Building Sustainable Performance in Agriculture 4.0: The Roles of Green Intellectual Capital, Green HRM, Innovation, and AgTech Adoption

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Abstract

The agribusiness sector faces increasing pressure from rising food demand and environmental challenges. For small and medium-sized enterprises (SMEs), sustainability requires more than operational efficiency; it encompasses environmental knowledge, human resource management, innovation, and digital technology adoption. This study employs a Systematic Literature Review to synthesize research on Green Intellectual Capital (GIC), Green Human Resource Management (GHRM), Green Innovation (GI), AgTech Adoption, and Sustainable Performance. The findings reveal that sustainable performance does not arise directly from green resources. Instead, GIC and GHRM act as foundational enablers that foster innovation capability. Green Innovation subsequently facilitates AgTech Adoption, translating environmental strategies into operational outcomes. Sustainable performance, including economic, environmental, and social dimensions, emerges from this sequential capability development. The study proposes an integrated conceptual framework illustrating how environmental knowledge and human capital are transformed into technology-driven sustainability, providing a basis for future empirical testing.

Keywords: Green Intellectual Capital, Green Human Resource Management, Green Innovation, AgTech Adoption, Sustainable Performance

Introduction

The global agricultural sector is at a critical turning point, facing the dual challenge of increasing food production while addressing escalating environmental pressures. With the global population projected to reach 9.8 billion by 2050, agricultural output must expand significantly (Phokwe & Manganyi, 2023). At the same time, climate change, biodiversity loss, land degradation, and water scarcity continue to threaten long-term sustainability. These pressures have accelerated a structural transformation in agribusiness, in which sustainability-oriented practices are increasingly integrated with technological advancements to align with the Sustainable Development Goals (SDGs) (Henderson & Loreau, 2023).

Within this transformation, small and medium-sized enterprises (SMEs) play a central role. SMEs contribute significantly to employment, income distribution, and economic development, particularly within agrifood value chains (Madhavan et al., 2022). In many regions, especially Asia, SMEs form the backbone of agricultural production and food security (OSMEP, 2017). Southeast Asia, in particular, represents a key agricultural hub, where SMEs are essential for both economic stability and regional food systems.

Despite their importance, agribusiness SMEs operate under substantial constraints, including limited resources, technological barriers, and high environmental uncertainty. Traditional production approaches are increasingly insufficient, while unsustainable practices in developing economies have contributed to environmental degradation (Alisjahbana & Busc, 2017). At the same time, changing consumer preferences toward environmentally sustainable products are intensifying competition. Consequently, achieving sustainable competitive advantage requires firms to develop adaptive, innovation-driven capabilities that respond effectively to both environmental and market dynamics (Ngugi et al., 2010).

Sustainability-oriented innovation depends on strong internal strategic foundations. Prior research highlights the role of intangible resources, particularly Green Intellectual Capital (GIC) and Green Human Resource Management (GHRM). GIC provides environmentally oriented knowledge and capabilities that support ecological decision-making, while GHRM embeds environmental values through organizational practices (Chen, 2008). These resources enable knowledge sharing and problem-solving, which facilitate the development of Green Innovation and enhance firms' ability to address sustainability challenges.

In parallel, digital transformation has emerged as a key driver of competitiveness in agribusiness. The integration of technologies such as Artificial Intelligence (AI) and the Internet of Things (IoT) improves decision-making and operational efficiency (Savastano et al., 2024). Technology adoption, particularly AgTech, enables firms to operationalize innovation capabilities and translate environmental strategies into measurable performance outcomes.

Despite growing research on GIC, GHRM, innovation, and digital technologies, the literature remains fragmented. Existing studies often examine these constructs independently, providing a limited understanding of how they interact within an integrated framework. Insufficient attention has been given to the combined mediating roles of Green Innovation and AgTech Adoption in transforming environmental resources into sustainable performance. This gap highlights the need for a comprehensive perspective explaining how knowledge-based and human-centered resources are converted into competitive advantage.

