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CLIMATE SMART FARMING: UNLOCKING CARBON FINANCE FOR INDIA'S AGRICULTURAL TRANSFORMATION

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Abstract

Agriculture is central to India's economy and climate goals: it emits 13–19% of national greenhouse gases while supporting 58% of rural livelihoods. This study explores how Indian farming can both reduce emissions and capture carbon through practices like soil organic carbon enhancement, agroforestry, and direct-seeded rice. Key emission sources—enteric fermentation (52%) and rice cultivation (17%)—contrast with a national carbon stock of 30.43 billion tonnes CO_2e, bringing India close to its 2030 target of adding 2.5–3.0 billion tonnes of sequestration. Policy support from the National Mission for Sustainable Agriculture, PM-KUSUM, and the new Voluntary Carbon Market framework lays the groundwork for carbon finance. Yet high transaction costs, complex MRV, low farmer awareness, and policy gaps remain hurdles. This research shows that a farmer-focused carbon market, backed by digital MRV, can help India meet its 2070 carbon-neutral goal, cut emission intensity by 45% by 2030, and boost incomes for 150 million smallholders.

Keywords: Carbon Sequestration, Climate-Smart Agriculture, Carbon Finance, Sustainable Agriculture, Greenhouse Gas Emissions

1. INTRODUCTION

India, home to over 600 million people dependent on agriculture, stands at a decisive point where sustainable farming must synchronize with climate action. Agriculture, while vital to food security and rural livelihoods, contributes 14–19% of India's greenhouse gas (GHG) emissions—primarily methane (CH_4) from rice cultivation and livestock, and nitrous oxide (N_2O) from fertilizer use. Approximately 60% of India's farmland is rainfed, making it vulnerable to climate extremes. Between 2016 and 2019, agricultural emissions rose by 4.5%, reaching 2,647 $MtCO_2e$, although its relative share in total national emissions declined slightly from 14.4% to 13.4%.

India's commitments under the Paris Agreement aim for net-zero emissions by 2070 and a 45% reduction in emission intensity by 2030 from 2005 levels (UNFCCC). These goals align with SDG 2 (Zero Hunger), SDG 12 (Sustainable Production), and SDG 13 (Climate Action). In this context, India's agricultural transformation through programs like the National Mission for Sustainable Agriculture (NMSA) plays a key role in enabling climate-resilient and resource-efficient farming systems.

Globally, India is responsible for 12.7% of agricultural GHGs, emitting around 0.73 billion tonnes of CO_2e annually (Climate Scorecard, 2023). To mitigate this, carbon finance offers a market-driven solution. The Voluntary Carbon Market Framework introduced by India in 2023 empowers farmers to generate and trade carbon credits from practices like agroforestry and biochar. This could unlock $480 billion by 2070, providing farmers with supplementary income and climate benefits.

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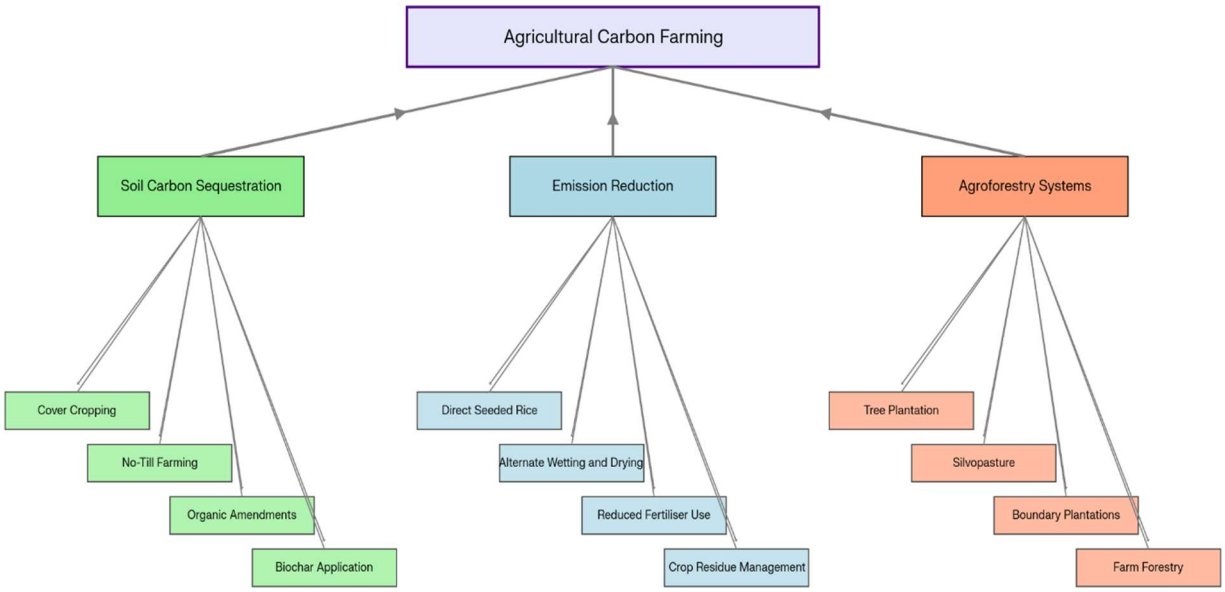
Scope of the Study

