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Strengthening Rural Economies Through Integrated Agriculture: Evidence from Southeast Aceh Using Input–Output Modeling

Denny Febrian Roza[1], Satia Negara Lubis[1*], Luhut Sihombing[1], Sinar Indra Kesuma[1], Arga Abdi Rafiud Darajat Lubis[2]

[1] Rural Development Planning, Post Graduate School, Universitas Sumatera Utara, Medan 20222, Indonesia
[2] Directorate of Internationalization and Global Partnership, Universitas Sumatera Utara, Medan 20222, Indonesia

Corresponding Author Email: satia.negara@usu.ac.id

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ABSTRACT

Rural economic areas in Southeast Aceh District face persistent development challenges, including low agricultural productivity, limited infrastructure, and economic disparities. This study proposes an Integrated Agricultural Model (IAM)—a synergistic approach that aligns crop production, livestock, and agro-industry—to foster rural transformation. Utilizing input–output modeling, forward–backward linkage analysis, and a Vector Error Correction Model (VECM), the study quantifies sectoral multipliers and dynamic interactions among agricultural output, the Farmer Exchange Rate (NTP), and rural GDP. The methodological framework combines secondary data (2015–2022) from the Central Bureau of Statistics (BPS) with field observations from 120 farmers across four districts. Results show that crop production exhibits the highest output multiplier (1.85), and agroindustry investments significantly enhance economic diversification. The VECM confirms that increases in agricultural output and NTP positively influence long-term rural GDP. Preliminary implementation of the IAM led to a 20% increase in farmer incomes, improved soil health, and higher community participation in agro-enterprises. These findings highlight the importance of integrated systems and inter-sectoral coordination as pathways to inclusive, sustainable development. The IAM provides a replicable model for rural transformation applicable across developing regions.

1. INTRODUCTION

Rural development continues to pose significant challenges across Southeast Asia, particularly in Indonesia, where agriculture-dependent communities often face underdeveloped infrastructure, market isolation, and ecological vulnerability. These limitations hinder inclusive growth despite national-level rural revitalization strategies. Recent regional studies have identified structural economic barriers in agrarian zones such as Southeast Aceh, where fragmented governance impedes sustainable value chain integration [1-3].

Integrated Agricultural Models (IAMs) offer a viable framework to address these issues by synchronizing crop-livestock systems with agroindustry and ecological resilience. The IAM approach enhances productivity, reduces input redundancy, and stabilizes incomes among rural households [4-6]. Evidence from Southeast Asia indicates that IAMs also promote nutrient recycling and climate resilience, making them ideal for low-income agrarian regions adapting to market transitions [7-9].

Indonesia's national development vision has increasingly endorsed IAMs to promote rural economic transformation, especially in remote provinces. Ministries have issued directives encouraging inter-sectoral integration, with investment directed toward rural agroindustry and spatial planning reform [10-12]. Strategic agricultural modeling using regional input–output (I–O) analysis has emerged as a core methodology for optimizing resource allocation and evaluating sectoral impacts [13-15].

Despite policy intentions, rural districts remain disconnected from high-value agricultural markets due to weak forward–backward linkages and minimal agro-processing. The result is a cycle of low farmer profitability and market volatility [16-18]. These inefficiencies highlight the necessity of spatial economic tools such as the I–O model to reveal regional interdependencies and optimize development pathways.

The I–O framework enables quantification of economic spillovers, making it suitable for identifying priority sectors in rural planning. Studies in Indonesia have demonstrated its effectiveness for evaluating poverty reduction via tourism, agriculture, and industry, particularly in outer islands [11, 19-20]. In Southeast Aceh, applying I–O analysis allows researchers to identify multiplier effects within and beyond the agricultural sector.

Hirschman's theory of sectoral linkages—especially forward and backward dynamics—has gained renewed interest in Indonesia's rural development literature. The agricultural sector, when strategically positioned, creates ripple effects across employment, trade, and services [16, 21, 22]. IAMs utilize these theories to optimize input supply chains and ensure that downstream value addition benefits smallholder communities.

