5 DHARTEEPUTRA Model: An AI-Enabled Agrivoltaics Framework for Sustainable Agro Economy and Rural Transformation in India

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Abstract

India's Vision 2047 emphasizes the transition toward a self-reliant, sustainable, and climate-resilient agro economy driven by renewable energy and technological innovation. However, conventional approaches to agriculture and solar energy deployment often operate in isolation, limiting their potential to enhance farmer income and rural livelihoods. This chapter proposes the DHARTEEPUTRA model (Dual Harvesting in Agrovoltaics and Renewables Through Eco-Efficient Powering for Transformative Rural Advancement), an integrated agrivoltaics-based framework that combines solar energy generation, agriculture, post-harvest management, decentralized rural enterprises, and bioenergy systems within a single land parcel. The model promotes the productive use of energy by linking solar generation directly with irrigation, processing, and value-added activities, thereby enabling multiple income streams and improving economic resilience. A key advancement presented in this chapter is the integration of Artificial Intelligence (AI) and Internet of Things (IoT) technologies into the DHARTEEPUTRA framework. IoT-enabled sensors facilitate real-time data collection on soil, water, crop conditions, and energy systems, while AI-driven analytics support decision-making related to irrigation, crop planning, energy optimization, and market linkage. This integration transforms the model into a smart, data-driven rural production system. The chapter demonstrates that such integrated systems can significantly enhance land-use efficiency, reduce post-harvest losses, improve market access, and strengthen climate resilience. In addition to economic benefits, the model contributes to environmental sustainability through reduced fossil fuel dependence and supports social inclusion by generating employment and enabling participation of women and rural enterprises. The study concludes that AI-enabled agrivoltaics models such as DHARTEEPUTRA offer a scalable pathway for building a green energy economy and transforming rural livelihoods in India.

Keywords: Agrivoltaics, AI-Enabled Agriculture, Sustainable Agro Economy, Decentralized Renewable Energy, Rural Livelihoods.

Introduction

Agriculture remains the backbone of India's rural economy, supporting nearly half of the country's workforce while ensuring food and nutritional security for a population exceeding 1.4 billion. Despite significant technological advancements, the sector continues to face multiple challenges including declining farm profitability, fragmented landholdings, rising input costs, climate variability, post-harvest losses, and increasing pressure on natural resources. Simultaneously, the demand for reliable and affordable energy in agriculture is growing rapidly, making the transition toward sustainable and decentralized energy systems a national priority.

The concept of DHARTEEPUTRA carries both conceptual and cultural significance. As an acronym, it represents Dual Harvesting in Agrovoltaics and Renewables Through Eco-Efficient Powering for Transformative Rural Advancement. Beyond its technical meaning, the term "Dharteeputra" (Son of the Soil) symbolizes the farmer as a steward of land, energy, food systems, and rural prosperity. The model is therefore envisioned as a farmer-centric framework that integrates renewable energy, agriculture, entrepreneurship, and digital technologies to create resilient rural economies.

Challenges in Indian Agriculture

Indian agriculture is undergoing a period of transformation driven by changing climatic conditions, resource constraints, and evolving market dynamics. Increasing frequency of droughts, heat waves, and erratic rainfall patterns are adversely affecting agricultural productivity and farm incomes. Dependence on conventional energy sources such as diesel and subsidized electricity further increases production costs and environmental burdens.

Additionally, inadequate post-harvest infrastructure and limited access to value addition facilities result in substantial economic losses. Small and marginal farmers often face challenges in accessing modern technologies, organized markets, and institutional support systems. These challenges highlight the need for integrated solutions capable of enhancing productivity, resource efficiency, and income diversification.

Vision 2047 and Rural Transformation

India's Vision 2047 envisages a developed nation characterized by economic prosperity, technological leadership, environmental sustainability, and inclusive growth. Rural transformation forms a critical component of this vision, requiring innovative approaches that combine renewable energy, digital technologies, entrepreneurship, and sustainable agriculture.

Several national initiatives provide a supportive ecosystem for renewable energy, sustainable agriculture, and rural entrepreneurship. However, these interventions often operate independently, limiting their cumulative impact.

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Digital Agriculture, AI and Energy Convergence

Recent advances in Artificial Intelligence (AI), Internet of Things (IoT), remote sensing, cloud computing, and data analytics are transforming global agriculture. AI-driven decision support systems can optimize irrigation scheduling, crop planning, pest management, energy utilization, and market forecasting. Similarly, digital platforms are enabling farmers to access real-time information, connect directly with buyers, and participate more effectively in agricultural value chains.

When integrated with decentralized renewable energy systems, these technologies have the potential to create intelligent and self-sustaining rural production ecosystems. Such convergence can improve resource efficiency, reduce operational costs, strengthen climate resilience, and enhance market access for rural communities.

Need for Integrated Agro-Energy Systems

While agrivoltaics has emerged as an innovative approach for combining solar energy generation with crop cultivation, most existing models remain limited to dual land use applications. They often fail to integrate critical components such as post-harvest management, decentralized enterprises, resource recycling, AI-enabled decision support systems, and rural entrepreneurship.