To address this gap, this study employs a Systematic Literature Review (SLR) to synthesize research on green intellectual capital, green human resource management, innovation, and technology adoption in agribusiness. The objective is to develop an integrated conceptual framework that clarifies the sequential mechanisms linking environmental strategic resources to sustainable performance in the context of Agriculture 4.0. This study contributes by offering a multi-stage perspective on capability development, particularly in emerging economies such as those in Southeast Asia.

RQ1: How do Green Intellectual Capital (GIC) and Green Human Resource Management (GHRM) influence Green Innovation and subsequent AgTech Adoption in agribusiness SMEs?

RQ2: How do Green Innovation and AgTech Adoption jointly mediate the relationship between environmental strategic resources and Sustainable Performance in the context of Agriculture 4.0?

Objectives

1. To systematically review literature on Green Intellectual Capital, Green HRM, Green Innovation, and AgTech Adoption in agribusiness SMEs.
2. To synthesize structural relationships linking environmental strategic resources with sustainable performance.
3. To develop a conceptual framework explaining the serial mediation mechanism of green innovation and technological adoption.

Literature Review

This section reviews the conceptual foundations of environmental strategic resources, innovation mechanisms, and sustainability outcomes, grounded in the Resource-Based View (RBV) and Knowledge-Based View (KBV), which explain how firms leverage internal capabilities to achieve competitive advantage.

Green Intellectual Capital (GIC)

GIC refers to intangible environmental knowledge assets, capabilities, and relational networks that support sustainability and green innovation (Chen, 2008). It comprises Green Human Capital, Green Structural Capital, and Green Relational Capital (Marco-Lajara et al., 2022). From RBV and KBV perspectives, GIC provides the cognitive foundation for environmental decision-making and eco-friendly practices. However, empirical findings suggest that GIC alone does not consistently lead to performance improvements. Its effectiveness depends on its transformation into operational processes, particularly through innovation mechanisms.

Green Human Resource Management (GHRM)

GHRM encompasses HR practices that promote environmentally responsible

behavior, including green training, performance evaluation, and reward systems (Tang et al., 2018). These practices enhance employee capabilities and support knowledge sharing, thereby facilitating innovation. Nevertheless, prior research reports mixed results regarding its direct effect on performance, suggesting that GHRM functions primarily as an enabling mechanism rather than a direct driver.

Green Innovation (GI)

Green Innovation refers to environmentally oriented improvements in products and processes that reduce resource consumption and environmental impact (Chen, 2008). It plays a mediating role between strategic resources and performance. In agribusiness, GI enhances efficiency, reduces costs, and supports differentiation. However, its benefits are context-dependent, and short-term implementation costs may constrain SMEs. This highlights the importance of complementary capabilities such as technological adoption.

Agricultural Technology Adoption (AgTech)

AgTech involves integrating AI, IoT, and precision agriculture technologies into agricultural operations (Savastano et al., 2024). It improves efficiency, resource utilization, and decision-making. Adoption is largely driven by internal knowledge capabilities, particularly GIC. However, financial constraints, technological complexity, and limited human capital may hinder adoption, especially in developing economies.

Sustainable Performance (SP)

Sustainable Performance encompasses economic, environmental, and social outcomes within the Triple Bottom Line framework (Yusliza et al., 2020). Research indicates that such outcomes do not arise directly from resources but emerge through intermediate mechanisms such as innovation and technology adoption. These effects are often indirect and delayed.

Concept theory framework

The conceptual framework of this study explains how agribusiness organizations generate sustainable performance through a structured capability development process. Environmental strategic resources, specifically Green Intellectual Capital (GIC) and Green Human Resource Management (GHRM), are positioned as foundational drivers of value creation (Shahbaz & Malik, 2025).

Green Intellectual Capital comprises environmentally oriented knowledge assets, technical expertise, and relational networks that support sustainable agricultural practices (Marco-Lajara et al., 2022; Xu et al., 2020). Complementing this, Green Human Resource Management embeds environmental values through training, incentives, and capability development (Bindeeba et al., 2025). Together, GIC and GHRM function as primary antecedents of innovation capability (Shahbaz & Malik, 2025).

