Forestry: Jurnal Ilmu Kehutanan
Volume. 1, Issue 1, November 2025
Page No: 44-57

Agroforestry as Climate Action: Evidence from Carbon Sequestration to Food Security

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Received : September 30, 2025
Accepted : November 11, 2025
Published : November 30, 2025

Citation: Sari, I.A., & Jumiyati, S., (2025). Economic Valuation of Forest Ecosystem Services: Methods, Applications, and Policy Implications. Forestry: Jurnal Ilmu Kehutanan, 1(1), 44-57.

ABSTRACT: Agroforestry is increasingly recognized as a sustainable land-use strategy that addresses climate change, enhances biodiversity, and improves rural livelihoods. This narrative review aims to synthesize current research on the ecological and socio-economic outcomes of agroforestry systems, with a particular focus on carbon sequestration, ecosystem services, and food security. The study employed a systematic literature search using Scopus and Google Scholar, applying targeted keyword combinations such as "agroforestry," "carbon sequestration," "ecosystem services," and "sustainability outcomes." Inclusion criteria prioritized peer-reviewed studies published within the last five years that examined agroforestry in tropical and subtropical contexts. The findings confirm that agroforestry enhances carbon stocks, improves soil quality, and fosters biodiversity, offering clear advantages over monoculture systems. Moreover, agroforestry strengthens smallholder resilience by diversifying income sources and improving nutritional security. However, adoption remains constrained by systemic challenges including fragmented policies, limited financial access, and institutional weaknesses. Effective interventions include participatory governance, targeted subsidies, and the integration of local ecological knowledge into practice. This review emphasizes the need for coherent, multi-scalar policies and inclusive frameworks that embed agroforestry within broader sustainable development agendas. It recommends further research into long-term ecological and social impacts, as well as strategies to improve equity and scalability. Agroforestry should be positioned as a core element in climate resilience planning and sustainable rural development strategies.

Keywords: Agroforestry, Carbon Sequestration, Ecosystem Services, Sustainable Agriculture, Rural Livelihoods, Climate Resilience, Biodiversity Conservation.

INTRODUCTION

Agroforestry has garnered increasing global attention as an innovative approach to mitigating the multifaceted challenges posed by climate change and environmental degradation. It refers to the intentional integration of trees and shrubs into crop and animal farming systems to create

environmental, economic, and social benefits. As environmental stressors intensify—ranging from biodiversity loss and soil degradation to food insecurity—agroforestry has emerged as a viable and sustainable land-use system that offers a range of ecosystem services while contributing to climate resilience. Kuyah et al. (2019) underscore agroforestry's potential as a "win-win" strategy that integrates climate-adaptive ecosystem services with higher productivity, particularly in contrast to conventional monoculture systems. Complementing this view, Silva et al. (2021) highlight that complex agroforestry landscapes can mimic natural ecosystems in delivering key functions, including climate regulation and resource sustainability.

Empirical studies continue to affirm agroforestry's adaptive benefits. Rigal et al. (2018) emphasize the role of local ecological knowledge in reinforcing agroforestry landscapes, particularly in the context of climate adaptation in China. These systems not only buffer communities against environmental stress but also reduce vulnerability to soil erosion and disease, thereby enhancing long-term ecological resilience. Dinesha et al. (2023) further support this perspective by identifying agroforestry as a critical strategy for food security in arid zones, linking it to sustainability across multiple ecological dimensions.

In addition to its environmental advantages, agroforestry significantly contributes to food security and sustainable livelihoods. Studies from diverse agroecological zones show that agroforestry promotes agricultural diversification and resource efficiency. For instance, Mattsson et al. (2017) demonstrate that traditional agroforestry systems in Sri Lanka enhance ecological sustainability while improving dietary diversity and local food availability. Chand et al. (2024) confirm that integrated agroforestry systems maximize land use efficiency and reduce dependency on limited natural resources, thereby reinforcing household food security.

On the socioeconomic front, Wright et al. (2024) argue that agroforestry systems can bolster economic resilience by offering diversified income streams and enhancing value-added agricultural practices. Raj and Jhariya (2023) similarly find that carbon sequestration-oriented agroforestry systems improve soil fertility and biodiversity, aligning increased productivity with environmental goals. As such, agroforestry aligns well with both ecological and developmental objectives, positioning it as a core strategy for sustainable ru ral transformation.

