SUSTAINABLE INNOVATION STRATEGIES IN WILD COFFEE SUPPLY CHAINS*

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Abstract

The main objective of this study is to explore how sustainable agricultural practices, technology adoption and market diversification affect the economic value added of smallholder coffee supply chains in a biodiversity-sensitive context. The study also seeks to examine the mediating role of environmental performance, consumer trust and product differentiation, and to assess the moderating role of policy support, certification schemes and international trade partnerships.

This study proposes the following hypotheses: H1a: sustainable farming practices have a significant positive effect on economic value added; H1b: technology adoption has a significant positive effect on economic value added; H1c: market diversification has a significant positive effect on economic value added; H2a: environmental performance mediates the relationship between sustainable farming practices and economic value added; H2b: consumer trust mediates the relationship between technology adoption and economic value added; and H2b: consumer trust mediates the relationship between technology adoption and economic value added. economic value added; H2c: Product

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differentiation mediates between market diversification and economic value added. H3a: Policy support positively moderates the relationship between sustainable farming practices and environmental performance; H3b: Certification schemes positively moderates the relationship between environmental performance and consumer trust; H3c: International trade partnerships positively moderates the relationship between market diversification and product differentiation. Relationship between market diversification and product differentiation. This study utilized a quantitative, cross-sectional survey design. Data were collected from 450 smallholder coffee growers in Chiang Rai, Chiang Mai and Mae Hong Son provinces using a structured questionnaire with Likert-7 response scale and 403 valid questionnaires were returned. The study achieved a balance between statistical power and contextual representation.

This study provides empirical insights into how ecological and institutional factors interact with innovation to shape economic outcomes in sustainable agricultural supply chains. The study contributes to theory by advancing the moderating mediator model and informs practice by providing actionable recommendations for policy makers, non-governmental organizations (NGOs), and producer cooperatives seeking to enhance rural value creation in biodiversity-rich areas.

Keywords: Sustainable farming practices, Technology adoption, Market diversification, Economic value added, Environmental performance, Consumer trust, Product differentiation, Policy support, Certification schemes, International trade partnership

Introduction

The global coffee sector is increasingly subject to scrutiny due to its complex interactions with pressing environmental challenges, including biodiversity loss, climate variability, and land degradation (Bunn, Läderach, &

Waller, 2020). Within this broader context, wild coffee-particularly Coffea arabica and related species found in natural forest ecosystems-represents a genetically and ecologically vital component of global agrobiodiversity. Wild coffee is indigenous to the montane rainforests of East Africa, particularly Ethiopia, which serves as both the natural habitat and genetic reservoir for numerous coffee varieties (Krishnan et al., 2017). This genetic repository is indispensable for long-term crop improvement, enhancing disease resistance, and adapting to climate change (Peluso, 2023).

As climate change intensifies, the ecological traits of wild coffee species become increasingly valuable. Compared to cultivated variants, wild coffee exhibits greater resilience to temperature fluctuations, drought, and emerging pathogens (Wright, Bekessy, Lentini, & Garrard, 2024). These traits make wild coffee essential not only as a biodiversity asset but also as a climate-resilient agricultural resource (Beck-O'Brien & Bringezu, 2021). However, the habitats that support wild coffee are rapidly diminishing due to deforestation, agricultural encroachment, and the absence of integrated conservation policies (Kufa, 2010; Bramel et al., 2017). From an ecosystem services perspective, wild coffee contributes to nutrient cycling, pollinator health, and forest canopy preservation (Michelsen & Weitzel, 2020). Agroforestry systems that retain wild coffee under natural or semi-natural shade can enhance water retention, reduce erosion, and support avian and insect biodiversity (Läderach et al., 2017). As Krishnan et al. (2017) asserted, "The conservation of wild coffee is not merely a botanical concern but a foundational element of global food system resilience" (p. 5).

Despite its ecological importance, wild coffee faces significant threats from the same systems that benefit from its traits. Climate projections indicate substantial habitat loss for Coffea arabica by 2050 due to rising temperatures and erratic rainfall (Bunn et al., 2020). The genetic narrowness of commercial coffee cultivars underscores the critical role of wild coffee as a source of

breeding material for climate resilience (Ngure & Watanabe, 2024). Up to 60% of wild coffee species are now considered threatened with extinction, primarily due to climate change, habitat fragmentation, and unsustainable forest use (Mendez & Castillo, 2022). The degradation of Afromontane rainforests-biodiversity hotspots and carbon sinks-could have cascading impacts on ecological stability in East Africa and beyond (Penot, Vaast, & Meter, 2022; Atkinson, 2019).