However, these resources do not directly generate performance outcomes. Instead, they are transformed into operational practices through Green Innovation (GI), which acts as the first mechanism of mediating. GI enables firms to redesign products and processes to reduce environmental impact and improve resource efficiency (Ismail, 2025; Shehzad et al., 2023).

Green Innovation subsequently facilitates AgTech Adoption, which serves as the second mediating (Ismail, 2025). The integration of AI, IoT, and precision agriculture technologies enhances decision-making, reduces resource losses, and improves operational performance (Savastano et al., 2024; Anim & Odoom, 2025).

AgTech Adoption ultimately contributes to Sustainable Performance across economic, social, and environmental dimensions (Anim & Odoom, 2025; Yusliza et al., 2020). The framework thus proposes a serial mediation structure in which environmental resources influence performance indirectly through innovation and technological implementation (Ismail, 2025; Shahbaz & Malik, 2025; Savastano et al., 2024).

Materials and Methods

This study employs a Systematic Literature Review to examine prior research on Green Intellectual Capital, Green Human Resource Management, Green Innovation, AgTech Adoption, and Sustainable Performance in the agribusiness context. Rather than aggregating findings statistically, the review aims to develop an integrated conceptual framework grounded in sustainability and innovation literature. The process follows established systematic research principles to ensure transparency and analytical rigor (Tranfield et al., 2003; Snyder, 2019).

A structured search strategy was developed in accordance with systematic evidence synthesis guidelines (Page et al., 2021). Core keywords, including “Green Intellectual Capital,” “Green Human Resource Management,” “Green Innovation,” “AgTech Adoption,” “Precision Agriculture,” “Digital Agriculture,” and “Sustainable Performance,” were combined with contextual terms such as agribusiness and SMEs. Searches were conducted across major academic databases, including Scopus, ScienceDirect, Web of Science, Emerald Insight, and Google Scholar.

The review focused on peer-reviewed English-language journal articles published between 2019 and 2025, while incorporating seminal studies where necessary. Explicit inclusion and exclusion criteria were applied. Studies were included if they examined relationships among key constructs, provided empirical evidence in agribusiness or SME contexts, or contributed theoretical insights. Articles lacking methodological rigor were excluded. The review follows the PRISMA 2020 framework to ensure transparency (Page et al., 2021).

The selected studies were analyzed using thematic content analysis (Braun & Clarke, 2006). Structural relationships among constructs were coded to identify key mechanisms linking environmental resources to sustainable outcomes. The synthesis revealed three consistent patterns: GIC and GHRM act as antecedents of Green Innovation; Green Innovation facilitates AgTech Adoption; and AgTech Adoption enhances Sustainable Performance. These findings support a serial mediation structure. The review is limited to English-language publications and selected databases, which may introduce publication bias.

Results

The systematic search across Scopus, ScienceDirect, and Web of Science identified 412 records. After removing 32 duplicates, 380 records were screened, resulting in the exclusion of 282 articles. A total of 98 full-text articles were assessed, with 53 excluded based on predefined criteria, leaving 45 studies for qualitative synthesis.

Methodologically, 82% (37 studies) employed Partial Least Squares Structural Equation Modeling (PLS-SEM), demonstrating its suitability for complex sustainability models (Hair et al., 2019). Covariance-based SEM and regression analyses accounted for 13%, while qualitative and mixed-method approaches represented 5%. Geographically, over 65% of studies were conducted in emerging economies, particularly in Southeast and South Asia (Madhavan et al., 2022).

Publication trends show that 14 studies (31.1%) were published between 2018 and 2021, while 31 studies (68.9%) appeared between 2022 and 2025, indicating increasing scholarly attention. Thematic synthesis reveals two key patterns: Green Intellectual Capital and Green Human Resource Management act as strategic antecedents (Shahbaz & Malik, 2025), while Green Innovation and technological adoption function as transformation mechanisms (Ismail, 2025). These findings support a serial mediation structure linking environmental resources, innovation, technology adoption, and sustainable performance.

