The Entrepreneurial Roots of the Green Transition in Global Agriculture: Harnessing Innovation for Sustainability

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Abstract

As humanity confronts strategic issues such as climate change, biodiversity loss, and resource degradation, the need for a sustainable transformation of our global agriculture systems is imperative. This paper examines the critical role of agricultural entrepreneurship (agripreneurs) in driving the green transition across global food systems. It focuses on how agripreneurs are advancing sustainability by adopting a range of strategies such as bio-based inputs, circular economy practices, and climate-smart technologies to reduce emissions, improve soil health, and foster bio-resilience. The paper brings together case studies from countries including Kenya, the Netherlands, India, Brazil, and Sri Lanka, to illustrate how agripreneurs are innovating toward environmentally and economically viable farming. It critically evaluates the concept of the bioeconomy and its applications across diverse socio-economic contexts and agricultural sectors. The paper also explores enablers such as green finance, market incentives, and supportive policies, alongside challenges including technological gaps, regulatory barriers, and capacity limitations. Policy recommendations and further research are proposed to strengthen the global ecosystem for green agricultural entrepreneurship.

Purpose
This paper examines the role of agricultural entrepreneurship in hastening the green transition across global food systems, focusing on how entrepreneurial actors contribute to sustainability through the adoption of bioeconomy, circular economy, and climate-smart agriculture practices.

Design/methodology/approach
Using a qualitative, multi-country case study approach, the paper draws on secondary data, academic literature, and policy documents to analyse entrepreneurial innovations in six countries with large agricultural sectors: India, Brazil, the United States, China, Nigeria, and Sri Lanka. Each case illustrates context-specific applications of sustainable agricultural frameworks.

Findings
The study identifies shared enabling factors for green agricultural entrepreneurship, including access to digital platforms, supportive policy environments, market incentives, and youth engagement. It also highlights systemic challenges such as regulatory inconsistencies, limited access to finance, infrastructural deficits, and climate-related risks. A key insight is the critical role of context in shaping the scalability and effectiveness of green innovations.

Research limitations/implications
The research is limited by its reliance on secondary sources and illustrative case studies, which may not capture the full range of entrepreneurial activity or local variations. Future research should include field-based data collection and longitudinal analysis of enterprise performance across diverse agroecological zones.

Practical implications
Policymakers, development agencies, and investors can leverage the findings to design targeted interventions that support sustainable agricultural entrepreneurship, including enabling regulatory reforms, capacity-building initiatives, and blended finance models tailored to SMEs.

Originality/value

This paper contributes to the literature by positioning entrepreneurship as a central mechanism in operationalizing global sustainability frameworks in agriculture. It offers a novel synthesis of green entrepreneurial practices across diverse geographies and proposes a comprehensive set of policy recommendations to support inclusive and scalable transitions.

Introduction

Agriculture lies at the heart of some of the greatest challenges—and opportunities—of the 21st century. It is simultaneously a victim and driver of climate change, a source of livelihood for billions, and a cornerstone of food security. Globally, agriculture accounts for approximately one-quarter of greenhouse gas emissions, consumes over 70% of freshwater, and is the leading cause of biodiversity loss and land degradation (FAO, 2021; IPCC, 2022). In response, calls for a green transition in agriculture are intensifying (Boix-Fayos & de Vente, 2023), pushing toward farming systems that are environmentally sustainable, climate-resilient, and socially inclusive. While much media and research attention has focused on international and national government policies, technological innovation, and consumer behaviour, a powerful yet underexplored driver of this transition is entrepreneurship, more immortally the agripreneurs, the entrepreneurial actors who will drive and manage this change.

From Sri Lankan smallholders trialling organic amendments, to Indian agritech firms deploying AI-guided irrigation systems, and Dutch pioneers refining vertical farming techniques, agripreneurs are reimagining the agricultural landscape in ways both disruptive and deeply rooted in local context. These actors are not merely adopting technologies—they are crafting new green paradigms. Many are engaging with the principles of the bioeconomy by substituting fossil-based inputs with renewable, biologically derived alternatives. Others are embedding circular economy frameworks into agricultural practice, striving to reduce waste streams and close nutrient cycles in ecologically sound ways. Climate-smart agriculture, too, is gaining traction—offering integrated approaches that aim to reconcile increased yields with lower emissions and greater resilience to climate volatility.

What is particularly compelling is that such shifts are not confined to the technologically advanced or capital-rich settings one might expect. On the contrary, these innovations are increasingly emerging from, and being adapted to, resource-constrained environments. In rural and transitional economies, agripreneurs are tailoring sustainable solutions to the socio-economic and environmental realities they confront—often with remarkable ingenuity. This decentralized wave of transformation challenges the assumption that systemic change must originate from global centres of innovation. And yet, questions remain: How scalable are these localized solutions? Can they endure beyond the pilot phase? As a researcher, I find myself both hopeful and cautious—hopeful about the creativity and commitment on display, but mindful of the structural barriers that persist.

