



Natural Resource Management as a Green Growth Pathway for the Livestock Economic Sustainability in Tropical Forest Ecosystems

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Abstract

Tropical forest ecosystems support livestock production and rural livelihoods but face increasing pressure from land conversion and inefficient resource use. Integrating natural resource management (NRM) into livestock systems is therefore critical to achieving economic sustainability while conserving forest landscapes. This study aims to quantify the impact of NRM practices on the economic sustainability of livestock systems in tropical forest areas of East Kalimantan, Indonesia. A mixed-methods approach was applied, including a survey of 120 livestock households, supported by field observations and multiple regression analyses. Economic sustainability was measured using income level, cost-benefit ratio, feed cost proportion, and income variability. The results show that NRM variables explain 63% of the variation in livestock economic sustainability ($R^2 = 0.63$). Land and soil management ($\beta = 0.312$; $p = 0.001$) and waste recycling practices ($\beta = 0.294$; $p = 0.002$) had the most potent positive effects, followed by agroforestry integration ($\beta = 0.267$; $p = 0.004$). Livestock systems with high NRM adoption generated higher annual income (IDR 39.6 million) than low-adoption systems (IDR 27.3 million), achieved a higher cost-benefit ratio (1.76 vs. 1.38), and exhibited lower income variability (17.8% vs. 29.6%). The study concludes that NRM adoption enhances productivity, stabilizes income, and reduces pressure on forest land, thereby supporting green-growth-oriented livestock development in tropical forest ecosystems; only abbreviations firmly established in the field may be eligible.

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INTRODUCTION

Tropical forest ecosystems constitute a vital foundation for environmental sustainability and rural economic activities, particularly livestock production systems that depend on land, water, and biological resources. In many tropical regions, forest landscapes provide essential ecosystem services, including soil fertility maintenance, hydrological regulation, and biodiversity support, which are fundamental to livestock productivity and rural livelihoods (Apriyani et al., 2024; Das & Mallick, 2024). Rapid land-use change driven by extractive industries, agricultural expansion, and infrastructure development has intensified pressure on forest ecosystems, increasing the risk of environmental degradation and deforestation (Bas et al., 2024; Ngoma & Yang, 2024). These conditions highlight the need for integrated approaches that reconcile livestock economic development with forest ecosystem conservation.

Natural resource management (NRM) plays a central role in promoting sustainability within agricultural and livestock systems by integrating ecological, economic, and social dimensions. Practices such as integrated bio-cycles farming, agroforestry, soil and water conservation, and circular resource utilization have been shown to enhance ecosystem resilience while supporting farm productivity and income stability (Agus et al., 2020; Nalluri & Karri, 2024; Nungula et al., 2024). Environmental economics perspectives emphasize that effective NRM reduces negative externalities, improves resource efficiency, and strengthens long-term economic performance in livestock-based systems (Anderson, 2024; Moldavan et al., 2024). Adoption and impacts of these practices remain highly context-dependent, particularly in tropical forest ecosystems characterized by complex socio-economic structures and sensitive ecological conditions.

East Kalimantan provides a strategic empirical context for examining the relationship between natural resource management and the economic sustainability of livestock. The region is characterized by extensive tropical forests alongside intensive land-use transformation associated with mining activities, plantation development, and regional infrastructure expansion (Raihan, 2024; Widiarta et al., 2025b). Livestock production systems increasingly operate in fragmented, environmentally sensitive landscapes, requiring adaptive management strategies that balance economic objectives with forest conservation goals. Integrated crop-livestock-forestry systems and agro-livestock development models demonstrate potential to improve land-use efficiency, diversify rural income sources, and reduce environmental pressure on forest-adjacent areas (de Faccio Carvalho et al., 2024; Qamara et al., 2025a; Timsina, 2024).

Empirical studies linking natural resource management practices to the sustainability of livestock economies in tropical forest ecosystems remain limited, particularly from a socio-economic and policy-oriented perspective. Existing literature frequently emphasizes ecological outcomes or sectoral productivity while providing limited analysis of economic resilience, livelihood sustainability, and institutional dynamics (Meybeck et al., 2024; Fatima et al., 2024). Recent research on circular economy approaches and livestock waste management indicates promising pathways toward green growth and sustainable agribusiness development, although comprehensive assessments of their regional economic impacts are still scarce (Azzara et al., 2025; Widiarta et al., 2025a).

