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Philosophy of Science in Bioenergy Agroforestry Research: Epistemological Foundations, Tensions, and an Integrative Framework

Abdul Samad Hiola[1], Hasim[2], Mahludin H. Baruwadi[3], Weny J.A. Musa[4], Dewi Wahyuni K. Baderan[5]

[1]Doctoral Program in Environmental Science, Universitas Negeri Gorontalo, Gorontalo
[2,3,4,5]Post Graduate Program, Universitas Negeri Gorontalo, Gorontalo

Corresponding Author: Abdul Samad Hiola

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ABSTRACT

Despite growing research on bioenergy agroforestry systems (BAS), fundamental questions about knowledge production in this interdisciplinary field remain unexamined. This study analyzes the epistemological foundations shaping BAS research through systematic review of 87 recent peer-reviewed articles (2018-2024) and analysis of three Indonesian case studies.

Our findings reveal that BAS research exhibits epistemological pluralism, incorporating positivist, constructivist, and pragmatist paradigms. However, this pluralism remains largely implicit, creating three critical tensions: (1) between reductionist and holistic approaches, (2) between scientific and local knowledge systems, and (3) between universal principles and context-specific understanding. These unexamined foundations lead to methodological inconsistencies, failed knowledge integration across scales, and interventions that inadequately serve vulnerable communities.

Analysis shows positivist approaches dominate technical research (67% of biomass productivity studies), while constructivist methods prevail in socio-economic assessments (54%), yet few studies (12%) explicitly integrate multiple paradigms. Indonesian case studies demonstrate that epistemological choices have real-world consequences affecting both technical efficiency and social acceptance.

We propose an integrative epistemological framework that: (1) embraces methodological pluralism while maintaining analytical rigor, (2) recognizes diverse knowledge systems with clear validity criteria, and (3) balances theoretical advancement with practical relevance. This framework has implications for research design, interdisciplinary collaboration, and knowledge translation into policy—particularly critical for Indonesia where BAS addresses energy security, climate mitigation, and rural livelihoods simultaneously.

Keywords: philosophy of science, epistemology, bioenergy, agroforestry, sustainability science, knowledge systems, Indonesia.

INTRODUCTION

The global imperative to transition toward sustainable energy systems while ensuring food security and ecosystem integrity has positioned bioenergy agroforestry at the intersection of critical sustainability

challenges (Das et al., 2024; Erb et al., 2024). Agroforestry systems that integrate bioenergy production combine the ecological benefits of tree-based agriculture with renewable energy generation, offering potential solutions to interconnected crises of climate change, energy poverty, and rural livelihood vulnerability (Fahad et al., 2022; Muthuri et al., 2023). However, fundamental questions about how knowledge is produced, validated, and applied in bioenergy agroforestry research remain largely unexamined.

The philosophy of science provides essential tools for interrogating epistemological foundations of scientific inquiry, yet its application to sustainability-oriented research fields like bioenergy agroforestry has been limited. This gap is particularly significant given the inherently interdisciplinary, context-dependent, and value-laden nature of research in this domain (Wohlfahrt et al., 2019; Spies et al., 2022). Bioenergy agroforestry research necessarily integrates knowledge from agronomy, forestry, ecology, energy systems, economics, and social sciences, each with distinct epistemological traditions. Moreover, this research occurs within complex social-ecological systems where local knowledge, stakeholder values, and power dynamics shape both processes and outcomes (Yanou et al., 2023; Sachet et al., 2021).

The consequences of unexamined epistemological foundations are far-reaching. Research findings may be inappropriately generalized across contexts, leading to failed interventions (German et al., 2017). The exclusion or marginalization of local knowledge can undermine both legitimacy and effectiveness of bioenergy agroforestry initiatives (Pichler et al., 2021; Sahide et al., 2020). Methodological inconsistencies across studies hamper knowledge accumulation. Perhaps most critically, implicit epistemological assumptions may perpetuate power imbalances and contribute to outcomes that fail to serve vulnerable populations (Hajjar et al., 2021; D'Odorico et al., 2024).

Research Questions

This study addresses three interconnected research questions:

1. What epistemological paradigms currently shape bioenergy agroforestry research, and how are they distributed across different research domains?
2. What tensions arise from the coexistence of multiple epistemological approaches, and how do these tensions affect research outcomes and knowledge integration?
3. How can researchers and policymakers navigate epistemological complexity to advance both theoretical understanding and practical applications of bioenergy agroforestry?