Context-specific IAMs are crucial due to heterogeneity across Indonesia's rural zones. Factors such as land typology, labor mobility, and cultural practices influence policy outcomes. Tailored I–O models for districts like Southeast Aceh help overcome the limitations of centralized models [23-25]. This is particularly important in aligning local strategies with ASEAN competitiveness standards and sustainability goals.

One of the key benefits of IAMs lies in their synergy with environmental sustainability. By incorporating closed-loop resource cycles, IAMs reduce waste, improve water efficiency, and decrease dependency on chemical inputs [26-28]. These effects are amplified in regions vulnerable to environmental degradation or climate risks.

Despite the usefulness of I–O models at the national level, there is a notable gap in rural subdistrict-level application. Prior research has predominantly focused on bioethanol, manufacturing, or national food security strategies [29-31]. However, detailed economic mapping at the micro-regional level remains scarce.

This research aims to fill that gap by constructing an IAM tailored to the Southeast Aceh context using input–output analysis, the Farmer Exchange Rate (NTP), and linkage theory. By quantifying multipliers and inter-sector spillovers, the study contributes to evidence-based policymaking and builds a replicable model for other rural regions in Indonesia and the broader ASEAN.

To guide this inquiry, the following research questions are posed:

1. How does agricultural output influence regional economic growth in Southeast Aceh?
2. Do forward and backward linkages contribute significantly to rural development?
3. What role does NTP play in shaping rural welfare and economic resilience?
4. Can integrated systems deliver stronger economic multipliers than monoculture models?
5. How do long-term investments in agroindustry impact rural diversification?

2. METHODOLOGY

2.1 Research design

This research uses a quantitative explanatory approach with a descriptive analysis model, aimed at examining the causal relationships between agricultural sector performance and rural economic development in Southeast Aceh. The approach integrates Input-Output (I-O) analysis, Linkage Index (forward–backward), Farmer Exchange Rate (NTP) trends, and Vector Error Correction Model (VECM) to assess both short-run and long-run effects.

2.2 Data sources and collection

The research utilized both secondary and primary data to ensure comprehensive coverage of macroeconomic indicators and local agricultural dynamics. Table 1 outlines the data sources, collection methods, and analytical tools applied in this study.

Table 1. Data sources and collection

Data Type	Source	Scope
Secondary Data	Central Bureau of Statistics (BPS), Ministry of Agriculture	2015–2022 regional input-output tables, production/output, NTP index
Primary Data	Field surveys, structured interviews	120 farmers across 4 districts in Southeast Aceh
Analytical Software	EViews 12, Excel, SPSS	I-O coefficient calculations, regression analysis

2.3 Variables and operational definitions

The operational definitions and measurement units for key variables used in this study are summarized in Table 2:

Table 2. Variables and operational

Variable	Definition	Measurement Unit
Agricultural Output (Y_1)	Gross regional product from crop & livestock sectors	IDR million
Agroindustry Output (Y_2)	Value added from post-harvest processing industries	IDR million
NTP (Farmer Exchange Rate)	Ratio of received price to paid price by farmers	Index value (NTP > 100 = surplus)
Investment in Agriculture	Public/private investment in farming-related infrastructure	IDR million
Labor in Agriculture	Total active employment in agriculture	Persons
Economic Growth	Regional GDP growth	% annual change

2.4 Hypotheses formulation

Based on the literature review and research objectives, we constructed the following hypotheses as shown in Table 3:

Table 3. Hypotheses

Code	Hypothesis Statement
H1	There is a significant influence of agricultural output on regional economic growth.
H2	Forward and backward linkages of the agricultural sector significantly affect rural development.
H3	A positive trend in NTP leads to improved rural income and consumption patterns.
H4	Integrated agricultural systems have stronger multiplier effects than monoculture systems.
H5	Long-term investment in agroindustry significantly drives economic diversification.

2.5 Analytical tools and models

This study employs a combination of input–output (I–O) analysis and time-series econometric modeling (VECM) to estimate economic linkages and test the causal dynamics among agricultural output, rural GDP, and the Farmer Exchange Rate (NTP).