Table 1: Synthesized Constructs, Definitions, and Structural Relationships Identified in the Systematic Review

Constructs	Synthesized Definitions	Role in the Model	Key Reference
Green Intellectual Capital (GIC)	Environmental knowledge-based intangible resources.	Drives GI and AgTech Adoption	Anim & Odoom (2025); Shahbaz & Malik (2025)
Green HRM	HR practices supporting pro-	Enhances GI	Setyanti et al.

Constructs	Synthesized Definitions	Role in the Model	Key Reference
(GHRM)	environmental behavior.		(2024); Shahbaz & Malik (2025)
Green Innovation (GI)	Environmentally oriented innovation activities.	Mediates resource–technology link	Ismail (2025); Shehzad et al. (2023)
AgTech Adoption	Adoption of digital agricultural technologies.	Enables sustainable outcomes	Savastano et al. (2024); Anim & Odoom (2025)
Sustainable Performance (SP)	Triple Bottom Line performance outcomes.	Triple Bottom Line outcome	Yusliza et al. (2020)

Based on the synthesized relational patterns, a serial mediation conceptual structure emerged. The systematic synthesis supports a set of interrelated hypotheses (H1–H7) forming a serial mediation structure: Green Intellectual Capital (GIC) positively influences Green Innovation (GI); Green Human Resource Management (GHRM) positively influences Green Innovation; Green Innovation positively influences AgTech Adoption; and AgTech Adoption positively influences Sustainable Performance (SP). Furthermore, GI and AgTech Adoption function as sequential mediating mechanisms linking environmental strategic resources to sustainability outcomes. The proposed conceptual structure, derived from the systematic integration of prior literature, is illustrated in Figure 1.

Hypotheses Development

H1: GIC positively influences Green Innovation

H2: GHRM positively influences Green Innovation

H3: Green Innovation positively influences AgTech Adoption

H4: Green Innovation positively influences Sustainable Performance

H5: AgTech Adoption positively influences Sustainable Performance

H6: Green Innovation mediates the relationship between GIC/GHRM and AgTech Adoption

H7: Green Innovation and AgTech Adoption sequentially mediate the relationship between GIC/GHRM and Sustainable Performance

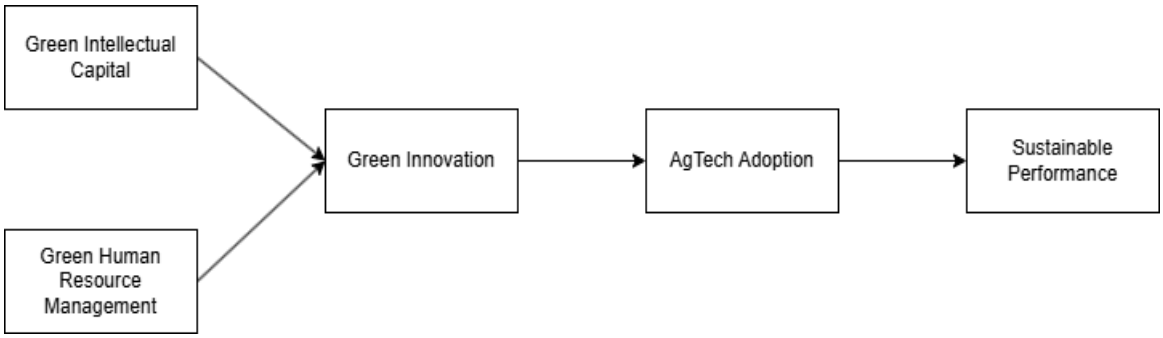

Figure 1: The proposed framework

To provide an overview of the 45 empirical studies included in this Systematic Literature Review (SLR), this study adopts a narrative synthesis approach to summarize key patterns across three dimensions: regional context, methodological approach, and publication trends.