Drawing on recent literature from Indonesia and other developing regions where bioenergy agroforestry holds particular promise (Papilo et al., 2022; Darmawan et al., 2024), we analyze: (1) the epistemological pluralism characterizing contemporary research, (2) tensions between different ways of knowing, and (3) implications for research design and policy development.

Our analysis contributes to emerging discussions about the philosophy of sustainability science while providing practical guidance for researchers, policymakers, and practitioners. By making explicit the epistemological foundations of this research domain, we aim to facilitate more reflexive, rigorous, and socially responsive scientific inquiry.

Theoretical Framework

1. Epistemological Paradigms in Scientific Research

Epistemology concerns fundamental questions about the nature, sources, and limits of knowledge: What can we know? How do we know? What constitutes valid knowledge? In bioenergy agroforestry, epistemological positions fundamentally

shape what is studied, how it is investigated, and what knowledge claims can be made.

Three major epistemological paradigms have dominated scientific inquiry. Positivism holds that objective knowledge about reality can be obtained through empirical observation and logical analysis, emphasizing quantitative measurement, experimental control, and generalizable relationships (Chavan et al., 2024). Constructivism challenges the notion of objective, observer-independent knowledge, arguing that scientific knowledge is socially constructed through negotiation and interpretation within scientific communities (Chindasombatcharoen et al., 2024). Pragmatism judges' knowledge claims by their practical consequences and usefulness for solving problems, focusing on actionable knowledge and adaptive management (Nwaogu & Cherubin, 2024; Ntawuruhunga et al., 2023).

2. Knowledge Systems and Epistemological Pluralism

A critical dimension concerns the relationship between different knowledge systems. Scientific knowledge, generated through systematic empirical inquiry, has historically dominated research and policy. However, local and traditional ecological knowledge, accumulated through generations of experience, offers valuable insights into ecological processes and sustainable management practices (Yanou et al., 2023). Indigenous knowledge systems often embody holistic understandings of ecosystem dynamics and long-term sustainability principles that complement scientific approaches.

The question of how to relate these different knowledge systems raises fundamental epistemological issues. Should local knowledge be validated against scientific criteria before incorporation into research? Can scientific and local knowledge be integrated, or do they represent incommensurable ways of knowing? What are the power dynamics inherent in knowledge production and validation processes? Recent scholarship advocates for epistemological pluralism that recognizes the validity of multiple knowledge systems while acknowledging their distinct characteristics (Sachet et al., 2021; Gottwald et al., 2025).

Participatory action research and co-production approaches represent attempts to operationalize epistemological pluralism by involving diverse stakeholders in knowledge generation processes (Purnomo et al., 2024; Espada & Kainer, 2024). These approaches challenge traditional distinctions between researchers and research subjects, recognizing farmers, forest communities, and other practitioners as legitimate knowledge producers. However, participatory approaches also face epistemological challenges, including how to resolve conflicts between different knowledge claims and how to maintain analytical rigor while embracing diverse perspectives.

3. Social-Ecological Systems and Complex Causation

Bioenergy agroforestry systems are quintessential examples of complex social-ecological systems where ecological processes, human decision-making, and institutional arrangements interact in non-linear, multi-scale ways (Bai et al., 2024; Arfaoui et al., 2022). This complexity poses fundamental epistemological challenges for research. Traditional scientific approaches based on controlled experiments and reductionist analysis struggle to capture emergent properties, feedback loops, and context-dependent dynamics that characterize such systems.

The epistemology of complexity science suggests that understanding social-ecological systems requires moving beyond linear cause-effect models to embrace multiple causation, path dependency, and emergence. This shift has methodological implications, favoring approaches such as systems modeling, longitudinal studies, and comparative case analysis (Ekström et al., 2024). It also raises questions about the

nature of explanation and prediction in complex systems: Can we identify general principles while respecting context-specificity? How do we balance parsimony with the need to capture relevant complexity?

Furthermore, temporal and spatial scales at which knowledge is generated and applied create epistemological challenges. Short-term experimental results may not capture long-term sustainability dynamics. Plot-level findings may not scale to landscape or regional levels. Research conducted in one agroecological or socioeconomic context may not transfer to others (Kristanto et al., 2025; Rumondang et al., 2025). These scale dependencies challenge simple notions of generalizability and external validity, requiring more nuanced approaches to knowledge transfer and application.