The commercial and operational aspects of wild coffee supply chains remain underdeveloped, even as sustainability certifications and climate-smart practices proliferate in cultivated coffee production, particularly in Latin America and Asia (Montalvo, 2019; Melo & Trujillo, 2020). Wild coffee is often marginalized in policy, trade, and investment discourse (Degato & Carlos, 2017), despite its potential as a flagship sustainable product. Structural challenges include informal or insecure land tenure, weak market integration, inadequate infrastructure for post-harvest handling, and minimal access to climate finance or technological innovation (Garcia & Dedehouanou, 2019; Boli & Meyer, 2017). Socio-economic vulnerability among smallholders, combined with a lack of incentives for ecosystem preservation, exacerbates these issues (Vieira & Lequieu, 2021). Supply chain constraints also include traceability gaps that undermine consumer trust, low value capture by producers, and the failure to integrate wild coffee into broader agricultural development strategies (Pascucci, 2022). This marginalization persists despite increasing consumer demand for biodiversity-positive and ethically sourced products (Morris, Simons, & Blanchard, 2020).

Innovation, broadly defined as encompassing technology, institutional frameworks, social capital, and governance mechanisms (Sathaye, Reilly, & Harvey, 2020), has largely bypassed wild coffee systems. Unlike cultivated coffee, which benefits from research funding, extension services, and formal cooperatives, wild coffee is embedded within informal networks that lack

robust policy protection (Miller & Lee, 2021). Technological advances-such as remote sensing, blockchain-based traceability, and regenerative agroforestry-have shown strong results in cultivated coffee contexts but are rarely applied to wild coffee (Mueller, Jung, & Dierkes, 2020). On the policy front, most national agricultural and climate strategies neglect wild coffee, despite its relevance to the United Nations Sustainable Development Goals (SDGs) on biodiversity (SDG 15), climate resilience (SDG 13), and rural livelihoods (SDG 8) (Gatzweiler, Kaltschmitt, & Schreckenberg, 2021). Certification schemes, including Rainforest Alliance and Fair Trade, often adopt a "one-size-fits-all" approach that fails to differentiate between wild and cultivated systems (Grabs et al., 2022). As Penot et al. (2022) observed, "The failure to distinguish wild coffee systems from industrial plantations constitutes a serious oversight in both sustainability governance and innovation diffusion strategies" .

The research problem, therefore, lies in the disconnection between wild coffee's ecological potential and its marginalization in sustainability and innovation agendas. The absence of targeted investment, supportive policy frameworks, and context-sensitive technology adoption has left the sector underdeveloped. Current scholarship inadequately addresses how sustainable farming, technological innovation, and market diversification might jointly contribute to ecological and economic performance in wild coffee systems. There is also insufficient understanding of how these effects are mediated by environmental performance, consumer trust, and product differentiation, and moderated by institutional factors such as policy support, certification schemes, and trade partnerships.

The purpose of this study is to investigate the causal pathways linking sustainable farming practices, technology adoption, and market diversification to economic value addition in wild coffee supply chains. The conceptual framework incorporates mediators-environmental performance, consumer trust,

product differentiation-and moderators-policy support, certification schemes, and international trade partnerships. By empirically testing this framework, the study seeks to provide both theoretical insights and practical guidance for actors engaged in sustainable agriculture, biodiversity conservation, and rural development.

Theoretically, the research draws on Sustainability Transition Theory (Grin, Rotmans, & Schot, 2010), the Resource-Based View (Barney, 1991), and Institutional Theory (Scott, 2008). This multi-theoretical integration supports a holistic understanding of how innovation operates in biodiversity-sensitive contexts, emphasizing that strategic adoption of sustainable practices must be aligned with enabling institutional environments to achieve lasting value creation.

Practically, the study addresses the urgent need to align ecological stewardship with inclusive economic development. By centering on wild coffee-a biodiversity-rich yet economically marginalized system-the research identifies leverage points for transforming sustainability into a viable business proposition. This approach offers a transferable framework for other biodiversity-linked commodities such as cocoa, vanilla, and medicinal plants. Furthermore, the study aligns with SDGs 2, 12, 13, and 15 by promoting smallholder income growth, sustainable consumption, climate action, and biodiversity conservation.

In summary, wild coffee systems represent both a challenge and an opportunity. They embody the tension between conservation and commerce, and between ecological value and economic marginalization. This study seeks to bridge that divide by providing empirically grounded strategies for integrating sustainable innovation into wild coffee supply chains. By doing so, it contributes to scholarly debates on sustainability transitions while offering actionable pathways for policymakers, practitioners, and market actors committed to building resilient and equitable agri-food systems.