Similarly, decentralized renewable energy programmes frequently focus on energy access rather than productive energy utilization. There is therefore a need for a holistic framework that links energy generation directly with agricultural production, value addition, enterprise development, and digital market connectivity.

The DHARTEEPUTRA model seeks to address this gap by transforming conventional farming systems into integrated agro-energy-economic ecosystems capable of generating multiple income streams while improving sustainability and resilience.

Objectives and Scope of the Chapter

This chapter proposes the DHARTEEPUTRA model as a scalable and replicable national framework for sustainable agro-economic development under Vision 2047. The specific objectives are:

- To present an integrated agrivoltaics-based framework combining agriculture, renewable energy, processing, and rural enterprises.
- To examine the role of productive use of renewable energy in enhancing farmer income and livelihood resilience.
- To explore the integration of AI, IoT, and digital agriculture technologies within decentralized farming systems.
- To assess the economic, environmental, and social benefits of the proposed model.

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- To identify policy measures and institutional mechanisms required for large-scale replication through PM-KUSUM, FPOs, Digital Agriculture Mission, and other national programmes.

Literature Review

- **Agrivoltaics and Land Use Efficiency**

Agrivoltaics, also referred to as agro-photovoltaics, was first conceptualized by Dupraz et al. (2011) as an innovative approach to optimize land-use efficiency through simultaneous production of agricultural crops and solar energy. The concept emerged as a response to increasing competition between food production and renewable energy development for limited land resources.

Subsequent research has demonstrated that agrivoltaic systems can enhance overall land productivity, often measured through the Land Equivalent Ratio (LER), while providing environmental benefits such as improved soil moisture retention, reduced evapotranspiration, and microclimate regulation (Amaducci et al., 2018; Barron-Gafford et al., 2019). Several studies have reported that specific crops can maintain or even improve yields under partial shading conditions created by photovoltaic structures.

- **Decentralized Renewable Energy and Rural Development**

Decentralized Renewable Energy (DRE) systems have increasingly been recognized as important drivers of rural development. International organizations such as the IEA, IRENA and the World Bank have highlighted the role of decentralized solar systems in supporting productive applications including irrigation, agro-processing, rural enterprises, and livelihood enhancement.

In India, programmes such as the Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) have accelerated deployment of solar-powered irrigation systems and decentralized solar generation. These initiatives have improved energy access and reduced dependence on diesel-based agricultural operations. However, most interventions remain focused on energy generation and substitution rather than integrated rural economic development.

- **Sustainable Agro Economy and Rural Value Chains**

A sustainable agro economy extends beyond primary agricultural production and includes post-harvest management, value addition, processing, storage, marketing, logistics, and entrepreneurship. Research indicates that inadequate post-harvest infrastructure contributes significantly to losses in agricultural commodities, particularly fruits and vegetables.

The Food and Agriculture Organization (FAO) estimates that substantial quantities of agricultural produce are lost annually due to deficiencies in storage,

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transportation, and processing infrastructure. These losses reduce farmer income and weaken overall agricultural competitiveness.

Value chain integration through local processing, aggregation, and decentralized enterprises has emerged as a key strategy for enhancing rural prosperity. Farmer Producer Organizations (FPOs), Self-Help Groups (SHGs), and rural cooperatives have demonstrated significant potential in improving market access, reducing transaction costs, and strengthening bargaining power of farmers.

- **Artificial Intelligence and Digital Agriculture**

Recent advances in Artificial Intelligence (AI), Internet of Things (IoT), machine learning, remote sensing, cloud computing, and geospatial analytics are transforming agricultural systems worldwide. AI-based applications are increasingly being used for crop monitoring, precision irrigation, nutrient management, pest detection, weather forecasting, and yield prediction.

IoT-enabled sensor networks facilitate real-time monitoring of soil moisture, temperature, humidity, crop health, and energy consumption. AI algorithms can analyze this data to generate actionable insights that improve resource utilization and farm productivity.

Precision agriculture technologies have demonstrated potential to reduce water consumption, optimize fertilizer use, improve crop yields, and lower operational costs. These capabilities are particularly relevant in regions facing climate variability and resource constraints.

The integration of AI with decentralized renewable energy systems creates opportunities for intelligent farm management, enabling optimization of both agricultural and energy resources within a unified framework.

- **AI-Enabled Marketing and Rural Entrepreneurship**

One of the emerging applications of AI in agriculture lies in market intelligence and value chain optimization. AI-enabled platforms can analyze market trends, consumer preferences, price fluctuations, logistics patterns, and demand forecasts to support informed decision-making by farmers and agribusinesses.

Digital marketplaces and e-commerce platforms are increasingly enabling direct linkages between producers and consumers, reducing dependency on intermediaries and improving price realization. AI-supported demand forecasting can assist farmers in crop planning and harvesting decisions based on anticipated market conditions.

The emergence of digital agriculture ecosystems has also created new opportunities for rural entrepreneurship. Services such as drone-based crop monitoring, digital advisory systems, farm mechanization support, renewable energy

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maintenance, and agri-tech startups are generating new employment opportunities for rural youth.