This research examines agricultural carbon emissions and financial mechanisms within the Indian context, analyzing policy frameworks, technological solutions, and market mechanisms that can facilitate the transition to low-carbon agriculture. The study encompasses soil carbon sequestration potential, emission reduction strategies, institutional frameworks supporting carbon finance, and the challenges and opportunities for scaling up carbon farming initiatives across India's diverse agricultural landscape.

2. THEORETICAL FRAMEWORK

2.1 Concepts of Carbon Farming and Carbon Finance

Carbon farming represents a paradigm shift in agricultural production systems, where farmers are compensated for implementing practices that sequester atmospheric carbon dioxide or reduce greenhouse gas emissions. This concept transforms agriculture from being primarily a carbon source to becoming a carbon sink, creating economic incentives for sustainable land management practices.



Structure of Agricultural Carbon Farming Practices in India

2.1.1 Types of Carbon Farming Practices: India's diverse agro-climatic conditions support various carbon farming approaches. Direct Seeded Rice (DSR) has emerged as a particularly promising practice, requiring 12-35% less water and labor while reducing methane emissions by 10-90% compared to conventional puddled transplanted rice. Research from ICAR-National Rice Research Institute demonstrates that DSR systems can achieve 64% reduction in environmental impact compared to conventional transplanted rice-wheat systems.

Agroforestry systems show remarkable carbon sequestration potential, with studies indicating 0.25-76.55 Mg C/ha/yr for tree components and 0.01-0.60 Mg C/ha/yr for crop components. The conversion to agroforestry systems results in 25.34% higher carbon sequestration compared to non-agroforestry systems. Zero tillage practices combined with residue retention demonstrate higher soil water content and reduced greenhouse gas emissions compared to conventional tillage systems.

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2.1.2 Overview of Carbon Markets: Carbon markets operate through two primary mechanisms: compliance markets driven by regulatory requirements and voluntary markets where entities purchase credits to meet sustainability goals. The Verified Carbon Standard (VCS) Program, administered by Verra, represents the world's most widely used greenhouse gas crediting program, having facilitated the reduction of over one billion tons of carbon emissions.

India's carbon market landscape includes both domestic and international components. The Carbon Credit Trading Scheme (CCTS), notified in December 2023, establishes the framework for domestic carbon trading. Additionally, more than 140 agriculture land management projects are listed in the Verra registry with annual estimated emissions reduction exceeding 27 million tons CO_2e, equivalent to removing 6 million gasoline-powered vehicles from roads annually.

2.1.3 MRV Systems and Certification: Monitoring, Reporting, and Verification systems form the backbone of credible carbon markets. Traditional MRV approaches in agriculture rely heavily on manual data collection and field surveys, which can be costly and time-consuming. Digital MRV systems leverage satellite imagery, IoT sensors, and artificial intelligence to reduce costs by 80-90% while improving accuracy and transparency.

The agricultural sector presents unique MRV challenges due to the spatial and temporal variability of carbon sequestration and emission processes. Standardized methodologies are essential for quantifying accurate GHG benefits and generating Verified Carbon Units (VCUs). ICAR and the National Agricultural Research and Education System play vital roles in developing Tier-2 and Tier-3 emission factors for major agricultural practices.

2.2 Agricultural Emissions and Carbon Potential in India

2.2.1 GHG Profile of Indian Agriculture: India's agricultural emissions profile reflects the sector's production systems and practices. Enteric fermentation from livestock contributes 52% of agricultural emissions, primarily from the country's large cattle population (38% of global cattle). Rice cultivation accounts for 17% of emissions, with methane release from flooded paddies estimated at 3.396 teragrams annually. Synthetic fertilizer application contributes 12% of emissions, while manure management and crop residue burning contribute 14% and 2% respectively.