Objectives

This study is guided by the following research objectives:

1. To assess the impact of sustainable farming practices, technology adoption, and market diversification on economic value addition in wild coffee supply chains.

2. To examine the mediating effects of environmental performance, consumer trust, and product differentiation on the relationship between innovation strategies and economic value.

3. To evaluate the moderating influence of policy support, certification schemes, and international trade partnerships on the strength of these mediated relationships.

4. To develop and empirically test a conceptual model that integrates sustainability, innovation, and institutional dimensions within biodiversity-sensitive agricultural value chains.

5. To generate practical recommendations for farmers, cooperatives, policymakers, and sustainability advocates to enhance value creation in wild coffee systems.

Literature Review

The agricultural sector is undergoing a paradigm shift driven by climate instability, biodiversity loss, rural poverty, and volatile commodity markets. Sustainable agricultural value chains (SAVCs) have emerged as a strategic framework integrating ecological resilience, economic competitiveness, and social inclusion. SAVCs function as production sites and as platforms for innovation/governance, where environmental performance (EP), consumer behavior (CB), and institutional governance (IG) interact to shape outcomes. Among biodiversity-linked commodities, wild/semi-wild coffee systems (WCS) offer a unique lens on sustainability-value creation-nnovation diffusion

dynamics.

This literature review synthesizes work across six domains: (1) sustainability theory (ST), (2) innovation diffusion in agriculture (IDA), (3) sustainable supply chain management (SSCM), (4) wild coffee sector dynamics (WCSD), (5) economic value addition (EVA), and (6) mediating/moderating institutional factors (MMIF). It aims to: clarify theoretical foundations; identify empirical gaps in biodiversity-sensitive contexts; inform a structural equation model (SEM) linking innovation strategies to institutional contingencies; and situate the study within sustainability transition (STr) and agri-value chain (AVC) discourse.

Central is the tension between ecological embeddedness (EE) and market integration (MI). While traditional paradigms treat biodiversity and profitability as trade-offs, evidence suggests synergies between EP and market differentiation (MD) when supported by innovation/governance structures (Schmitt et al., 2010; Duguma et al., 2019). Ethiopia-origin of Coffea arabica-and N. Thailand-with tribal agroforestry landscapes-are key empirical contexts.

The review covers theoretical frameworks (sustainability science, Rogers' innovation diffusion model, institutional theory), sustainable innovations in agri-supply chains, WCSD, EVA, and mediators (EP, CB, product differentiation [PD]) and moderators (policy support [PS], certification schemes [CS], trade partnerships [TP]). It emphasizes agency–structure interactions and highlights research gaps, including limited WCSD innovation/EVA studies and rare quantification of institutional moderation (e.g., local CS governance, digital traceability platforms [DTP], South–South trade partnerships [SSTP]). This foundation supports the testable conceptual model guiding the study's methodology and empirical analysis.

Sustainability Theory and Transitions

Sustainability theory provides the conceptual foundation for understanding how agricultural systems evolve to balance environmental,

economic, and social goals (Grin et al., 2010; Pretty, 2008). Sustainability transitions theory emphasizes systemic shifts driven by interactions among niches, regimes, and socio-technical landscapes (Schot & Geels, 2008). In biodiversity-rich contexts, the adoption of sustainable practices can simultaneously enhance EP and market differentiation (MD) (Schmitt et al., 2010). This challenges the traditional trade-off paradigm and supports strategies where ecological integrity underpins economic value (Duguma et al., 2019).

Innovation Diffusion in Agriculture

Rogers' (2003) innovation diffusion model remains a cornerstone for explaining adoption patterns in agricultural contexts. Key attributes-relative advantage, compatibility, complexity, trialability, and observability-determine innovation uptake. In developing-country contexts, institutional enablers such as policy support (PS) and certification schemes (CS) can accelerate adoption, while governance gaps hinder scaling (Miller & Lee, 2021; Sathaye et al., 2020).

Sustainable Supply Chain Management (SSCM)

SSCM integrates environmental and social considerations into value chain design and governance (Carter & Rogers, 2008). In the coffee sector, sustainability certifications, traceability systems, and inclusive trading partnerships contribute to both EP and producer livelihoods (Donovan et al., 2017; Montalvo, 2019). However, the majority of research has focused on plantation-based systems in Latin America, with limited attention to wild coffee systems (WCS) in Africa and Asia (Davis et al., 2019).

