrated Regenerative Agrivoltaic Rural Economy (IRARE) Model

This paper proposes the Integrated Regenerative Agrivoltaic Rural Economy (IRARE) model. The farm is organized around five interconnected systems: (1) regenerative biological production, (2) photovoltaic energy generation, (3) efficient water management, (4) circular biomass and nutrient management, and (5) collective value addition and marketing.

The model is designed to reduce external purchased-input dependence rather than to claim literal zero inputs. Seeds, labour, knowledge, infrastructure, maintenance and capital remain necessary. The more defensible objective is Near-Zero External Purchased Input Agriculture, in which a larger share of energy and nutrient requirements is generated or recycled within the farm or local rural economy.

5. Regenerative Agriculture as Natural Capital Management

Under an extractive production model, soil is often treated primarily as a medium for crop production. Under a regenerative model, soil is treated as productive natural capital. Soil organic matter, microbial activity, structure, infiltration and water-holding capacity can influence productivity and resilience [6,7].

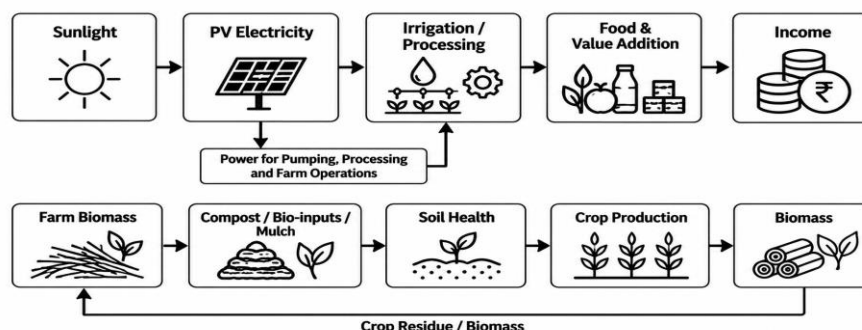
The economic implication is that soil improvement should be considered an investment rather than only a cost. Over time, better soil condition may reduce dependence on purchased inputs and irrigation while improving resilience to climatic variability. However, the magnitude and speed of these effects are site-specific and require longitudinal measurement.

6. Agrivoltaics and Microclimate

Photovoltaic structures alter the microenvironment below and around the panels. Depending on configuration and crop type, they can change solar radiation, temperature, wind exposure and evapotranspiration. These changes can be beneficial for some crops and harmful for others. Consequently, crop-panel matching is central to economic viability.

ICAR-IARI inaugurated a 100 kWp Agri-PV pilot facility in December 2025 to study Indian agrivoltaic configurations, including single-axis tracking and ground-screw foundations [4]. This institutional research is important because India's agrivoltaic systems must be adapted to diverse agro-climatic conditions rather than copied from other countries.

7. Food–Energy–Water Nexus



The proposed model should be evaluated through a food–energy–water nexus. Solar electricity can support irrigation, cold storage, food processing, drying, lighting and other productive uses. Regenerative practices can improve water infiltration and soil moisture retention. Efficient irrigation can reduce water

demand while increasing crop-water productivity.