This paper explores the entrepreneurial roots of the green transition in agriculture with a global lens. It investigates how diverse actors, including independent farmers, cooperatives, agri-startups, and plantation enterprises are leading sustainability innovations in agriculture. While the analysis centres on pivotal practices—including the application of biofertilizers, composting techniques, the integration of renewable energy, agroecological approaches, and the deployment of digital farming technologies—it also extends to examine the broader enabling conditions that shape their adoption and impact. These include market dynamics, patterns of investment, the orientation and coherence of policy frameworks, as well as the structure and accessibility of knowledge systems. This dual focus seeks to illuminate not only the technical dimensions of sustainable agricultural innovation but also the institutional and systemic factors that facilitate or constrain its diffusion.

The paper aims to make three contributions:

1. **Conceptual**: It clarifies how entrepreneurship interfaces with the bioeconomy, circular economy, and climate-smart agriculture paradigms in different global contexts.

2. **Empirical**: It provides illustrative examples of how green entrepreneurship is emerging in varied agricultural sectors, drawing lessons across developed and developing economies.

3. **Practical and Policy-Oriented**: It identifies key enablers and barriers, and offers policy recommendations to scale green entrepreneurship, especially in rural and underserved regions.

The structure of the paper is as follows: The Literature Review defines key sustainability frameworks and situates the role of entrepreneurship within them. The Methodology outlines the comparative, case-based qualitative approach. The Findings present cross-regional case studies highlighting innovations, drivers, and outcomes. The discussion synthesizes common enablers and challenges. Finally, the policy recommendations and areas for further research provide pathways to support a more inclusive and impactful global green transition in agriculture.

Literature Review

The transition toward environmentally sustainable agriculture is increasingly understood through interconnected frameworks: the bioeconomy, the circular economy, and climate-smart agriculture (CSA). These frameworks each propose shifts in how food is produced, processed, and consumed to reduce negative environmental impacts, foster resilience to climate change, and maintain economic viability. Across all three, entrepreneurship is emerging as a central mechanism for innovation and adoption.

1. Bioeconomy in Agriculture

The bioeconomy refers to the production, utilization, and conservation of biological resources—including crops, forests, animals, and microorganisms—to provide products, services, and energy sustainably (OECD, 2009; European Commission, 2012, McCormick, & Kautto, 2013)). In agricultural systems, this involves replacing synthetic and fossil-based inputs with bio-based alternatives—such as biofertilizers, biopesticides, and compost—and integrating renewable processes that enhance ecosystem services. The Food and Agriculture Organization (FAO, 2021) emphasizes the “agroecological bioeconomy,” which prioritizes diversity, soil health, and local knowledge to build productive and regenerative systems.

Globally, bioeconomy policies have been developed in countries such as Germany, Brazil, Finland, and Kenya (El-Chichakli et al., 2016, Wesseler, & von Braun, 2017). In Brazil, the sugarcane industry has evolved into a bioeconomy hub, producing ethanol, bioplastics, and bioelectricity from biomass residues (Goldemberg, 2019). In Kenya, biofertilizer startups like SynBio Kenya are developing microbial-based inputs for smallholder use, reducing reliance on costly synthetic nitrogen (Glatzel et al., 2020). However, realizing the bioeconomy’s potential in agriculture requires not just technology but entrepreneurial action to translate innovation into viable and scalable business models (Pfau et al., 2014). This includes creating bio-input production enterprises, decentralized waste-to-energy businesses, and bio-based product lines linked to global green markets (Busch, 2011).

2. Circular Economy in Agriculture

The circular economy (CE) aims to reduce or even eliminate waste and keep resources in use through regeneration, reuse, recycling, and upcycling (Ellen MacArthur Foundation, 2015, Huma et al., 2023). In agriculture, CE principles involve the recycling of organic waste into compost or bioenergy, nutrient cycling, the use of renewable packaging, and the valorisation of by-products (Jurgilevich et al., 2016). The Netherlands provides a global benchmark in applying circularity to horticulture through innovations like aquaponics, vertical

farming, and organic waste bioconversion (De Boer & Van Ittersum, 2018). Similarly, India's EcoZen has pioneered solar-powered cold storage solutions and circular irrigation systems, helping reduce food loss and water waste (Sarma, 2021).

Entrepreneurs play a key role in operationalizing CE models by launching agro-waste management firms, input substitution ventures, or closed-loop farming systems. For instance, in Uganda, Green Bio Energy converts agricultural residues into clean cookstove briquettes, reducing deforestation while creating rural employment (UNEP, 2020). In the UK, farmers are collaborating with brewers and dairy processors to feed surplus food to livestock or convert it to biogas (WRAP, 2019). However, CE in agriculture remains constrained by infrastructure gaps, global supply chain constraints, weak markets for bio-based products, and regulatory uncertainties—challenges that entrepreneurs must navigate (Human, et al., 2023).

3. Climate-Smart Agriculture (CSA)

Climate-smart agriculture is a framework developed by the FAO that aims to (1) sustainably increase productivity, (2) enhance resilience (adaptation), and (3) reduce or remove greenhouse gas emissions (mitigation) where possible (FAO, 2013). CSA promotes practices such as agroforestry, conservation agriculture, drought-tolerant crops, precision farming, and renewable energy adoption. The CSA concept has gained traction globally, with policy uptake in countries from Rwanda to Bangladesh, and pilot initiatives in nearly 100 nations (World Bank, 2020).

