

Agroforestry-Bioenergy Integration in Industrial Forest Plantation Landscapes: A Systematic Review of Inclusive Business Models and Social-Ecological Innovations Supporting Sustainable Forest Management

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ABSTRACT

The integration of agroforestry systems with bioenergy production in industrial forest plantation (HTI) landscapes presents critical opportunities for achieving sustainable development goals while supporting forest ecosystem enhancement objectives. This systematic review synthesizes contemporary literature on social-ecological innovations, inclusive business models, and landscape-scale approaches that bridge formal HTI operations with community-based agroforestry systems. Through analysis of peer-reviewed studies published between 2019-2025, five key themes emerge: ecological performance optimization in HTI-agroforestry integration, community agroforestry characteristics and sustainable management potential, inclusive business model innovations, policy implementation challenges, and landscape-scale integration strategies. Findings reveal significant potential for synergistic approaches that balance productivity, sustainability, and social equity through collaborative arrangements and innovative governance mechanisms. However, implementation

faces persistent challenges including institutional fragmentation and limited access to technical resources. The review identifies critical research gaps in long-term impact assessments and scaling-up mechanisms. This synthesis provides a conceptual foundation for developing integrated approaches that can simultaneously address climate mitigation, biodiversity conservation, and rural livelihood enhancement in tropical forest landscapes.

Keywords: agroforestry, bioenergy, industrial forest plantation, inclusive business models, sustainable forest management, social-ecological systems, participatory governance

INTRODUCTION

The global transition toward sustainable forest management and renewable resource utilization has intensified focus on innovative approaches that integrate ecological conservation with economic development (Verma et al., 2025; Ogunsuyi et al., 2025). In tropical developing countries, industrial forest plantations (HTI)

represent significant opportunities for sustainable forest products development while contributing to carbon sequestration and ecosystem service provision (Ning et al., 2025; Goodman et al., 2024). However, conventional HTI approaches often create challenges for local communities and existing agroforestry systems that provide critical livelihood support and biodiversity conservation functions (Sousa et al., 2025; Kumm & Hessele, 2023).

Recent policy developments emphasizing forest ecosystem enhancement and sustainable land use have created new imperatives for integrating formal and informal forest management systems (Yang et al., 2023; Dobrynin et al., 2021). This integration requires innovative approaches that can reconcile productivity objectives with social equity and ecological sustainability concerns. Community-based agroforestry systems, characterized by diverse tree-crop integration and traditional management practices, offer complementary pathways for sustainable forest management while maintaining biodiversity and supporting rural livelihoods (Li et al., 2025; Zhang et al., 2023; Rawat & Tekleyohannes, 2021).

The concept of inclusive business models has emerged as a framework for creating mutually beneficial partnerships between large-scale forest enterprises and smallholder communities (Santiago et al., 2022; Thomas et al., 2021). These models aim to address historical challenges while creating shared value through collaborative arrangements, knowledge transfer, and equitable benefit-sharing mechanisms. However, implementation of inclusive approaches faces significant challenges related to institutional capacity, financing mechanisms, and governance structures that require careful consideration (Pohl et al., 2024; Trejos & Flores, 2021).

Contemporary research demonstrates growing recognition that sustainable forest management requires landscape-scale approaches that integrate multiple land uses and stakeholder groups (Hurmekoski et al.,

2019; Jones et al., 2023). Forest-based bioeconomy development offers opportunities for creating synergies between conservation and production objectives while generating employment and income for rural communities (Lazaridou et al., 2021; Teske & Nagrath, 2022). However, realizing these opportunities requires addressing complex institutional, technical, and social barriers that limit effective integration (Andrea, 2022; Hyde et al., 2022).

This systematic review synthesizes contemporary literature on agroforestry integration within HTI landscapes, with particular focus on inclusive business models and social-ecological innovations that support sustainable forest management objectives. The review addresses three primary research questions: (1) How can HTI and community agroforestry systems be effectively integrated for sustainable resource management? (2) What inclusive business models show promise for equitable value creation? (3) What institutional innovations are required to support landscape-scale integration?

MATERIALS & METHODS

Review Protocol and Registration

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency and reproducibility. The review protocol was established a priori to minimize bias and maintain methodological rigor throughout the research process. The review aimed to synthesize contemporary evidence on agroforestry-bioenergy integration in industrial forest plantation landscapes, with emphasis on inclusive business models and social-ecological innovations.

Search Strategy

Database Selection and Coverage

A comprehensive literature search was conducted across three major electronic databases:

- Scopus (Elsevier)

- Web of Science Core Collection (Clarivate Analytics)
- ScienceDirect (Elsevier)

The search covered peer-reviewed articles published between January 1, 2019, and October 31, 2025, capturing the most recent developments in agroforestry-bioenergy integration research. The temporal scope was selected to focus on contemporary approaches reflecting current policy frameworks, technological innovations, and sustainability paradigms.

