



Research Article

An Integrated Agro-Livestock Model for Sustainable Intensification of Marginal Lands

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Abstract: Degraded post-mining lands in East Kalimantan suffer from low soil fertility, reduced biodiversity, and limited economic value for local communities. Previous efforts, such as monoculture reforestation or single-sector agriculture, have produced limited ecological recovery and economic resilience. This study aims to develop a community-based sustainable business model and assess the ecological and economic impacts of an integrated cattle–forage–stingless bee system in post-mining regions. A mixed-methods approach combined qualitative techniques (in-depth interviews, focus group discussions) with quantitative analyses (carbon footprint, R/C ratio, B/C ratio) across five regencies, involving five key informants and thirty farmers. The system advances SDGs by increasing income through diversified products (SDGs 1, 2, 8), converting degraded land into carbon sinks (-12.05 tCO₂e/ha/year) (SDGs 13, 15), and supporting biodiversity through pollination (SDG 15). Its cyclical approach, aligned with SDG 12, transforms wastelands into sustainable agricultural landscapes, addressing climate and livelihood challenges. This is the first empirical study to link carbon sequestration and biodiversity gains with economic viability in a three-tier cattle–forage–stingless bee integration for post-mining landscapes.

Keywords: carbon sequestration; community empowerment; integrated farming; land rehabilitation; sustainability

1. Introduction

Agricultural development is a critical component in achieving national welfare, particularly in an agrarian country such as Indonesia. Agriculture is not only the primary source of food, but it is also the largest employer and economic driver in rural areas. However, Indonesia's agricultural industry is today confronted with a number of increasingly complicated difficulties, such as land degradation, climate change, low productivity, and unequal distribution of agricultural outputs (Qamara et al., 2024). To solve these difficulties and meet 21st-century global expectations, agricultural growth must take a long-term approach—one that is economically productive, resource efficient, environmentally benign, and socially inclusive.

To address these global concerns, the Sustainable Development Goals (SDGs) offer a comprehensive framework for reforming agriculture and food systems. Of the 17 goals, at least five are directly relevant to sustainable agriculture in Indonesia: SDG 1: No Poverty, SDG 2: Zero Hunger, SDG 8: Decent Work and Economic Growth, SDG 12: Responsible Consumption and Production, and SDG 13: Climate Action (Nasrullah, 2022). At the national level, Indonesia's Asta Cita development strategy stresses poverty eradication, food and energy security, and environmental sustainability. In this scenario, agricultural reform must shift away from traditional sectoral thinking and toward a holistic and integrative paradigm that addresses economic, social, and environmental issues at the same time.

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The Agro-Livestock Integration System is a potential method to sustainable agriculture that blends agricultural cultivation with livestock keeping into a single, mutually beneficial production environment (Widiastuti et al., 2024). In this method, agricultural waste such as crop residues, leaves, and post-harvest byproducts are utilized as animal feed, while livestock waste (manure and urine) is converted into organic fertilizer or sustainable energy sources such as biogas (Rathore et al., 2022). This synergy increases land productivity, improves soil quality, lowers the carbon footprint of farming activities, and strengthens smallholder farmers' resilience to climatic and market fluctuations (V. D. Silva, R. S. Nascimento, J. P. Lopes Neto, J. Miranda, F. F. M. Lopes, 2022).

Empirical evidence supports the potential of this system. Agro-livestock integration enhanced smallholder farmers' incomes by up to 25% compared to monoculture farming (Lankoski et al., 2025). This strategy might reduce greenhouse gas emissions by around 18% while increasing household resilience. Peatlands in West Kalimantan, demonstrating the successful implementation of a corn-cattle integrated system, which considerably enhanced local economic efficiency and promoted circular agriculture practices (Widiastuti et al., 2024).

Despite these advantages, agro-livestock integration in remote locations is still underutilized, particularly in Kalimantan. Despite its huge land resources, including peatlands, acidic soils, and post-mining areas, Kalimantan has struggled to establish itself as a hub for sustainable agriculture innovation. Farmers in these areas continue to rely on low-productivity monocultures, which exposes them to significant crop failure risks and increasing input costs due to the usage of chemical fertilizers and pesticides. These practices contribute to environmental degradation while failing to achieve long-term food and income security.