This study examines the impact of natural resource management practices on the sustainability of the livestock economy in tropical forest ecosystems, with a specific focus on East Kalimantan. A socio-economic analytical framework is employed to assess the influence of resource management strategies on economic performance, resource efficiency, and long-term resilience of livestock systems operating within forest-dominated landscapes. The results are expected to support evidence-based policymaking and integrated management strategies that strengthen sustainable livestock development while maintaining forest ecosystem integrity and inclusive rural transformation.

METHODS

Study Design

This study adopted a mixed-methods research design integrating quantitative and qualitative approaches to analyze the impact of natural resource management practices on the

sustainability of the livestock economy in tropical forest ecosystems. Mixed-methods designs are widely applied in sustainability and natural resource studies due to their capacity to capture complex interactions between ecological processes and socio-economic outcomes (Meybeck et al., 2024; Anderson, 2024). A cross-sectional approach was selected to assess prevailing management practices and economic conditions of livestock systems operating within forest-dominated landscapes, which is appropriate for evaluating sustainability performance under current institutional and environmental settings (Fatima et al., 2024).

Study Area

The research was conducted in East Kalimantan Province, Indonesia, a region characterized by extensive tropical forests and rapid land-use transformation associated with extractive industries and agricultural expansion. Tropical forest regions undergoing structural economic change provide a relevant empirical context for examining the trade-offs between natural resource use and livestock-based livelihoods (Bas et al., 2024; Ngoma & Yang, 2024). East Kalimantan was selected due to the coexistence of forest ecosystems, mining activities, and livestock production systems that increasingly rely on adaptive natural resource management strategies (Widiarta et al., 2025b; Raihan, 2024).

Data Sources and Research Instruments

Primary data were collected using structured questionnaires, semi-structured interviews, and direct field observations. Structured questionnaires are commonly used in socio-economic livestock studies to quantify production performance, income structure, and resource utilization patterns (Qamara et al., 2025a; Qamara et al., 2025b). Semi-structured interviews enabled in-depth exploration of farmers' perceptions, institutional arrangements, and adaptive strategies, which are critical for understanding sustainability dynamics in forest-based production systems (Das & Mallick, 2024; Darman & Elrix Doirebo, 2024). Field observations were employed to validate reported practices and document land-use integration, waste management, and agroforestry components, as recommended in integrated farming system assessments (Agus et al., 2020).

Sampling Technique and Respondents

A purposive sampling technique was applied to select livestock farmers operating within or adjacent to tropical forest ecosystems. Purposive sampling is appropriate for sustainability research where respondents possess specific characteristics relevant to natural resource management practices (Meybeck et al., 2024). Selection criteria included the type of livestock enterprise, the degree of land-use integration, farm scale, and the duration of farming activities. Key informants, including extension officers and local policymakers, were included to capture institutional perspectives that influence resource governance and livestock development (Widiarta et al., 2025b).

Variables and Measurement

Natural resource management practices were operationalized using indicators related to land stewardship, soil and water conservation, agroforestry integration, and livestock waste recycling. Indicator-based measurement is widely used to assess sustainability performance in integrated agricultural and livestock systems (Agus et al., 2020; Nungula et al., 2024). Livestock economic sustainability was measured through indicators of income stability, production efficiency, cost-benefit ratios, and livelihood diversification. Composite sustainability indices were constructed using standardized scores to enable comparison across farming systems, following approaches applied in sustainable agribusiness and green growth studies (Azzara et al., 2025; Widiarta et al., 2025a).

Data Analysis

Quantitative data analysis employed descriptive statistics to characterize farming systems and inferential analysis to examine relationships between natural resource management practices and economic sustainability indicators. Multiple regression analysis was applied to estimate the influence of key management variables on livestock economic performance, consistent with analytical approaches used in environmental economics and land-use studies (Anderson, 2024; Ngoma & Yang, 2024). Qualitative data were analyzed using thematic content analysis to identify recurring patterns related to institutional support, adaptive capacity, and perceived benefits of sustainable resource management. Quantitative and qualitative findings were integrated at the interpretation

stage to enhance analytical robustness, as recommended in sustainability and rural development research (Meybeck et al., 2024).