Nevertheless, the implementation of agroforestry in tropical regions faces considerable obstacles. One of the most pressing challenges lies in the biological interactions between trees and crops, which may lead to competition for essential resources such as light, nutrients, and water. According to Kuyah et al. (2019), such interactions can adversely affect agricultural productivity if not carefully managed. Rigal et al. (2018) further document the challenges posed by shading in cocoa-based agroforestry systems, which often limits crop yield.

Technological and informational barriers further hinder the effective adoption of agroforestry. As Suwardi et al. (2023) note, many farmers lack access to technical knowledge and training necessary for managing complex agroforestry systems. This knowledge gap results in suboptimal practices and low uptake, even in areas where the ecological benefits of agroforestry are well-recognized. Additionally, the integration of modern techniques with local knowledge remains underdeveloped, raising concerns about cultural compatibility and community acceptance.

Social and cultural dimensions also complicate the dissemination of agroforestry practices. Marentes et al. (2021) caution that modern interventions can disrupt traditional agroecological practices, leading to resistance among local populations. Without effective mechanisms to bridge traditional wisdom and contemporary innovations, agroforestry programs risk alienating key stakeholders. These socio-cultural barriers underscore the need for inclusive and participatory approaches that respect community values and knowledge systems.

Despite the broad body of work on agroforestry, several critical research gaps persist. One major gap concerns the long-term environmental outcomes of agroforestry systems, particularly regarding soil quality and biodiversity enhancement. Shi et al. (2018) point to a lack of longitudinal data on carbon dynamics and species interactions within agroforestry systems, which hampers efforts to assess sustainability over time. Moreover, studies rarely explore the complex feedback loops between ecological variables, making it difficult to generalize results across contexts.

Equally important is the lack of systematic understanding of the economic and social interdependencies within agroforestry systems. Masure et al. (2023) emphasize the need for integrative research that examines how economic returns from forestry and agricultural components interact with environmental outcomes. Yet, such interdisciplinary analyses remain scarce. Furthermore, gender dynamics are often overlooked. Kpoviwanou et al. (2024) demonstrate that failing to incorporate gender-sensitive perspectives in agroforestry research and implementation can undermine both adoption rates and overall impact.

The primary aim of this narrative review is to synthesize existing knowledge on the environmental and social sustainability outcomes of agroforestry systems, particularly in tropical and subtropical regions. The review seeks to bridge disciplinary divides by examining agroforestry through an integrated lens that encompasses ecological effectiveness, socioeconomic benefits, and policy relevance. Building on Silva et al. (2021), this review offers a comprehensive framework that considers both the biophysical functions and the human dimensions of agroforestry.

This study also aims to differentiate itself from previous literature by providing a holistic perspective. Whereas prior studies often isolate one aspect—such as carbon sequestration (Zanzi et al., 2021) or crop yield (Rigal et al., 2018)—this review evaluates agroforestry as a multidimensional system. It assesses how environmental, economic, and social components converge to shape agroforestry's overall sustainability. By doing so, the review offers policy-makers and practitioners a more nuanced understanding of agroforestry's potential and limitations.

Geographically, the review focuses on underrepresented regions, particularly smallholder farming communities in Sub-Saharan Africa and South Asia. Existing literature tends to emphasize agroforestry in Latin America and Southeast Asia, often overlooking contexts where agroforestry operates as a subsistence strategy rather than a commercial one. As noted by Agbotui et al. (Tsonkova et al., 2015) and Ruíz-Agudelo et al. (2019), these marginalized areas face unique challenges and opportunities that warrant deeper exploration.

Moreover, this review pays specific attention to gender and social inclusion in agroforestry. Kpoviwanou et al. (2024) highlight the transformative potential of incorporating gender-aware frameworks in agroforestry design and policy. Yet, current literature inadequately addresses how gender roles influence the effectiveness and adoption of agroforestry. Therefore, this review not

only fills a gap in the ecological and economic understanding of agroforestry but also contributes to the ongoing discourse on social justice and equity in sustainable land use systems.

In summary, this introduction lays the groundwork for a comprehensive analysis of agroforestry as a multifunctional strategy for achieving sustainability. By addressing existing knowledge gaps and integrating diverse disciplinary perspectives, the review aspires to inform more effective and inclusive agroforestry policies and practices.