Kalimantan's marginal lands are distinguished by low soil fertility, high acidity, insufficient infrastructure, and restricted access to agricultural technology and markets (Mansyur et al., 2019). Conventional agricultural models are rendered inefficient due to these limits. The fundamental gap is the lack of a localized agro-livestock integration model that is uniquely tailored to the biophysical and socioeconomic constraints of Kalimantan. Existing models from Java and Sumatra cannot be duplicated due to differences in microclimates, land ownership systems, farming cultures, and logistical constraints.

This study aims to close the identified gap by creating a novel, context-specific Agro-Livestock Integration System that is suited to the particular biophysical and socioeconomic characteristics of Kalimantan's marginal land. The suggested system is intended to use locally available resources, adopt relevant and accessible technologies, and prioritize community-based empowerment as a basis for long-term viability. This model's originality goes beyond the technical integration of agricultural and animal components; it also considers economic viability, ecological resilience, and social inclusivity as critical implementation pillars. According to SDGs 1 (No Poverty) and 8 (Decent Work and Economic Growth), the model specifically seeks to raise farmers' incomes and stimulate local economic growth; support SDG 2 (Zero Hunger) by increasing the availability of local food supplies while reducing reliance on outside sources; reduce carbon emissions and the need for external agricultural inputs, which is in line with SDG 13 (Climate Action); and encourage the circular, efficient use of natural resources, which is in line with SDG 12 (Responsible Consumption and Production).

The impending global food crisis and mounting strain on natural ecosystems make such a strategy even more urgent. Agriculture and food systems are vital sectors for climate

mitigation because they contribute around one-third of the world's greenhouse gas emissions (Mekouar, 2024). It is widely acknowledged that integrated farming systems are essential to the shift to resilient, low-carbon food systems. Additionally, carbon credit programs in agriculture are made possible by national rules like Presidential Regulation No. 98 of 2021 on Carbon Economic Value, which encourage farmers to implement climate-smart methods.

There are important social aspects to the suggested paradigm as well. Local farmers and livestock keepers will participate in integrated farming systems' planning, production, and value chain through a community-based approach. Smallholder households can lessen their vulnerability and increase their economic stability by diversifying their sources of income through biogas, organic fertilizer production, and animal husbandry (Lee & Ignaciuk, 2025). The approach may be replicated in other marginal areas outside of Kalimantan because it is inclusive, participatory, and scalable.

The Agro-Livestock Integration System ultimately has the ability to achieve several development objectives inside a single integrated framework: it helps to reduce poverty, guarantees food and income security, improves ecological balance, and lowers emissions. In line with the SDGs and Asta Cita's goal, this model serves as an example of how Indonesia might develop a resilient, inclusive, and green rural economy.

2. Literature Review

Land Condition in Kalimantan

Based on research by Mansyur et al. (2019) (Mansyur et al., 2019) conducted in North Kalimantan at two sites with different parent materials—clay sand sedimentation (Location 1) and sandstone (Location 2)—soils developed from acidic sedimentary rocks exhibited distinct morphological and chemical characteristics, with dark A horizon colors (10YR 4/3 and 3/2) that became lighter with depth, sand-dominated texture, crumb to granular structure, and low to very low levels of organic matter, nitrogen, phosphorus, and potassium, while aluminum saturation was high due to acidic soil pH (4.1–4.9); through the identification of diagnostic horizons, both soil profiles were found to have umbric epipedons and cambic endopedons, leading to their classification as Inceptisols, specifically Haplucepts at Location 1 and Endoaquepts at Location 2, indicating low natural fertility and necessitating amelioration and fertilization efforts to enhance productivity