- **Policy Ecosystem and Research Gap**

India has introduced several policy initiatives that collectively support the transition toward sustainable and technology-enabled agriculture. These include PM-KUSUM, the Digital Agriculture Mission, National Mission on Natural Farming, Startup India, FPO promotion programmes, and various renewable energy initiatives implemented by the Ministry of New and Renewable Energy (MNRE).

Despite significant progress, most existing interventions continue to operate within sector-specific boundaries. Agrivoltaics research primarily focuses on land-use efficiency and energy generation. Renewable energy programmes largely emphasize energy access. Digital agriculture initiatives focus on data and advisory services. Similarly, enterprise development programmes often remain disconnected from renewable energy systems.

A critical gap therefore exists in the development of integrated frameworks that simultaneously combine agrivoltaics, decentralized renewable energy, AI-enabled agriculture, digital market systems, rural entrepreneurship, circular economy principles, and institutional convergence.

The DHARTEEPUTRA model seeks to address this gap by proposing a comprehensive and scalable framework that integrates these components into a unified rural development ecosystem aligned with Vision 2047, Atmanirbhar Bharat, Sustainable Development Goals (SDGs), and India's long-term climate commitments.

DHARTEEPUTRA Model: Conceptual Framework

- **Meaning and Philosophy of DHARTEEPUTRA**

The term DHARTEEPUTRA possesses both technical and socio-cultural significance. As an acronym, it represents **Dual Harvesting in Agrovoltaics and Renewables Through Eco-Efficient Powering for Transformative Rural Advancement**. Simultaneously, the word "**DHARTEEPUTRA**," meaning "Son of the Soil," symbolizes the farmer as a custodian of land, natural resources, food systems, and rural prosperity.

The philosophy of the DHARTEEPUTRA model extends beyond conventional agricultural production. It envisions the farmer as an energy producer, entrepreneur, processor, environmental steward, and participant in the digital economy. The model seeks to transform traditional farming systems into integrated rural production ecosystems that generate economic, social, and environmental value simultaneously.

The framework is founded on the belief that future rural prosperity cannot be achieved through isolated interventions. Instead, sustainable development requires

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convergence of renewable energy, agriculture, digital technologies, entrepreneurship, resource efficiency, and institutional support mechanisms.

- **Core Design Principles**

The DHARTEEPUTRA model is built upon six core design principles:

- **Integrated Resource Utilization**

Land, water, energy, biomass, infrastructure, and human resources are utilized in a coordinated manner to maximize productivity and minimize waste.

- **Productive Use of Renewable Energy**

Renewable energy generation is directly linked to income-generating activities such as irrigation, food processing, storage, hydroponics, and rural enterprises.

- **Multi-Dimensional Income Generation**

The framework promotes diversified income streams through agriculture, solar energy, livestock, processing, tourism, and entrepreneurship, thereby reducing financial vulnerability.

- **Circular Economy and Resource Recycling**

Outputs from one subsystem become inputs for another subsystem. Organic residues are converted into biogas and biofertilizer, while renewable energy powers productive activities.

- **Digital and AI-Enabled Decision Making**

Artificial Intelligence, IoT systems, and digital platforms support efficient farm management, resource optimization, market access, and enterprise development.

- **Community-Centered Development**

The framework encourages participation of Farmer Producer Organizations (FPOs), Self-Help Groups (SHGs), women entrepreneurs, and rural youth, creating inclusive and locally driven development pathways.

- **DHARTEEPUTRA Pillars**

The DHARTEEPUTRA framework is supported by twelve strategic pillars encompassing decentralized renewable energy, resource efficiency, AI-enabled agriculture, value addition, entrepreneurship, environmental sustainability, post-harvest management, social inclusion, resilient communities, and self-reliant rural development. Together, these pillars integrate technological innovation with socio-economic transformation and environmental stewardship.

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- **Integrated Resource Flow Framework**

At the core of the DHARTEEPUTRA model lies an integrated resource flow mechanism connecting agriculture, energy, processing, livestock, entrepreneurship, and digital systems into a self-reinforcing cycle.

Solar photovoltaic systems generate clean electricity that supports irrigation, hydroponics, processing units, cold storage, and other productive applications. Agricultural production generates biomass residues that are utilized in biogas systems. The biogas generated provides thermal energy, while nutrient-rich slurry is recycled back into agricultural fields as organic fertilizer.

The integration of renewable energy with value-added processing enables production, storage, grading, packaging, and marketing activities to occur within the same ecosystem. Digital technologies facilitate real-time monitoring and decision-making, ensuring efficient utilization of resources across all subsystems.