RESULTS AND DISCUSSION

Characteristics of Respondents and Livestock Systems

Livestock farming systems in forest-adjacent areas of East Kalimantan were predominantly managed by small- and medium-scale producers operating under mixed production orientations. Cattle farming constituted the primary livestock activity, reflecting its economic importance and adaptability to forest-margin environments, while small ruminants were commonly integrated as complementary enterprises utilizing crop residues and underutilized forage resources. The average farming experience exceeded 10 years, indicating that most respondents had accumulated local knowledge and adaptive capacity to manage livestock under ecological and land-use constraints.

Socio-demographic characteristics revealed that livestock farming was dominated by economically active age groups, with an average farmer age of 46.8 years. This age structure suggests a balance between physical labor capacity and decision-making experience, which is critical for adopting sustainable management practices. Formal education levels were moderate, with most farmers completing secondary education, implying potential receptiveness to technical innovations when supported by effective extension services. Household labor availability averaged three working members per farm, supporting labor-intensive integrated systems commonly practiced in forest-adjacent landscapes.

Table 1. Characteristics of Farmers and Production Systems in Tropical Forest Areas

Variable	Mean
Age of farmers (years)	46.8
Formal education (years)	10.6
Farming experience (years)	13.4
Household labor (persons)	3.1
Herd size (Animal Unit)	6.2
Cattle-based farming (%)	68.9
Small ruminant integration (%)	41.3
Integrated crop-livestock system (%)	61.5
Agroforestry-based livestock system (%)	34.7
Livestock waste recycling (%)	42.1
Use of crop residues as feed (%)	73.6
Reliance on natural grazing (%)	56.4

Source: Primary data analysis (2025)

From a production perspective, average herd size reached 6.2 animal units, reflecting semi-subsistence to semi-commercial production scales. Integrated crop-livestock systems were adopted by more than 60% of respondents, indicating a strategic response to land limitations and feed scarcity. Agroforestry-based livestock integration remained lower, primarily due to tenure restrictions and limited technical assistance, although farms adopting this system demonstrated diversified feed sources and improved microclimatic conditions. Livestock waste

recycling practices, including composting and organic fertilizer application, were adopted by over 40% of respondents, signaling an early-stage transition toward circular and resource-efficient livestock systems.

Characteristics reflect adaptive livestock production strategies shaped by proximity to forests, land fragmentation, and resource availability. High utilization of crop residues and mixed feeding strategies illustrate farmers' responses to forage constraints while maintaining economic viability. Comparable structural patterns have been reported in integrated livestock systems across tropical Asia, where mixed land-use arrangements enhance livelihood resilience and resource-use efficiency under environmental pressure (Timsina, 2024; Qamara et al., 2025a). The observed dominance of integrated systems provides a critical foundation for analyzing the role of natural resource management practices in strengthening the economic sustainability of livestock in tropical forest ecosystems.

Adoption Level of Natural Resource Management Practices

Adoption of natural resource management practices among livestock farmers in tropical forest areas of East Kalimantan varied considerably across management dimensions, reflecting differences in resource access, institutional support, and perceived economic returns. Land and soil management practices recorded the highest adoption levels, indicating farmers' strong awareness of soil fertility and forage productivity as critical determinants of livestock performance. Water use efficiency, agroforestry integration, and livestock waste recycling exhibited moderate adoption, suggesting transitional stages toward more integrated and circular production systems.

Table 2. Adoption Level and Indicators of Natural Resource Management Practices in Tropical Forest Livestock Systems

NRM Component	Key Indicators	Adoption Index (0–1)	Category
Land and soil management	Controlled grazing, forage plots, erosion control	0.72	High
Water use efficiency	Rainwater harvesting, efficient drinking systems	0.58	Moderate
Agroforestry integration	Tree-livestock integration, shade and fodder trees	0.49	Moderate
Livestock waste recycling	Composting, organic fertilizer, manure reuse	0.61	Moderate
Composite NRM index	Aggregated NRM indicators	0.60	Moderate

Source: Primary data analysis (2025)

Land and soil management practices, including controlled grazing, forage plot establishment, and erosion control, achieved a high adoption index of 0.72. Farmers adopting these practices reported improved pasture condition and reduced seasonal feed shortages. High adoption levels were closely linked to direct and observable economic benefits, notably reduced feed costs and more stable animal productivity. These findings are consistent with sustainability studies that highlight land stewardship as the entry point for broader adoption of natural resource management in livestock systems (Nungula et al., 2024; Timsina, 2024).