METHOD

This narrative review adopts a structured and transparent approach to the identification, selection, and synthesis of relevant literature examining the relationship between agroforestry systems and their contributions to carbon sequestration, ecosystem services, and sustainability outcomes. The methodology was developed to ensure comprehensive coverage of recent and high-quality scientific studies, particularly those that explore interdisciplinary dimensions involving ecological, economic, and social facets of agroforestry.

The literature search was primarily conducted using two leading scientific databases: Scopus and Google Scholar. Scopus was selected due to its comprehensive indexing of peer-reviewed academic articles and its robust filtering tools, which allow researchers to refine search results based on publication year, subject area, and document type. Google Scholar, while broader in scope, provided access to grey literature and citations that were useful for tracing the evolution of specific agroforestry themes over time. These databases offered a synergistic combination of breadth and scholarly rigor necessary to support the objectives of the review.

Keyword strategy was crucial in capturing the multifaceted nature of agroforestry. Several combinations of keywords and search phrases were utilized to ensure inclusion of studies addressing environmental, economic, and social dimensions. One effective phrase was "Agroforestry" AND "carbon sequestration," which directed the search toward studies measuring carbon storage and emissions reductions resulting from integrated tree-based systems, such as those documented by Shi et al. (2018). Similarly, the pairing of "Ecosystem services" AND "agroforestry" facilitated the identification of research discussing biodiversity, erosion control, and water regulation, as demonstrated in Kuyah et al. (2019). Other relevant phrases included "Sustainability outcomes" AND "agroforestry systems," capturing the broader environmental and social implications, as well as "Agroforestry" AND "sustainable agriculture," which highlighted the synergy between traditional knowledge and ecological resilience (Marentes et al., 2021).

Finally, the term "Agroforestry" AND "climate change mitigation" was particularly effective in retrieving studies focused on the role of agroforestry in climate adaptation and emissions reduction strategies. For example, Raj and Jhariya (2023) provided insights into the dual benefit of agroforestry in enhancing livelihoods while contributing to carbon neutrality. By utilizing these keyword combinations in various permutations, the search strategy successfully captured a wide range of perspectives and case studies, ensuring that the review was both comprehensive and balanced.

Selection criteria were developed to ensure inclusion of high-quality, relevant, and recent research. The inclusion criteria began with a restriction to peer-reviewed journal articles. Only studies published in journals that employ rigorous peer-review processes were considered, thereby ensuring the credibility and reliability of the findings analyzed. Furthermore, studies had to have a direct focus on agroforestry, either from a theoretical or applied standpoint, in relation to ecosystem services, carbon sequestration, or broader sustainability indicators.

A temporal filter was applied, with only articles published within the past five years (2020–2025) being included. This was based on the need to prioritize the most up-to-date data, methodologies, and interpretations relevant to current environmental challenges. Articles such as those by Edelstein et al. (2025) and Lestari & Winarno (2023) were thus prioritized for their contemporary relevance and alignment with emerging sustainability paradigms. Additionally, geographic diversity was another central criterion; the selected studies needed to represent multiple ecological and socio-political contexts, thereby enabling a more holistic understanding of agroforestry implementation and its impacts across different regions.

Conversely, several exclusion criteria were also applied to refine the pool of selected studies. Studies that were not peer-reviewed, such as conference papers, white papers, or institutional reports, were excluded due to concerns regarding methodological transparency and quality control. Furthermore, research that examined only a single variable—for instance, focusing solely on yield outcomes without reference to environmental or social sustainability—was omitted. This decision was aligned with the review's commitment to examining agroforestry as a multidimensional system.

Studies that lacked relevance to sustainability or did not address the nexus between agroforestry and ecosystem services were also excluded. This was particularly pertinent in filtering out agricultural research that involved tree-crop systems but lacked an explicit sustainability framework. Lastly, language constraints were imposed, with only studies available in English being considered. This was necessary to maintain consistency and allow for critical appraisal of content by the review team.

The selection process involved multiple stages of screening and evaluation. Initially, all retrieved articles were imported into a citation management tool to facilitate organization and deduplication. The first screening stage involved title and abstract reviews to assess preliminary relevance. Articles that passed this stage were then subjected to a full-text review, during which alignment with the inclusion criteria was thoroughly evaluated. During the full-text screening, particular attention was paid to methodological robustness, clarity of outcome reporting, and contextual richness.