2.2.2 Emissions by Subsector: Rice cultivation represents a critical area for emission reduction interventions. India produces rice on approximately 45 million hectares, with traditional puddled transplanting methods contributing significantly to methane emissions. Alternative practices like Direct Seeded Rice and Alternate Wetting and Drying (AWD) can reduce emissions while maintaining productivity levels.

The livestock sector's contribution to emissions is substantial but also represents significant mitigation opportunities through improved feed management, breeding programs, and manure management systems. Crop residue burning, particularly in states like Punjab and Haryana, contributes both to agricultural emissions and air quality concerns, with emissions rising by approximately 75% between 2011 and 2020.

2.2.3 Potential for Carbon Sequestration: India's carbon sequestration potential through agriculture is considerable. The country's carbon stock has reached 30.43 billion tonnes of CO_2 equivalent, indicating achievement of 2.29 billion tonnes of additional carbon sequestration compared to the 2005 baseline, approaching the target of 2.5-3.0 billion tonnes by 2030.

Soil organic carbon sequestration represents the largest opportunity, with Indian agricultural soils being severely depleted (often <1 g/kg) and having potential for significant enhancement. Research indicates that each 1 Mg/ha increase in soil organic carbon pool can enhance crop yields by 20-70 kg/ha for wheat, 10-50 kg/ha for rice, and 30-300 kg/ha for corn.

Biochar application shows promising results for soil carbon sequestration, with meta-analysis indicating average increases in soil organic carbon stocks by 13.0 Mg/ha corresponding to 29% enhancement. Agroforestry systems demonstrate carbon sequestration ranging from 0.003 to 3.98 Mg C/ha/yr in soil, with total carbon sequestered varying greatly depending on region, species, system type, and previous land use.

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2.3 Policy Landscape and Institutional Framework

India has built a leading agricultural carbon market through the Carbon Credit Trading Scheme (CCTS) and sector-specific frameworks designed for smallholder inclusion and rural priorities. Oversight is provided by the National Steering Committee for the Indian Carbon Market (NSC-ICM), while the Bureau of Energy Efficiency administers the schemes and the Ministry of Agriculture develops practice guidelines. The Framework for Voluntary Carbon Market in Agriculture, launched January 2024, details procedures for project validation, monitoring, credit issuance, and trading—drawing from global best practices but tailored to India's unique agricultural landscape.

Current projects, with the potential to abate 27 million tonnes of CO2e annually, cut across conservation agriculture, agroforestry, water management, and improved crop varieties, especially in Punjab, Haryana, Madhya Pradesh, and Maharashtra.

Policy alignment is underpinned by major national programs:

- The National Mission on Sustainable Agriculture (NMSA) promotes climate-resilient agriculture in rainfed areas, integrating soil health, water use, and sustainable farming through dedicated sub-schemes (Rainfed Area Development, On Farm Water Management, Soil Health Management, and climate monitoring).

- Clean energy integration is advanced by PM-KUSUM, supporting widespread deployment of solar pumps and decentralized renewable power in agriculture.

- Organic farming is supported through the Paramparagat Krishi Vikas Yojana (PKVY), which has organized over 25 lakh farmers into certified clusters.

Institutional support comes from NABARD, which has set up a ₹300 crore Carbon Fund and collaborates with FAO to pioneer smallholder-friendly carbon finance models, and from ICAR, which provides MRV methodologies, emissions data, and technical guidance for upscaling carbon farming in India. State agriculture departments and the National Agricultural Research and Education System are integral in implementation, capacity building, and technical validation.

2.4 Carbon Finance in Agriculture: Mechanisms and Market Access

2.4.1 Carbon Credit Generation from Agriculture: To generate agricultural carbon credits, farmers adopt practices that either sequester carbon or reduce greenhouse gas emissions. The process involves registering a project under approved standards, implementing the new methods, and having the results verified by a third-party auditor. Once validated, a registry issues the official, tradable credits.

India's framework, developed by the Ministry of Agriculture, guides this process for the voluntary market. It aims to educate and empower farmers, encouraging them to adopt sustainable practices by creating a new source of income from selling these carbon credits.

2.4.2 Voluntary Carbon Markets and Standards: The global voluntary carbon market operates through standards like Verra's VCS, Gold Standard, and emerging domestic frameworks. Verra's registry lists more than 140 agricultural land management projects from India with estimated annual emissions reduction potential exceeding 27 million tons CO_2e.