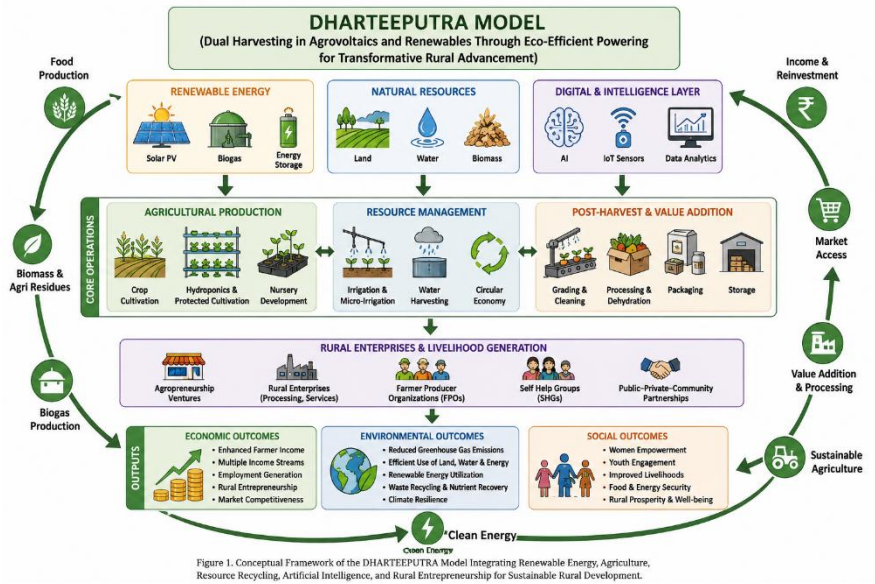

Figure 1. Conceptual Framework of the DHARTEEPUTRA Model Integrating Renewable Energy, Agriculture, Resource Recycling, Artificial Intelligence, and Rural Entrepreneurship for Sustainable Rural Development.

Figure 1: Conceptual Flow Diagram of the DHARTEEPUTRA Model Illustrating Integrated Energy–Agriculture–Resource Cycle

This integrated approach significantly enhances land productivity, energy productivity, and economic productivity simultaneously.

- **Circular Economy and Sustainability Framework**

The DHARTEEPUTRA model adopts circular economy principles by minimizing waste generation and maximizing resource recovery.

Agricultural residues, livestock waste, and organic by-products are converted into useful energy and organic inputs through biogas systems. Solar energy replaces

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fossil fuel consumption, reducing greenhouse gas emissions and improving environmental performance. Water resources are utilized efficiently through precision irrigation and hydroponic systems, minimizing losses and enhancing productivity.

The model thereby creates a closed-loop production system where economic activities are aligned with ecological sustainability. Such integration contributes to climate-resilient agriculture while supporting national commitments toward carbon reduction and sustainable resource management.

- **Alignment with Vision 2047 and Sustainable Development Goals**

The DHARTEEPUTRA framework aligns closely with India's Vision 2047 and multiple national development priorities. The model aligns with national priorities related to renewable energy, sustainable agriculture, digital transformation, and rural entrepreneurship.The framework also contributes directly to several Sustainable Development Goals (SDGs), including:

  - SDG 1: No Poverty
  - SDG 2: Zero Hunger
  - SDG 7: Affordable and Clean Energy
  - SDG 8: Decent Work and Economic Growth
  - SDG 9: Industry, Innovation and Infrastructure
  - SDG 12: Responsible Consumption and Production
  - SDG 13: Climate Action

By integrating renewable energy, AI-enabled agriculture, value addition, entrepreneurship, and social inclusion within a single framework, the DHARTEEPUTRA model offers a scalable pathway for transforming rural economies into resilient, sustainable, and self-reliant systems.

- **DHARTEEPUTRA as a Rural Energy and Agropreneurship Hub**

A distinctive feature of the DHARTEEPUTRA model is its ability to function as a decentralized Rural Energy and Agropreneurship Hub. Beyond agricultural production, the framework creates opportunities for establishment of solar-powered micro-enterprises including food processing, flour milling, spice grinding, dehydration units, dairy processing, nursery development, and agri-service centres.

The model also promotes women-led enterprises through Self-Help Groups engaged in processing, packaging, nursery management, and value-added agricultural products. Rural youth can participate through emerging opportunities such as drone services, AI-enabled advisory systems, solar system maintenance, e-commerce support, and digital agriculture services.

This dimension significantly strengthens the model's role in advancing inclusive growth and rural prosperity under India's Vision 2047.

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System Design and Technical Architecture

The DHARTEEPUTRA model is conceived as an integrated agrivoltaics-based rural production system implemented on approximately one acre (4047 m²) of agricultural land. The framework combines renewable energy generation, agricultural production, protected cultivation, post-harvest infrastructure, and resource recycling within a single ecosystem. The objective is to maximize land productivity, energy productivity, and economic returns while promoting environmental sustainability.

The core component of the model is a 50 kWp grid-connected solar photovoltaic (PV) system installed on an elevated agrivoltaic structure. High-efficiency solar modules are mounted at an optimized height and spacing to facilitate simultaneous agricultural activities beneath the solar array. Under typical North Indian climatic conditions, the system is expected to generate approximately 70,000–75,000 kWh of electricity annually. The generated electricity can be utilized for productive agricultural applications, while surplus power may be exported to the grid through net-metering arrangements.