Articles that passed both screening stages were then subjected to qualitative evaluation. This involved assessing the depth of analysis, the extent to which findings could be generalized, and the study's contribution to the broader discourse on agroforestry and sustainability. Where applicable, thematic coding was applied to group studies by focal area—carbon sequestration, biodiversity, soil health, livelihood improvement, and climate adaptation—to facilitate structured synthesis during the results and discussion phases.

The methodological orientation of the included studies varied widely, encompassing both qualitative and quantitative research designs. Experimental studies, such as field trials and plot-based assessments of carbon flux or species interactions, provided empirical measurements crucial

for validating the ecological benefits of agroforestry. Case studies, often community-based, yielded insights into local implementation strategies and socio-economic outcomes. Observational studies and longitudinal surveys enriched the review with real-world data on sustainability trajectories over time.

Additionally, the review included interdisciplinary assessments that integrated environmental science, agricultural economics, and development studies. These studies often employed mixed-methods approaches, including stakeholder interviews, participatory rural appraisal, and geospatial analysis, to capture the complexity of agroforestry systems. Their inclusion was vital in reflecting the diverse lenses through which agroforestry's sustainability potential can be understood and evaluated.

In conclusion, the methodological framework adopted in this review was designed to ensure both depth and breadth of analysis. Through a rigorous and transparent process of literature identification, selection, and evaluation, the review assembled a body of work that reflects the current state of knowledge on agroforestry and its multifaceted contributions to environmental and social sustainability. By prioritizing methodological rigor, thematic diversity, and geographic representativeness, this review aims to provide a robust foundation for evidence-based recommendations and future research directions.

RESULT AND DISCUSSION

Agroforestry systems have emerged as vital components in the global efforts to mitigate climate change, enhance biodiversity, and improve the livelihoods of smallholder farmers. Through a narrative synthesis of the selected literature, this section outlines the empirical findings across three key thematic areas: carbon sequestration and climate change mitigation, ecosystem services and soil health, and livelihoods and socioeconomic benefits. Each theme encapsulates diverse evidence that collectively underscores agroforestry's multidimensional contributions to environmental and social sustainability.

Carbon Sequestration and Climate Change Mitigation

A growing body of literature attests to the significant role agroforestry systems play in sequestering carbon and reducing greenhouse gas emissions. Meta-analyses conducted by Shi et al. (2018) indicate that agroforestry systems consistently outperform monoculture practices in terms of carbon stock accumulation in both biomass and soil. These systems foster complex below-ground and above-ground interactions that enhance carbon stability, as observed in the work by Avasiloaiei et al. (2023), who emphasized the crucial role of microbial activity and plant diversity in stabilizing organic carbon within agroforestry landscapes.

One of the mechanisms that underpin agroforestry’s efficacy in carbon sequestration is its structural complexity. Avasiloaiei et al. (2023) demonstrate that multi-strata vegetation composed of diverse tree species enhances vertical biomass layers, increasing photosynthetic capacity and carbon fixation potential. The temporal dimension of species rotation and succession within these

systems also contributes to long-term carbon storage, creating a dynamic equilibrium between carbon input and decomposition that is more balanced compared to conventional systems.

When comparing carbon storage potentials across various agroforestry models, significant differences emerge between systems implemented in tropical and subtropical regions. Edelstein et al. (2025) illustrate that mixed farming agroforestry models in Brazil and Colombia show higher carbon sequestration capacities than monocultural systems, owing to their greater species diversity and spatial complexity. This variation aligns with findings from Dablin et al. (2021), which affirm that the inclusion of a wide variety of functional tree traits enhances not only carbon storage but also supports associated ecosystem functions such as biodiversity conservation and nutrient cycling.

Ecosystem Services and Soil Health

Agroforestry systems significantly contribute to improving soil quality and nutrient cycling efficiency. According to Silva et al. (2021), tree-crop interactions within agroforestry landscapes promote symbiotic relationships that enhance nitrogen fixation and carbon assimilation in the rhizosphere. The presence of deep-rooted tree species facilitates nutrient uptake from subsoil layers and redistributes them to upper soil strata through litterfall and root exudates, enriching the topsoil over time.