Entrepreneurs are at the forefront of CSA implementation. In India, companies like Kheyti provide smallholder farmers with "Greenhouse-in-a-Box" solutions that protect crops from climate shocks while reducing water and pesticide use (Kheyti, 2023). In Senegal, digital agri-startups like Manobi Africa deliver real-time climate and market information, improving decision-making and crop resilience (CTA, 2019). These innovations often blend low-tech and high-tech solutions, grounded in user-centred design. However, CSA's broader diffusion requires coordinated action: entrepreneurs need enabling environments including access to finance, extension services, and supportive policy ecosystems(Lipper et al., 2014; Westermann et al., 2018).

4. Entrepreneurship as a Catalyst for Green Transitions

It is clear that for all three frameworks to move forward, agripreneurship serves as a catalyst as these actors will foster change by spotting sustainability gaps, mobilizing resources, testing new models, and driving market behaviour. They will also manage risk and reduce the time lag between research and practical application, especially when working in dynamic sectors like climate-tech or sustainable food systems (Schaltegger & Wagner, 2011).

Green entrepreneurship in agriculture is increasingly recognized as vital to achieving the UN Sustainable Development Goals (SDGs), especially SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). Research highlights that green agricultural ventures can enhance rural livelihoods, promote resource efficiency, and stimulate job creation (Bocken et al., 2014, more cites). Yet, barriers persist: lack of investment, poor policy coherence, limited capacity for business planning, and weak linkages between entrepreneurs and formal agricultural systems (Pachal, 2012; Dordmond et al., 2021; Makki et al., 2020).

Emerging literature emphasizes the need for ecosystem-level interventions—such as incubators, innovation hubs, blended finance platforms, and inclusive policy dialogue—to foster entrepreneurship in the green transition (FAO & IFAD, 2021, Muo et al., 2019). Moreover, in emerging economies where the majority of the population is under 25 years old, the role of social and youth entrepreneurship is progressively important, particularly in regions where traditional agribusiness structures do not serve marginal communities effectively.

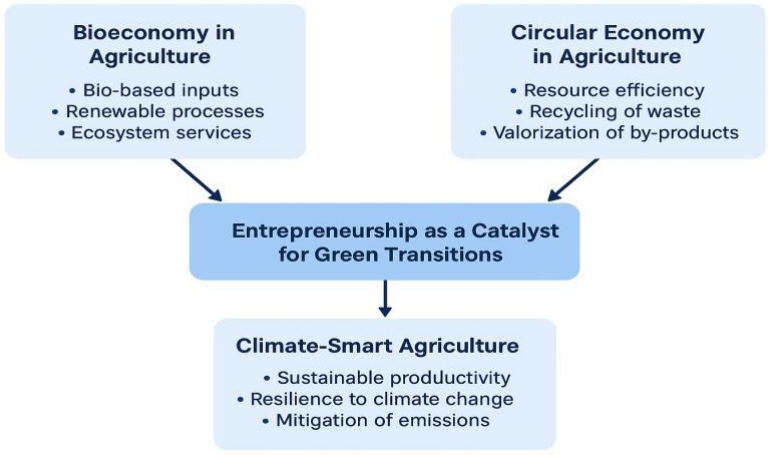

Figure 1 – Entrepreneurial Green Transition Framework – text to explain

Findings

This section presents global case studies illustrating how agripreneurship is catalysing the green transition in agriculture. Drawing from six countries with large agricultural sectors, the instances show how our framework is being applied in practice.

1. India: Agritech Startups Driving Climate-Smart Innovation

India, where agriculture continues to employ over 40% of the labour force, confronts a convergence of critical pressures—climate volatility, widespread soil degradation, and the long-standing overuse of chemical inputs. These challenges are neither abstract nor distant; they are daily realities for millions of farmers whose livelihoods depend on fragile ecosystems. In recent years, however, a vibrant cohort of agritech entrepreneurs has emerged, offering a distinctly localised and often technologically sophisticated reimagining of what sustainable agriculture might look like in this context.

Consider the case of Kheyti, a social enterprise that has developed a compact, cost-effective solution known as the “Greenhouse-in-a-Box.” Designed specifically for smallholder farmers, this innovation provides protection against erratic weather, extreme temperatures, and pest infestations. By incorporating drip irrigation and offering ongoing agronomic support, the system reportedly reduces pesticide and water use by more than 90% and can boost yields on small plots by as much as 300% (Kheyti, 2023). While such figures are compelling, they also raise important questions around long-term affordability, scalability, and the support infrastructure required to maintain adoption across diverse geographies. Nevertheless, the model stands as a promising illustration of climate-smart agriculture (CSA)—advancing productivity and resilience while lowering the environmental burden of inputs.