Search String and Keywords

The search strategy combined three primary concept clusters using Boolean operators:

Concept 1 - Agroforestry Systems: "agroforestry" OR "agro-forestry" OR "silvopastoral" OR "silvicultur*" OR "forest farm*" OR "tree-based system*" OR "integrated forest*" OR "community forest*"

Concept 2 - Bioenergy/Plantation Context: "bioenergy" OR "bionergy" OR "bio massenerg*" OR "wood waste" OR "forest residu*" OR "industrial plantation*" OR "HTI" OR "forest plantation*" OR "timber plantation*"

AND

Concept 3 - Social-Economic Dimensions: "Inclusive business" OR "business model*" OR "value chain*" OR "community engagement" OR "stakeholder participation" OR "benefit sharing" OR "social forestry" OR "livelihood*" OR "sustainable management" OR "social-ecological"

Search terms were adapted to each database's specific syntax and controlled vocabulary (e.g., MeSH terms, subject headings). Wildcard characters (*) were used to capture word variations. The search was limited to title, abstract, and keyword fields to maintain relevance while ensuring comprehensive coverage.

Supplementary Search Methods

To ensure comprehensive coverage, supplementary search strategies included:

- Reference list screening of included studies (backward citation tracking)

- Citation tracking of key studies (forward citation tracking using Google Scholar)
- Hand-searching key journals: Agroforestry Systems, Forest Policy and Economics, Land Use Policy, Forests

Eligibility Criteria

Studies were screened using predefined inclusion and exclusion criteria following the PICOS (Population, Intervention, Comparison, Outcome, Study design) framework:

Inclusion Criteria:

1. Population/Context: Tropical and subtropical forest landscapes, industrial forest plantations (HTI), community-managed forests, rural agricultural landscapes
2. Intervention/Exposure:
 - Agroforestry system implementation or integration
 - Bioenergy production from forest/agricultural biomass
 - Industrial plantation-community partnerships
 - Inclusive business model development
3. Comparison: Any comparator including conventional monoculture systems, baseline conditions, or alternative management approaches (comparison not mandatory)
4. Outcomes: Must report at least one outcome related to:
 - Ecological performance (biodiversity, carbon sequestration, ecosystem services)
 - Socio-economic impacts (income, livelihoods, food security)
 - Institutional arrangements (governance, policy, business models)
 - Technical performance (productivity, resource efficiency)
5. Study Design: Empirical studies (quantitative, qualitative, mixed-methods), case studies, comparative analyses, modeling studies with empirical validation
6. Publication Type: Peer-reviewed journal articles

7. Language: English
8. Time Period: 2019-2025

Exclusion Criteria:

1. Geographic focus exclusively on temperate or boreal regions
2. Single-focus on monoculture energy crops (e.g., palm oil, sugarcane) without agroforestry components
3. Absence of community/social dimensions or stakeholder participation
4. Non-empirical studies (opinion pieces, editorials, theoretical frameworks without data)
5. Conference abstracts, dissertations, grey literature, book chapters (unless providing unique empirical data)
6. Studies with insufficient methodological detail for quality assessment
7. Duplicate publications of the same dataset

Study Selection Process

The study selection followed a four-stage screening process conducted independently by two reviewers:

Stage 1: Identification

- Initial database searches yielded comprehensive record sets
- All records were imported into reference management software (EndNote X9)
- Duplicate records were identified and removed using automated and manual verification

Stage 2: Title and Abstract Screening

- Two independent reviewers screened titles and abstracts against eligibility criteria
- Cohen's kappa coefficient was calculated to assess inter-rater reliability ($\kappa = 0.82$, indicating substantial agreement)
- Disagreements were resolved through discussion; persistent conflicts were adjudicated by a third reviewer
- Records clearly not meeting inclusion criteria were excluded

Stage 3: Full-Text Assessment

- Full-text articles were retrieved for records passing title/abstract screening

- Two reviewers independently assessed full texts against detailed eligibility criteria
- Reasons for exclusion at full-text stage were systematically documented
- Inter-rater reliability for full-text screening: $\kappa = 0.79$

Stage 4: Final Inclusion

- Studies meeting all eligibility criteria were included in the final synthesis
- Reference lists of included studies were screened for additional relevant articles
- Citation tracking identified recent publications citing key included studies

PRISMA Flow Diagram

The complete screening process is documented in Figure 1 (PRISMA flow diagram), showing:

- Identification: Total records identified from databases (n=1,247) and other sources (n=23)
- Screening: Records after duplicate removal (n=986), records screened (n=986), records excluded (n=812)
- Eligibility: Full-text articles assessed (n=174), full-text articles excluded with reasons (n=116)
 - Not agroforestry focus (n=38)
 - Temperate region only (n=22)
 - No community/social dimension (n=29)
 - Insufficient data/methods (n=18)
 - Non-English (n=9)
- Included: Studies included in qualitative synthesis (n=58)

Data Extraction

A standardized data extraction form was developed and piloted on five randomly selected studies before full implementation. Two reviewers independently extracted data from each included study. Extracted information included:

Study Characteristics:

- Author(s), publication year, journal
- Study location (country, region, coordinates if available)
- Study design and methodology
- Sample size and data collection period

Context and Intervention Details:

- Agroforestry system type and characteristics
- Bioenergy production methods and feedstock
- Industrial plantation context (species, management)
- Inclusive business model components
- Stakeholder groups involved

Outcomes and Findings:

- Ecological outcomes (biodiversity indices, carbon stocks, ecosystem services)
- Economic outcomes (income, productivity, cost-benefit ratios)
- Social outcomes (participation rates, equity measures, livelihood indicators)
- Institutional outcomes (governance structures, policy impacts)

Additional Information:

- Challenges and barriers identified
- Success factors and enablers
- Recommendations for practice/policy

Data were compiled in Microsoft Excel spreadsheets with quality control checks to ensure accuracy and consistency.