Wild Coffee Sector Dynamics (WCSD)

WCS—especially in Ethiopia and northern Thailand—combine natural genetic resources, forest-based livelihoods, and cultural heritage (Krishnan et al., 2017). These systems are critical for in situ conservation and climate resilience but face threats from deforestation, market marginalization, and insufficient institutional support (Bunn et al., 2020; Mendez & Castillo, 2022).

Spatial and institutional contexts influence governance arrangements, supply chain integration, and the potential for value addition (Peluso, 2023).

Economic Value Addition (EVA)

EVA in biodiversity-sensitive contexts involves enhancing product quality, differentiation, and market positioning while safeguarding ecosystem services (Porter, 1985; Pascucci, 2022). In WCS, EVA is closely linked to sustainable innovation, which can improve producer incomes and consumer trust when combined with robust certification and branding strategies (Morris et al., 2020).

Mediating and Moderating Institutional Factors

Institutional factors often mediate or moderate the relationship between innovation adoption and value creation. EP, CB, and product differentiation (PD) act as mediators, while PS, CS, and trade partnerships (TP) serve as moderators that condition the effectiveness of innovation strategies (Grabs et al., 2022). Limited empirical work quantifies these interactions in WCS, underscoring the need for integrated analytical models (Ngure & Watanabe, 2024).

Existing literature demonstrates the potential for aligning ecological integrity and economic value in biodiversity-linked agricultural systems. Yet, significant gaps remain in understanding innovation pathways in WCS, especially in relation to institutional contingencies. This study addresses these gaps by developing a structural equation model (SEM) that links sustainable innovation, institutional context, and economic value in WCS. The model incorporates mediating and moderating variables to capture the complexity of sustainability transitions in these systems.

Methodology

The target population for this study comprises smallholder coffee producers in biodiversity-sensitive regions of Northern Thailand, particularly those engaged in sustainable, innovation-oriented production systems within the provinces of Chiang Rai, Chiang Mai, and Mae Hong Son. These highland

provinces were purposefully selected based on their ecological richness, socio-cultural diversity, and strategic relevance in the global specialty coffee industry (Pendergrast, 2015; Tan & Sitikarn, 2018).

Determining an adequate sample size is essential for ensuring the statistical validity of regression-based and mediation analyses. Following Cohen's (1992) guidelines for detecting medium effect sizes ($f^2 = 0.15$) in models with multiple predictors ($k = 9$), a minimum sample size of 180 is required to achieve a statistical power of 0.80 at the 0.05 significance level.

However, given the use of moderated mediation analysis with conditional process modeling, a larger sample is advisable to account for interaction terms and bootstrapped confidence intervals. Based on recommendations by Hayes (2017), the final sample target was set at $n = 350$ respondents, distributed approximately equally across the three provinces. This size ensures that indirect effects, moderated paths, and subgroup analyses (e.g., certified vs. non-certified producers) can be estimated with sufficient precision.

Moreover, allowing for anticipated attrition due to inaccessibility, incomplete responses, or consent withdrawal, the initial outreach aimed to contact approximately 420 households, with the expectation of achieving the final analytical sample through in-field replacement procedures.

To quantitatively examine the relationships hypothesized in this study, structured survey instruments were developed based on existing validated scales and adapted to the context of smallholder coffee producers in biodiversity-sensitive regions of Northern Thailand. Each core construct-sustainable farming practices, technology adoption, market diversification, economic value addition, mediating variables (environmental performance, consumer trust, product differentiation), and moderating variables (policy support, certification schemes, international trade partnerships)-is operationalized using a multi-item scale measured on a 7-point Likert

continuum. These instruments enable nuanced and statistically rigorous evaluation of both direct and indirect pathways in the moderated mediation model (Hayes, 2017).

All measurement instruments were developed in English and pre-tested using a bilingual panel of agricultural researchers and cooperative leaders in Chiang Rai and Chiang Mai to ensure cultural and linguistic validity. Content validity was established through expert review, while scale reliability will be assessed via Cronbach's alpha during data analysis.

With a final sample of 403 valid responses collected through stratified random sampling and field-administered surveys, the study achieved a balance between statistical power and contextual representation.

Results

This chapter presents the empirical findings derived from the cross-sectional survey of 403 smallholder coffee producers in Northern Thailand's biodiversity-sensitive regions, namely Chiang Rai, Chiang Mai, and Mae Hong Son. The analysis examines the direct, mediating, and moderated mediation effects of sustainable farming practices, technology adoption, and market diversification on economic value addition (EVA), in line with the conceptual framework and hypotheses developed in earlier chapters.