A second example, DeHaat, represents a different but complementary innovation pathway. As one of India's most rapidly expanding agri-startups, DeHaat has developed a platform that connects over 1.5 million farmers with AI-driven crop advisories, organic input providers, and tailored market linkages. Its strategy rests on the digitization and decentralization of agri-services, enabling more precise input application and encouraging the transition toward biofertilizers—often through partnerships with rural micro-entrepreneurs (Bain & Company, 2022).

On the policy front, national schemes such as Startup India and the Paramparagat Krishi Vikas Yojana (PKVY) (Reddy, 2018) signal governmental recognition of the importance of sustainable innovation in agriculture, particularly around organic practices. Yet structural gaps persist—notably in rural connectivity and credit access—which may hinder the inclusive scaling of these promising models. In reflecting on India's agritech landscape, I am struck by both the ingenuity of its entrepreneurial responses and the complexity of the systemic barriers they must navigate.

2. Brazil: Scaling the Bioeconomy Through Agro-Industrial Innovation

Brazil stands as a prominent player in the global bioeconomy, particularly through its leadership in bioenergy production and the sustainable intensification of key commodity crops such as sugarcane, soy, and maize. Its experience reflects both the possibilities and the tensions inherent in aligning large-scale agricultural production with environmental sustainability goals.

A particularly illustrative example is Raízen Bioenergia, a joint venture between Shell and Cosan, which has established one of the world's most expansive platforms for bioethanol and bioelectricity. Raízen's model leverages sugarcane not only for ethanol production but also uses bagasse—the fibrous residue left after juice extraction—to generate electricity. This surplus energy is fed back into the grid, effectively closing the loop on sugarcane processing and offsetting fossil fuel emissions in the process (Goldemberg, 2019). While the model showcases the potential of circular bioeconomy principles in a high-volume agro-industrial context, one might still question the replicability of such systems outside of Brazil's unique agro-climatic and economic conditions.

In contrast, the case of Native Organic offers a smaller-scale yet no less impactful vision of bioeconomic innovation (Coti-Zelati, 2021). As one of the world's leading organic sugar producers, Native collaborates with more than 1,000 smallholder farmers, promoting agroecological practices such as biodiversity corridors, cover cropping, composting, and natural pest management. These methods significantly reduce chemical inputs while enhancing ecosystem health. Notably, Native has succeeded in exporting organic sugar to over 30 countries, suggesting that green entrepreneurship—when embedded in strong producer networks and ecological principles—can indeed achieve scale and market relevance (FAO, 2021).

Yet, despite these encouraging developments, Brazil's bioeconomy is far from unproblematic (de Queiroz-Stein et al., 2024). Persistent land use conflicts, particularly in frontier zones of the Amazon and Cerrado, coupled with periodic lapses in environmental enforcement, cast a long shadow over progress. These challenges highlight the ongoing tension between economic expansion and ecological preservation, and they underscore the urgent need for more coherent, enforceable frameworks for sustainable land governance. As a researcher, I am struck by Brazil's dual identity—both as a bioeconomy innovator and as a site of profound ecological risk. The interplay between these roles remains a subject of critical reflection and continued inquiry.

3. United States: Tech-Enabled Green Agriculture and Regenerative Models

The United States presents a complex and often contradictory agricultural landscape—one where highly industrialized agribusiness systems coexist with a growing, if still fragmented, movement toward regenerative practices, organic production, and agri-tech entrepreneurship. This duality reflects both the depth of institutional capacity, and the tensions embedded in transitioning toward more sustainable models.

A notable example is **Indigo Ag**, a Boston-based company at the intersection of biotechnology, remote sensing, and financial innovation. By integrating satellite imagery, machine learning, and microbial seed treatments, Indigo aims to enhance crop resilience and monitor soil carbon levels with precision. Its "carbon farming" platform provides financial incentives to farmers who adopt regenerative practices such as cover cropping and no-till cultivation—essentially creating a monetizable pathway for verified CO_2 removal (Indigo

Ag, 2022). While the model is undeniably ambitious and technologically sophisticated, one might question how accessible it is to smaller-scale farmers or those operating outside digitally integrated systems. The potential of such fintech-enabled climate-smart agriculture (CSA) is promising, but its inclusivity and long-term viability warrant further scrutiny.

In contrast, the work of the **Rodale Institute** reflects a more grassroots, systems-based approach. As a nonprofit research and education centre, Rodale supports a broad network of organic and regenerative farmers through entrepreneurship training, applied research trials, and strategic collaborations with food retailers. Its emphasis on low-input, high-diversity farming not only challenges the economic assumptions of conventional monoculture but also provides practical pathways for farm transition (Rodale, 2021). I find Rodale's approach particularly compelling for its blend of scientific rigor and farmer-cantered support, though I remain curious about how scalable these models are within a policy environment still largely shaped by commodity subsidies.

Despite the country's immense technological capacity, systemic barriers persist. Chief among these are the consolidation of agribusiness power, which can stifle innovation at the farm level; limited access to land for new and younger entrants; and entrenched subsidy regimes that continue to favour monocultures over diversified or regenerative systems. These obstacles underscore the paradox of American agriculture: a sector rich in innovation and resources, yet constrained by structural inertia. As a researcher, I find myself oscillating between admiration for the ingenuity on display and concern over the enduring policy and market configurations that inhibit broader transformation.