Regional Context:

Most studies were conducted in emerging economies, accounting for more than 70% of the sample, with a strong concentration in Asia. This includes Southeast Asia, such as Thailand (Madhavan et al., 2022), and South Asia, such as Pakistan (Shahbaz & Malik, 2025). These regions are particularly relevant due to their agricultural importance and increasing pressure on SMEs to adopt sustainable practices. Additional studies are distributed across Europe and Africa, where research emphasizes technological adoption and resource management (Marco-Lajara et al., 2022; Ismail, 2025).

Methodological Approach:

The majority of studies employ quantitative methods, with Partial Least Squares Structural Equation Modeling (PLS-SEM) emerging as the dominant technique, accounting for approximately 85% of the sample. This reflects its suitability for analyzing complex models with multiple mediating variables. Emerging trends include advanced hybrid approaches, such as SEM-ANN and Meta-Analytic SEM, which enhance predictive accuracy (Yan et al., 2022).

Publication Trends and Key Findings:

Research activity has increased significantly during 2022–2025, reflecting growing interest in sustainability and digital transformation. The literature consistently shows that Green Intellectual Capital (GIC) and Green Human Resource Management (GHRM) do not directly generate sustainable performance. Instead, their effects operate through mediating mechanisms, particularly Green Innovation (GI) and AgTech adoption. However, variations across contexts suggest that these relationships are not universally consistent, especially in resource-constrained SME environments.

Conclusions and Discussion

This systematic literature review consolidates research on how environmental strategic resources contribute to sustainable performance in digitally transforming agribusiness. The synthesis consistently identifies Green Intellectual Capital (GIC) and Green Human Resource Management (GHRM) as foundational drivers of Green Innovation (GI). Consistent with Marco-Lajara et al. (2022) and Shahbaz and Malik (2025), environmentally oriented knowledge assets and sustainability-focused HR practices provide the structural basis for eco-innovation. The examination of H1 and H2 indicates that firms with strong green knowledge systems and HR policies that reinforce environmental values demonstrate more sustained green innovation capability. As emphasized by Bindeeba et al. (2025) and Shehzad et al. (2023), environmentally innovative behavior emerges from integrating knowledge-based resources and supportive organizational culture. This confirms the antecedent role of GIC and GHRM in forming innovation.

The findings further position Green Innovation as a catalytic mechanism for AgTech Adoption (H3). Organizations with advanced green innovation capabilities are more prepared to implement digital agricultural technologies. These include Artificial Intelligence (AI), IoT systems, and precision agriculture tools (Ismail, 2025; Savastano et al., 2024). This shift represents a move from process improvement to technology-enabled transformation. Both Green Innovation and AgTech Adoption contribute to Sustainable Performance across economic, social, and environmental dimensions (H4 and H5). Digital technologies enhance resource efficiency and improve decision accuracy (Anim & Odoom, 2025; Novani et al., 2021). Green innovation strengthens ecological outcomes and builds organizational legitimacy (Yusliza et al., 2020).

Most critically, the review supports a serial mediation mechanism (H6 and H7). Environmental strategic resources do not directly generate sustainable performance. Their influence unfolds in a sequence. GIC and GHRM enhance Green Innovation. Green Innovation then facilitates AgTech Adoption. This chain ultimately leads to Sustainable Performance. By integrating constructs previously examined in isolation (Shahbaz & Malik, 2025; Ismail, 2025), this synthesis clarifies that sustainable performance in agribusiness emerges through a structured process: resource development, innovation capability, and then technological implementation in Agriculture 4.0.

From a managerial perspective, agribusiness SME owners should prioritize the development of green human capital and environmental knowledge before investing in advanced digital technologies. Strengthening internal capabilities through training, knowledge sharing, and organizational learning enhances the effectiveness of subsequent innovation and AgTech adoption. This sequential approach ensures that technological investments are not only adopted but effectively utilized to generate sustainable

performance outcomes.

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