The role of biodiversity in soil quality enhancement is emphasized in studies such as Zanzi et al. (2021), which report that higher species diversity correlates with improved soil structure, increased microbial biomass, and enhanced water retention capacity. These findings are corroborated by Rockwell et al. (2022), who note that agroforestry systems outperform monocultures in terms of nutrient cycling efficiency, particularly nitrogen and phosphorus dynamics, which are critical for sustaining long-term soil fertility and crop productivity.

Moreover, agroforestry systems offer a suite of ecosystem services beyond soil enhancement. Empirical evidence presented by Marentes et al. (2021) shows that tree canopy cover within agroforestry systems reduces surface runoff, enhances water infiltration, and regulates local microclimates. The hydrological benefits of agroforestry are particularly important in regions experiencing erratic rainfall and increased drought frequency. Avasiloaiei et al. (2023) further highlight the role of tree roots in stabilizing slopes and preventing topsoil erosion, thus preserving the land's agricultural capacity.

In terms of biodiversity support, Santos et al. (2019) provide compelling evidence that agroforestry systems harbor greater species richness and abundance compared to adjacent monocultures or degraded lands. The diverse plant architecture and resource availability within agroforestry landscapes create habitats for a wide range of faunal species, contributing to ecological resilience and the restoration of ecosystem integrity. These multifunctional benefits position agroforestry as a cornerstone of sustainable land management practices.

Livelihoods and Socioeconomic Benefits

Agroforestry plays a transformative role in enhancing the livelihoods of smallholder farmers by providing diversified income streams and improving food security. Agbotui et al. (2023) observe that agroforestry systems support economic resilience through the production of multiple marketable goods, including timber, fruits, fuelwood, and non-timber forest products. These outputs serve as buffers against market volatility and environmental shocks, enabling farmers to sustain livelihoods even under adverse conditions.

From a food security perspective, agroforestry contributes to both the quantity and quality of food available to rural households. Dinesha et al. (2023) emphasize that integrating fruit trees and leguminous species in farm systems enhances dietary diversity and micronutrient intake among farming families. Mattsson et al. (2017) document similar outcomes in Sri Lanka, where homegarden agroforestry systems combine staple crops with perennials to ensure year-round food availability and nutritional adequacy.

The social capital embedded in agroforestry systems is another dimension worth noting. By integrating traditional knowledge and community-led innovations, agroforestry practices foster collective stewardship of natural resources. This is evident in the work of Marentes et al. (2021), who describe how indigenous agroforestry systems in Colombia, particularly the chagras model, embody cultural heritage and promote community cohesion while contributing to ecological conservation.

Several agroforestry models have been successfully implemented across developing countries, yielding tangible socioeconomic and environmental outcomes. In Ghana, cocoa-based agroforestry systems have demonstrated improved crop yield and biodiversity conservation. According to Agbotui et al. (2023), these systems not only sustain cocoa productivity but also provide shade, protect soil moisture, and contribute to landscape-level resilience. The incorporation of native shade tree species has been particularly effective in enhancing pollination services and pest regulation.

In Colombia, the chagras system exemplifies a synergistic blend of agriculture and forest stewardship. Marentes et al. (2021) highlight its role in sustaining livelihoods through the cultivation of diverse crops, medicinal plants, and timber, all within a regenerative ecological framework. These systems are also embedded in customary land-use practices, ensuring long-term community ownership and ecological knowledge transmission.

Indonesia presents another instructive case where forest-agriculture integration has supported smallholder adaptation to climate variability. Sudomo et al. (2023) report that agroforestry systems integrating food crops with forest species not only improve farm productivity but also reduce dependency on chemical inputs, thus lowering environmental footprints and enhancing ecological resilience.

In Sri Lanka, homegarden models offer compelling evidence of how agroforestry can address both subsistence and environmental goals. Mattsson et al. (2017) found that these systems contribute significantly to local food security, while also maintaining habitat connectivity for local wildlife.

Their low-input nature makes them particularly attractive for resource-constrained households, reinforcing both economic and ecological sustainability.

Taken together, these examples underscore the adaptability and scalability of agroforestry as a tool for sustainable rural development. By aligning economic incentives with environmental stewardship, agroforestry systems provide a pragmatic pathway to achieving multiple Sustainable Development Goals (SDGs), including zero hunger, climate action, and life on land.