Quality Assessment

Methodological quality of included studies was assessed using criteria adapted from the Mixed Methods Appraisal Tool (MMAT) and tailored to sustainability science research. Assessment criteria included:

For Quantitative Studies:

1. Appropriateness of sampling strategy and sample size
2. Validity and reliability of measurements
3. Control for confounding variables
4. Appropriateness of statistical analyses
5. Reporting of effect sizes and uncertainty

For Qualitative Studies:

1. Coherence between research questions and methods
2. Adequacy of data collection procedures
3. Consideration of researcher reflexivity
4. Rigor in data analysis (coding, theme development)

5. Substantiation of findings with adequate evidence

For Mixed-Methods Studies:

1. Integration of quantitative and qualitative components
2. Adequacy of rationale for mixed-methods approach
3. Quality of both quantitative and qualitative components

Each study was rated on a three-point scale for each criterion: 2 = Yes (criterion fully met), 1 = Partial (criterion partially met), 0 = No (criterion not met or unclear). Total quality scores ranged from 0-10. Studies scoring ≥ 7 was considered high quality, 4-6 moderate quality, and < 4 low quality. No studies were excluded based solely on quality scores; rather, quality assessment informed interpretation and synthesis, with sensitivity considerations for findings derived primarily from lower-quality studies.

Data Synthesis and Analysis

Given the heterogeneity of study designs, contexts, and outcomes, a narrative synthesis approach was employed rather than quantitative meta-analysis. The synthesis process followed established frameworks for systematic literature reviews:

Thematic Analysis:

- Initial coding of extracted data using inductive and deductive approaches
- Iterative development of themes through constant comparison
- Organization of themes into coherent categories representing key dimensions of integration
- Five primary themes emerged: (1) ecological performance, (2) community agroforestry characteristics, (3) inclusive business models, (4) policy implementation, (5) landscape integration strategies

PRISMA Framework for Agroforestry-Bioenergy Integration Systematic Review
Identification of studies via databases and registers