A distinguishing feature of the model is its multi-level spatial configuration. The upper level of the structure is designed to accommodate hydroponic cultivation, nursery development, and protected farming of high-value crops. The lower level provides space for storage, grading, packaging, equipment housing, and operational activities. The remaining land area can be utilized for conventional crop cultivation, fodder production, agroforestry, and livestock-related activities. This integrated arrangement enables simultaneous production of food, energy, and value-added products from the same land parcel.

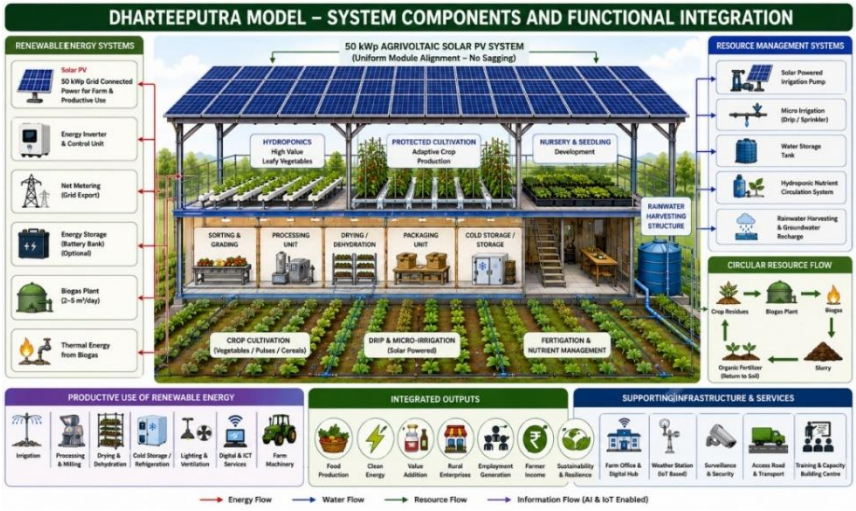

Figure 2: Structural Components and Functional Integration of the DHARTEEPUTRA Model

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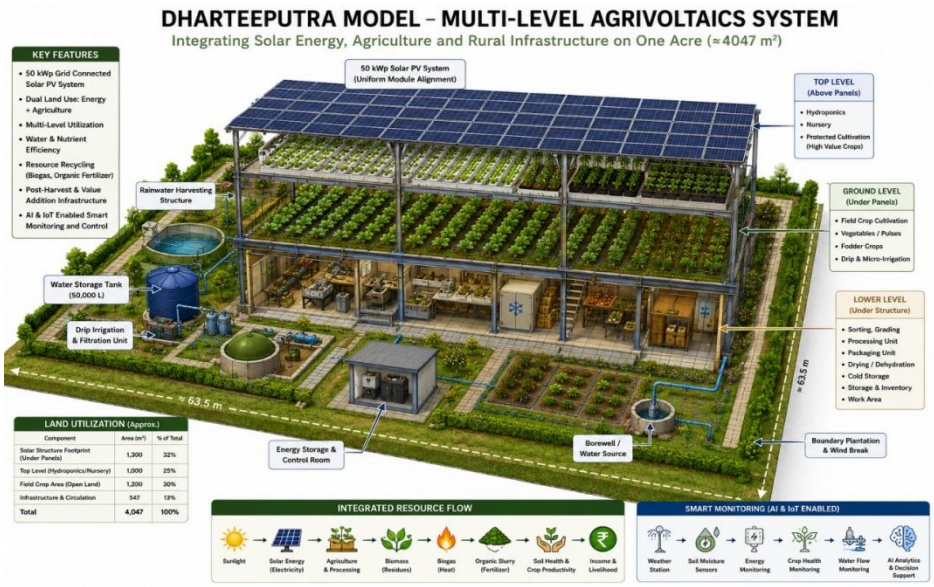

Figure 3: Multi-Level Agrivoltaics System Integrating Solar Energy, Agriculture and Rural Infrastructure

To support efficient farm operations, the model incorporates solar-powered irrigation, micro-irrigation systems, rainwater harvesting structures, and hydroponic nutrient circulation systems. Basic digital monitoring technologies may be integrated to improve resource management and operational efficiency.

The framework also includes post-harvest infrastructure such as cleaning, grading, drying, packaging, and storage facilities to reduce post-harvest losses and improve value realization. In addition, a small biogas unit utilizing livestock waste and agricultural residues supports resource recycling by producing thermal energy and organic fertilizer.

The modular architecture of the DHARTEEPUTRA model allows adaptation across different agro-climatic regions and implementation scales. The framework can therefore be adopted by individual farmers, Farmer Producer Organizations (FPOs), cooperatives, and rural enterprise clusters, making it suitable for large-scale replication and sustainable rural development.

Productive Use of Renewable Energy

A distinguishing feature of the DHARTEEPUTRA model is its emphasis on the **Productive Use of Renewable Energy (PURE)**, wherein renewable energy serves not merely as a source of electricity but as a catalyst for income generation, value addition, and rural economic development. The model directly links solar

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energy generation with productive agricultural and enterprise activities, thereby enhancing the economic value of each unit of energy produced.