Integrated Agroforestry Systems

Integrated agroforestry systems offer multiple benefits, as demonstrated by Rathore et al. (2022) (Rathore et al., 2022), including enhanced system productivity—exemplified by the combination of phalsa (*Grewia asiatica*) with mung bean (*Vigna radiata*) and potato (*Solanum tuberosum*), which yielded the highest output of 25.9 Mg/ha and a production efficiency of 101 kg/ha/day due to synergistic resource use and improved light, water, and nutrient utilization. Economically, the karonda (*Carissa carandas*) + mung bean - potato system generated the highest net returns (3,529.1 US\$/ha), while the karonda + cowpea - mustard system achieved the best benefit-cost ratio (3.85), with product diversity boosting income and reducing economic risks. Moreover, these systems significantly improved water use efficiency (WUE), with the phalsa + mung bean - potato system recording the highest WUE (33.0 kg/ha-mm), crucial in water-scarce semi-arid regions. Additionally, agroforestry enhanced soil organic

carbon (SOC) and carbon sequestration potential (CSP), particularly in phalsa and moringa-based systems, which increased SOC by up to 0.41% and CSP by 0.6–0.67 Mg/ha/year, largely due to litter and pruned biomass contributing to soil organic matter.

3. Proposed Method

This study takes a mixed-methodologies approach, combining quantitative and qualitative methods to completely evaluate integrated agriculture-livestock systems on marginal land in East Kalimantan (Plano Clark, 2017). The quantitative approach assesses system efficiency, economic viability, and environmental impact, whereas the qualitative approach looks at farmers' views, obstacles, possibilities, and social-institutional dynamics (Bhagat et al., 2024). The study was undertaken in numerous locations of East Kalimantan, including Kutai Kartanegara, Paser, Berau, East Kutai, West Kutai Regencies, and Samarinda City, based on preliminary surveys and the availability of primary data. These sites were chosen because of their marginal land conditions and potential for integrated farming.

The research lasted five months (January-May 2025), and included planning, data collecting, analysis, and manuscript drafting. The target demographic consists of farmers and livestock breeders who are involved in or have the potential for integrated systems. A purposive sample of 30 respondents and five key informants was chosen. Primary data was collected using questionnaire surveys (with Likert scales for perceptions), in-depth interviews with stakeholders, focus group discussions (FGDs), and field observations. Secondary data were gathered from literature reviews and official reports on climate, soil, and demographics.

The quantitative analysis used descriptive data, economic assessments (gross/net margins, R/C and B/C ratios), and carbon footprint comparisons. Data triangulation ensures the validity and dependability of qualitative findings, which are reviewed thematically. This methodology aims to provide a comprehensive understanding of the regional feasibility and sustainability of the integrated system (Murthy & Muninarayanappa, 2023; Parmawati et al., 2022).

4. Results and Discussion

Commodity Prices for the Cattle-Forage-Stingless Bee Integration System on Former Mining Land in East Kalimantan

Investing on post-mining land for livestock integration necessitates cautious crop choice. The crops chosen must be able to grow in damaged soil conditions, have a high feed value for cattle, and, ideally, help to remediate the land. Furthermore, the presence of biodiversity, such as Stingless bees, can boost diversity and income for farmers and ranchers. Table 1 shows more detailed results.

Table 1. Commodity Prices for the Cattle-Forage-Stingless Bee Integration System on Former Mining Land in East Kalimantan.

Category	Item	Unit	Cattle Monoculture	Cattle-Forage Integration	Cattle-Forage-Stingless Integration
Commodity Prices					
Feeder Cattle	Price	/head	IDR 20,000,000	IDR 20,000,000	IDR 20,000,000

Slaughter Cattle	Price	/head	IDR 26,000,000	IDR 26,000,000	IDR 26,000,000
Cattle Feed Concentrate	Price	/kg	IDR 3,500	IDR 3,500	IDR 3,500
Stingless Honey	Price	/bottle (250ml)	-	-	IDR 150,000
Stingless Starter Colony	Price	/stup	-	-	IDR 500,000
Labor	Daily Wage	/day	IDR 120,000	IDR 120,000	IDR 120,000
Productivity					
ADG Cattle	Increased Daily Weight Gain	kg/day	0.9	1.1	1.1
Feed Efficiency	Reduced Concentrate Costs	%	-	50-60%	50-60%
Forage Production	Elephant Grass/Odot	tons/ha/year	-	80	80
ADG Cattle	Calliandra grass	tons/ha/year	-	15	15
Stingless Honey Production	Volume	bottles/stup/year	-	-	2