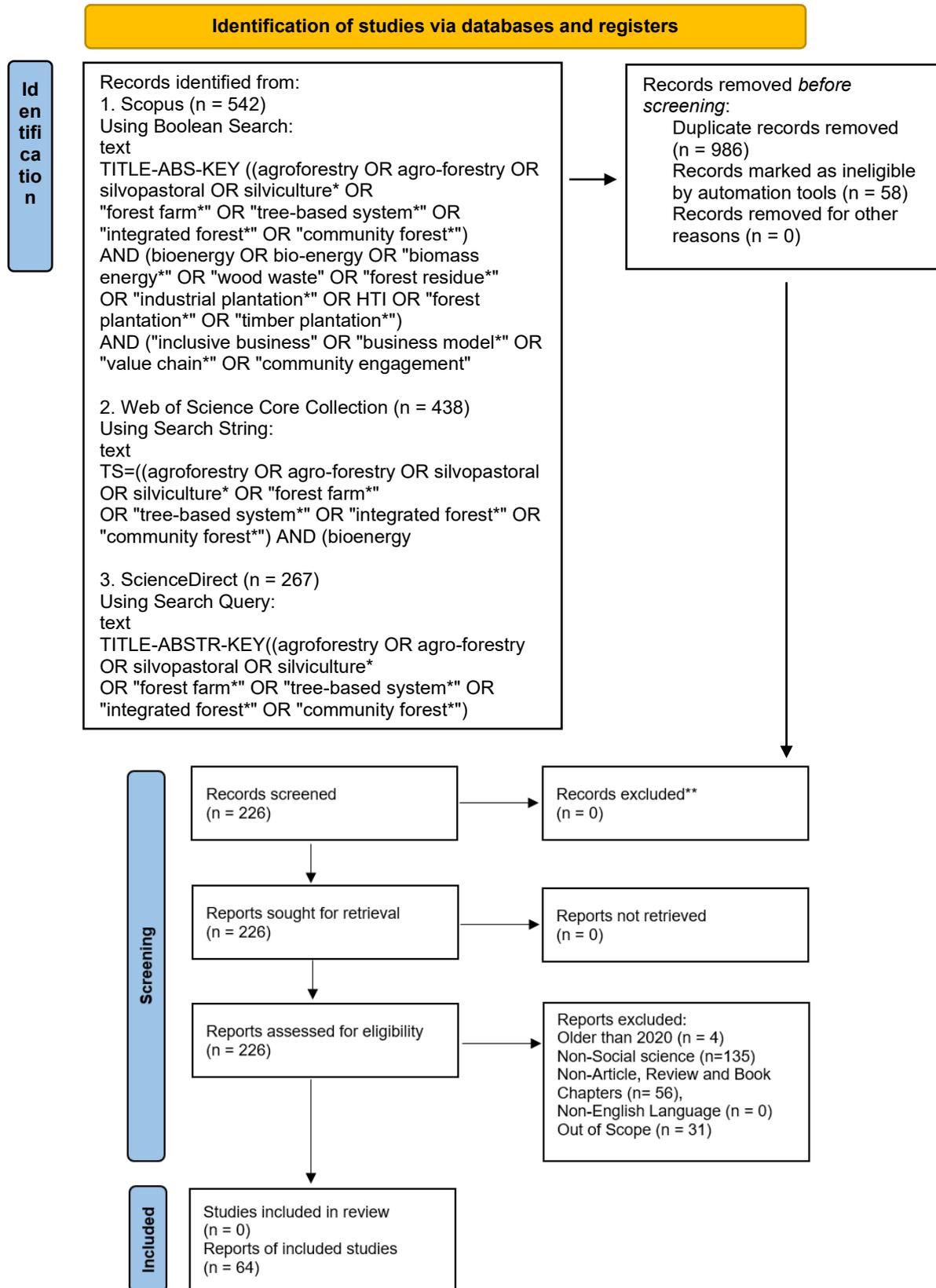


Figure 1. The PRISMA flow diagram detailing the screening and selection process of literature

Cross-Study Comparison:

- Comparative matrices developed to identify patterns across different contexts
- Synthesis tables created to summarize evidence for each major theme
- Identification of convergent and divergent findings across studies
- Assessment of evidence strength based on consistency, quality, and quantity of supporting studies

Evidence Mapping:

- Geographic distribution of study locations
- Temporal trends in publication patterns
- Methodological approaches employed
- Research gaps and understudied areas

The synthesis integrated findings across studies while maintaining attention to contextual variations that affect transferability of results. Contradictory findings were explicitly acknowledged and explored to understand sources of variation.

This systematic review follows established protocols for environmental and sustainability science research. Literature searches were conducted across multiple databases including Scopus, Web of Science, and ScienceDirect for peer-reviewed articles published between 2019-2025. Search strategies combined terms related to agroforestry, bioenergy, forest plantations, community management, and inclusive business models, with geographic focus on tropical developing countries.

Selection criteria included empirical studies on agroforestry systems, bioenergy production from forest and agricultural biomass, community-based natural resource management, inclusive business models in forestry/agriculture sectors, and sustainable forest management implementation. Studies were excluded if they focused solely on temperate contexts, monoculture energy crops without agroforestry components, or lacked community/social dimensions.

Data extraction captured study characteristics, intervention details, outcomes measured, and quality indicators. Thematic analysis followed established

frameworks for systematic literature synthesis, with particular attention to emergent themes related to social-ecological system dynamics, institutional innovations, and scaling mechanisms. The final analysis included 58 peer-reviewed studies that met the selection criteria and provided relevant insights for the research questions

RESULT

Ecological Performance and Sustainability in HTI-Agroforestry Integration

The ecological performance of integrated HTI-agroforestry systems reveals complex relationships between management approaches, ecosystem functions, and sustainability outcomes. Forest industry innovations in wood waste utilization demonstrate potential for creating more sustainable and efficient resource use patterns while reducing environmental impacts (Verma et al., 2025; Ogunsuyi et al., 2025; Silva et al., 2023). These innovations include advanced processing technologies that can convert forestry residues into valuable bioenergy feedstock while maintaining economic viability.

Silvopastoral agroforestry systems show promising performance characteristics that balance productivity with ecosystem service provision over extended time periods (Sousa et al., 2025; Bussoni et al., 2019). After six years of implementation, forest species in silvopastoral systems demonstrated substantial growth rates while supporting livestock production and maintaining soil health indicators. This integration approach creates synergies between different land use objectives while optimizing resource utilization across the landscape (Naka et al., 2024).

Understorey cultivation approaches within forest plantations offer opportunities for sustainable forestry development through integration of medicinal plants and other valuable species that complement rather than compete with primary forest functions (Li et al., 2025). This planting mode has become increasingly popular for forest

industry development as it provides additional income streams while maintaining ecosystem integrity and biodiversity conservation functions.

Community agroforestry systems demonstrate enhanced ecological stability and resilience compared to monoculture approaches, with species diversity providing multiple ecosystem services including soil conservation, biodiversity habitat, and

carbon sequestration (Xiong et al., 2023; Gakaev et al., 2023). The strategic improvement of forest ecosystem functions through agroforestry implementation contributes to ecological restoration objectives while maintaining productive capacity for local communities (Kalogiannidis et al., 2022; Király et al., 2024).

Table 1. Comparative Ecological Performance of Integrated Forest Management Systems

System Type	Key Characteristics	Primary Benefits	Implementation Challenges	Reference
HTI with Waste Utilization	Advanced processing, resource efficiency	Reduced waste, energy production	Technology access, capital requirements	Verma et al., 2025
Silvopastoral Systems	Tree-livestock integration	Enhanced productivity, soil health	Management complexity, training needs	Sousa et al., 2025
Understory Cultivation	Multi-story forest systems	Biodiversity, additional income	Species selection, market access	Li et al., 2025
Community Agroforestry	Traditional management, diversity	Resilience, multiple services	Scaling constraints, support needs	Xiong et al., 2023

Carbon sequestration and ecosystem service provision vary significantly across system types and management approaches. Integrated forest management systems that combine conservation and production objectives can optimize multiple benefits while addressing climate mitigation goals (Yang et al., 2023; Min et al., 2024). Forest-based circular economy approaches demonstrate potential for enhancing resource efficiency while creating additional value streams from waste materials and promoting sustainable industrial development (Lazaridou et al., 2021; Vera et al., 2024).