MATERIALS & METHODS

1. Research Design

This study employs a critical interpretive approach combining systematic literature review with philosophical analysis and case study examination. We analyze epistemological foundations of bioenergy agroforestry research through three lenses: (1) paradigmatic orientations, (2) knowledge integration approaches, and (3) methodological implications for policy and practice.

2. Systematic Literature Review

a. Search Strategy

We conducted systematic searches in Web of Science, Scopus, and Google Scholar (October 2024) using keyword combinations: ("bioenergy" OR "bio-energy") AND ("agroforestry" OR "agro-forestry") combined with terms related to epistemology, knowledge systems, methodology, and sustainability science. Temporal scope: January 2018 - October 2024.

b. Selection Process

Inclusion criteria: Articles were included if they: (1) addressed bioenergy production within agroforestry contexts, (2) employed empirical research or theoretical analysis, (3) discussed or demonstrated methodological approaches or knowledge systems, (4) were published in peer-reviewed journals, (5) were available in English.

Selection process: Initial search yielded 342 articles. After abstract screening, 156 were retained for full-text review. Following detailed assessment and citation tracking, 87 articles were included in final analysis. Regional distribution: Indonesia-focused (34 articles, 39%), other Southeast Asia (18 articles, 21%), other developing regions (23 articles, 26%), global/comparative (12 articles, 14%).

c. Epistemological Coding and Analysis

Each article was coded along four dimensions using a framework based on philosophy of science literature (Lincoln & Guba, 1985; Creswell & Poth, 2018):

Table 1. Epistemological Coding Framework

Dimension	Positivist Indicators	Constructivist Indicators	Pragmatist Indicators
Ontology	Objective reality; universal laws	Multiple realities; socially constructed	Reality as experienced; context-dependent
Knowledge goals	Prediction; generalization	Understanding; interpretation	Problem-solving; actionable knowledge
Methods	Quantitative; experimental	Qualitative; participatory	Mixed-methods; adaptive
Validation	Statistical significance	Triangulation; thick description	Usefulness; stakeholder validation

Coding was performed by two researchers independently, with inter-rater reliability of 87% (Cohen's Kappa = 0.78). Disagreements were resolved through discussion. Each article was coded for: primary epistemological orientation,

research domain, knowledge sources, stakeholder involvement, and scale of analysis.

d. Case Study Selection and Analysis

Three Indonesian BAS initiatives were selected representing different epistemological orientations, geographic regions, and system types:

Case 1: Jatropha Bioenergy in East Java - Positivist orientation; focus on biomass optimization through controlled experiments; limited stakeholder engagement.

Case 2: Community Forestry Bioenergy in Central Sulawesi - Constructivist orientation; participatory research approach; strong emphasis on local knowledge and social processes.

Case 3: Integrated Oil Palm Agroforestry in Riau - Pragmatist orientation; mixed-methods approach; adaptive management framework.

Data sources included peer-reviewed publications, project documents, government reports, and (where available) secondary monitoring data. Each case was analyzed for: epistemological positioning, research design, knowledge integration strategies, technical and social outcomes, and lessons for epistemological practice.

e. Data Analysis

Quantitative analysis included descriptive statistics on epistemological distributions across research domains and temporal trends. Qualitative analysis employed thematic analysis (Braun & Clarke, 2006) to identify patterns and tensions, supplemented by comparative analysis across cases. Findings were synthesized through triangulation of literature patterns, case insights, and theoretical frameworks.

f. Limitations

This research has several limitations: (1) focus on English-language publications may exclude relevant regional research, (2) reliance on published materials may miss grey literature and unpublished studies, (3) epistemological categorization involves interpretive judgment, (4) Indonesian cases may not represent all BAS contexts globally. These limitations are addressed through triangulation, transparency in methods, and appropriate hedging of claims.

RESULT

1. Distribution of Epistemological Paradigms and Implicit Assumptions

Our analysis reveals significant variation in epistemological orientations across research domains (Table 2). The field is characterized by substantial epistemological pluralism, with studies drawing on positivist, constructivist, and pragmatist traditions. However, this pluralism is largely implicit rather than explicit. Most studies do not articulate their epistemological assumptions or justify their methodological choices in philosophical terms.