The integrated cattle-forage-stingless bee system in East Kalimantan's ex-mining areas has the potential to improve both economic efficiency and environmental sustainability. According to commodity pricing statistics, the initial input costs (feeding cattle, concentrate, and labor) are comparable across the three systems (monoculture, cattle-forage integration, and cattle-forage-stingless bee integration). However, the cattle-forage-stingless bee integration system offers significant added value in the following ways: (1) local forage production, such as calliandra (15 tons/ha/year) and elephant grass (80 tons/ha/year), reduces feed costs by 50–60%, replacing commercial concentrate (IDR 3,500/kg); (2) additional revenue from stingless bee honey (IDR 150,000/bottle), which has a productivity of 2 bottles/hive/year, as well as revenue from stingless bee colonies (IDR 500,000/hive); and (3) increased cattle farming efficiency through higher average daily gain (ADG) (1.1 kg/day) compared to monoculture systems (0.9 kg/day), which shortens the rearing period.

In East Kalimantan, former mining sites are ideal for growing hardy feed crops like calliandra and elephant grass, which also help to restore degraded soils (Franceschi et al., 2020). In addition to improving pollination of forage crops, stingless bee integration increases the benefit-cost (B/C) ratio to 1.5–2.0 in degraded lands by producing high-value honey with an inexpensive initial capital (IDR 500,000/hive) (Gupta & Palsaniya, 2020). Through feed cost savings and product diversification (beef and honey), this system has the ability to economically boost gross income by 25–40% as compared to monoculture (van Noordwijk et al., 2020).

Despite the initial cost of purchasing stingless bee colonies, research indicates that honey sales can yield a return on investment (ROI) in as little as one to two years (Barbosa et al., 2024). Farmers must receive technical training in integrated management and stingless bee honey commercialization in order to maximize implementation (Mwakatobe et al., 2017).

Economic Analysis of Integrated Cattle-Forage-Stingless Bee Farming System

Despite requiring a larger initial investment, the integrated cattle-forage-stingless bee system in East Kalimantan's former mining fields exhibits a viable business model, according to economic indicator data. Cattle sales (IDR 520 million), the economic value of manure (IDR 3 million), and stingless bee honey (IDR 15 million) generate the largest gross revenue (IDR 538 million) for the fully integrated system. The production of honey, which accounts for 2.8% of total revenue, is a game-changing element that generates steady extra income that can be scaled with more colonies (Ansahar et al., 2025). The detailed results can be seen in Table 2.

Table 1. The Result of Economic Analysis of Integrated Cattle-Forage-Stingless Bee Farming System.

Economic Component	Monoculture Cattle System (IDR)	Cattle-Forage Integrated System (IDR)	Cattle-Forage-Stingless Bee System (IDR)
GROSS INCOME			
Cattle Sales (20 heads)	520,000,000	520,000,000	520,000,000
Economic Value of Manure	-	3,000,000	3,000,000
Stingless Bee Honey Sales	-	-	15,000,000
TOTAL INCOME	520,000,000	523,000,000	538,000,000
VARIABLE COSTS			
Feeder Cattle Purchase	400,000,000	400,000,000	400,000,000
Concentrate Feed Cost	100,000,000	40,000,000	40,000,000
Purchased Forage Cost	20,000,000	-	-
Medicines & Vaccines	12,000,000	12,000,000	12,000,000
Forage Land Development	-	5,000,000	5,000,000
Forage Maintenance	-	3,000,000	3,000,000
Initial Bee Colony Purchase	-	-	25,000,000
Bee Maintenance	-	-	1,000,000
Direct Labor	10,000,000	15,000,000	16,000,000
TOTAL VARIABLE COSTS	542,000,000	475,000,000	502,000,000

Economic Component	Monoculture Cattle System (IDR)	Cattle-Forage Integrated System (IDR)	Cattle-Forage-Stingless Bee System (IDR)
GROSS MARGIN	(22,000,000)	48,000,000	36,000,000
FIXED COSTS			
Barn & Equipment Depreciation	5,000,000	5,000,000	5,000,000
Forage Equipment Depreciation	-	2,000,000	2,000,000
Honey Harvest Equipment Deprec.	-	-	1,000,000
Electricity & Water	1,000,000	1,000,000	1,000,000
Land Rent (if applicable)	-	4,000,000	4,000,000
TOTAL FIXED COSTS	6,000,000	12,000,000	13,000,000
NET MARGIN	(28,000,000)	36,000,000	23,000,000

Profitability depends on feed cost efficiency, as evidenced by the 66% savings in integrated systems (IDR 40 million) over monoculture (IDR 120 million). Local forage production (elephant grass/calliandra) on rehabilitated land replaces 60% of commercial concentrate and 100% of purchased forage, resulting in these savings. The costs of forage development (IDR 5 million) and maintenance (IDR 3 million) can be recovered in a year.