4. China: Modernizing Agriculture with a Circular and Digital Approach

China's agricultural sector is undergoing a significant transformation—one shaped by the urgent need to curb environmental degradation, rehabilitate depleted soils, and narrow the persistent income gap between urban and rural populations. These efforts, while bolstered by strong state-led initiatives, also reflect a more subtle shift toward entrepreneurial and locally adaptive solutions. The path forward, however, remains uneven, shaped as much by structural ambition as by on-the-ground experimentation.

One illustrative case is the collaboration between **Netafim China**—a subsidiary of the global precision irrigation firm—and **Alibaba Cloud**, which together are pioneering smart irrigation systems in water-scarce regions such as Xinjiang. By combining drip irrigation technologies with IoT-enabled platforms and mobile-based access for rural cooperatives, these initiatives aim to reduce both water waste and the overuse of chemical fertilizers (OECD, 2021). The digital layer, driven by Alibaba's infrastructure, makes the system remarkably scalable in theory, though one wonders whether the learning curve and infrastructure requirements might still exclude less-connected farming communities.

Another compelling example comes from **Hebei Province**, where small-scale green entrepreneurs are deploying household biogas units that convert animal manure and crop residues into renewable energy and nutrient-rich organic slurry. These decentralized systems contribute to circular farming practices, reducing greenhouse gas emissions while addressing energy poverty in rural areas (World Bank, 2019). The role of local enterprises in installing and maintaining these systems is particularly noteworthy, hinting at a quietly growing ecosystem of rural innovation. Yet, despite their promise, such models often remain limited to demonstration zones, and questions linger about the financing and policy mechanisms needed for widespread replication.

At the national level, China's **Green Rural Revival Program** and expansive rural revitalization funding streams have provided critical support for these types of innovations. The state's top-down coordination undoubtedly facilitates rapid deployment, especially in strategically prioritized regions. Still, the challenge of scaling beyond pilot areas persists. I often reflect on the tension between China's capacity for mobilizing large-scale

infrastructure and the need for more adaptive, farmer-led approaches that build lasting local ownership. The transformation is real—but like many systemic shifts, it is a work in progress, layered with both progress and uncertainty.

5. Nigeria: Youth Agripreneurs Championing Climate-Smart Solutions

Nigeria's demographic profile—a rapidly growing and predominantly youthful population—presents a dual narrative for agriculture: one of immense pressure on food systems, but also a fertile ground for innovation. The rise of green entrepreneurship, particularly among young Nigerians, signals a notable shift toward climate-smart and circular farming solutions. While this momentum is still emerging, it suggests a generational rethinking of agriculture's role in sustainable development.

An illustrative example is **Farmcrowdy**, a digital platform that bridges the gap between investors and smallholder farmers engaged in sustainable agriculture. Through input financing, climate-resilient training, and access to organic markets, the platform empowers farmers with the tools to adapt to environmental and market fluctuations. To date, Farmcrowdy has supported over 25,000 farmers, promoting practices such as mulching and agroforestry (CTA, 2020). This blend of fintech and agronomy is promising, though I remain cautiously optimistic—success depends not only on digital access but also on farmers' capacity to absorb and implement new methods amidst ongoing infrastructural and financial constraints.

In the urban context, **Greenhill Recycling + Urban Farms** in Lagos offers a compelling model of circularity. These entrepreneurs are integrating organic waste collection with vertical farming systems and compost production, creating self-reinforcing loops that support peri-urban vegetable cultivation (UNEP, 2021). By diverting biodegradable waste from landfill and turning it into productive input, they are tackling both waste management and food security—a rare convergence in many urban African contexts. The ingenuity here is striking, though scalability beyond Lagos remains uncertain without broader municipal support or infrastructural alignment.

Despite the energy behind such initiatives, persistent barriers remain. Weak rural infrastructure, an underdeveloped cold chain, and chronically underfunded agricultural extension services continue to hamper broader transformation. Yet, what is particularly striking about Nigeria is the vibrancy of its entrepreneurial response—driven by necessity, yes, but also by a sense of possibility. As a researcher, I find this convergence of urgency and innovation deeply compelling, even as I acknowledge the systemic gaps that still need to be addressed to move from scattered successes to national-scale impact.

6. Sri Lanka: Tea Sector Innovations Amid Policy Turbulence

Though relatively modest in scale compared to major agricultural economies, **Sri Lanka's tea sector** offers a nuanced lens through which to examine the complexities of transitioning toward greener, more sustainable export agriculture. The country's efforts reveal both the opportunities for innovation and the pitfalls of poorly sequenced policy shifts—a delicate balance between environmental ambition and practical implementation.

A leading example is **Bogawantalawa Tea Estates PLC**, which has embraced what it terms a "climate-positive" production model. The estate operates entirely on renewable energy, relies on organic soil amendments, and has developed an in-house composting system to close nutrient loops. Perhaps most notably, the company markets its product as "uncompensated carbon-neutral tea," a bold claim that has allowed it to command premium prices in discerning international markets (Daily FT, 2024). This case illustrates the power of aligning sustainability credentials with market positioning, though one might ask how such models could be replicated across smaller, less capitalized producers without similar resources or branding infrastructure.