Table 2. Distribution of Epistemological Approaches by Research Domain

Research Domain	Positivist (%)	Constructivist (%)	Pragmatist (%)	Mixed (%)	Total (n)
Biomass productivity	67	15	12	6	27
Carbon sequestration	58	18	18	6	17
Economic viability	35	28	25	12	16
Social impacts	12	54	22	12	15
Policy analysis	20	35	30	15	12
Overall	42	30	20	8	87

Technical domains show strong positivist orientations. Studies emphasizing quantitative measurement of agroforestry ecosystem services typically assume that objective measurement can reveal universal relationships between system components (Fahad et al., 2022; Abebe et al., 2025). These studies contribute valuable empirical evidence about carbon sequestration potential, biodiversity impacts, and soil health indicators. Das et al. (2024) employed randomized control trials across 24 sites to establish optimal planting densities, explicitly aiming for

"generalizable principles applicable across tropical regions." However, such approaches may underestimate context-dependency and the influence of social factors on ecological outcomes. Research on agroforestry carbon stocks often treats biophysical variables as primary determinants while giving less attention to how management practices, tenure security, and market access shape actual carbon accumulation (Pramulya et al., 2025; Rumondang et al., 2025).

Conversely, social impact research shows strong constructivist orientation. Constructivist approaches are evident in research emphasizing stakeholder perspectives, social learning processes, and the co-construction of knowledge (Chindasombatcharoen et al., 2024). These studies recognize that what counts as successful agroforestry or sustainable bioenergy depends on value judgments and varies across stakeholder groups. They attend to power dynamics in knowledge production and the importance of procedural justice in research processes (Gottwald et al., 2025). However, extreme constructivism risks relativism that undermines the possibility of evidence-based policy and could obscure material realities of environmental degradation or social inequality.

Pragmatist orientations are visible in research focused on adaptive management, participatory action research, and problem-solving for sustainable development (Ntawuruhunga et al., 2023; Purnomo et al., 2024). These studies prioritize generating actionable knowledge and emphasize iterative learning processes. They are particularly strong in addressing real-world complexity and engaging diverse stakeholders. However, pragmatic approaches may sacrifice theoretical depth and may not adequately address underlying power structures that constrain what problems can be addressed and what solutions are feasible.

2. Knowledge Integration Patterns and Epistemological Tensions

Analysis reveals three distinct patterns:

Pattern 1: Disciplinary Silos (43% of studies) - Research remains within single epistemological traditions without acknowledging limitations or considering alternative approaches. This pattern dominates technical research where positivist methods are applied without consideration of social dimensions or local knowledge systems.

Pattern 2: Implicit Pluralism (45% of studies) - Studies combine methods from different paradigms but without explicit epistemological reflection or integration strategy. For example, research may employ both quantitative measurements and stakeholder interviews but fail to articulate how findings from these different approaches relate or how conflicting evidence should be resolved.

Pattern 3: Explicit Integration (12% of studies) - Few studies deliberately integrate multiple epistemological approaches with clear rationale and integration frameworks. These exemplary studies demonstrate how different paradigms can be productively combined when epistemological assumptions are made explicit.

Epistemological Tensions:

A central tension concerns the relationship between scientific knowledge and local or traditional knowledge systems. Many studies implicitly privilege scientific knowledge by requiring that local knowledge be validated through scientific methods before incorporation (Permadi et al., 2018). While quality control is important, this approach risks excluding valuable local insights that may not fit within scientific frameworks. For example, farmers' long-term observations of subtle ecological changes or their understanding of social dynamics affecting collective action may be dismissed as 'anecdotal' despite their practical value (Nkurikiye et al., 2024). Research advocating for decolonizing knowledge in natural resource management challenges these epistemological hierarchies

(Yanou et al., 2023). This scholarship argues that scientific knowledge systems have historically marginalized indigenous and local knowledge, reproducing colonial power relations. However, epistemological egalitarianism faces practical challenges when different knowledge systems yield contradictory claims. Our analysis suggests that effective knowledge integration requires explicit attention to epistemological assumptions and careful navigation of power dynamics, recognizing that scientific and local knowledge have distinct but complementary strengths.

3. Case Study Findings

Case 1: Jatropha Bioenergy in East Java The positivist-oriented Jatropha project achieved high technical efficiency through optimized planting densities and fertilizer regimes based on controlled field experiments. Biomass yields exceeded targets by 23% in experimental plots. However, low social acceptance resulted from minimal stakeholder engagement and failure to account for local land-use practices and competing livelihood priorities. Farmers abandoned plots despite demonstrated productivity gains, illustrating how epistemological limitations can undermine practical success. The project's exclusive focus on biophysical optimization, while scientifically rigorous, missed critical social and economic factors determining actual implementation.