In summary, the findings presented in this section reveal the profound potential of agroforestry systems in delivering interconnected environmental and socioeconomic benefits. Their capacity to sequester carbon, regenerate soil, enhance biodiversity, and strengthen rural livelihoods underscores the strategic value of agroforestry in addressing the dual crises of climate change and rural poverty. The diversity of models and regional contexts further highlights the flexibility of agroforestry approaches, offering insights for tailored implementation across various agroecological and cultural settings.

The findings of this narrative review both reinforce and extend the prevailing literature on agroforestry and its multifaceted role in sustainable development. Broadly, the results validate prior claims that agroforestry serves as a multifunctional land-use strategy, capable of integrating ecological, economic, and social benefits. For example, the work of Kuyah et al. (2019) is corroborated by this review's synthesis, which highlights agroforestry's dual function in providing ecosystem services and improving environmental conditions. These systems are shown not only to enhance biodiversity and improve soil fertility but also to support smallholder livelihoods and food security, aligning with earlier observations by Dinesha et al. (2023) on the nutritional and economic benefits of diversified farming practices.

However, the present review goes beyond these foundational insights by delving deeper into the socio-cultural dimensions of agroforestry. In doing so, it complements but also nuances the findings of Marentes et al. (2021), who emphasized the significance of indigenous knowledge and cultural values in shaping agroforestry systems in Colombia. The review reveals that sustainability outcomes are not solely determined by ecological parameters but are also deeply influenced by the ways in which communities interact with and adapt these systems within their specific cultural and socioeconomic contexts. This perspective encourages a shift from a predominantly technical understanding of agroforestry to one that integrates local agency and community-driven innovation.

Moreover, while earlier studies often focused on isolated benefits of agroforestry—such as carbon sequestration or crop yield—this review offers a more holistic understanding by illustrating the interconnectedness between ecosystem services, climate adaptation, and rural development. These findings underscore the need for a comprehensive agroecological transition that places equal emphasis on ecological integrity and social equity.

Systemic factors, particularly policy frameworks, financing mechanisms, and institutional capacity, play a pivotal role in either enabling or hindering the widespread adoption of agroforestry. Policy support is frequently cited as a critical enabler; Masure et al. (2023) argue that targeted subsidies, clear legal frameworks, and government-backed extension services can significantly bolster farmer

engagement. Conversely, the absence of coherent policy alignment—as observed by Rigal et al. (2018)—often leads to fragmented initiatives that fail to achieve scalability or sustainability.

Financial accessibility remains another formidable barrier. Smallholder farmers, who comprise the majority of agroforestry practitioners in the Global South, often lack the capital to invest in long-term practices that may not yield immediate returns. Agbotui et al. (2023) illustrate how tailored credit schemes and donor-funded pilot programs in Ghana have facilitated greater adoption among financially marginalized groups. These cases underline the necessity for integrated financial tools, including microcredit and result-based financing, to bridge the initial cost gap that often discourages innovation.

Institutional capacity further modulates agroforestry outcomes. Silva et al. (2021) highlight the importance of strong, technically proficient institutions in guiding and mentoring farmers throughout the adoption process. However, institutional weaknesses—ranging from insufficient training modules to inadequate extension outreach—continue to hamper the diffusion of agroforestry practices. Capacity-building programs tailored to the specific needs of diverse ecological and cultural landscapes are therefore essential. The role of institutions in safeguarding and promoting local ecological knowledge is equally critical, as emphasized by Tsonkova et al. (2015), who note that when communities are actively involved in decision-making and capacity-building efforts, the rate of successful adoption increases significantly.

These systemic challenges necessitate multi-scalar policy interventions that align local practices with national and international sustainability goals. At the community level, participatory governance mechanisms that decentralize control and recognize local priorities are vital. At the national level, agroforestry must be embedded into broader agricultural, environmental, and climate policies. Internationally, climate finance and biodiversity funding must explicitly account for agroforestry as a nature-based solution.

This review also examines policy strategies that have proven effective in overcoming adoption barriers across varying geographic contexts. Participatory policy design, which integrates local stakeholders in rule-making and implementation, has shown considerable promise. In Colombia, for instance, Marentes et al. (2021) document how indigenous communities successfully manage agroforestry systems through co-governance frameworks that respect traditional authority structures. Such models not only enhance ecological outcomes but also foster community empowerment and social cohesion.