According to a strategic profitability analysis, the whole integration yields IDR 36 million, while the cattle-forage system yields the largest gross margin (IDR 48 million). The initial stingless bee investments (IDR 25 million colony purchase + IDR 1 million equipment) are the reason for the lower net margin of the entire system (IDR 23 million vs. IDR 36 million). Its strategic advantages include: free manure fertilizer for grazing land; enhanced cattle daily weight increase (1.1 kg/day) through bee pollination; and long-term bee colonies (5-7 years lifespan) with minimum upkeep (IDR 1 million/year).

Long-term ecosystem restoration investments include the IDR 4 million land leasing fee, the IDR 3 million equipment depreciation, and a 23% increase in soil organic carbon in just two years (Pambudi et al., 2023). Two stages are necessary for effective implementation: After forage stabilization, Phase 2 involves bee integration, whereas Phase 1 focuses on cattle-forage integration to establish economic foundations (IDR 36 million net margin). 50% stingless bee colony subsidies (bringing the cost down to IDR 12.5 million) and integrated management training are examples of crucial policy support (Harun et al., 2022).

R/C and B/C Ratios of Integration Systems on Ex-Mining Sites in East Kalimantan

Economic ratio data indicates that the cattle-forage-stingless bee integration system on East Kalimantan's former mine area exhibits exceptional operational efficiency; nonetheless,

long-term profitability optimization necessitates a particular approach. The outcomes of processing the data are as follows.

Table 2. The Result of R/C and B/C Ratios of Integration Systems on Ex-Mining Sites in East Kalimantan

Indicator	Monoculture	Cattle-Forage Integration	Cattle-Forage-Stingless Bee Integration
R/C Ratio	0.95	1.07	1.04
B/C Ratio	-0.05	0.07	0.04
Net Margin (IDR)	-28,000,000	36,000,000	23,000,000

Achieving a positive B/C ratio of 0.07, which indicates benefits outweigh costs, and an R/C ratio of 1.07, which generates IDR 1,070 in revenue for every IDR 1,000 invested, the cattle-forage integration system exhibits exceptional first-year economic performance. As a result of their over-reliance on commercial feed inputs, monoculture systems are economically unviable (R/C 0.95, B/C -0.05). Due mainly to high startup costs (IDR 25 million for initial bee colonies plus IDR 1 million for maintenance) and suboptimal first-year honey yields at only 50% capacity (2 bottles per hive versus a potential 4 bottles), the full integrated system incorporating stingless bees shows reduced initial profitability (net margin of IDR 23 million compared to IDR 36 million for cattle-forage alone).

However, long-term forecasts show significant progress starting in the second year. The R/C ratio is 1.25 and the B/C ratio is 0.15, as Bueno et al. (2023) (Bueno et al., 2023) show, when colony acquisition expenditures are eliminated (reduced to merely IDR 1 million annually for maintenance) and honey output is doubled (earning IDR 30 million annually). A 22% increase in cattle's average daily gain (from 1.1 to 1.34 kg/day) due to improved pollination and a 30% decrease in fertilizer costs because of the improved manure quality from the integrated system are just two of the system's significant indirect benefits.

A phased strategy is advised for best results: concentrating only on cattle-forage integration in Year 1 to provide the groundwork for the system (reaching an R/C of 1.07), followed by the introduction of stingless bees in Year 2 following forage stabilization. While technical training in non-disruptive harvesting methods and smart hive placement near Calliandra would increase productivity, financial incentives like 50% subsidies for initial colony costs could raise first-year B/C ratios to 0.08 (Esch et al., 2021). The fully integrated system achieves peak profitability in later years as early investments amortize, honey production maximizes, and pollination synergies boost total system productivity, even if the cattle-forage system yields the best first-year returns (IDR 36 million net margin).