At the other end of the spectrum, smallholder farmers—often working with support from NGOs and certification bodies like the **Rainforest Alliance**—have begun experimenting with low-cost biofertilizers and organic pesticides derived from locally available materials. Reports from the field suggest some encouraging outcomes: improved crop resilience during drought periods, lower input costs, and reduced dependency on chemical inputs (Rainforest Alliance, 2018). These grassroots innovations carry a certain quiet promise. Yet, I remain cautiously optimistic, aware that anecdotal success does not always translate into broader adoption without sustained technical support and market incentives.

The 2021 policy decision to abruptly ban synthetic fertilizers and pesticides—an experiment that was later reversed—serves as a stark reminder of the risks of top-down mandates in complex agricultural systems. While well-intentioned, the sudden nature of the policy disrupted production and sowed confusion among farmers. In hindsight, it reinforced a lesson that many in the sustainability community already suspected: meaningful green transitions are more likely to succeed when driven by entrepreneurs and supported by evidence, gradual implementation, and responsive markets. Interestingly, that policy shock did have an unintended upside—it spurred a surge in private investment in the local production of bio-inputs and composting services, perhaps laying the groundwork for more durable, bottom-up change in the years ahead.

Discussion

The case studies drawn from India, Brazil, the United States, China, Nigeria, and Sri Lanka offer valuable empirical insights into the emergence and proliferation of green agricultural entrepreneurship across diverse economic, environmental, and cultural contexts. Despite significant variation in institutional capacities, technological readiness, and market dynamics, these examples reveal a set of converging enabling factors and persistent structural challenges that shape the trajectory of sustainable agricultural transitions globally.

1. Enabling Conditions for Green Agricultural Entrepreneurship

a. Technological Innovation and Access to Digital Platforms

The advancement of innovative agricultural technologies has proven instrumental in facilitating the green transition. Entrepreneurs are deploying a combination of high- and low-tech solutions, including precision agriculture, remote advisory services, renewable energy systems, and bio-based inputs. Notably, digital platforms such as DeHaat (India) and Farmcrowdy (Nigeria) exemplify how entrepreneurs leverage information and communication technologies (ICTs) to enhance access to sustainable practices for smallholders.

Furthermore, the integration of data science and climate mitigation frameworks—exemplified by Indigo Ag's soil carbon monetization model in the United States—illustrates the potential of entrepreneurial ventures to create new markets for environmental services. The presence of innovation ecosystems, such as specialist agri-incubators (Bose et al.,2019), public–private research partnerships, and open data initiatives, has been critical in accelerating the prototyping and diffusion of such technologies.

b. Market Incentives and Certification Schemes

The emergence of sustainability-oriented market segments—particularly in the Global North—has incentivized green practices through price premiums, certification programmes, and reputational advantages. Certifications such as organic, Fair for Life, and regenerative agriculture function as both market access enablers and tools for differentiating entrepreneurial ventures.

For instance, the success of Native Organic in Brazil and Bogawantalawa Tea Estates in Sri Lanka underscores how sustainability certifications can create pathways to premium export markets while reinforcing

environmental stewardship. Additionally, the commodification of environmental goods, such as carbon credits from bioenergy production, represents a compelling business case for regenerative practices globally.

c. Supportive Policy and Institutional Frameworks

Policy frameworks play a pivotal role in facilitating green entrepreneurship. In countries such as India and China, targeted policy instruments—e.g., the Paramparagat Krishi Vikas Yojana (PKVY) and the Rural Green Revival Program—have provided public support for transitioning to sustainable inputs and farming methods. Similarly, national bioeconomy strategies in Brazil and the Netherlands illustrate how coherent policy visions can align innovation with environmental objectives.

Moreover, policies designed to promote entrepreneurship, such as India's Startup India initiative and Brazil's Embrapa (Corra & Schmidt, 2014) public–private partnership model, foster synergistic relationships between government, research institutions, and the private sector.

d. Access to Green Finance and Investment Mechanisms

Access to finance remains a cornerstone for enabling green innovation, particularly in contexts where sustainable agriculture involves substantial upfront investment and delayed returns. Blended finance mechanisms—ranging from carbon farming contracts to climate-resilient credit schemes and crowdfunding—are increasingly being leveraged by entrepreneurs to mitigate risk and scale operations.

Development finance institutions, including the World Bank and IFAD, play a catalytic role in seeding early-stage innovation, particularly in the Global South. In India, for example, impact investors and accelerators are instrumental in supporting climate-smart startups through capacity-building and capital access.

e. Youth Engagement and Digital Agricultural Economies

The role of youth in driving green innovation cannot be overstated. Across regions such as Sub-Saharan Africa and South Asia, a new generation of digital-native agripreneurs is redefining agriculture through mobile-first, tech-enabled, and sustainability-oriented ventures. Initiatives that integrate young people into agricultural value chains—through agripreneurship training, innovation bootcamps, and digital platforms—represent a long-term investment in green transformation.