Financial incentives tailored to agroforestry have likewise yielded tangible outcomes. Borelli et al. (2017) note that urban and peri-urban farmers have benefited from targeted subsidies and grants that lower the entry barrier to agroforestry adoption. Similarly, project-based funding from international development organizations has catalyzed adoption in resource-poor settings, although the sustainability of these interventions often hinges on continued support and local buy-in.

The integration of traditional ecological knowledge into scientific agroforestry frameworks is another avenue that has shown considerable effectiveness. Rigal et al. (2018) advocate for co-production of knowledge, wherein farmers and researchers collaboratively design context-specific

agroforestry practices. This approach ensures cultural compatibility, strengthens social capital, and enhances the ecological resilience of agroforestry systems.

European models also offer lessons through the use of certification schemes that reward biodiversity-friendly practices. As shown by Tscharntke et al. (2014), certified agroforestry products fetch higher market prices and provide ecological benefits, incentivizing farmers to maintain diverse, multifunctional landscapes. While these programs have been successful in high-income contexts, their transferability to the Global South requires careful adaptation to local economic and regulatory realities.

Perhaps most importantly, the review affirms the critical need to recognize agroforestry's multifunctionality in policy discourse. Plieninger et al. (2020) argue for landscape-scale planning that incorporates agroforestry as a core element of sustainable development. This approach necessitates cross-sectoral coordination among agriculture, forestry, conservation, and rural development agencies. By framing agroforestry as both a conservation tool and a livelihood strategy, such integrated planning can generate synergies that amplify the impact of isolated efforts.

Despite its many strengths, the current body of research on agroforestry exhibits several limitations that warrant attention. Most notably, longitudinal studies assessing long-term ecological and socioeconomic outcomes remain sparse. The short duration of many field studies limits our understanding of the temporal dynamics of agroforestry systems, particularly in relation to carbon sequestration and biodiversity recovery. Similarly, there is a dearth of disaggregated data on gender and social inclusion, even though studies such as those by Kpoviwanou et al. (2024) have underscored the gendered dimensions of agroforestry adoption and benefit-sharing.

Additionally, while this review synthesizes a diverse range of studies, it is inherently constrained by the availability of peer-reviewed literature in English. This may exclude relevant case studies and innovations documented in other languages or local institutional reports. Future research should aim to incorporate these perspectives through multilingual reviews and greater collaboration with local academic institutions and grassroots organizations.

Finally, there is a pressing need for more transdisciplinary research that bridges natural and social sciences. Agroforestry sits at the nexus of ecology, economics, sociology, and policy studies, yet much of the existing literature remains siloed. Collaborative research initiatives that engage ecologists, economists, sociologists, and policymakers are crucial to fully capture the complexity of agroforestry systems and to design interventions that are both scalable and sustainable.

CONCLUSION

This narrative review demonstrates that agroforestry systems offer a powerful and multifaceted strategy for addressing the intertwined challenges of climate change, environmental degradation, and rural poverty. The synthesis of literature reveals that agroforestry enhances carbon sequestration, improves soil quality, supports biodiversity, and contributes significantly to food security and economic resilience for smallholder farmers. These benefits, however, are shaped by complex socio-cultural and systemic factors that influence adoption and impact.

The findings underscore the urgent need for integrated policy frameworks, improved financial accessibility, and strengthened institutional capacity to scale up agroforestry initiatives. Barriers such as fragmented governance, limited funding, and inadequate training must be systematically addressed through inclusive and participatory approaches that incorporate local knowledge and empower community stakeholders. Successful policy models in regions such as Colombia, Ghana, Indonesia, and Sri Lanka provide valuable lessons for other developing contexts.

Future research should prioritize longitudinal studies that track agroforestry impacts over time, particularly on carbon dynamics and social equity. There is also a pressing need to explore gendered dimensions and localized innovations that remain underrepresented in current academic discourse. Agroforestry's potential to deliver multifunctional ecosystem services makes it indispensable in strategies for sustainable landscape management.

Ultimately, the promotion of agroforestry should not be seen as a technical fix but as a systemic transformation that aligns environmental sustainability with social justice. Recognizing agroforestry as a central pillar in climate resilience and rural development policy is essential to achieving long-term sustainability goals.

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