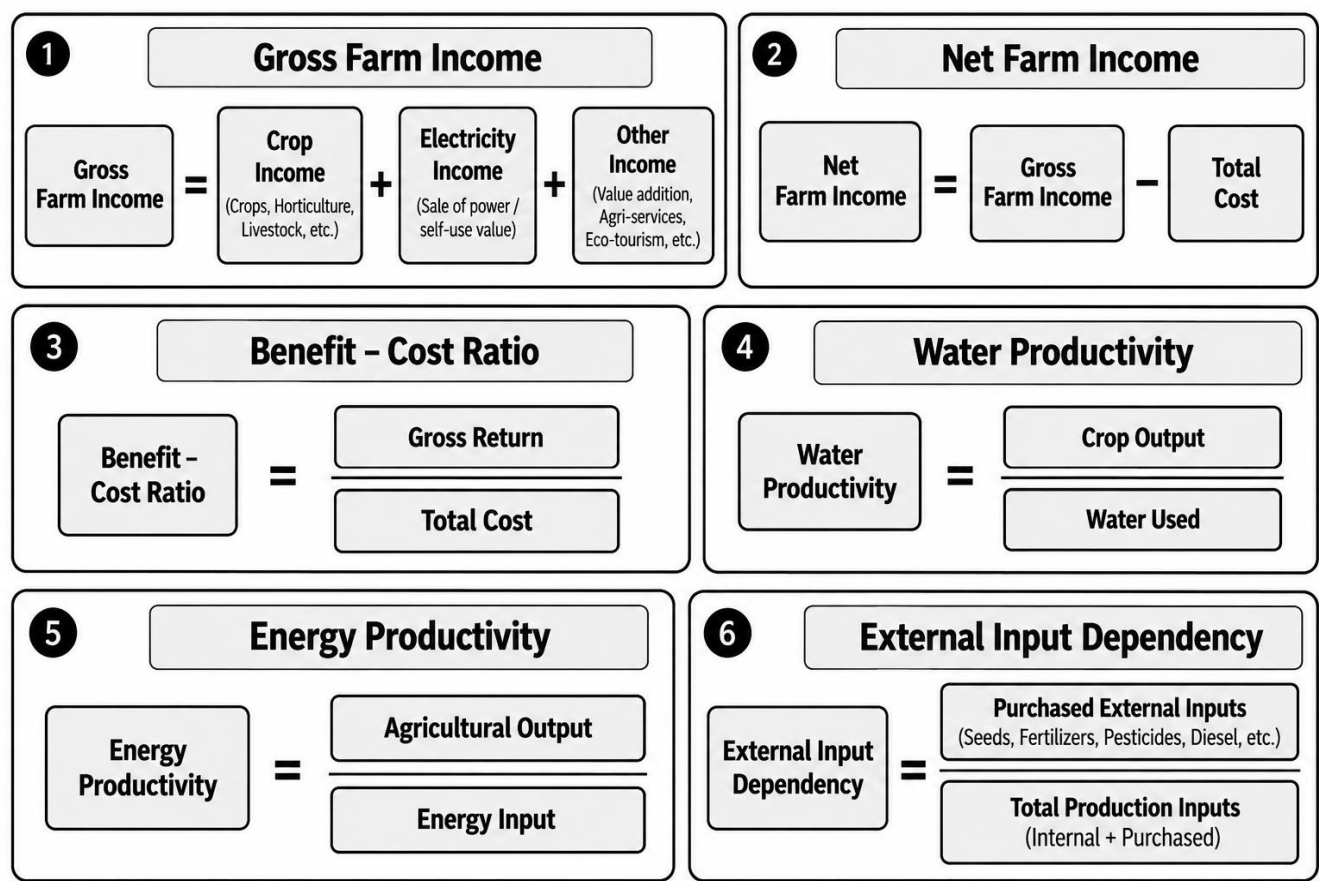
The relationship can be summarized as:

Together these loops create energy circularity and biological circularity.

8. Economic Viability Framework

A rigorous economic assessment should compare conventional agriculture, regenerative/natural farming, agrivoltaic agriculture and integrated regenerative agrivoltaics. The key variables are crop yield, crop price, electricity generation, electricity value, water use, purchased inputs, labour, capital cost, finance cost, maintenance and value-added revenue.