These youth-led ventures often demonstrate agility, user-centred design, and cross-sectoral collaboration, thereby enhancing both technological diffusion and social inclusion.

2. Structural Barriers and Constraints

a. Fragmented Value Chains and Inadequate Infrastructure

Despite the diffusion of innovation, many agricultural systems—particularly in low- and middle-income countries—are hampered by fragmented value chains and infrastructure deficits. Weak linkages between producers, processors, and markets constrain the scalability of sustainable practices. Inadequate cold chain infrastructure, limited storage capacity, and poor transportation networks undermine the viability of perishable, certified, or circular products.

In countries such as Nigeria and India, the logistical burden of maintaining product integrity across supply chains impedes entrepreneurial efforts to implement traceable and climate-smart innovations.

b. Policy Incoherence and Regulatory Ambiguities

While policy frameworks can catalyze innovation, abrupt or poorly designed regulations can have deleterious effects. The example of Sri Lanka's 2021 chemical fertilizer ban underscores the risks associated with top-down interventions lacking transitional support or stakeholder engagement. Policy incoherence—particularly conflicting subsidies for chemical and organic inputs—can distort markets and reduce investor confidence.

Additionally, regulatory uncertainty surrounding emerging innovations (e.g., bio-inputs, carbon farming) and the absence of standardized performance metrics hinder the commercialization and public acceptance of green solutions.

c. Limited Access to Capital for SMEs and Smallholders

Sustainable agricultural entrepreneurs, particularly small- and medium-sized enterprises (SMEs) and smallholders, often face acute constraints in accessing working capital, insurance, and investment. Green technologies—such as solar-powered cold storage or composting infrastructure—require significant upfront expenditure with extended payback periods.

Although donor-led initiatives partially address these gaps, a structural disconnect remains between available financing instruments and the specific risk-return profiles of sustainable agricultural ventures.

d. Skills Gaps and Capacity Constraints

Adoption of circular, climate-smart, and bioeconomy practices necessitates both technical and managerial competencies. However, extension services in many regions remain under-resourced and oriented toward conventional agriculture. Entrepreneurs frequently bear the cost of farmer training, impeding their ability to scale and diversify.

Further, agricultural education systems often lack curricula emphasizing sustainability, entrepreneurship, or systems thinking—resulting in a skills mismatch that hinders innovation.

e. Environmental Uncertainty and Climate Risks

Ironically, climate variability—the very condition sustainable agriculture aims to address—poses a significant threat to green entrepreneurs. Extreme weather events, such as droughts, floods, and heatwaves, disproportionately affect farms in transition, where soils and systems are still stabilizing.

Without effective risk mitigation mechanisms such as index-based insurance, diversified cropping systems, or adaptive infrastructure, climate shocks can destabilize entrepreneurial ventures and discourage investment in long-term sustainability.

3. Cross-Cutting Themes and Strategic Insights

a. Context-Specificity and Local Adaptation

The heterogeneity of agricultural systems necessitates locally tailored approaches to green entrepreneurship. Practices that succeed in capital-intensive, vertically integrated systems (e.g., the Netherlands or the United States) may not be suitable for smallholder-dominated, labour-intensive contexts (e.g., India or Nigeria).

For example, while Brazil's sugarcane bioeconomy is industrial in scale and technologically advanced, composting initiatives in Sri Lanka are more community-driven and resource-constrained. Contextualization is therefore critical to the success and sustainability of green ventures.

b. Multi-Stakeholder Collaboration as a Catalyst

Collaborative models that integrate public institutions, private innovators, civil society, and farmer organizations are essential for creating robust ecosystems of innovation. Cross-sectoral partnerships, such as those between Netafim and Alibaba Cloud or Embrapa and Native Organic, illustrate how collective action can align sustainability goals with market development and national priorities.

Such collaboration enhances trust, reduces transaction costs, and facilitates knowledge exchange—key ingredients for system-wide transformation.

c. The Social Dimensions of Sustainability Transitions

Sustainable agricultural transitions are as much sociocultural as they are technological. They entail shifts in practices, attitudes, and value systems among producers, consumers, and intermediaries. Entrepreneurs must therefore navigate social acceptance, behavioural inertia, and community norms.

Narratives, storytelling, and trust-building—often achieved through demonstration farms or peer-to-peer networks—play a pivotal role in legitimizing new practices. The dissemination of success stories, such as those of Kheyti farmers in India or climate-positive estates in Sri Lanka, can act as powerful catalysts for wider adoption.

Policy Recommendations and Areas for Further Research

The evidence presented in this study underscores the transformative role of agricultural entrepreneurs in advancing the global green transition. However, to scale impact equitably and sustainably, targeted policy measures and continued research are needed. Below are strategic recommendations for governments, donors, investors, and institutions.

1. Policy Recommendations

a. Develop National Bioeconomy and Circular Agriculture Strategies

Governments should establish or strengthen national strategies that integrate **bioeconomy** and **circular economy** principles into agricultural policy. These strategies should:

- Define clear targets for organic input use, waste recycling, and emissions reductions.
- Align subsidy structures to support bio-based fertilizers, biopesticides, and renewable energy.
- Create national platforms to promote bio-based entrepreneurship, particularly in input manufacturing and waste valorisation.