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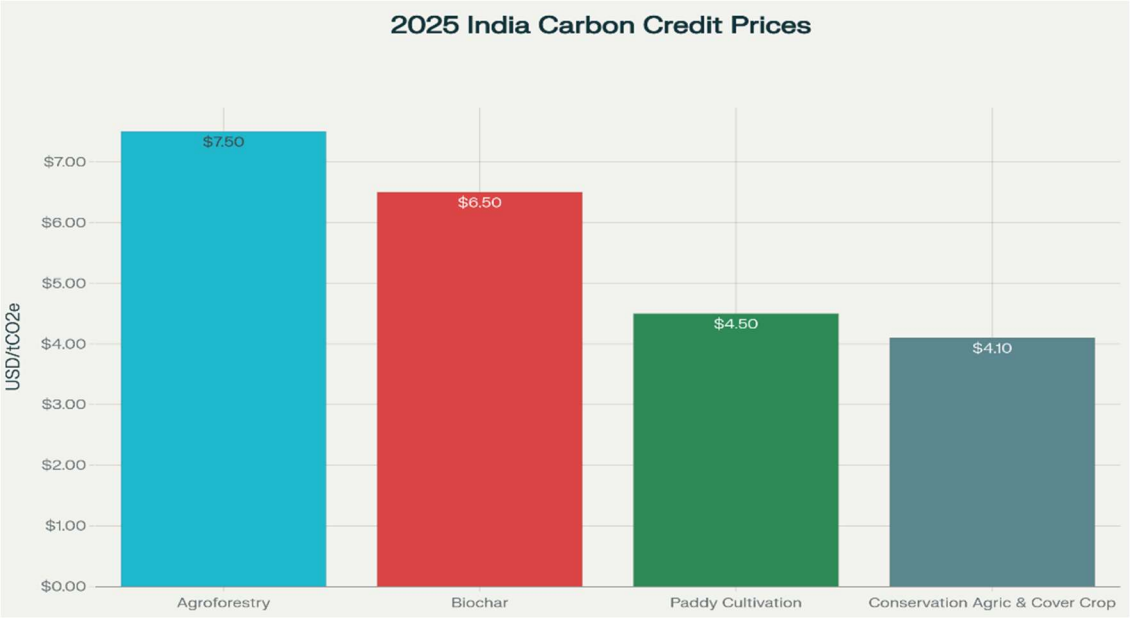
Agricultural carbon credits typically trade at $4-6 per ton CO_2e, nearly 15% below forestry premiums, but represent significant income potential for farmers. Projects focusing on soil carbon sequestration, emission reduction through improved practices show promise for Indian conditions.



2.4.3 Role of Aggregators and FPOs: Farmer Producer Organizations (FPOs) play crucial roles in aggregating small farmers for carbon market participation. By bundling credits from multiple farmers, FPOs can achieve economies of scale, reduce transaction costs, and make carbon projects attractive to buyers seeking larger credit volumes.

Carbon Mint, an Andhra Pradesh-based company, demonstrates the aggregator model by working with farmer groups to support transitions to practices that restore soil health, conserve water, and reduce emissions. Their platform provides codified packages of practices along with farm advisory services, enabling farmers to access carbon credit opportunities while improving agricultural productivity.

In Telangana and Andhra Pradesh, the Centre for Sustainable Agriculture (CSA) is at the forefront of implementing Climate-Smart Agriculture practices to help farmers engage in carbon farming. These programs introduce proven techniques that reduce greenhouse gas emissions and enhance soil carbon, creating new income opportunities for farmers through carbon credits.

2.4.4 Finance and Certification Insights: International experiences highlight the importance of standardized methodologies, reliable MRV systems, and strong institutional support for carbon market success. The evolution from proof-of-concept initiatives to scaled implementation requires substantial investment in capacity building, technology infrastructure, and market development.

Lessons from global programs emphasize the need for farmer-centric approaches that prioritize simplicity, transparency, and direct benefits to participants. Economic incentive design must account for local conditions, production systems, and socio-economic contexts to ensure sustainable adoption.

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2.5 Challenges and Barriers

High Costs and Low Awareness**:** Smallholder farmers face high upfront costs for adopting carbon farming practices and technologies, with 56% in emerging markets citing cost as the main barrier. Limited awareness of carbon markets and support schemes further reduces participation.

Complex MRV Systems**:** Traditional MRV (Monitoring, Reporting, Verification) systems are costly and labor-intensive due to the variability of agricultural emissions. While digital MRV offers promise, it requires significant investment in infrastructure, training, and standardization.