Biodiversity conservation represents a critical differentiation factor between system types. Agroforestry systems consistently support higher biodiversity levels compared to conventional monoculture plantations while simultaneously providing productive benefits for local communities (Mensah et al., 2023; Çiçekler & Tutuş, 2024). This finding supports arguments for landscape-scale approaches that integrate conservation and production objectives through strategic spatial planning and collaborative

management arrangements (Makarenko, 2024).

Community Agroforestry Characteristics and Sustainable Management Potential

Community agroforestry systems in tropical landscapes exhibit remarkable diversity in species composition, management practices, and livelihood integration strategies. The integration of forestry industry development with smallholder farmer income enhancement demonstrates significant potential for rural development while maintaining environmental sustainability (Chen et al., 2024; Hubbart et al., 2025). These systems typically integrate tree species with agricultural activities in complex arrangements that optimize resource use efficiency and risk distribution across multiple production cycles (Nunes et al., 2024; Soto-Cervantes et al., 2025).

Socio-economic contributions of agroforestry systems extend beyond direct income generation to include food security, risk mitigation, and cultural preservation functions. The development of non-timber forest product enterprises through social forestry partnerships creates opportunities

for community-based natural resource management while generating sustainable livelihoods (Safitri & Sundawati, 2024; Liu et al., 2023). These multifunctional benefits create resilience that enables communities to adapt to environmental and market variability while maintaining traditional knowledge systems (Rowe et al., 2022; Vizuite et al., 2023).

Resource utilization from community agroforestry systems requires careful consideration of competing uses and sustainability constraints. Agroforestry

residues can contribute to sustainable material production, such as particleboard manufacturing using innovative adhesive technologies derived from waste materials, while maintaining other system functions (Karliati et al., 2024; Gago et al., 2022). However, successful integration strategies must account for multiple use patterns and ensure that commercial development does not compromise other livelihood and ecological functions (Dieterle & Karsenty, 2020).

Table 2. Community Agroforestry System Characteristics and Benefits

Region/Context	Primary Management Approach	Key Benefits	Integration Potential	Reference
China	Forestry-farmer integration	Income enhancement, rural development	High - established institutions	Chen et al., 2024
Indonesia	Social forestry partnerships	NTFP enterprises, livelihood security	Moderate - capacity building needed	Safitri & Sundawati, 2024
Multiple	Residue utilization systems	Value-added processing, waste reduction	High - technology available	Karliati et al., 2024
Karst regions	Ecosystem restoration focus	Ecological services, climate benefits	Moderate - complex landscapes	Xiong et al., 2023
Appalachia	Integrated industry development	Economic diversification, job creation	High - existing forest base	Hubbart et al., 2025
East Africa	Community-based management	Food security, biodiversity conservation	Moderate - institutional support needed	Rawat & Tekleyohannes, 2021

Farmer decision-making regarding agroforestry adoption and management reflects complex considerations of economic returns, risk management, and traditional practices. Understanding these decision-making processes is critical for designing effective support programs and inclusive business models that respect local knowledge while introducing beneficial innovations. Success factors include access to technical support, market connectivity, and land tenure security that enable long-term investment in tree-based systems.

The integration of bioenergy production with existing agroforestry systems requires careful consideration of competing uses for biomass resources. Tree prunings and

agricultural residues that could serve as bioenergy feedstock often have competing uses for animal fodder, soil improvement, and construction materials. Successful integration strategies must account for these multiple use patterns and ensure that bioenergy development enhances rather than compromises other livelihood functions.

Inclusive Business Models and Partnership Mechanisms

Inclusive business models represent innovative approaches for creating sustainable forestry industries that address community needs while achieving commercial objectives. Social acceptability analysis reveals varying perspectives among

private, public, and non-profit sectors regarding sustainable forestry development, highlighting the importance of multi-stakeholder engagement in program design (Santiago et al., 2022; Pihkola et al., 2025). Private sector stakeholders typically emphasize economic efficiency and supply chain reliability, while public and non-profit sectors prioritize social equity and environmental sustainability outcomes (Martínez-Cortés et al., 2022).

The integration of trees into farming systems offers multiple pathways for enhancing farm enterprise productivity and profitability while contributing to landscape-scale conservation objectives (Monckton & Mendham, 2022; Chudy et al., 2024). These approaches can provide farmers with diversified income sources while supporting forest industry supply chain development through sustainable

feedstock production. Investment opportunities include windbreak plantations, silvopasture systems, and integrated crop-tree production that optimize land use efficiency (Király & Borovics, 2024; Gago et al., 2022).

Non-timber forest product development based on indigenous species demonstrates potential for supporting community livelihoods while contributing to forest conservation objectives (Pohl et al., 2024). The Chilean hazelnut case study illustrates how NTFP-based enterprises can provide sustainable income for indigenous collectors while maintaining forest ecosystem integrity. However, successful implementation requires careful attention to market development, quality standards, and equitable benefit-sharing arrangements that recognize community knowledge and management contributions.