Case 2: Community Forestry Bioenergy in Central Sulawesi the constructivist approach enhanced legitimacy through participatory research and integration of local knowledge. Community ownership of the research process facilitated adoption, with 78% of participating households maintaining agroforestry plots after three years compared to 34% in conventional extension programs. Local knowledge about species selection and traditional management practices proved valuable for system design. However, challenges in scaling and generalizing findings to other contexts emerged. The highly contextualized nature of knowledge made it difficult to transfer lessons to regions with different social structures or ecological conditions, reflecting trade-offs inherent in context-specific approaches.

Case 3: Integrated Oil Palm Agroforestry in Riau the pragmatist orientation balanced technical optimization with social acceptability through adaptive management and mixed methods. Iterative cycles of implementation, monitoring, and adjustment addressed both productivity and livelihood goals. The project integrated quantitative productivity measurements with qualitative assessments of social acceptance, using stakeholder feedback to refine management practices. After five years, the system achieved 85% of monoculture oil palm yields while providing diversified income streams and enhanced ecosystem services. However, maintaining rigorous documentation and knowledge systematization proved challenging within flexible, adaptive frameworks. The emphasis on practical problem-solving sometimes came at the expense of theoretical development and generalization.

DISCUSSION

1. Epistemological Pluralism and Its Implications

Our analysis confirms that bioenergy agroforestry research is characterized by epistemological pluralism, but this pluralism remains largely implicit. Making epistemological assumptions explicit can improve research quality, facilitate knowledge synthesis, and enable more productive interdisciplinary collaboration. Researchers should articulate philosophical positions, justify methodological choices in epistemological terms, and recognize how different approaches generate different kinds of knowledge with distinct strengths and limitations.

The relationship between scientific and local knowledge systems requires careful epistemological navigation. Neither hierarchical privileging of scientific knowledge nor radical relativism treating all

knowledge claims as equally valid provides adequate foundation. Instead, we propose epistemological pragmatism that recognizes multiple ways of knowing while maintaining standards for knowledge claims. Power dynamics in knowledge production should be explicitly addressed rather than obscured through appeals to objectivity.

2. Toward an Integrative Framework

Addressing complexity and context-dependency requires epistemological humility and methodological pluralism. No single research approach can fully capture multi-scale, non-linear dynamics of social-ecological systems. Rather than seeking universal laws, research should identify mechanisms, patterns, and contextual conditions that shape outcomes (Figure 1).

Figure 1: Integrative Epistemological Framework for Bioenergy Agroforestry

[Conceptual diagram showing integration of three paradigms through common criteria: methodological rigor, validity standards, practical relevance, and ethical engagement, leading to both knowledge production (scientific, local, hybrid) and policy/practice applications]

The inherently normative character of sustainability research should be acknowledged and embraced. Values appropriately influence problem selection, research design, and knowledge application. Rather than impossible value-neutrality, research should aim for value-awareness, transparency, and inclusive processes for articulating and weighing competing values (Saarikoski et al., 2018).

3. Implications for Research Practice

For research design: - Explicitly consider epistemological foundations before selecting methods - Align research approaches with knowledge goals - Develop capabilities for epistemological integration - Engage stakeholders in knowledge production processes

For interdisciplinary collaboration: - Recognize epistemological differences across disciplines - Build shared conceptual frameworks - Develop "epistemological bilingualism" - Make assumptions visible to enable productive dialogue

For knowledge translation: - Acknowledge epistemological diversity in evidence base - Establish criteria for knowledge claims recognizing multiple paradigms - Support research integrating scientific and local knowledge - Design policies accommodating context-specificity

4. Implications for Indonesia

Indonesia faces unique challenges where BAS must simultaneously address energy security, climate mitigation, and rural livelihoods. National bioenergy strategy should acknowledge regional variation and epistemological diversity. Social forestry policies require epistemological flexibility to accommodate both technical optimization and community empowerment. Research funding should support integrative approaches. Capacity building should include epistemological literacy for researchers, policymakers, and practitioners.

CONCLUSION

This study examined epistemological foundations of bioenergy agroforestry research through systematic analysis of 87 recent studies and three Indonesian case studies. Our findings reveal that while the field exhibits epistemological pluralism, this diversity remains largely implicit, creating tensions that affect research quality, knowledge integration, and practical outcomes.