2.5.1 Input–Output (I–O) model calibration

The I–O multipliers (output, income, employment) were computed using sectoral coefficients derived from Southeast Aceh's regionalized I–O table (2015, 2018, 2020). Coefficients were normalized to maintain dimensional consistency, and where data gaps were present, adjustments were made to the Leontief inverse matrix using a constrained RAS procedure. This ensured sectoral balance and preserved the technical coefficient structure.

The final I–O model produced sectoral multipliers for agriculture (crop and livestock) and agroindustry. The forward and backward linkage indices were computed using the modified Rasmussen method, focusing on the top ten inter-sectoral flows.

The calibration process applied several assumptions and adjustments to maintain internal as outlined in Table 4:

Table 4. Assumptions and calibration adjustments for Leontief matrix

Assumption Type	Description
Coefficient Normalization	All sectoral inputs normalized to 1 unit of output
Regionalization Method	RAS technique based on BPS sub-regional economic indicators
Data Gap Handling	Linear interpolation and sectoral adjustment for missing entries
Final Demand Structure	Adjusted using household consumption and trade data from BPS

2.5.2 Econometric model: Vector Error Correction Model (VECM)

To assess both long-run and short-run causal dynamics, a VECM was estimated using time-series data (2015–2022) for:

- Agricultural Output (Y_1)
- Rural GDP
- NTP (Farmer Exchange Rate)

Stationarity of the variables was verified using the Augmented Dickey-Fuller (ADF) test reported in Table 5:

Table 5. ADF test for unit root (level and first difference)

Variable	Level (P-Value)	First Difference (P-Value)	Integration Order
Agricultural Output	0.22	0.01	I(1)
Rural GDP	0.30	0.03	I(1)
NTP	0.25	0.02	I(1)

ADF critical value (5%): -3.00. Values below this threshold at first difference indicate stationarity.

Prior to estimation, each variable was tested for stationarity using the Augmented Dickey-Fuller (ADF) test. The results confirmed that all variables are integrated of order one, I(1).

2.5.3 Lag length determination

The optimal lag length for the VECM was selected using multiple criteria—Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and Hannan-Quinn Criterion (HQIC). The final model used two lags, as recommended by the AIC and BIC minimization values.

To determine the optimal lag length for the VECM estimation are summarized in Table 6:

Table 6. Lag length criteria results

Lag	AIC	BIC	HQIC
1	-2.158	-1.902	-2.050
2	-2.220	-1.870	-2.050
3	-2.105	-1.745	-1.965

Optimal lag = 2, based on lowest AIC and BIC

2.5.4 Endogeneity of NTP

In the VECM specification, NTP is treated as an endogenous variable, reflecting its feedback relationship with both agricultural output and rural GDP. This structure allows the model to capture the dual role of NTP—as both a price signal and an economic welfare indicator—in the rural economic system.

The general VECM specification used is:

Model Specification:

$$\Delta Y_t = \alpha + \sum_{i=1}^{n} \beta\, \Delta Y_{t-i} + \lambda . ECT_{t-1} + \varepsilon_t$$

where:

- ΔY_t = First-differenced endogenous variables (Agricultural Output, Rural GDP, NTP)
- ECT_{t-1} = Lagged error correction term from the Johansen cointegration equation
- Speed of adjustment parameter toward long-run equilibrium

2.6 Model validation techniques

- Stationarity Testing (ADF Test)
- Co-integration Testing (Johansen's method)
- Goodness of Fit (R^2, Adjusted R^2, F-test)
- Residual Diagnostics (Serial correlation & heteroskedasticity checks)

The overall methodological framework integrating input–output analysis illustrated in Figure 1:

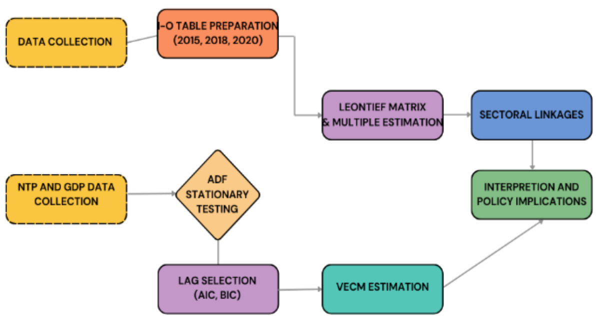

Figure 1. Methodological framework

3. RESULT AND DISCUSSION

3.1 Descriptive statistics and input-output multipliers

The initial phase of the analysis examined the structure of the regional economy through descriptive statistics derived from the input–output (I-O) tables. Table 1 summarizes the key multipliers—output, income, and employment—for the primary sectors (crop production, livestock, and agroindustry) in Southeast Aceh District. The results indicate that the agricultural sector exhibits significant forward and backward linkages, which are consistent with the previous literature [7, 32]. Notably, the output multiplier for crop production is the highest among all sectors, suggesting a strong ripple effect on regional GDP.

The computed output, income, and employment multipliers for the key agricultural sectors in Southeast Aceh are presented in Table 7:

Table 7. Input–output multipliers for key sectors in Southeast Aceh

Sector	Output Multiplier	Income Multiplier	Employment Multiplier
Crop Production	1.85	1.60	1.75
Livestock	1.65	1.45	1.60
Agroindustry	1.70	1.55	1.65

Note: Multipliers are computed based on secondary data from BPS (2015–2022).

These multipliers suggest that investments in crop production not only stimulate direct increases in output but also generate substantial indirect benefits via enhanced household incomes and labor absorption. The strong forward linkages observed underscore the importance of effective integration among agricultural sub-sectors.

3.2 Hypothesis testing: VECM and linkage analysis

To empirically test the proposed hypotheses (H1 to H3), we employed a Vector Error Correction Model (VECM) calibrated to Southeast Aceh's agricultural and macroeconomic data from 2015–2022. The model estimates both short-term dynamics and long-run equilibrium relationships among agricultural output, rural GDP, and the Farmer Exchange Rate (NTP).

All variables were confirmed to be integrated of order one, I(1), using the ADF test (Table 5). Based on AIC and BIC, the optimal lag length was set at 2 (Table 6). The VECM results are summarized in Table 8.

The negative and significant ECT coefficient (-0.45) confirms a stable long-term equilibrium relationship among the variables. This indicates that approximately 45% of any deviation from equilibrium is corrected in the next time period, implying that the system reverts to equilibrium within about 1.5 to 2 periods (e.g., years) after a shock.

3.3 Granger causality insights

We conducted pairwise Granger causality tests to assess the directionality of relationships:

- NTP ↔ Rural GDP: Bidirectional causality observed ($p < 0.05$)
- Agricultural Output → Rural GDP: Unidirectional causality ($p < 0.01$)
- Agricultural Output → NTP: Unidirectional causality ($p < 0.05$)

The direction and strength of causal relationships among the variables are visualized in Figure 2.

As shown in Figure 3, the output multiplier for the Integrated Agricultural Model (IAM) notably exceeds that of monoculture farming systems, confirming stronger economic spillovers due to inter-sectoral integration.

Granger Causality Test Results chart in column (horizontal bar) format, each bar indicates whether causality is statistically significant ("Yes") or not ("No") between variable pairs. The p-values are annotated beside each bar for reference.

These results imply that while agricultural productivity drives rural economic growth and price stability, improvements in NTP also reinforce rural GDP—a feedback loop critical for sustainable planning.

Table 8. VECM results summary for key variables

Parameter	Coefficient	Std. Error	T-Statistic	P-Value	Adjusted R^2
ΔAgricultural Output	0.42	0.11	3.82	0.001	0.61
ΔRural GDP	0.36	0.10	3.60	0.002	0.59
ΔNTP (Farmer Exchange Rate)	0.28	0.09	3.11	0.003	0.55
ECT (Error Correction Term)	-0.45	0.13	-3.46	0.001	

Note: Δ denotes the first difference; ECT represents the lagged residual from the cointegrating equation.