Environmental Impact of the Cattle-Forage-Stingless Bee Integration System on Former Mining Land in East Kalimantan

The cattle-forage-stingless integration system on former mining soil in East Kalimantan, according to carbon footprint research, demonstrates exceptional efficacy in reducing greenhouse gas emissions and boosting carbon sequestration, two mechanisms that mitigate climate change. This is a thorough interpretation:

Table 3. Greenhouse Gas Emission Reduction.

Emissions Source	Conventional System (tons of CO ₂ e)	Integrated System (tons of CO ₂ e)	Reduction	% Reduction
CH ₄ (cattle)	30.8	28.0	2.8	9.1%
N ₂ O (waste)	13.25	7.95	5.3	40.0%
CO ₂ (Energy)	5.0	2.0	3.0	60.0%

Based on table 4, through three main methods, the combined cattle-forage-stingless bee system dramatically lowers greenhouse gas emissions: (1) feeding local forages (calliandra/elephant grass) to cattle reduces CH₄ emissions by 9.1% by improving feed digestibility and reducing enteric fermentation (Apriani et al., 2025); (2) integrated waste management reduces N₂O emissions from manure by 40% by inhibiting nitrification-denitrification processes (Pambudi et al., 2023; Zhang & Song, 2014); and (3) reducing the use of heavy machinery and external feed transportation reduces CO₂ emissions by 60%.

Due to significant soil damage, traditional ex-mining sites exhibit negligible carbon absorption for carbon sequestration. A 23% increase in soil organic matter within two years, deep-rooted calliandra carbon storage (0-2m soil depth), and pasture biomass production (elephant grass stores 12 tons C/ha/year) are the ways in which the integrated system provides 25 tons CO₂e sequestration annually. This conversion promotes sustainable agricultural output while converting degraded land into an active carbon sink (Bhati et al., 2024).

Table 4. Total Carbon Footprint Transformation.

Indicator	Conventional System	Integrated System	Change
Total Emissions	+49.05 tons CO ₂ e	+12.95 tons CO ₂ e	
Absorption	0	-25.00 tons CO ₂ e	
Net Carbon	+49.05 tons CO ₂ e	-12.05 tons CO ₂ e	-61.1 tons CO ₂ e

Amazing environmental change is fueled by the integrated cattle-forage-stingless bee system, which transforms degraded former mine sites from sources of carbon emissions (+49.05 tons CO₂e) into net carbon sinks (-12.05 tons CO₂e). This climate efficiency is equivalent to reducing five passenger cars' worth of emissions per hectare per year (EPA, 2024). Beyond carbon measurements, the system provides a wide range of ecosystem benefits: the 40% decrease in nitrogen waste (N₂O) greatly improves groundwater quality, and calliandra roots and bovine manure promote the carbon-sequestering soil microbiota (Liu et al., 2024). By assisting with pollination for 68 native plant species, the introduction of stingless bees enhances local biodiversity even more (Bueno et al., 2023).

Based on IDR 300,000/ton CO₂e, this ecological restoration has the potential to produce IDR 3.6 million in carbon credit revenue per hectare per year, which would provide financial incentives for sustainable land rehabilitation. These results show how, in post-mining

environments, agricultural innovation can concurrently address ecosystem restoration, climate change mitigation, and rural economic growth.

5. Conclusions

A sustainable solution that balances social, ecological, and economic factors is the cattle-forage-bees integration system on East Kalimantan's former mining site. This approach not only turns deteriorated land into usable land but also gives nearby people more robust and varied sources of income. A multifaceted strategy is necessary to ensure the successful adoption of the integrated cattle-forage-stingless bee system. The first step is participatory education and training through field schools that emphasize hands-on learning in integrated system management by fusing traditional knowledge with technological innovations. Concurrently, collective capacity will be increased by fortifying local institutions through the formation of farmer groups that are competent to run their businesses from start to finish and by developing shared knowledge networks for problem-solving. Equally critical is improving access to productive resources, including quality seeds, basic equipment, and tailored financing schemes aligned with agricultural cycles.

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