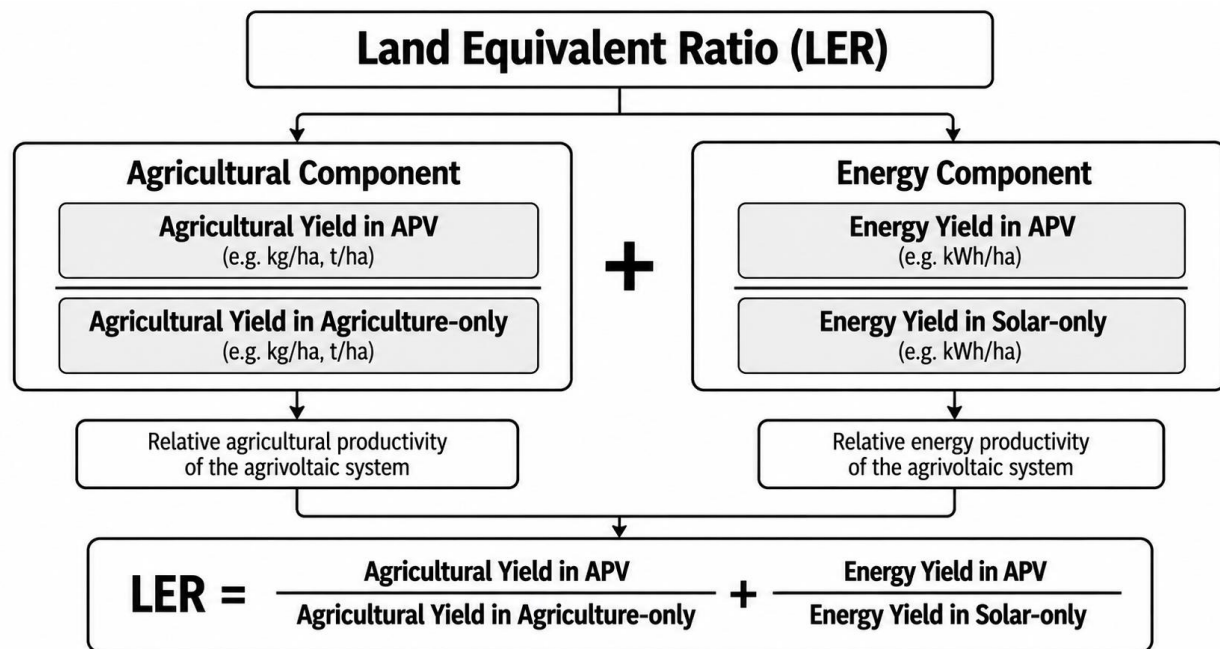
The core equations are:



The model should also use lifecycle analysis because PV systems require substantial upfront capital and have long operating lives. Payback should not be interpreted as a universal number; it is determined by local capital cost, electricity value, agricultural performance and financing.

9. Land Equivalent Ratio

Land Equivalent Ratio (LER) is a useful indicator for dual-use systems. Conceptually:



An LER above 1 indicates that the combined system can generate more equivalent land productivity than the corresponding separate-use systems, subject to the definitions and baselines adopted. ICAR has reported technology-specific agrivoltaic results with LER values above 1 and a break-even estimate for a particular system [11]. A 2026 review of Indian agrivoltaics similarly reports that LER can exceed 1.5 in some contexts but stresses that benefits are highly condition-dependent [10]. These figures should therefore be used as research benchmarks, not universal expectations.

10. The “Zero-Input” Hypothesis Reframed

The expression “zero-input agriculture” is attractive but scientifically and economically misleading if interpreted literally. Every functioning farm requires some combination of land, labour, knowledge, seeds, water, tools, infrastructure, finance and maintenance.

This paper therefore proposes the term Low-External-Input, Renewable-Energy-Powered Regenerative Agriculture. The objective is to progressively replace costly external inputs with biological processes, farm biomass, livestock integration, renewable electricity, local knowledge and efficient water management.

The relevant performance question becomes:

How far can external purchased input dependency be reduced while maintaining acceptable productivity, profitability, resilience and food quality?

11. FPO and Village-Level Scaling

Small and marginal farmers may face difficulty financing and maintaining sophisticated Agri-PV systems individually. Farmer Producer Organisations (FPOs), cooperatives, Panchayats and water-user groups can potentially aggregate land, finance, energy demand, processing capacity and marketing. PM-KUSUM explicitly provides a framework in which farmers, farmer groups, cooperatives, Panchayats and FPOs can participate in renewable-energy projects under its relevant components [5].

A village-level model could therefore integrate farm clusters, shared solar infrastructure, common irrigation, processing, cold storage, aggregation and marketing. Such a model converts individual fragmented production into a rural enterprise ecosystem.