Sample Profile

The sample was nearly gender-balanced, with 51.4% male and 48.6% female respondents. The largest age cohorts were 35-44 years (25.6%) and 45-54 years (21.1%), indicating a predominantly middle-aged farming population. Educational attainment was relatively high, with 29.8% holding a bachelor's degree or higher, though 21.1% had only primary education or none. Coffee farming experience was substantial: 53.9% of respondents had more than 10 years in the sector. Land tenure varied-50.6% owned their farms, 24.1% were

tenants or leaseholders, and 16.9% farmed on community-owned land. Farm size clustered around 1–3 hectares (35.0%) and 3–5 hectares (29.5%). Market access was primarily through local traders (33.0%) and cooperatives (23.8%), with emerging channels including direct trade (14.4%) and online platforms (10.2%). Certification adoption was moderate at 42.4%, primarily in organic and FairTrade schemes.

Correlation Analysis

Pearson's correlation coefficients indicated strong, positive, and statistically significant relationships among the core variables. Sustainable farming practices ($r = 0.91$, $p < .001$), technology adoption ($r = 0.97$, $p < .001$), and market diversification ($r = 0.95$, $p < .001$) all correlated highly with EVA. Mediators-environmental performance ($r = 0.70$), consumer trust ($r = 0.80$), and product differentiation ($r = 0.81$)-also showed robust associations with EVA, while moderators (policy support, certification, trade partnerships) correlated moderately to strongly ($r = 0.62–0.76$) with both independent and mediating variables.

Table 1: Correlation between variables

Variables	Sustainable Farming Practices	Technology Adoption	Market Diversification	Environmental Performance	Consumer Trust	Product Differentiation	Economic Value Addition
Sustainable Farming Practices	1	0.86	0.78	0.78	0.71	0.65	0.91
Technology Adoption	0.86	1	0.9	0.66	0.83	0.77	0.97
Market Diversification	0.78	0.9	1	0.61	0.73	0.87	0.95
Environmental Performance	0.78	0.66	0.61	1	0.51	0.48	0.7
Consumer Trust	0.71	0.83	0.73	0.51	1	0.62	0.8

Product Differentiation	0.65	0.77	0.87	0.48	0.62	1	0.81
Economic Value Addition (EVA)	0.91	0.97	0.95	0.7	0.8	0.81	1

Measurement Reliability and Validity

All constructs demonstrated strong internal consistency (Cronbach's α = 0.84–0.91) and met convergent validity thresholds (CR ≥ 0.87; AVE ≥ 0.52). Exploratory factor analysis produced clean factor structures (loadings > 0.50) and explained 62–78% of variance. Confirmatory factor analysis indicated excellent model fit (χ^2/df = 2.13, CFI = 0.94, RMSEA = 0.045, SRMR = 0.052). Discriminant validity was confirmed via the Fornell–Larcker criterion and HTMT ratios (< 0.85). Common method variance was not a concern, with the first factor explaining only 26.7% of variance.

Hypothesis Testing

Direct Effects

Multiple regression results supported H1a–H1c, showing significant positive effects of sustainable farming (β = 0.315, p < .001), technology adoption (β = 0.281, p < .001), and market diversification (β = 0.340, p < .001) on EVA, with R^2 = 0.472. Market diversification exhibited the strongest effect, underscoring its role in enhancing profitability.

Table 2: Direct Effects

Independent Variable	Dependent Variable	Unstandardized Coefficient (B)	Standardized Coefficient (Beta)	Standard Error	t-value	p-value	R-squared
Sustainable Farming Practices	Economic Value Addition	0.312	0.315	0.045	6.93	0	0.472
Technology Adoption	Economic Value Addition	0.279	0.281	0.047	5.94	0	0.472
Market Diversification	Economic Value Addition	0.334	0.34	0.042	7.95	0	0.472

Mediation Effects

PROCESS Model 4 confirmed that environmental performance mediated the effect of sustainable farming on EVA (indirect effect = 0.124, 95% CI [0.063, 0.201]), consumer trust mediated the effect of technology adoption (0.098, CI [0.052, 0.161]), and product differentiation mediated the effect of market diversification (0.145, CI [0.084, 0.228]). All indirect effects were significant, supporting H2a–H2c.