Water use efficiency practices recorded a moderate adoption index of 0.58. Practices such as rainwater harvesting, improved drinking troughs, and efficient water distribution were applied

primarily by farmers facing seasonal water scarcity. Limited infrastructure investment and low perceived short-term economic returns constrained wider adoption. Similar constraints have been identified in tropical agricultural systems, where water management innovations require collective action and institutional facilitation (Nalluri & Karri, 2024).

Agroforestry integration exhibited the lowest adoption index at 0.49. Tree–livestock integration was practiced mainly by farmers with secure land tenure or access to community-managed forest areas. Limited technical guidance and uncertainty regarding tree ownership rights reduced farmers’ willingness to adopt agroforestry-based livestock systems. These structural barriers reinforce evidence that land tenure security and institutional clarity are decisive factors in agroforestry adoption within tropical forest landscapes (Darman & Elix Doirebo, 2024; Bas et al., 2024).

Livestock waste recycling practices reached a moderate adoption index of 0.61. Composting, organic fertilizer application, and limited bioconversion of manure were increasingly practiced by farmers seeking to reduce fertilizer costs and improve soil productivity. Adoption was higher among farmers participating in extension programs or farmer groups promoting circular economy approaches. These results support previous findings emphasizing the role of knowledge transfer and institutional networks in accelerating circular resource utilization in livestock systems (Agus et al., 2020; Azzara et al., 2025).

The composite natural resource management index of 0.60 indicates that livestock systems in forest-adjacent areas of East Kalimantan are undergoing a gradual transition toward sustainability-oriented management. Higher adoption of land stewardship practices reflects farmers’ immediate perception of benefits related to soil productivity and forage availability. Lower adoption of agroforestry practices highlights structural challenges related to land tenure and limited technical assistance. These findings align with empirical evidence demonstrating that institutional frameworks, access to extension services, and land governance strongly shape the adoption of sustainable natural resource management practices in tropical forest regions (Nungula et al., 2024; Darman & Elix Doirebo, 2024).

Economic Performance of Livestock Systems

Economic performance analysis revealed substantial differences between livestock systems with low and high levels of natural resource management (NRM) adoption. Livestock farms with high NRM adoption consistently outperformed low-adoption systems across all key economic indicators, indicating stronger economic sustainability and resilience. Annual livestock income among high-NRM farms reached IDR 39,600,000 per year, compared with IDR 27,300,000 per year for farms with low NRM adoption. This income disparity reflects productivity gains from more efficient resource allocation, improved feed self-sufficiency, and reduced exposure to input price volatility in forest-adjacent production environments.

Table 3. Economic Performance of Livestock Systems by Level of NRM Adoption

Economic Indicator	Low NRM Adoption	High NRM Adoption
Annual livestock income (IDR/year)	27,300,000	39,600,000
Cost–benefit ratio	1.38	1.76
Feed cost proportion (%)	54.2	41.7
Income variability (CV %)	29.6	17.8

Source: Primary data analysis (2025)

Production efficiency, measured through the cost–benefit ratio, was markedly higher in high-NRM systems. A cost-benefit ratio of 1.76 in high-adoption farms indicates a more favorable return on production costs relative to output value, compared with 1.38 observed in low-adoption farms. These efficiency gains suggest that investments in soil management, forage development, and livestock waste recycling generate tangible economic returns in tropical forest livestock systems. Sustainable resource management thus serves not only as an environmental safeguard but also as a strategy to enhance farm-level economic efficiency.