12. Women and Youth in the New Rural Economy

The proposed model can create employment beyond crop cultivation. Rural youth can participate as solar technicians, drone operators, IoT technicians, irrigation managers, farm-data assistants, processing operators and digital marketers. Women's groups can participate in seed banks, nurseries, bio-input preparation, food processing, packaging, branding and direct marketing.

This is important for Viksit Bharat because rural prosperity depends not only on farm output but also on the ability of villages to create skilled, technology-enabled employment.

13. Policy Convergence

The proposed model can build upon existing programmes rather than requiring an entirely separate policy architecture. Relevant policy areas include PM-KUSUM, National Mission on Natural Farming, Paramparagat Krishi Vikas Yojana, Soil Health initiatives, micro-irrigation, FPO development and renewable-energy programmes [2,5,8,12].

The National Mission on Natural Farming was approved in November 2024 and provides an institutional framework for natural-farming clusters, farmer support, bio-input resource centres and training. Government reporting in 2026 indicates substantial expansion of clusters and farmer participation [8,12]. PM-KUSUM provides a parallel energy framework for decentralized renewable generation and solarisation of agricultural pumps [5]. The research opportunity is to connect these streams into a common rural production architecture.

14. Research Hypotheses

H1: Regenerative agriculture combined with agrivoltaics reduces external purchased-input expenditure per hectare compared with conventional agriculture.

H2: Integrated agrivoltaic farms can achieve greater combined land productivity than single-use agricultural land under suitable crop and system configurations.

H3: Solar-powered irrigation combined with regenerative soil practices improves water-use efficiency.

H4: Diversification into agricultural and electricity revenues reduces farm-income volatility.

H5: The economic viability of agrivoltaics is strongly influenced by electricity value, capital cost, crop selection, water conditions and panel configuration.

H6: FPO-based ownership can improve the scalability of agrivoltaic systems for small and marginal farmers.

H7: Regenerative agrivoltaic systems can create more diversified rural employment than conventional crop production alone.

15. Proposed Research Methodology

The exploratory framework should be tested through a multi-state, multi-year study covering contrasting agro-climatic zones. Suggested zones include arid Rajasthan; semi-arid Gujarat/Maharashtra; Indo-Gangetic regions such as Punjab/Haryana/Uttar Pradesh; peninsular regions such as Karnataka/Telangana/Andhra Pradesh; eastern India; and selected North-Eastern locations.

A four-group comparative design is proposed:

- A. Conventional agriculture
- B. Regenerative/natural farming
- C. Agrivoltaic agriculture
- D. Regenerative agrivoltaic agriculture.

Data should include yield per hectare, electricity generation, water use, fertilizer and pesticide expenditure, diesel/electricity expenditure, labour cost, solar O&M, capital cost, crop price, electricity revenue, soil organic carbon, biodiversity indicators, employment and household income. A 10–25 year lifecycle model can then estimate NPV, IRR, payback period, benefit–cost ratio and risk sensitivity.

16. Integrated Rural Sustainability and Viability Index

To support comparison among farm models, the paper proposes an Integrated Rural Sustainability and Viability Index (IRSVI):

$$\text{IRSVI} = w_1E + w_2A + w_3W + w_4S + w_5C + w_6R + w_7L$$

where E = energy productivity; A = agricultural profitability; W = water productivity; S = soil-health improvement; C = climate/carbon performance; R = rural employment; and L = livelihood resilience. The weights should be determined through expert consultation and empirical validation rather than assumed.

The index would allow researchers to move beyond a single metric such as yield or electricity generation.