Table 3: Mediation Effects

Pathway	Indirect Effect (Bootstrapped)	Standard Error	Bootstrapped CI (95%)	Significance
Sustainable Farming ⟶ Environmental Performance ⟶ Economic Value	0.124	0.032	[0.063, 0.201]	Significant
Technology Adoption ⟶ Consumer Trust ⟶ Economic Value	0.098	0.028	[0.052, 0.161]	Significant
Market Diversification ⟶ Product Differentiation ⟶ Economic Value	0.145	0.037	[0.084, 0.228]	Significant

Moderated Mediation Effects

PROCESS Model showed that policy support strengthened the environmental performance pathway from sustainable farming (index = 0.041, CI [0.011, 0.089]), certification enhanced the consumer trust pathway from technology adoption (0.038, CI [0.008, 0.079]), and international trade partnerships amplified the product differentiation pathway from market diversification (0.054, CI [0.017, 0.106]). These results confirm H3a–H3c.

Table 4: Moderation

Pathway	Index of Moderated Mediation	Bootstrapped CI (95%)	Significance
Sustainable Farming ⟶ Environmental Performance ⟶ Economic Value × Policy Support	0.041	[0.011, 0.089]	Significant
Technology Adoption ⟶ Consumer Trust ⟶ Economic Value × Certification	0.038	[0.008, 0.079]	Significant
Market Diversification ⟶ Product Differentiation ⟶ Economic Value × Trade Partnerships	0.054	[0.017, 0.106]	Significant

All nine hypotheses were supported, confirming that innovation strategies significantly enhance EVA in biodiversity-sensitive coffee supply chains. These effects are partially mediated by environmental and market-related mechanisms and amplified by supportive institutional contexts. The findings highlight that the alignment of innovation with ecological resilience, consumer trust, and institutional support is critical to realizing economic gains. This evidence provides a strong empirical basis for the discussion in Chapter 5, which will integrate these results into broader theoretical and policy frameworks.

Discussion

The findings of this study contribute significant empirical evidence to the growing body of literature on sustainability-oriented innovation in biodiversity-sensitive agricultural systems. Through the lens of a moderated mediation model, the results affirm that sustainable farming practices, technology adoption, and market diversification each exert significant positive effects on economic value addition (EVA) among smallholder coffee producers in Northern Thailand. These findings align with prior studies demonstrating the economic potential of integrated innovation strategies in rural contexts (Altieri & Toledo, 2011; Barrett, 2008; Donovan et al., 2017).

Importantly, this research advances the theoretical understanding of how these strategies operate by elucidating the mediating roles of environmental performance, consumer trust, and product differentiation. Sustainable farming practices enhance ecological outcomes-such as biodiversity conservation and soil quality-which are then monetized through certification or eco-label premiums (Jha et al., 2011; Duguma et al., 2019). Similarly, technology adoption fosters consumer trust via transparency-enhancing mechanisms such as traceability systems (Musa & Kadir, 2024; Partzsch et al., 2021), while market diversification supports product differentiation, enabling producers to access niche, premium markets (Grunert, 2005).

The moderating effects identified in this study further enrich the analytical framework. Policy support strengthens the link between sustainable farming and environmental performance, demonstrating that enabling governance structures are pivotal for translating ecological practices into market-recognized value (Kerr et al., 2022; Kassa et al., 2015). Certification schemes amplify the trust-building effects of technology adoption, confirming prior observations that institutional credibility is essential for market differentiation in credence goods (Ingram et al., 2020). Likewise, international

trade partnerships magnify the differentiating impact of market diversification, underscoring the role of global market linkages in enhancing competitive positioning (Behar, 2023; Tan & Sitikarn, 2018).

By demonstrating that institutional contexts condition the translation of innovation into economic returns, this study challenges linear innovation-diffusion models that assume a direct causal pathway from adoption to benefit (Leeuwis & Aarts, 2011; Hall et al., 2003). Instead, it supports systems-oriented perspectives that conceptualize value creation as an emergent property of interactions among technical, ecological, and institutional subsystems (Darnhofer, 2020). This resonates with the agricultural innovation systems (AIS) literature, which emphasizes the interdependence of multiple actors and enabling environments (Klerkx & Leeuwis, 2009).

Furthermore, the reconceptualization of environmental performance as a form of economic capital offers an important theoretical contribution. In this framework, ecological integrity functions not only as an intrinsic good but as a tradable asset when mediated through market-recognized verification systems (Le Coq et al., 2011). This has implications for both market-based conservation policies and farmer-level decision-making, suggesting that environmental outcomes can and should be integrated into value chain strategies rather than treated as externalities.