Example: Brazil’s national bioeconomy framework and India’s PKVY provide models for structured transitions with entrepreneurial incentives.

b. Expand Access to Green Finance and Insurance

Financial instruments tailored for sustainable agriculture are critical. Policymakers and development banks should:

- Develop **green loan products** with flexible terms for agribusinesses adopting CSA or bio-circular practices.

- Introduce **risk-sharing instruments** (e.g., partial guarantees, blended finance) to de-risk investments in emerging innovations.

- Promote **index-based crop insurance** and carbon finance mechanisms to reward environmental services.

Example: The U.S. and EU offer payments for ecosystem services (e.g., carbon sequestration, biodiversity corridors)—similar tools could be adapted for Global South contexts.

c. Strengthen Research, Extension, and Entrepreneurial Training

Building human capital is vital for adoption and innovation. Governments and educational institutions should:

- Expand **agricultural research** on bio-based solutions, regenerative systems, and climate-resilient crops.

- Invest in **extension services** trained in circular and climate-smart practices.

- Establish **green entrepreneurship academies** or hubs to provide business training for rural youth and women.

Example: The Rodale Institute and African Agripreneurship Incubators offer replicable models for entrepreneurial education in sustainability.

d. Simplify Regulatory Frameworks for Green Inputs and Products

Entrepreneurs often face delays or restrictions in bringing sustainable solutions to market. Policymakers should:

- Streamline approval processes for **bio-inputs**, **compost products**, and **sustainable packaging**.

- Establish clear standards and labelling for **organic**, **regenerative**, or **low-emission** products.

- Harmonize **certification schemes** and reduce compliance costs for smallholders and SMEs.

Example: Global platforms like IFOAM (for organics) and RegenAgri (for regenerative agriculture) provide scalable models for standardization.

e. Foster Inclusive Innovation Ecosystems

To ensure broad participation in the green transition, especially among marginalized groups:

- Support **youth and women-led ventures** through targeted grants, mentorship, and recognition schemes.

- Facilitate **public-private partnerships** for inclusive product co-development and distribution.
- Establish **open data platforms** for soil health, weather, and market access to level the information playing field.

Example: Nigeria's Farmcrowdy and India's FPOs (Farmer Producer Organizations) demonstrate how tech and finance can empower smallholder networks.

2. Areas for Further Research

a. Measuring Impact of Green Entrepreneurship

More research is needed to quantify the **environmental, social, and economic outcomes** of sustainable agribusinesses. This includes:

- Life-cycle assessments of bio-inputs and low-carbon practices.
- Comparative yield and income studies across farming systems.
- Gender-disaggregated impact evaluations of green innovation adoption.

b. Mapping Regional Bioeconomy Potential

Countries should conduct assessments of local **biomass availability**, **waste streams**, and **innovation readiness** to identify priority sectors and geographic clusters for bioeconomy development.

Example: FAO's country-level bioeconomy assessments (e.g., in Kenya and Colombia) offer useful templates.

c. Designing Just Transition Pathways in Agriculture

Research should examine how to make green transitions **socially inclusive**, particularly in regions dependent on conventional input-intensive farming. Topics include:

- Labor implications of mechanization or input changes.
- Retraining needs for agri-input retailers.
- Compensation mechanisms for communities facing short-term yield drops.

d. Understanding Behaviour Change and Adoption Dynamics

Beyond economics, transitions depend on perceptions, trust, and community influence. Studies should explore:

- How narratives, peer influence, and risk perceptions shape farmer decisions.
- What types of demonstration plots, extension messages, or digital nudges are most effective.

e. Strengthening Climate Adaptation via Entrepreneurship

Further research is needed on how agri-entrepreneurs can build climate resilience, especially in vulnerable ecosystems. This includes:

- Innovations in water harvesting, flood-resistant infrastructure, and crop diversification.
- Index-based microinsurance products tailored to smallholder entrepreneurs.
- Integrated climate-smart planning at the community and landscape level.

Conclusion

The global green transition in agriculture is not a distant ideal—it is already underway, powered by a diverse and growing movement of agricultural entrepreneurs. From regenerative tea plantations in Sri Lanka to digital agritech hubs in India, from bioenergy firms in Brazil to youth-led circular farming startups in Nigeria, entrepreneurial innovation is reshaping how food is produced, marketed, and consumed.

However, the transition is uneven, and systemic barriers remain. Scaling the impact of green entrepreneurship will require a **converging effort**: policies that align incentives with sustainability, financial tools that match risk with innovation, educational systems that empower the next generation, and research that deepens our understanding of what works.

This paper has shown that entrepreneurship is not just an economic driver—it is a **cultural and ecological force**. It redefines agriculture not as a source of problems but as a solution to global challenges—from climate change to soil degradation, from rural poverty to food insecurity. Empowering green entrepreneurs today will help secure a resilient, regenerative, and inclusive agricultural future for all.

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