The 50 kWp agrivoltaics system generates approximately 70,000–75,000 kWh of electricity annually, which is primarily utilized for irrigation, hydroponic cultivation, post-harvest management, processing activities, and operation of rural enterprises. This approach ensures efficient utilization of renewable energy while reducing dependence on diesel and conventional grid power.

Solar-powered irrigation, protected cultivation, hydroponics, and post-harvest operations improve productivity, reduce losses, and enhance value realization while lowering dependence on conventional energy sources.

The model further promotes electrification of agricultural operations through the use of energy-efficient equipment and machinery. Integration of a biogas unit complements the solar component by providing thermal energy for cooking and processing applications, while simultaneously generating organic fertilizer through slurry recycling.

By integrating renewable energy with agricultural production, value addition, and rural enterprises, the DHARTEEPUTRA model transforms the conventional farm into a decentralized agro-industrial ecosystem. Such integration enhances resource efficiency, reduces operational costs, strengthens climate resilience, and creates multiple income streams for rural households.

The productive use of renewable energy thus emerges as a central pillar of the DHARTEEPUTRA framework, demonstrating how decentralized energy systems can contribute not only to energy security but also to sustainable livelihoods, rural entrepreneurship, and inclusive economic growth.

Economic Viability and Rural Enterprise Potential

The economic strength of the DHARTEEPUTRA model lies in its ability to transform a conventional farm into a diversified agro-energy enterprise. Unlike traditional farming systems that depend primarily on seasonal crop income, the proposed framework generates multiple revenue streams through agriculture, renewable energy, value addition, livestock integration, and rural enterprises.

The model is designed around a 50 kWpagrivoltaic system integrated with hydroponics, post-harvest infrastructure, and decentralized enterprise activities. Capital investment requirements can be substantially reduced through convergence of various government programmes such as PM-KUSUM, horticulture missions, food processing schemes, MSME support programmes, and NABARD-assisted financing. Such convergence improves affordability and accelerates adoption.

Economic benefits are derived from multiple sources, including crop cultivation, protected farming, solar energy generation, post-harvest processing,

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livestock activities, and enterprise-based services. This diversification reduces dependence on a single income source and enhances resilience against market fluctuations, climate variability, and production risks.

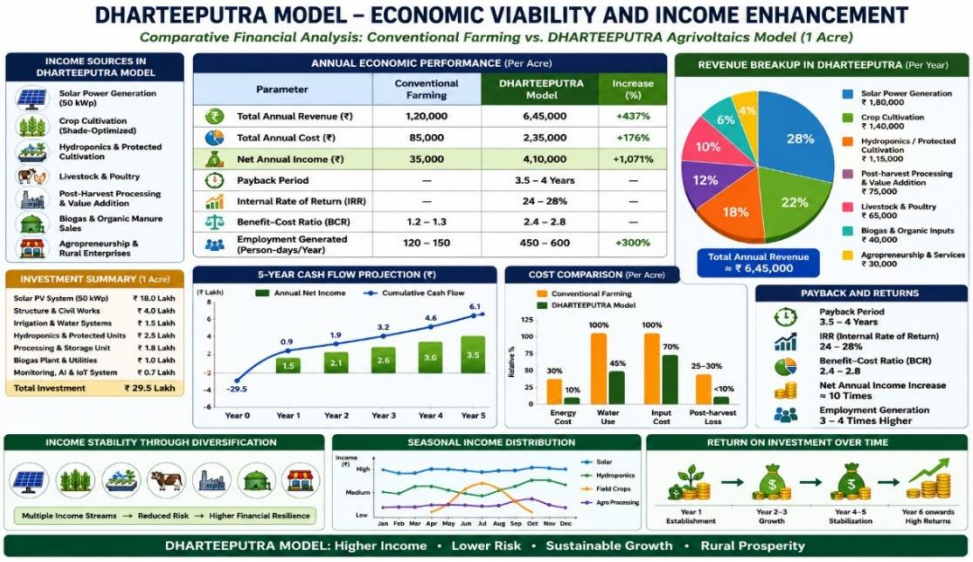

Figure 4: Comparative Annual Income Analysis of Farmers under the DHARTEEPUTRA Model and Conventional Farming Systems

A significant advantage of the model is its emphasis on value addition at the farm level. Activities such as grading, packaging, dehydration, storage, and processing improve product value and enable farmers to capture a greater share of the agricultural value chain. The integration of renewable energy further reduces operational costs and improves profitability.

Beyond farm income, the model creates opportunities for rural entrepreneurship through solar-powered micro-enterprises, Agri-service centres, hydroponic nurseries, food processing units, and digital agriculture services. Such enterprises can generate local employment while supporting rural economic diversification.

Compared to centralized renewable energy projects, the DHARTEEPUTRA framework promotes distributed wealth creation by enabling direct participation of farmers in energy generation and productive utilization. This decentralized approach enhances local economic development and contributes to inclusive growth.

Overall, the model demonstrates strong potential for improving farm profitability, strengthening livelihood resilience, and fostering rural entrepreneurship, making it a financially viable and scalable framework for sustainable agro-economic development.