17. Challenges and Limitations

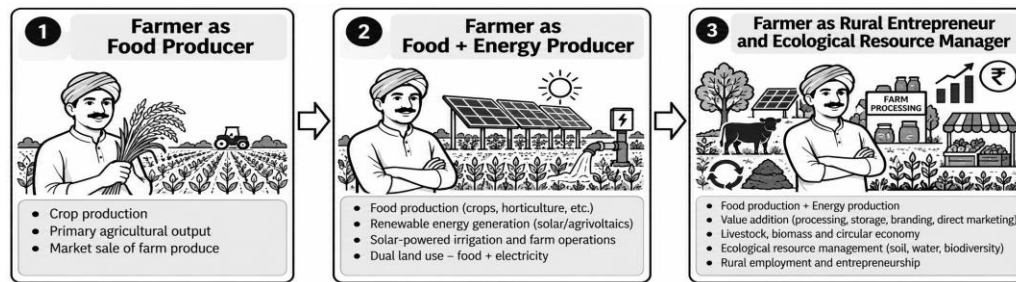
The model should not be presented as a universal solution. Major constraints include high initial capital requirements; crop-shading uncertainty; electricity-market and tariff uncertainty; fragmented landholdings; technical maintenance; transition risks in regenerative systems; limited premium markets for organic/natural produce; and the need for farmer training.

The agrivoltaic literature emphasizes that system design and local context strongly influence outcomes [3,9,10]. Similarly, regenerative agriculture outcomes vary by soil, climate, crop, management and transition period [6,7]. Therefore, the strongest research strategy is not advocacy but controlled field testing and transparent economic accounting.

18. Viksit Bharat@2047 Perspective

The integrated model connects several dimensions of developed-nation building: energy security, food security, rural prosperity, climate resilience, employment, technology adoption, water security, circular economy and local value addition.

The strategic transition can be represented as:



This transformation can help shift rural development from production maximization toward systems optimization.

19. Conclusion

Regenerative agriculture and agrivoltaics represent two complementary transitions: one restores the biological foundations of production, while the other adds renewable-energy production to agricultural landscapes. Individually, both have limitations. Regenerative agriculture does not guarantee higher yields in every location, while agrivoltaics requires careful design, capital and market conditions. Their integration nevertheless creates a powerful research proposition.

The proposed Integrated Regenerative Agrivoltaic Rural Economy (IRARE) model treats the farm as a food, energy, water, biological and enterprise system. Its objective is not literal zero-input agriculture but a low-external-input rural economy in which a growing proportion of energy and nutrient requirements are met through renewable electricity, biological cycling, farm biomass, livestock integration and efficient resource use.

For Viksit Bharat@2047, the relevant development metric is therefore broader than agricultural output. Rural progress should also be evaluated through net income, energy independence, water productivity, soil health, employment, resilience and local value creation. The proposed model warrants empirical testing through multi-location pilots, long-term lifecycle economics and transparent measurements of crop performance, electricity generation, water use, soil health and household income.

The central research question is consequently not “agriculture or solar energy?” but “how can agriculture and renewable energy be designed together so that the same rural landscape produces food, clean energy, livelihoods and ecological regeneration?”