Feed cost proportion emerged as a critical factor differentiating the two production systems. High-NRM farms allocated only 41.7% of total production costs to feed, while low-NRM farms devoted 54.2%. Lower feed expenditure among high-NRM adopters was associated with forage diversification, utilization of crop residues, and waste-based feed supplementation. These practices reduced dependence on purchased feed inputs, which are often vulnerable to market fluctuations and logistical constraints in forest-dominated regions. Resource-based feed strategies, therefore, contributed directly to improved cost structures and financial performance.

Income stability analysis further demonstrated the economic advantages of NRM adoption. Income variability, expressed as the coefficient of variation, was substantially lower in high-NRM farms at 17.8%, compared with 29.6% in low-NRM systems. Reduced income volatility indicates greater resilience to seasonal feed scarcity, climate variability, and market shocks. Livestock systems integrating natural resource management practices are consequently better positioned to sustain household livelihoods under conditions of ecological uncertainty characteristic of tropical forest ecosystems.

The economic outcomes observed in this study are consistent with environmental economics theory, which emphasizes the internalization of resource-efficiency gains through sustainable management practices. Improved utilization of locally available natural resources reduces dependency on external inputs and lowers long-term production risks. Empirical evidence from comparable tropical production systems confirms that NRM adoption enhances both profitability and income stability by optimizing ecological-economic interactions within farming systems (Anderson, 2024; Moldavan et al., 2024; Suryani et al., 2026). These findings reinforce the argument that economic sustainability in livestock production is inseparable from responsible natural resource governance, particularly in environmentally sensitive regions such as East Kalimantan.

Impact of Natural Resource Management on Livestock Economic Sustainability

Multiple regression analysis demonstrated a strong and statistically significant relationship between natural resource management (NRM) practices and livestock economic sustainability in tropical forest ecosystems. The estimated model explains a substantial proportion of variation in economic sustainability indicators, with an R^2 value of 0.63, indicating that NRM-related variables collectively account for 63% of the observed variation in livestock economic performance. This level of explanatory power is considered high for socio-economic analyses conducted in heterogeneous rural production systems operating under ecological and institutional constraints.

Table 4. Multiple Regression Results on Livestock Economic Sustainability

Variable	Coefficient	t-value	Significance (p-value)
Land and soil management	0.312	3.41	0.001
Agroforestry integration	0.267	2.98	0.004
Waste recycling practices	0.294	3.12	0.002

Water use efficiency	0.181	1.97	0.051
R ²	0.63	-	-

Source: Primary data analysis (2025)

Land and soil management emerged as the most influential determinant of livestock economic sustainability. The positive and highly significant coefficient indicates that improvements in soil conservation, forage land management, and controlled grazing practices directly enhance productivity and income stability. Effective land stewardship supports sustained forage availability, reduces land degradation risks, and lowers production uncertainty, all of which are critical to the long-term economic viability of forest-adjacent livestock systems.

Waste recycling practices also exerted a strong and statistically significant influence on economic sustainability. Livestock systems that actively recycled manure and organic waste into fertilizer or feed inputs achieved superior cost efficiency and income performance. These results highlight the economic value of circular resource utilization, where internal resource flows reduce dependence on external inputs, stabilize production costs, and enhance farm profitability. Waste-based nutrient recycling, therefore, functions simultaneously as an environmental management strategy and an income-stabilizing economic mechanism.

Agroforestry integration showed a positive and significant relationship with livestock economic sustainability, reflecting the role of diversified land-use systems in strengthening economic resilience. Integration of trees within livestock production systems contributed to feed diversification, microclimate regulation, and supplementary income generation, thereby reducing vulnerability to climatic shocks and market volatility. The magnitude of the coefficient indicates that agroforestry adoption provides meaningful economic benefits, although its effectiveness remains influenced by land tenure security, institutional support, and access to technical assistance.

Water use efficiency demonstrated a positive, though marginally significant, effect on livestock economic sustainability. This outcome suggests that efficient water management contributes to economic performance, although its influence may be moderated by relatively abundant rainfall patterns and limited variability in water access across the study area. The reduced statistical significance of this variable relative to land and waste management practices suggests that water-efficiency gains may become more critical as climate variability increases or water scarcity intensifies.