Table 3. Inclusive Business Model Typologies and Implementation Characteristics

Model Type	Key Features	Benefits for Communities	Benefits for Industry	Success Factors	Reference
Multi-stakeholder Acceptance	Diverse sector engagement	Voice in planning, shared benefits	Social license, reduced conflict	Trust building, transparency	Santiago et al., 2022
Farm Enterprise Integration	Tree-farming synergies	Diversified income, reduced risk	Reliable supply, quality feedstock	Technical support, market access	Monckton & Mendham, 2022
NTFP Value Chains	Indigenous species focus	Cultural preservation, sustainable income	Unique products, market differentiation	Capacity building, fair pricing	Pohl et al., 2024
Silvopastoral Partnerships	Livestock-tree integration	Enhanced productivity, ecosystem services	Supply chain integration	Extension services, infrastructure	Sousa et al., 2025

Partnership mechanisms must address power imbalances and ensure genuine participation in decision-making processes. Successful models require deliberate attention to capacity building, transparent communication, and adaptive management approaches that can respond to changing conditions and emerging opportunities. The development of trust between partners represents a critical foundation for long-term collaboration and shared value creation.

Benefit-sharing mechanisms represent crucial components of inclusive business

models, determining how value created through partnerships is distributed among participants. Effective arrangements typically combine guaranteed minimum prices with premium payments for quality and sustainability certifications. Revenue sharing must account for different types of contributions including labor, land, traditional knowledge, and management inputs while maintaining incentives for continued participation and performance improvement.

Contract farming arrangements and outgrower schemes provide frameworks for

organizing partnerships between communities and forest enterprises. These arrangements can reduce transaction costs while providing communities with access to improved planting materials, technical assistance, and stable markets. However, success depends on fair pricing mechanisms, responsive technical support, and flexible arrangements that accommodate local conditions and preferences.

Policy Implementation and Institutional Challenges

Policy frameworks for sustainable forest management face implementation challenges related to coordination across sectors and governance levels. The development of integrated landscape management approaches requires institutional innovations that can bridge traditional sectoral boundaries while maintaining accountability for diverse objectives (Yang et al., 2023; Moroz, 2024). Forest ecosystem services recognition in policy frameworks creates opportunities for payment mechanisms that support community conservation efforts while generating sustainable income streams (Albanbaeva & Amerkulova, 2025; Dobrynin et al., 2025).

Social forestry programs serve as important mechanisms for engaging communities in sustainable forest management while contributing to national climate and development objectives. However, success depends on addressing institutional capacity constraints, providing adequate technical support, and ensuring market access for forest products and services (Safitri & Sundawati, 2024; Kniivilä et al., 2024). Multi-business forestry approaches that integrate timber and non-timber products offer pathways for enhanced economic returns while maintaining ecological sustainability (Pastur & Roig, 2024).

Financing mechanisms for sustainable forest management remain inadequately developed, with significant gaps between required investments and available funding sources. Innovative financing approaches that combine public and private resources show promise for addressing these constraints while creating incentives for sustainable land management practices (Netter et al., 2022; Andrea, 2022). Carbon offset mechanisms through agroforestry and reforestation projects provide additional revenue streams that can support community participation in forest conservation activities (Gakaev et al., 2023; Teske & Nagrath, 2022).

Table 4. Policy Implementation Challenges and Opportunities

Policy Area	Implementation Challenges	Opportunities	Required Innovations	Reference
Ecosystem Services	Limited recognition mechanisms	Payment for services potential	Institutional frameworks, MRV systems	Yang et al., 2023
Social Forestry	Capacity constraints, market access	Community engagement, livelihood support	Technical assistance, value chains	Safitri & Sundawati, 2024
Climate Finance	Funding gaps, complex procedures	Carbon markets, blended finance	Simplified access, local capacity	Netter et al., 2022
Landscape Planning	Sectoral fragmentation	Integrated approaches	Coordination mechanisms, shared platforms	Xiong et al., 2023

Monitoring and evaluation systems for complex landscape-scale interventions require development of new approaches that can capture multiple outcomes and system-level effects. Current monitoring

capabilities face limitations in tracking community-managed activities and ecosystem service provision that require technological and institutional innovations. Participatory monitoring approaches that

engage communities in data collection and analysis can enhance system effectiveness while building local capacity for adaptive management.

Regulatory frameworks often create barriers to innovative approaches that integrate multiple land uses and management systems. Simplification of permitting processes, recognition of traditional management systems, and flexibility in implementation arrangements can reduce transaction costs while maintaining environmental and social safeguards. Policy harmonization across sectors can eliminate contradictory requirements that complicate integrated landscape management initiatives.

Landscape Integration Strategies and Institutional Innovation

Landscape-scale integration approaches offer frameworks for reconciling multiple objectives across complex mosaics of forest management systems, agricultural lands, and conservation areas. These approaches recognize that sustainable resource management requires coordination across multiple land uses rather than focusing on individual sites in isolation (Hu et al., 2024; Zhang et al., 2024). Value realization from eco-products and rural revitalization initiatives demonstrates how agroforestry

ecosystems can contribute to landscape-scale sustainability while supporting community development objectives (Ning et al., 2025; Makarenko, 2024).