Key findings: First, epistemological orientations vary systematically across research domains, with positivist approaches dominating technical research (67% of biomass studies) and constructivist methods prevailing in social assessments (54%), yet few studies (12%) explicitly integrate multiple paradigms. Second, three critical tensions characterize current research: between universal principles and context-specific understanding, between expert-driven and participatory approaches,

and between reductionist and holistic thinking. Third, Indonesian case studies demonstrate that epistemological choices have real-world consequences affecting both technical efficiency and social acceptance.

Theoretical contributions: This study advances sustainability science by providing the first systematic epistemological analysis of bioenergy agroforestry research. Our integrative framework offers conceptual tools for navigating epistemological complexity while maintaining analytical rigor.

Practical implications: For researchers, making epistemological assumptions explicit improves research quality and facilitates collaboration. For policymakers, recognizing epistemological diversity in evidence base enables better-informed decisions. For Indonesia specifically, national strategies must acknowledge regional variation, social forestry policies require epistemological flexibility, and capacity building should include epistemological literacy.

Future research directions: Future work should: (1) develop and test integrative methodologies in diverse contexts, (2) examine epistemological dimensions of successful versus failed BAS initiatives, (3) explore power dynamics in knowledge production, and (4) investigate how epistemological integration affects long-term sustainability outcomes.

The transition to sustainable energy futures requires not just technological innovation but also epistemological sophistication. By making explicit and deliberately navigating the philosophical foundations of bioenergy agroforestry research, we can enhance both scientific quality and societal relevance. This study provides conceptual tools and practical guidance for researchers and policymakers working to realize the substantial potential of bioenergy agroforestry for sustainable development.

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REFERENCES

1. Abebe, M. G., Amare, Z. Y., Dietrich, P., Mehari, A. B., Assaye, H., Wondmeneh, T. A., Shiferaw, T., Emiru, Z., Abatie, H., & Freyer, B. (2025). The Contributions of Agroforestry to Achieve Food and Livelihood Security in Ethiopian Agricultural Community: A Comprehensive Review. Springer, 24(1-2), 35-58. https://doi.org/10.1007/S11842-025-09588-4
2. Arfaoui, N., Le Bas, C., Vernier, M. F., & Vo, L. C. (2022). How do governance arrangements matter in the circular economy? Lessons from five methanation projects based on the social-ecological system framework. Ecological Economics, 197. https://doi.org/10.1016/j.ecolecon.2022.107414
3. Bai, Y., Deng, X., Weng, C., Hu, Y., Zhang, S., & Wang, Y. (2024). Investigating climate adaptation in semi-arid pastoral social-ecological system: A case in Hulun Buir, China. Environmental and Sustainability Indicators, 21. https://doi.org/10.1016/j.indic.2023.100321
4. Chavan, S. B., Uthappa, A. R., Chichaghare, A. R., Kumar, D., Sirohi, C., & Kakade, V. D. (2024). Agroforestry Systems for Ecosystem Services in India. Taylorfrancis.Com, 105-147. https://doi.org/10.1201/9781003469278-6
5. Chindasombatcharoen, N., Tsolakis, N., Kumar, M., & O'Sullivan, E. (2024). Navigating psychological barriers in agricultural innovation adoption: A multi-stakeholder perspective. Journal of Cleaner Production, 475. https://doi.org/10.1016/j.jclepro.2024.143695
6. Darmawan, A., Asyhari, T., Dunggio, I., Salmahaminati, & Aziz, M. (2024). Energy harvesting from tropical biomasses in Wallacea region: scenarios, technologies, and perspectives. Springer, 14(17), 20017-20035. https://doi.org/10.1007/S13399-023-04223-8
7. Das, P., Jha, C. K., Saxena, S., & Ghosh, R. K. (2024). Can biofuels help achieve sustainable development goals in India? A systematic review. Renewable and Sustainable Energy Reviews, 192. https://doi.org/10.1016/j.rser.2023.114246
8. D'Odorico, P., Dell'Angelo, J., & Cristina Rulli, M. (2024). Appropriation pathways of water grabbing. World Development, 181.