Diagnostic tests confirmed the robustness of the regression model. Multicollinearity assessment using the Variance Inflation Factor showed VIF values ranging from 1.34 to 2.11, well below the critical thresholds and indicating no serious multicollinearity among the explanatory variables. Heteroskedasticity testing using the Breusch-Pagan procedure revealed no significant heteroskedasticity, confirming constant variance of residuals across observations. Residual diagnostics further indicated a normal error distribution and the absence of systematic patterns, supporting the validity of the coefficient estimates and inferential conclusions.

The empirical results align closely with environmental economics theory, which emphasizes productivity enhancement and risk reduction through efficient resource allocation and internalization of ecological benefits. Improved use of locally available resources reduces dependence on external inputs, lowers long-term production risks, and enhances income stability. Comparable findings from sustainable agribusiness and green growth studies similarly identify land-based efficiency, circular resource use, and integrated production systems as key drivers of resilient livestock economies (Azzara et al., 2025; Widiarta et al., 2025a).

The findings are highly relevant to the Sustainable Development Goals. Significant impacts of land and soil management support SDG 2 (Zero Hunger) through enhanced livestock

productivity and income stability. Waste recycling practices contribute directly to SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action) by promoting circular resource use and reducing environmental externalities. Agroforestry integration aligns with SDG 15 (Life on Land) by supporting biodiversity conservation and ecosystem service provision while maintaining economic viability. Positive effects of water-use efficiency align with SDG 6 (Clean Water and Sanitation) through improved resource efficiency and adaptive capacity.



Figure 1. Conceptual Model Linking NRM, Green Growth, and Economic Sustainability

From a green growth perspective, the results confirm that natural resource management operates as a productivity-enhancing investment rather than an economic constraint. Livestock systems adopting integrated NRM practices exhibit higher efficiency, reduced income volatility, and stronger resilience to ecological and market shocks. These outcomes reinforce the argument that sustainable livestock development in tropical forest ecosystems depends fundamentally on responsible natural resource governance and supportive institutional frameworks, particularly in environmentally sensitive regions such as East Kalimantan.

Implications for Forest Conservation and Rural Livelihoods

The findings of this study indicate that livestock systems with higher levels of natural resource management (NRM) adoption exert significantly lower pressure on forest land by achieving productivity gains through sustainable intensification rather than spatial expansion. Improved land and soil management, coupled with efficient feed utilization and circular waste recycling practices, enabled farmers to increase livestock output without further encroaching on forest areas. This intensification pathway is particularly critical in tropical forest landscapes, where agricultural expansion remains a major driver of biodiversity loss and ecosystem degradation (Apriyani et al., 2024; Ngoma & Yang, 2024). Consistent with environmental economics theory, productivity-enhancing NRM practices reduce the opportunity cost of forest conversion by increasing returns on existing agricultural land (Anderson, 2024).

Integrated crop-livestock-forestry systems emerged as a strategic mechanism for reconciling livestock development with forest conservation objectives. The incorporation of trees into livestock production systems enhanced ecosystem service provision, including soil fertility restoration, microclimate regulation, water retention, and carbon sequestration, while simultaneously maintaining economic viability. These multifunctional systems embody nature-based solutions that internalize environmental benefits into production processes, thereby reducing the trade-offs between conservation and economic performance (de Faccio Carvalho et al., 2024; Nungula et al., 2024). Similar evidence from Asian and tropical contexts confirms that agroforestry-based livestock systems contribute to sustainable land-use intensification and climate resilience (Timsina, 2024; Agus et al., 2020).