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Environmental and Social Benefits

The DHARTEEPUTRA model delivers significant environmental and social benefits by integrating renewable energy, sustainable agriculture, circular resource management, and rural livelihood enhancement within a single framework. The replacement of fossil fuel-based agricultural operations with solar energy contributes to substantial reductions in greenhouse gas emissions, while promoting cleaner and more sustainable farming practices.

The 50 kWp agrivoltaics system generates clean electricity that reduces dependence on diesel-powered irrigation and farm operations. The integration of biogas systems further strengthens environmental sustainability by converting livestock waste and crop residues into useful energy and organic fertilizer. This circular resource flow reduces waste generation, improves soil health, and lowers reliance on chemical inputs.

The model also supports climate-resilient agriculture through efficient water management, diversified cropping systems, protected cultivation, and renewable energy-based operations. Improved resource-use efficiency enhances the ability of farming systems to withstand climate variability and extreme weather conditions.

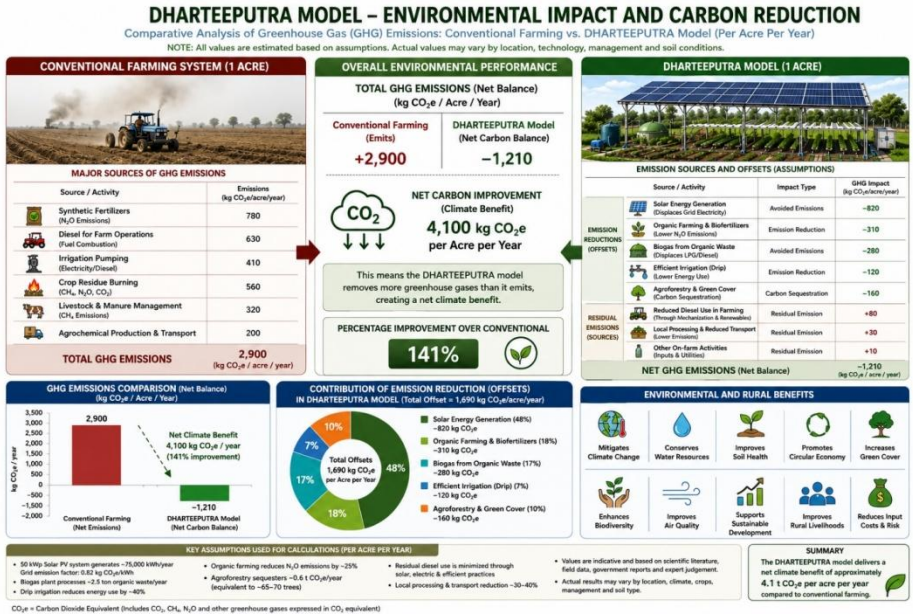

Figure 5: Activity-wise Carbon Emission Comparison between Conventional Farming and the DHARTEEPUTRA Model

From a social perspective, the framework promotes inclusive rural development by creating opportunities for employment, entrepreneurship, and skill development. Women and Self-Help Groups (SHGs) can participate in value-added

activities such as processing, packaging, nursery management, and micro-enterprises. Similarly, rural youth can engage in renewable energy services, digital agriculture, and agri-business ventures.

By integrating energy, agriculture, and enterprise at the local level, the model strengthens community resilience, reduces migration pressures, and contributes to sustainable livelihood generation. The framework aligns closely with multiple Sustainable Development Goals (SDGs), particularly those related to poverty reduction, clean energy, decent work, responsible production, and climate action, thereby supporting India's broader vision for sustainable and inclusive rural transformation.

AI-Enabled Agriculture, Marketing and Agropreneurship Hub

The integration of Artificial Intelligence (AI), Internet of Things (IoT), and digital technologies significantly enhances the transformative potential of the DHARTEEPUTRA model. While renewable energy and agrivoltaics provide the physical infrastructure for sustainable production, AI-enabled systems introduce intelligence, efficiency, and market responsiveness into the rural economy. This convergence transforms the model into a smart, data-driven agro-economic ecosystem,supporting intelligent and data-driven rural development.

At the farm level, IoT-based sensors can continuously monitor soil moisture, temperature, humidity, solar energy generation, water consumption, and crop conditions. These data streams can be analyzed using AI-driven decision support systems to optimize irrigation scheduling, nutrient management, crop planning, and energy utilization. Such precision agriculture practices improve productivity while reducing resource consumption and operational costs.

Beyond production, AI can play a critical role in market intelligence and value chain optimization. AI-enabled platforms can analyze historical and real-time market data to forecast demand, identify price trends, and support informed decision-making. Farmers can use these insights to select suitable crops, schedule harvests, and access profitable markets. Integration with digital marketplaces and Farmer Producer Organizations (FPOs) can further strengthen aggregation, logistics management, and direct market access.

A unique dimension of the DHARTEEPUTRA framework is its potential to function as a decentralized **Agropreneurship Hub**. Renewable energy availability, combined with digital technologies, creates opportunities for hydroponic nurseries, food processing, agri-services, digital advisory services, and renewable energy enterprises, thereby diversifying income and generating local employment.