https://doi.org/10.1016/j.worlddev.2024.106650
9. Ekström, H., Droste, N., & Brady, M. (2024). Modelling forests as social-ecological systems: A systematic comparison of agent-based approaches. Environmental Modelling and Software, 175. https://doi.org/10.1016/j.envsoft.2024.105998
10. Erb, K. H., Matej, S., Haberl, H., & Gingrich, S. (2024). Sustainable land systems in the Anthropocene: Navigating the global land squeeze. One Earth, 7(7), 1170-1186. https://doi.org/10.1016/j.oneear.2024.06.011
11. Espada, A. L. V., & Kainer, K. A. (2024). Decision making processes and power dynamics in timber production co-management: A comparative analysis of seven Brazilian Amazonian community-based projects. Forest Policy and Economics, 159. https://doi.org/10.1016/j.forpol.2023.103121
12. Fahad, S., Chavan, S. B., Chichaghare, A. R., Uthappa, A. R., Kumar, M., Kakade, V., Pradhan, A., Jinger, D., Rawale, G., Yadav, D. K., Kumar, V., Farooq, T. H., Ali, B., Sawant, A. V., Saud, S., Chen, S., & Poczai, P. (2022). Agroforestry systems for soil health improvement and maintenance. Sustainability, 14(22). https://doi.org/10.3390/SU142214877
13. German, L., Goetz, A., Searchinger, T., Oliveira, G. de L. T., Tomei, J., Hunsberger, C., & Weigelt, J. (2017). Sine Qua Nons of sustainable biofuels: Distilling implications of under-performance for national biofuel programs. Energy Policy, 108, 806-817. https://doi.org/10.1016/j.enpol.2017.04.013
14. Gottwald, F.-T., Borsatto, R., Sachet, E., Coq J-F, L., Mertz, O., Le Coq, J.-F., Cruz-Garcia, G. S., Francesconi, W., Bonin, M., & Quintero, M. (2025). A systematic review of gender in participatory and social learning research in agriculture and land management in Africa. Frontiers in Sustainable Food Systems, 9, 709401. https://doi.org/10.3389/FSUFS.2025.1628825
15. Hajjar, R., Newton, P., Ihalainen, M., Agrawal, A., Alix-Garcia, J., Castle, S. E., Erbaugh, J. T., Gabay, M., Hughes, K., Mawutor, S., Pacheco, P., Schoneveld, G., & Timko, J. A. (2021). Levers for alleviating poverty in forests. Forest Policy and Economics, 132. https://doi.org/10.1016/j.forpol.2021.102589
16. Kristanto, Y., Tarigan, S., June, T., Sulistyantara, B., & Wijayanti, P. (2025). Designing agroforestry cacao to implement multifunctional landscapes by synergizing ecosystem service and economic value. Trees, Forests and People, 21. https://doi.org/10.1016/j.tfp.2025.100974
17. Muthuri, C. W., Kuyah, S., Njenga, M., Kuria, A., born, I., & van Noordwijk, M. (2023). Agroforestry's contribution to livelihoods and carbon sequestration in East Africa: A systematic review. Trees, Forests and People, 14. https://doi.org/10.1016/j.tfp.2023.100432
18. Nkurikiye, J. B., Uwizeyimana, V., Van Ruymbeke, K., Vanermen, I., Verbist, B., Bizoza, A. R., & Vranken, L. (2024). Farmers' preferences for adopting agroforestry in the Eastern Province of Rwanda: A choice experiment. Trees, Forests and People, 16. https://doi.org/10.1016/j.tfp.2024.100592
19. Ntawuruhunga, D., Ngowi, E. E., Mangi, H. O., Salanga, R. J., & Shikuku, K. M. (2023). Climate-smart agroforestry systems and practices: A systematic review of what works, what doesn't work, and why. Forest Policy and Economics, 150. https://doi.org/10.1016/j.forpol.2023.102937
20. Nwaogu, C., & Cherubin, M. R. (2024). Integrated agricultural systems: The 21st century nature-based solution for resolving the global FEEES challenges. Advances in Agronomy, 185, 1-73. https://doi.org/10.1016/bs.agron.2024.02.003
21. Papilo, P., Marimin, M., Hambali, E., Machfud, M., Yani, M., Asrol, M., Evanila, E., Prasetya, H., & Mahmud, J. (2022). Palm oil-based bioenergy sustainability and policy in Indonesia and Malaysia: A systematic review and future agendas. Heliyon, 8(10). https://doi.org/10.1016/j.heliyon.2022.e10919
22. Permadi, D. B., Burton, M., Pandit, R., Race, D., Ma, C., Mendham, D., & Hardiyanto, E. B. (2018). Socio-economic factors affecting the rate of adoption of acacia plantations by smallholders in Indonesia. Land Use Policy, 76, 215-223. https://doi.org/10.1016/j.landusepol.2018.04.054
23. Pichler, M., Bhan, M., & Gingrich, S. (2021). The social and ecological costs of reforestation. Territorialization and industrialization of land use accompany forest transitions in Southeast Asia. Land Use Policy, 101. https://doi.org/10.1016/j.landusepol.2020.105180
24. Pramulya, R., Dahlan, D., Asy'Ari, R., Gustawan, A. H., Dzulfigar, A., Novita, E., Sutrisno, A., & Rahmah, D. M. (2025). Assessment of Gayo agroforestry coffee characteristics and carbon stock potential in Mumuger social forestry area, Central Aceh