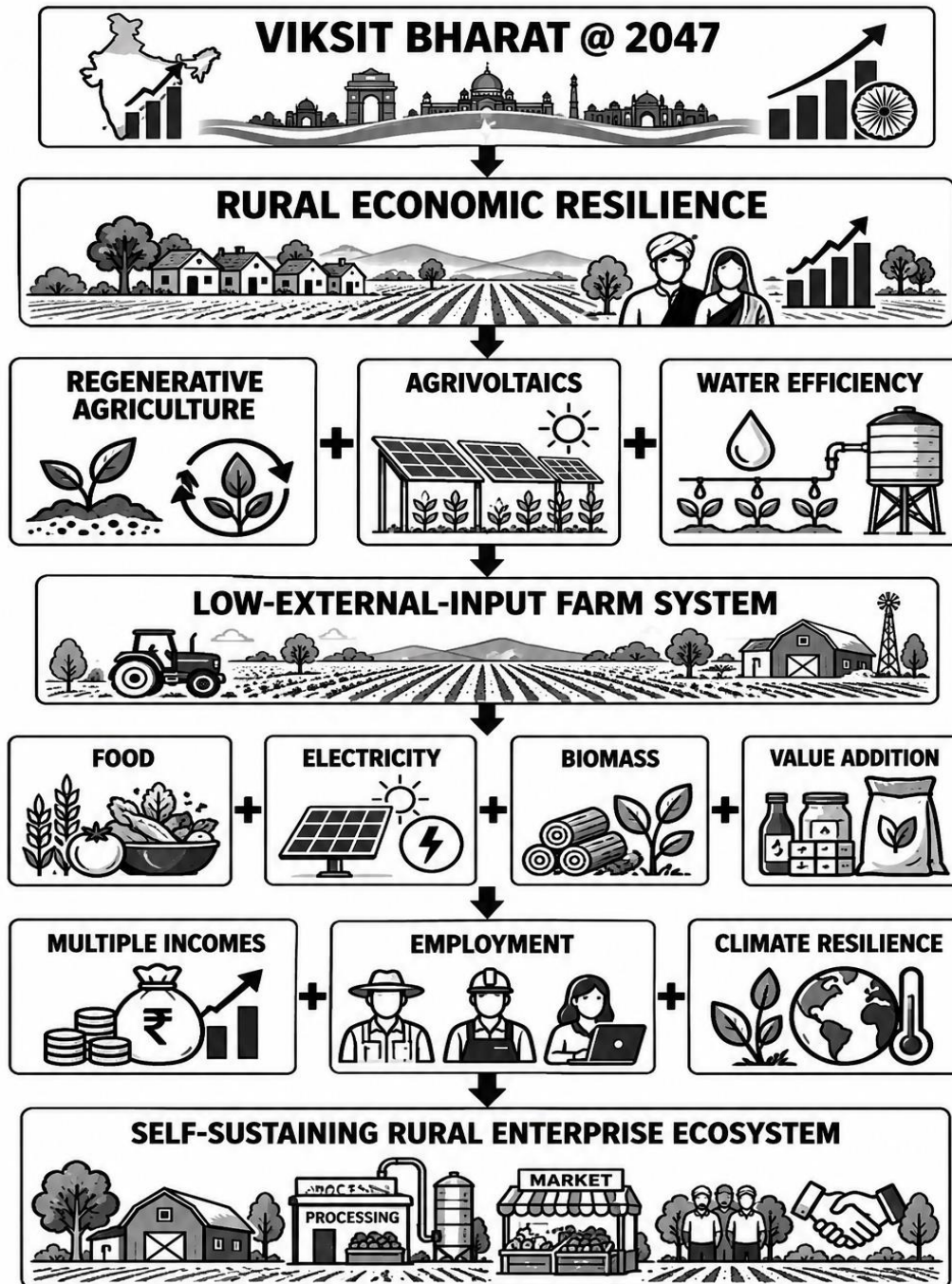
20. Proposed 5R Framework

Principle	Meaning	Illustrative Rural Application
R1 – Regenerate	Restore soil, biodiversity and ecological functions.	Cover crops, crop rotation, compost, agroforestry, livestock integration.
R2 – Renewable	Generate clean energy within/alongside the farm.	Agrivoltaics, solar irrigation, solar processing.
R3 – Reduce	Reduce external purchased inputs and avoidable losses.	Lower chemical input, diesel use and inefficient irrigation.
R4 – Recycle	Close biological and resource loops.	Crop residues, manure, compost, mulch, water reuse where appropriate.
R5 – Reinvest	Reinvest farm and energy income in productive rural assets.	Processing, storage, skills, maintenance and community infrastructure.

21. Comparative Evaluation Framework

Indicator	Conventional Farm	Regenerative Farm	Agrivoltaic Farm	Integrated IRARE Farm
Primary output	Food	Food + ecological services	Food + electricity	Food + electricity + value-added outputs
External input dependence	Generally higher	Potentially lower	Energy input may be lower	Target: progressively low
Energy source	Grid/diesel/other	Mixed	Solar + grid	Solar-led integrated system
Income streams	Mostly crop	Crop + possible premium/value	Crop + electricity	Crop + electricity + processing + services
Climate resilience	Context dependent	Potentially improved	Potentially improved by microclimate	Multi-system resilience
Capital intensity	Low–moderate to high	Low–moderate	Moderate–high	Moderate–high
Key research need	Baseline	Yield/cost/soil transition	Crop-energy design	Lifecycle system economics

22. Conceptual Model



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