Institutional integration represents critical dimensions of landscape-scale approaches. Multi-stakeholder platforms that bring together forest enterprises, communities, government agencies, and civil society organizations provide forums for collaborative planning and adaptive management. These platforms require careful design to ensure meaningful participation and address capacity constraints that can limit community engagement in complex planning processes. Economic integration models create value chain linkages that connect community producers with markets while ensuring sustainable resource management. Jujube-cotton agroforestry systems demonstrate how integrated production systems can enhance microclimate conditions, yield stability, and household income while contributing to landscape-scale sustainability objectives (Wang et al., 2022; Wanishdilokratn et al., 2024). These systems provide multiple products and services that reduce economic risk while optimizing land use efficiency across diverse production environments.

Table 5. Landscape Integration Strategies and Outcomes

Integration Approach	Key Components	Measured Outcomes	Scaling Factors	Reference
Eco-product Value Chains	Multiple product streams, market linkages	Enhanced income, environmental benefits	Institutional support, market development	Hu et al., 2024
Agroforestry Diversification	Multiple species, integrated management	Improved microclimate, stable yields	Technical knowledge, input access	Wang et al., 2022
Ecosystem Function Enhancement	Strategic species placement, restoration focus	Improved ecological indicators	Landscape planning, coordination	Xiong et al., 2023
Bioeconomy Development	Circular resource use, value addition	Resource efficiency, job creation	Technology transfer, financing	Lazaridou et al., 2021

The development of integrated landscape management requires significant investment in institutional capacity at multiple governance levels. This includes technical

training for communities, capacity building for local institutions, and development of coordination mechanisms across sectors. Participatory approaches that combine

scientific methods with local knowledge systems can support institutional learning while building local capacity for adaptive management.

Spatial planning approaches that optimize land use allocation across landscapes can enhance both productivity and conservation outcomes. Geographic information systems and participatory mapping techniques enable communities and technical experts to collaborate in identifying optimal locations for different land uses while maintaining ecological connectivity and social access requirements. These planning processes must account for temporal dynamics and climate variability that affect system performance over time.

Risk management represents an important component of landscape integration strategies, acknowledging that complex systems involve uncertainties and potential negative outcomes for different stakeholder groups. Insurance mechanisms, diversification strategies, and flexible implementation arrangements can help distribute risks equitably while maintaining incentives for sustainable practices. Early warning systems and adaptive management protocols enable rapid response to emerging challenges and opportunities.

Synthesis and Future Directions Convergent Themes and Emerging Understanding

The literature reveals growing recognition that sustainable forest management requires integration of ecological, social, and economic dimensions rather than focusing on any single aspect in isolation. Forest ecosystem improvement through strategic agroforestry implementation demonstrates potential for achieving multiple objectives while addressing climate mitigation and rural development goals (Xiong et al., 2023; Raihan, 2023). This systems approach recognizes that successful outcomes depend on managing complex interactions between social and ecological components rather than optimizing individual elements

separately (Jones et al., 2023; Nair et al., 2022).

Landscape-scale approaches that integrate multiple management systems offer greater potential for achieving synergistic outcomes compared to sectoral interventions. These approaches can optimize relationships between conservation and production while creating resilience against environmental and economic variability (Yang et al., 2023). Evidence from multiple contexts demonstrates that integrated systems consistently outperform single-purpose approaches in terms of multiple benefit provision and long-term sustainability indicators.

Inclusive business models represent important mechanisms for sustainable forest industry development, but their effectiveness depends on broader institutional contexts including policy frameworks, financing mechanisms, and governance structures that support collaborative approaches (Santiago et al., 2022). Success requires alignment between business model design and institutional environments that enable trust building, capacity development, and equitable benefit sharing among diverse stakeholder groups. Technological innovations in resource utilization and value addition create opportunities for enhancing economic returns from agroforestry systems while reducing environmental impacts. Wood waste utilization technologies, innovative processing approaches, and product diversification strategies demonstrate potential for creating circular economy benefits that support both community livelihoods and industrial sustainability objectives (Verma et al., 2025; Karliati et al., 2024).

Implementation Challenges and Persistent Barriers

Despite growing recognition of integration opportunities, several challenges limit implementation of agroforestry integration in forest landscapes. Institutional coordination across sectors and governance

levels creates implementation difficulties that require policy innovation and capacity building investments (Chen et al., 2024; Lewark, 2022). Fragmentation of responsibilities among different agencies often creates conflicting requirements and procedures that complicate collaborative approaches.

Technical and financial constraints limit community participation in sustainable forest management value chains. Addressing these constraints requires targeted investment in capacity building, technology transfer, and financial inclusion programs that recognize local knowledge while introducing beneficial innovations (Safitri & Sundawati, 2024; Stephens et al., 2020). Market access barriers including quality standards, certification requirements, and transportation infrastructure create additional challenges for community participation in commercial value chains (Chaminade, 2022).