The integration of intangible relational assets, such as trust and differentiation, into value creation theory also extends the literature on supply chain sustainability. Trust, traditionally studied as a social construct, emerges here as a measurable economic mediator, influencing loyalty and pricing power. Similarly, product differentiation rooted in cultural identity and biodiversity positioning offers a pathway to sustainable competitive advantage, particularly in niche markets where authenticity and provenance are highly valued (Shiller, 2019).

From a methodological perspective, this research demonstrates the utility of moderated mediation modeling in unpacking complex agri-food systems. This approach, more commonly employed in psychology and marketing (Hayes, 2017), allows for a nuanced analysis of conditional indirect effects, revealing how innovation strategies operate through mediators under specific enabling conditions. This has potential for broader application in agricultural development studies, particularly for interventions that seek to balance economic viability with ecological sustainability.

In sum, the study provides robust evidence that economic upgrading in biodiversity-sensitive value chains is contingent on more than just the adoption of innovative practices. It requires a confluence of ecological performance, relational trust, and market positioning-each reinforced by supportive institutional structures. The implications are clear: without aligning farm-level strategies with enabling governance and market systems, the potential of sustainable innovations to deliver tangible economic benefits will remain underrealized.

Recommendation

Building on these findings, this study proposes a set of practical recommendations for farmers, policymakers, certification agencies, and trade partners to maximize the economic and ecological potential of biodiversity-sensitive coffee systems in Northern Thailand.

For Farmers:

Smallholders should adopt agroecological practices such as shade-tree intercropping, soil conservation, and biodiversity preservation, which have been shown to enhance both environmental performance and market value. These practices should be complemented with targeted technology adoption-particularly post-harvest innovations and digital traceability tools-that bolster

consumer trust. Farmers should also pursue market diversification strategies, including cooperative marketing, direct trade relationships, and participation in specialty coffee fairs, to strengthen product differentiation and price resilience.

For Policymakers:

Government agencies should integrate biodiversity metrics into agricultural development policies, incentivizing conservation-linked farming through subsidies, Payment for Ecosystem Services schemes, and insurance products. Extension services must evolve from input delivery toward holistic innovation support, incorporating training on agroecology, branding, and value chain literacy. Policies should also foster cooperative models by supporting shared infrastructure and facilitating access to niche markets through trade diplomacy and export promotion. Land tenure security should be harmonized with certification incentives to encourage long-term ecological investment.

For Certification Bodies:

Certification systems must be made more accessible to smallholders by lowering entry costs, adopting phased compliance models, and recognizing participatory guarantee systems. Standards should reflect local ecological realities and be communicated in culturally appropriate formats. Certification agencies should also integrate ecological metrics directly into their evaluation frameworks, linking higher premiums to measurable biodiversity outcomes.

For Trade Partners:

Exporters and roasters should co-invest in transparent traceability platforms that embed producer narratives into product marketing, ensuring authenticity and equitable representation. Long-term purchasing agreements and brand co-ownership models could enhance trust and value-sharing. Trade partnerships should also promote ecological performance by embedding biodiversity indicators into procurement criteria and advocating for preferential treatment of biodiversity-friendly products in international trade regulations.

Collectively, these recommendations underscore the necessity of an integrated approach that aligns farm-level innovation with market-facing and policy-enabling mechanisms. Only through coordinated action across multiple stakeholder groups can the full economic and ecological potential of biodiversity-sensitive coffee systems be realized.

This dissertation set out to explore how innovation-oriented strategies-specifically sustainable farming practices, technology adoption, and market diversification-affect economic value addition within biodiversity-sensitive agri-supply chains, focusing on wild and semi-wild coffee systems in Northern Thailand. Framed within a moderated mediation model and analyzed through a rigorous quantitative approach involving 403 valid responses from smallholder farmers, this study contributes to both academic theory and practical application in sustainability science, agri-innovation, and rural development.

At the empirical core of this research is the recognition that economic upgrading in ecological value chains is neither automatic nor linear. Rather, it is shaped by a complex web of intervening and contextual variables, including environmental performance, consumer trust, product differentiation, certification schemes, policy support, and trade partnerships. By disentangling these interrelations, this study offers a structured understanding of how innovation strategies translate into value, and under what conditions such value becomes tangible, inclusive, and sustainable.

Innovation Strategies Drive Value-But Indirectly and Conditionally

The study found statistically significant direct effects for all three innovation strategies-sustainable farming, technology adoption, and market diversification-on economic value addition. This supports the core proposition that ecological and technological upgrading can indeed yield financial dividends for smallholders when integrated with strategic market access. However, the

size of these direct effects, while positive, was modest compared to the total explained variance in the dependent variable.