The framework also supports women-led and youth-led entrepreneurship. Self-Help Groups (SHGs) can engage in processing, packaging, nursery development, and value-added agricultural products, while rural youth can participate

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in emerging sectors such as drone-based crop monitoring, AI-enabled farm advisory services, digital marketing, and solar system operation and maintenance. Such opportunities contribute to skill development, local enterprise creation, and reduction of rural-to-urban migration.

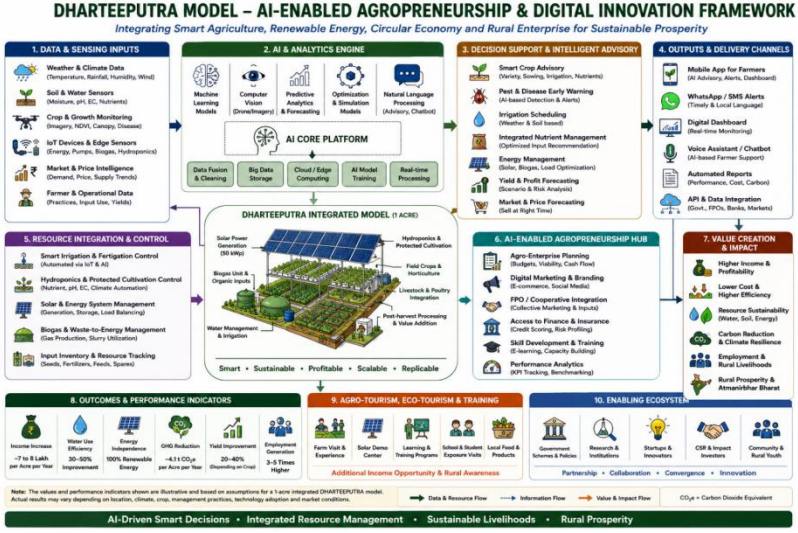

Figure 6: AI-Enabled DHARTEEPUTRA Framework Integrating Renewable Energy, Smart Agriculture, Digital Market Systems and Rural Entrepreneurship

By integrating renewable energy, AI-enabled agriculture, digital market connectivity, and entrepreneurship within a single ecosystem, the DHARTEEPUTRA model extends beyond conventional agrivoltaics. It establishes a scalable framework for creating intelligent, resilient, and self-reliant rural economies capable of generating sustainable livelihoods while supporting national goals of digital transformation, climate resilience, and inclusive growth.

Policy Implications and Scaling Strategy

The DHARTEEPUTRA model demonstrates how renewable energy, agriculture, digital technologies, and rural entrepreneurship can be integrated into a single framework for sustainable rural development. Its successful implementation, however, requires supportive policy mechanisms, institutional convergence, and innovative financing approaches.

The framework aligns closely with several national initiatives, including PM-KUSUM, the Digital Agriculture Mission, FPO promotion programmes, and related rural development initiatives. Convergence among these programmes can significantly improve project viability while reducing the financial burden on farmers and rural entrepreneurs.

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Farmer Producer Organizations (FPOs) can play a pivotal role in scaling the model through aggregation of resources, collective investment, shared infrastructure, and market linkage. Cluster-based implementation can further facilitate access to finance, technical services, processing facilities, and carbon market opportunities. Financial institutions such as NABARD, cooperative banks, and rural development agencies can support deployment through blended finance models combining subsidies, institutional credit, and private investment.

The integration of AI-enabled agriculture and digital platforms also requires strengthening of rural digital infrastructure, extension services, and capacity-building programmes. Training in smart agriculture, renewable energy management, and entrepreneurship will be essential for widespread adoption.

Given its modular and adaptable design, the DHARTEEPUTRA model can be replicated across diverse agro-climatic regions of India. By linking energy generation with productive use, value addition, and rural enterprise development, the framework offers a practical pathway for achieving the objectives of Vision 2047, Atmanirbhar Bharat, climate resilience, and inclusive rural prosperity.

Conclusion

The DHARTEEPUTRA model presents an integrated and future-ready framework for addressing the interconnected challenges of agricultural sustainability, energy security, climate resilience, and rural economic development. By combining agrivoltaics, decentralized renewable energy, productive use of energy, post-harvest management, artificial intelligence, and rural entrepreneurship within a single ecosystem, the model demonstrates how multiple development objectives can be achieved simultaneously.

Unlike conventional approaches that treat agriculture, energy, and enterprise as separate domains, the DHARTEEPUTRA framework promotes convergence, enabling efficient resource utilization, diversified income generation, and enhanced livelihood resilience. The integration of AI-enabled decision support systems, digital market platforms, and Farmer Producer Organizations further strengthens the model’s ability to create intelligent and market-responsive rural production systems.

Beyond an agrivoltaics intervention, DHARTEEPUTRA represents a decentralized rural development framework integrating renewable energy, AI-enabled agriculture, entrepreneurship, and community-led value creation..

As India advances toward a sustainable and inclusive future, the DHARTEEPUTRA model offers a practical pathway for transforming rural landscapes into resilient, prosperous, and self-reliant agro-economic ecosystems.

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