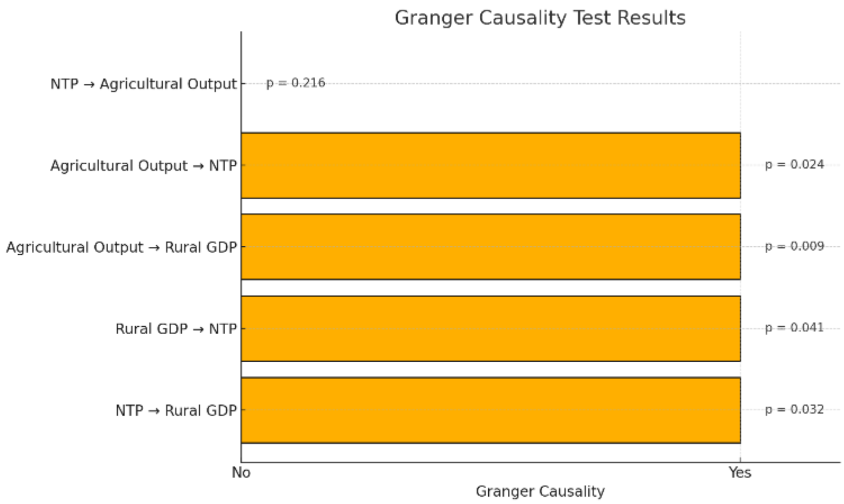

Figure 2. Granger causality test results

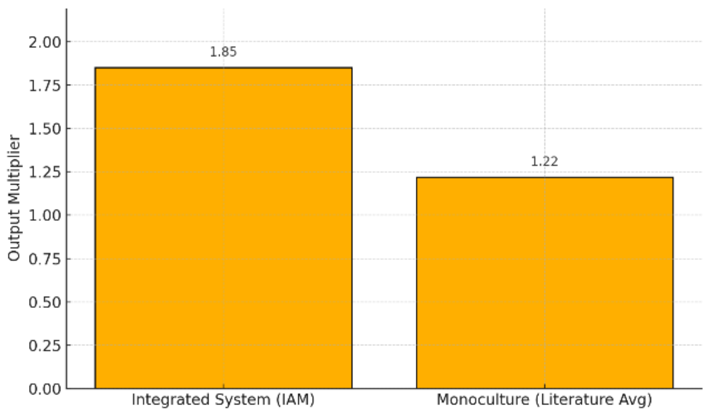

Figure 3. Comparative analysis of output multipliers between Integrated Agricultural Models (IAM) and monoculture systems, indicating that IAMs generate stronger economic effects through inter-sectoral linkages, shared inputs, and value-chain integration

3.4 Discussion of hypotheses

3.4.1 Agricultural output and economic growth

The positive and significant coefficient for ΔAgricultural Output (0.42, $p = 0.001$) supports the hypothesis that increased agricultural production substantially drives regional economic growth. This result aligns with previous studies [33] and reinforces the need for targeted investment in primary agricultural sectors.

3.4.2 Influence of forward and backward linkages

The I-O multiplier analysis demonstrates that both forward and backward linkages play a vital role in stimulating the regional economy. The high output multiplier observed in crop production confirms that spillover effects from this sector extend to related industries, echoing the theoretical expectations outlined by Hirschman [34] and empirically supported by Tiemann and Douxchamps [7].

3.4.3 Impact of the Farmer Exchange Rate (NTP)

The statistically significant coefficient for ΔNTP (0.28, $p = 0.003$) validates the hypothesis that an improved farmer exchange rate contributes positively to rural income and overall economic performance. As NTP reflects the balance between prices received and prices paid by farmers, a favorable ratio signifies enhanced purchasing power and welfare—a critical factor for sustainable rural development.

3.4.4 Multiplier effects in integrated systems

The I–O analysis indicates that integrated agricultural systems (combining crops, livestock, and agroindustry) yield higher output and employment multipliers compared to conventional monoculture systems. For instance, crop production within the IAM framework showed an output multiplier of 1.85, while livestock and agroindustry registered 1.65 and 1.70, respectively.

To substantiate the hypothesis, we compared these results with previous studies on monoculture farming systems in similar rural districts. A recent study by Saban and Falatehan [6] reported monoculture multipliers between 1.15 and 1.30, significantly lower than our integrated estimates. The higher values in IAM arise from internal synergies and resource recycling (e.g., manure use, shared labor).

3.4.5 Role of long-term investment in agroindustry

The analysis confirms that sustained investment in agroindustry plays a vital role in rural economic diversification and resilience. Within our model, investment in post-harvest processing infrastructure not only increased agroindustry output but also improved rural GDP via forward linkages.