Limited Access to Finance and Capacity**:** Farmers often lack access to credit and financial services for carbon farming investments. Weak institutional capacity and fragmented support systems hinder implementation at both grassroots and administrative levels.

Policy and Coordination Gaps**:** Insufficient alignment between agriculture and environment ministries, along with fragmented policies, creates confusion and limits the scaling of carbon initiatives. Better coordination and streamlined policies are essential for effective carbon farming adoption.

2.6 Opportunities and Enabling Conditions

Cost Savings and Efficiency Gains: Carbon farming reduces cultivation costs (e.g., Direct Seeded Rice saves ₹5,000–6,000/ha) while improving water and labor use. Organic practices under PMKVY cut input dependence and boost productivity, especially when integrated with carbon credit incentives.

Soil Health and Climate Resilience: Practices like agroforestry and conservation agriculture enhance soil health, water retention, and resilience to climate variability. Initiatives like Mission Kakatiya show how integrated approaches improve groundwater, reduce chemical use, and raise farm incomes.

Digital MRV & Technology: Technologies such as satellite monitoring, IoT sensors, and AI-powered analysis can cut MRV costs by up to 90%, making carbon markets accessible to smallholders. Platforms like Carbon Mint demonstrate cost-effective, transparent, end-to-end carbon credit generation.

Corporate Demand & ESG Finance: Rising corporate net-zero targets are fueling demand for agricultural carbon credits. NABARD's Carbon Fund and ESG-aligned investments offer capital to scale carbon farming, opening sustainable income streams for farmers.

3. Results

India possesses a vast carbon farming potential, with a national carbon stock of 30.43 billion tonnes CO_2 equivalent, marking strong progress towards its climate goals. Direct Seeded Rice (DSR) could cut methane emissions by 10–90% across 45 million hectares of rice fields, based on pilot results from leading agribusinesses. Alternate Wetting and Drying saves 20–30% water while reducing emissions, and zero tillage boosts energy efficiency by 20% and saves 31% of total energy compared to conventional methods.

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Agroforestry systems can sequester 0.25–76.55 Mg C/ha/yr in trees and 0.001–0.60 Mg C/ha/yr in crops, with soil carbon gains up to 3.98 Mg C/ha/yr—achieving 25% higher sequestration than conventional cropping. Biochar amendments further raise soil organic carbon by an average of 13.0 Mg/ha (a 29% boost).

India's agricultural carbon projects have generated over 27 million tons CO_2e in annual reductions, valued at nearly INR 2,200 crores ($10/credit), with close to 60% of this potentially reaching farmers. Agroforestry can deliver up to INR 10,000 per acre of extra annual income. Adoption of digital MRV systems can lower monitoring costs by 80–90% and make carbon markets accessible for smallholders, while IoT, blockchain, and AI technologies promise further accuracy and efficiency. Policy innovations like NABARD's Carbon Fund and integrated state programs have yielded sizable co-benefits, such as increased farm incomes and reduced fertilizer use, positioning India as a global leader in scalable, farmer-inclusive carbon farming.

4. Conclusion and Findings

India's agricultural carbon finance analysis reveals substantial potential for transformative change, with the sector contributing 13-19% of national GHG emissions while possessing significant carbon sequestration capacity, demonstrated by a national carbon stock of 30.43 billion tonnes CO_2 equivalent. Key findings show that climate-smart practices like Direct Seeded Rice and agroforestry can reduce emissions while generating up to ₹10,000 per acre annually for farmers, with total potential benefits exceeding ₹1,300 crores. Digital MRV systems promise 80-90% cost reductions, making carbon markets accessible to smallholders.

The study concludes that agricultural carbon finance represents a dual-benefit strategy addressing both climate mitigation and rural income enhancement, requiring scalable, inclusive mechanisms for widespread impact. Success depends on farmer-centric design prioritizing simplicity and direct benefits, supported by robust institutional frameworks including NABARD's ₹300 crore Carbon Fund and integrated policy coordination across ministries.

Strategic recommendations emphasize strengthening Farmer Producer Organizations for smallholder aggregation, investing in domestic carbon registries and digital infrastructure, integrating carbon finance with existing schemes like NMSA and PM-KUSUM, and implementing comprehensive capacity-building programs. This comprehensive approach positions India's agricultural carbon initiative as more than environmental policy—it embodies sustainable development addressing climate change, rural poverty, and food security while establishing global leadership in climate-smart agriculture innovation.

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