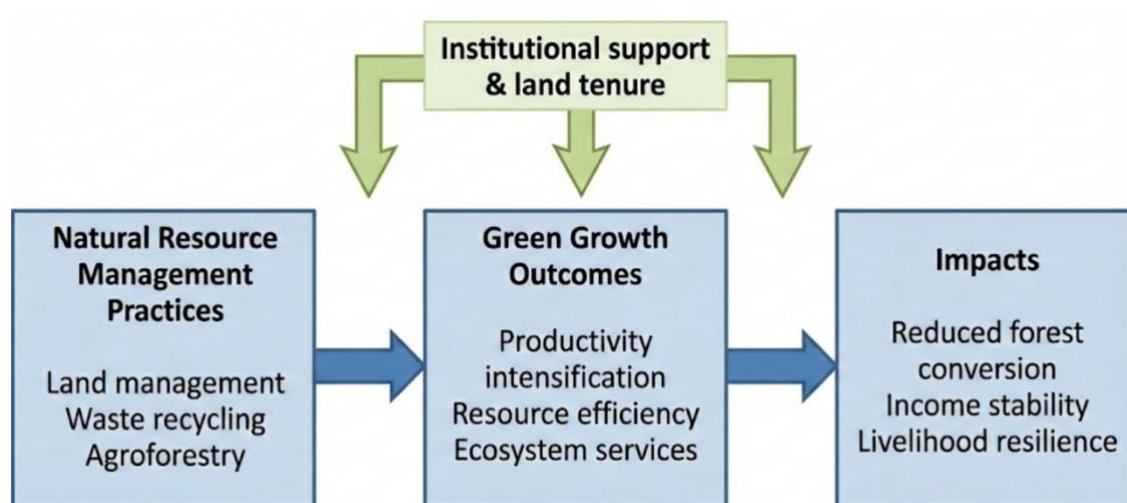


Figure 2. Implications of Natural Resource Management Adoption for Forest Conservation and Rural Livelihoods

Positive livelihood implications were also evident among rural households adopting integrated NRM practices. Improved income stability, reduced production costs, and enhanced resource-use efficiency strengthened household economic resilience, particularly in communities located adjacent to forest ecosystems and extractive industry zones. Income diversification through agroforestry products and circular livestock waste management reduced vulnerability to price volatility and climatic shocks, reinforcing NRM adoption as a livelihood-enhancing strategy rather than a constraint on economic opportunity (Meybeck et al., 2024; Azzara et al., 2025). These findings align with empirical studies demonstrating that sustainable agricultural practices can simultaneously support rural livelihoods and environmental stewardship in forest-dependent communities (Das & Mallick, 2024; Fatima et al., 2024).

Institutional and governance dimensions played a decisive role in shaping both conservation and livelihood outcomes. Secure land tenure, access to extension services, and effective coordination between livestock development and forest conservation policies significantly enhanced farmers' willingness to invest in long-term resource management practices, particularly agroforestry systems. In contrast, weak institutional coherence and tenure insecurity constrained NRM adoption and limited conservation gains. These results corroborate evidence that integrated governance frameworks and community participation are essential for successful and inclusive natural resource management in Indonesia and other tropical regions (Darman & Elrix Doirebo, 2024; Raihan, 2024).

Empirical evidence supports the premise that livestock development can be aligned with forest conservation when guided by adaptive, integrated NRM strategies. Comparable findings from tropical regions demonstrate that integrated crop-livestock-forestry models promote sustainable land-use intensification while maintaining ecosystem integrity and improving rural livelihoods (de Faccio Carvalho et al., 2024; Bas et al., 2024). These results underscore the importance of promoting NRM-based livestock systems as a viable policy pathway for achieving forest conservation, green growth, and inclusive rural development in tropical forest landscapes such as East Kalimantan

CONCLUSION

This study demonstrates that natural resource management is a critical determinant of economic sustainability in livestock systems within tropical forest ecosystems, as evidenced by improved productivity, greater income stability, and lower production costs achieved through integrated management of land, soil, water, and biological resources. Land and soil management, together with waste recycling practices, emerged as the most influential factors, underscoring the importance of resource-use efficiency and circular

production strategies in enhancing livestock resilience under ecological and institutional constraints. Agroforestry integration further strengthens economic sustainability by diversifying income sources while simultaneously delivering ecosystem services, enabling productivity gains through sustainable intensification rather than land expansion, and thereby reducing pressure on forest ecosystems and biodiversity. These findings confirm that integrated crop-livestock-forestry systems represent an effective nature-based solution that reconciles livestock development with forest conservation and green growth objectives. From a policy perspective, the results highlight the necessity of secure land tenure, effective extension services, and cross-sectoral coordination among livestock, agricultural, and forestry institutions to scale up NRM adoption. NRM-based livestock development offers a viable pathway to achieve economic sustainability, forest conservation, and inclusive rural livelihoods in tropical forest landscapes such as East Kalimantan.

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