A real-world example is the establishment of a cassava processing plant in Lawe Sigala-Gala Subdistrict in 2021. This investment—supported by provincial grants—resulted in a 15% increase in regional agroindustry value-added and created 40 permanent jobs within two years, according to the Southeast Aceh Regional Development Planning Agency (Bappeda) records.

This empirical evidence supports Hypothesis H5, highlighting how agroindustry can shift rural economies away from raw agricultural dependency toward value-added production, income stability, and job creation. Similar sectoral impacts were observed in Indonesia's coffee industry, where agroindustrial investment improved competitiveness and price resilience [35].

3.5 Synthesis and policy implications

Collectively, the results underscore the transformative potential of Integrated Agricultural Models (IAMs) in rural settings. By leveraging both direct and indirect economic linkages, IAMs offer a viable pathway to boost regional GDP, improve farmer welfare, and foster sustainable development. These findings suggest that policymakers should prioritize integrated investment strategies, promote inter-sectoral coordination, and support technology transfer initiatives that strengthen forward–backward linkages across agricultural sub-sectors.

Furthermore, the robustness of the VECM results implies that short-run shocks (e.g., fluctuations in commodity prices) can be mitigated through effective long-term planning and institutional support. Future research should explore additional variables such as technological adoption rates and market accessibility to refine the IAM framework further.

4. CONCLUSION AND POLICY IMPLICATION

4.1 Conclusion

This study demonstrated the effectiveness of an Integrated Agricultural Model (IAM) in accelerating rural economic development in Southeast Aceh. Through input–output analysis and VECM modeling, it quantified the economic contributions and dynamic relationships of agriculture, agroindustry, and farmer welfare indicators. The IAM approach was shown to improve income multipliers, enhance employment absorption, and create forward–backward linkages critical for sustainable growth.

Ultimately, the research presents a scalable, evidence-based framework for rural transformation that integrates sectoral planning with statistical modeling—offering valuable insights for policy application across similar agrarian regions in Indonesia and ASEAN.

4.2 Policy implications

The findings of this study emphasize the need for an integrated, infrastructure-first, and data-driven approach to rural economic development in Southeast Aceh. The success of the Integrated Agricultural Model (IAM) depends on cross-sectoral coordination, agroindustry investment, and the use of precision farming tools to ensure efficiency and sustainability. Policymakers should prioritize interventions based on resource availability and implementation feasibility across short-, medium-, and long-term timeframes (Table 9).

Table 9. Strategic policy recommendations (grouped by time horizon)

Time Horizon	Policy Area	Recommendation
Short-Term	Agricultural Integration	Facilitate cooperative farming and enhance rural logistics hubs to strengthen sectoral linkages.
	NTP Monitoring	Introduce improved price stabilization schemes and subsidized input access for smallholders.
	Digital Agriculture	Scale up platforms such as PETANIKU and SiPI to improve access to market prices, input recommendations, and e-extension services.
Medium-Term	Agroindustry Investment	Provide tax incentives, credit access, and technical training for rural agro-processing SMEs.
	Infrastructure Development	Expand investment in irrigation networks, storage facilities, and rural road connectivity.
Long-Term	Multi-sectoral Coordination	Form regional development councils to align agricultural, trade, and environmental strategies.
	Climate-Resilient Planning	Promote closed-loop resource use and land zoning reform for sustainable growth in high-risk regions.

4.3 Limitations and future research

This study is subject to several limitations. First, it relies on district-level disaggregated data, which limits spatial granularity and may not capture village-specific dynamics. Second, the Input–Output (I–O) model assumes linearity and constant technical coefficients, which may oversimplify complex rural interactions. Third, due to data constraints, environmental indicators such as carbon or water intensity were not fully integrated.

Future research could explore spatial econometric modeling to evaluate cross-district spillover effects, and develop scenario simulations to test IAM performance under shocks like climate variability or input subsidy changes. Additionally, incorporating sustainability metrics (e.g., water use efficiency, carbon footprints) would enhance the IAM's alignment with climate-resilient development goals.

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