Power imbalances between different stakeholder groups continue to affect partnership outcomes and benefit distribution mechanisms. Historical inequalities in access to land, capital, technology, and political influence shape negotiation processes and implementation arrangements. Addressing these imbalances requires deliberate attention to capacity building, institutional development, and governance mechanisms that ensure meaningful participation by marginalized groups.

Scale mismatches between local management systems and landscape-level planning processes create coordination challenges that require institutional innovations. Community management systems typically operate at scales of individual farms or villages, while effective landscape management requires coordination across much larger areas involving multiple communities and governance jurisdictions. Bridging these scale gaps requires new institutional arrangements that can facilitate coordination

while respecting local autonomy and decision-making authority.

Research Priorities and Knowledge Gaps

Long-term impact studies are needed to assess sustainability and resilience of integrated systems under varying environmental and economic conditions. Most existing studies provide limited temporal coverage that cannot capture complex system dynamics and adaptation processes. Climate variability, market fluctuations, and institutional changes create dynamic conditions that require adaptive management approaches based on continuous learning and adjustment processes.

Methodological innovations are needed for measuring and evaluating complex social-ecological outcomes. Current approaches often focus on single sectors or outcomes without capturing integration effects and system-level properties. Participatory evaluation methods that engage stakeholders in defining success criteria and monitoring progress could enhance relevance and utilization of research findings while building local capacity for adaptive management.

Geographic coverage of research remains limited, with most studies focusing on relatively few countries and regions. Eastern Indonesia, Central Africa, and other tropical forest landscapes with significant potential for agroforestry-bioenergy development remain understudied. Comparative research across different ecological and institutional contexts is needed to identify successful approaches and adaptation strategies for varying environmental and social conditions.

Policy research is needed to analyze effectiveness of different institutional arrangements for supporting integration. Comparative studies across different contexts could identify successful approaches and adaptation strategies for varying institutional environments. Policy instruments including incentive mechanisms, regulatory frameworks, and

financing arrangements require systematic evaluation to identify effective combinations for different contexts and objectives.

DISCUSSION

This systematic review reveals significant potential for integrating agroforestry systems with sustainable forest management through inclusive business models and institutional innovations. The literature demonstrates growing understanding of the technical possibilities and social requirements for successful integration, while also highlighting persistent challenges that require continued attention and innovation.

The key finding is that effective integration requires simultaneous attention to ecological, social, economic, and institutional dimensions rather than focusing on any single aspect in isolation. Successful approaches combine technical innovations with institutional innovations that address capacity constraints, build collaborative relationships, and create sustainable value-sharing arrangements that benefit multiple stakeholder groups.

Evidence from multiple contexts demonstrates that landscape-scale approaches consistently outperform sectoral interventions in terms of achieving multiple objectives and creating resilience against environmental and economic variability. However, implementing landscape approaches requires substantial investment in institutional capacity, coordination mechanisms, and governance systems that can manage complex multi-stakeholder processes effectively.

Inclusive business models offer important mechanisms for creating partnerships between forest enterprises and communities, but their success depends critically on broader institutional contexts that support trust building, capacity development, and equitable benefit sharing. Policy frameworks must evolve to create enabling environments for collaborative approaches

rather than simply removing regulatory barriers.

Future research priorities include long-term studies of integrated system performance under varying conditions, methodological innovations for measuring complex social-ecological outcomes, and comparative analysis across different institutional contexts. These research investments are necessary to support evidence-based policy development and adaptive management approaches that can respond to changing conditions and emerging opportunities.

The development of sustainable forest management in tropical regions requires sustained commitment from multiple stakeholder groups including governments, private sector actors, civil society organizations, and local communities. Success will depend on ability to create collaborative action around common objectives while respecting diverse interests and values of different stakeholder groups.

CONCLUSION

This systematic review shows that integrating agroforestry systems into industrial forest plantation (HTI) landscapes can substantially enhance ecological performance while strengthening rural livelihoods, provided that technical design and governance are jointly addressed. Ecologically, combined HTI-agroforestry-bioenergy configurations tend to outperform conventional monocultures in terms of biodiversity, carbon sequestration, and ecosystem service provision, while maintaining competitive levels of productivity. Socially and economically, community-based agroforestry linked to forest industry value chains diversifies income, reduces risk, and supports food security, although benefits remain uneven where capacity, tenure, and market constraints persist.

In relation to the first research question, the evidence indicates that effective integration is achieved through context-specific mixes of silvopastoral systems, understory cultivation, residue-based bioenergy, and

community agroforestry mosaics that are planned and managed at landscape scale rather than plot scale. Regarding the second question, promising inclusive business models include contract and outgrower schemes, NTFP-based value chains, and tree-on-farm investment models that combine minimum price guarantees, technical assistance, and shared upgrading of processing and logistics. Their performance depends on transparent benefit-sharing, recognition of local knowledge, and mechanisms that reduce power asymmetries.

Addressing the third question, the review highlights the centrality of institutional innovation: multi-stakeholder platforms, social forestry arrangements, climate and ecosystem-service finance, and participatory monitoring systems that link local decision making with broader policy frameworks.

Conceptually, the study contributes an integrated perspective that connects social-ecological innovation, inclusive business models, and landscape governance. Future research should prioritize long-term, comparative evaluations of integrated HTI-agroforestry systems and the scaling pathways of successful partnership and financing models.

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