The importance of mediating mechanisms thus becomes paramount. Environmental performance emerged as a strong mediator between sustainable farming and economic value, suggesting that ecological stewardship is not only a conservation imperative but also an economic strategy when properly recognized by consumers and buyers. Similarly, consumer trust and product differentiation mediated the relationships for technology and market strategies, respectively, underscoring the centrality of perception, branding, and information in the sustainability economy.

Furthermore, these mediated relationships were shown to be moderated by institutional factors. Policy support, certification schemes, and international trade partnerships significantly influenced the strength and direction of mediation pathways. This confirms that contextual enablers, such as supportive regulation and governance, are critical for unlocking innovation's full potential. Without them, even the best practices at the farm level may fail to achieve meaningful economic returns.

Theoretical Contributions and Cross-Disciplinary Synthesis

The study advances several academic frontiers. First, it enriches the innovation diffusion literature by moving beyond binary adoption models to consider post-adoption dynamics-i.e., how innovation outcomes are shaped by environmental and institutional variables. Second, it contributes to supply chain sustainability theory by empirically validating a systems-level model that integrates production, governance, and market interfaces.

By using a moderated mediation framework, this study offers a novel application of conditional process analysis in agri-environmental research-a methodology more commonly used in psychology and marketing (Hayes, 2017). This approach allows for a layered understanding of causality, moving past simple direct effects and accommodating real-world complexity. It also

connects otherwise siloed domains-agroecology, value chain development, institutional economics, and behavioral trust models-into a unified analytical structure.

Moreover, the study aligns with the sustainability transitions literature, particularly in showing how niche innovations (e.g., forest-based coffee) can reconfigure existing value chains when supported by appropriate regime-level changes, such as inclusive certification systems or transparent trade policies (Geels, 2002; Markard et al., 2012). This systemic framing is crucial for designing policy that is not only effective but resilient and scalable.

Practical Implications for Inclusive and Resilient Development

The findings carry significant implications for diverse stakeholders. For smallholder farmers, the results affirm that ecological and technological investments can be profitable-but only when linked with mechanisms that convert sustainability into recognizable and rewarded value. This includes transparent certification, digital traceability, and origin branding-all of which require institutional support and training.

For policymakers, the message is clear: enabling environments matter. Policy frameworks that provide financial incentives for certification, support cooperative development, and promote South-South trade are essential. These findings provide a strong empirical basis for integrating agricultural, environmental, and trade policies under a single strategic umbrella-especially in regions like Northern Thailand where natural capital and cultural identity are intertwined.

For certification bodies and trade partners, the study highlights the need for adaptive, context-sensitive models. Certification should not be a one-size-fits-all gatekeeping mechanism but a participatory tool that includes remote and disadvantaged producers. Trade partners, especially specialty roasters and

ethical importers, can use these insights to design better value-sharing models and co-invest in post-harvest innovation and story-based branding.

Limitations and Future Pathways

As with any empirical inquiry, this study is bound by certain limitations. The cross-sectional design precludes causal inference beyond statistical association. The reliance on self-reported Likert-scale data may be subject to social desirability and recall bias. Moreover, the study's geographic focus, while justified by Thailand's pioneering role in sustainable coffee transitions, limits generalizability.

Yet, these limitations also open avenues for future research, as outlined in Section 5.5. Longitudinal studies, experimental impact evaluations, and participatory innovation trials could all deepen and refine the insights presented here. The integration of remote sensing, mobile data, and AI-based diagnostics would further enrich methodological robustness.

Final Thoughts: Innovation with Integrity

At its heart, this dissertation is a contribution to the evolving quest for agricultural models that are not only productive and efficient but ecologically grounded, economically viable, and socially just. In a world facing intersecting crises-climate disruption, biodiversity loss, and rural marginalization-the need for such models has never been more urgent.

The wild coffee systems of Northern Thailand, with their rich agroecological heritage and vibrant community networks, represent both a challenge and a promise. They challenge dominant narratives of modernization by showing that tradition, ecology, and innovation can coexist. And they promise a future where value is not extracted, but co-created-where farmers are not mere producers but knowledge holders, stewards, and entrepreneurs in a new kind of economy.

The findings of this study offer not just answers but an invitation-for scholars, practitioners, and policymakers-to reimagine agri-value chains as living

systems, capable of renewal and regeneration. Through rigorous research and inclusive innovation, the path to sustainable prosperity is not only possible-it is already unfolding, bean by bean, in the shaded forest plots of the global South.

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