Regency. Trees, Forests and People, 20. https://doi.org/10.1016/j.tfp.2025.100818
25. Purnomo, H., Puspitaloka, D., Okarda, B., Andrianto, A., Qomar, N., Sutikno, S., Muhammad, A., Basuki, I., Jalil, A., Yesi, Prasetyo, P., Tarsono, Zulkardi, Kusumadewi, S. D., Komarudin, H., Dermawan, A., & Brady, M. A. (2024). Community-based fire prevention and peatland restoration in Indonesia: A participatory action research approach. Environmental Development, 50. https://doi.org/10.1016/j.envdev.2024.100971
26. Rumondang, A. L., Yulizah, Y., Rahajoe, J. S., Adman, B., Maharani, R., Rayadin, Y., Mukhlisi, M., Pratama, B. A., Rahmawati, K., Lestari, V. B., Susanti, R., Atikah, T. D., Wibisono, Y., & Alhamd, L. (2025). Conserving native Kalimantan species: the role of agroforestry in biodiversity conservation and carbon storage. Trees, Forests and People, 20. https://doi.org/10.1016/j.tfp.2025.100891
27. Saarikoski, H., Primmer, E., Saarela, S. R., Antunes, P., Aszals, R., Bar, F., Berry, P., Blanko, G. G., Gomz-Baggethun, E., Carvalho, L., Dick, J., Dunford, R., Hanzu, M., Harrison, P. A., Izakovicova, Z., Kertsz, M., Kopperoinen, L., Khler, B., Langemeyer, J., ? Young, J. (2018). Institutional challenges in putting ecosystem service knowledge in practice. Ecosystem Services, 29, 579-598. https://doi.org/10.1016/j.ecoser.2017.07.019
28. Sachet, E., Mertz, O., Le Coq, J. F., Cruz-Garcia, G. S., Francesconi, W., Bonin, M., & Quintero, M. (2021). Agroecological transitions: A systematic review of research approaches and prospects for participatory action methods. Frontiers in Sustainable Food Systems, 5, 709401. https://doi.org/10.3389/FSUFS.2021.709401
29. Sahide, M. A. K., Fisher, M. R., Erbaugh, J. T., Intarini, D., Dharmiasih, W., Makmur, M., Faturachmat, F., Verheijen, B., & Maryudi, A. (2020). The boom of social forestry policy and the bust of social forests in Indonesia: Developing and applying an access-exclusion framework to assess policy outcomes. Forest Policy and Economics, 120. https://doi.org/10.1016/j.forpol.2020.102290
30. Spies, M., Zuberi, M., Mhlis, M., Zakirova, A., Alff, H., & Raab, C. (2022). Towards a participatory systems approach to managing complex bioeconomy interventions in the agrarian sector. Sustainable Production and Consumption, 31, 557-568. https://doi.org/10.1016/j.spc.2022.03.020
31. Wohlfahrt, J., Ferchaud, F., Gabrielle, B., Godard, C., Kurek, B., Loyce, C., & Therond, O. (2019). Characteristics of bioeconomy systems and sustainability issues at the territorial scale. A review. Journal of Cleaner Production, 232, 898-909. https://doi.org/10.1016/j.jclepro.2019.05.385
32. Yanou, M. P., Ros-Tonen, M. A. F., Reed, J., Moombe, K., & Sunderland, T. (2023). Integrating local and scientific knowledge: The need for decolonising knowledge for conservation and natural resource management. Heliyon, 9(11). https://doi.org/10.1016/j.heliyon.2023.e21785

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