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Coconut Agribusiness Supply Chains and the Potential for Closed-Loop Models in North Sulawesi .

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Abstract. Coconut is a key smallholder crop in North Sulawesi Province, Indonesia, yet the agribusiness system remains characterised by low on-farm value addition, quality losses and underutilised by-products. A closed-loop supply chain model, which integrates forward flows of primary products with reverse flows of by-products and residues, has been proposed as a way to improve efficiency, market access and price incentives for farmers. This study analyses the coconut agribusiness supply chain in two major producing districts, Minahasa Tenggara and Minahasa Selatan, focusing on current configurations and the potential implementation of a closed-loop model. An applied case-study design was used, combining secondary data with primary data collected through questionnaires and interviews with farmers, traders, micro, small and medium enterprises (MSMEs), processing companies and supporting institutions between March and October 2024. Qualitative mapping and descriptive quantitative analysis were employed to examine supply chain structure, coordination, by-product utilisation, market access and price incentives. The results show that Minahasa Tenggara still operates a conventional, trader-driven supply chain with limited processing and minimal integration of by-products, whereas Minahasa Selatan exhibits emerging closed-loop features through partnership schemes linking farmer groups, processing companies and MSMEs, including the utilisation of husk, shell and coconut water for cocopeat, coir products, charcoal, briquettes and liquid organic fertiliser. These arrangements provide a foundation for improved market access and potentially better price incentives for farmers, but benefits remain uneven and depend on institutional support and the strengthening of farmer organisations and MSMEs.

Keywords: coconut; closed-loop supply chain; agribusiness; by-products; smallholder farmers.

INTRODUCTION

Coconut (*Cocos nucifera* L.) is one of the leading agricultural commodities in North Sulawesi Province and plays an important role in rural livelihoods and regional economic development. The crop is largely cultivated by smallholder farmers on relatively small and fragmented landholdings, as farm sizes have gradually decreased due to land conversion and inheritance[1], [2]. At the same time, the economic potential of coconut in North Sulawesi has increased with the growth of processing industries that demand a more stable supply of raw material and higher product quality[3], [4].

The coconut agribusiness system in the province has been gradually transforming from traditional to more modern supply chain arrangements. However, several analyses indicate that the performance of the coconut agribusiness system is still sub-optimal[5], [6]. A significant share of harvested nuts becomes “non-standard” because quality deteriorates during post-harvest handling, transportation, and marketing. This reduces the effective supply of marketable coconuts, weakens farmers’ bargaining position, and limits the benefits they can obtain from the expanding processing industry[7], [8].

At the same time, many by-products and residues along the coconut chain remain underutilized[9]. Husk, shell, and other parts of the coconut can be processed into higher value products such as cocopeat, charcoal or briquettes, liquid smoke, and organic fertilizers[10]. If these flows were better integrated into the agribusiness system, they could create additional income opportunities for farmers and micro, small and medium enterprises (MSMEs)[11],

while reducing waste and environmental pressure[12], [13].

A closed-loop supply chain model has been proposed as a promising approach to address these challenges[14]. In a closed-loop system, forward flows of products from farmers to processors and markets are linked with reverse flows of by-products and residues back into the economic system through reuse, recycling, or further processing[15], [16]. For coconut agribusiness, such a model is expected to improve the efficiency and effectiveness of the supply chain, strengthen market access, and enhance price incentives for farmers by connecting them more directly with processing industries and value-adding MSMEs[17].

In North Sulawesi, efforts to develop coconut agribusiness and increase the scale of farmers' operations have started to emerge in several districts, with varying degrees of progress. In some areas, the supply chain still resembles a conventional system dominated by traders and characterized by limited value addition at the farm level. In others, initiatives to link farmers with processing companies and to utilize coconut by-products have begun to take shape, indicating a gradual move toward more integrated and potentially closed-loop arrangements. This variation suggests that there is still a gap between the conceptual potential of closed-loop supply chains and their actual implementation in the field.

Previous studies on coconut in North Sulawesi have largely focused on production characteristics, marketing channels, or the evaluation of agribusiness system performance at different levels of the chain[1]. These studies provide important insights into the role of traders, processors, and supporting institutions, as well as the constraints faced by smallholders in accessing markets and improving product quality[9]. However, most of this work has examined forward supply chains in a relatively linear manner and has paid less attention to the systematic integration of by-product flows, recycling activities, and the design of closed-loop relationships between farmers, MSMEs, and processing industries[10].

As a result, there is still limited empirical evidence on how a closed-loop supply chain model could be structured and implemented in coconut agribusiness under smallholder-dominated conditions, and what this would imply for farmers' market access and price incentives. In particular, there is a need for studies that analyse the existing configuration of both forward and reverse flows, identify bottlenecks and opportunities for integrating closed-loop practices, and discuss how such integration might enhance the value captured at the farm level.

Against this background, the present study aims to analyse the coconut agribusiness supply chain in North Sulawesi Province with a particular focus on the potential implementation of a closed-loop model. Specifically, the study seeks to: (i) describe the structure and actors involved in the forward and reverse flows of coconut products, (ii) identify bottlenecks and opportunities for integrating closed-loop practices into the existing supply chain, and (iii) assess the implications of such a model for market access and price incentives at the farm level.

This study contributes to the literature in three main ways. First, it provides a detailed mapping of the coconut agribusiness supply chain in a major producing region of Indonesia, considering both forward and reverse flows. Second, it highlights practical opportunities and constraints for implementing closed-loop arrangements in a context dominated by smallholder farmers and emerging MSMEs. Third, it offers location-specific insights that can inform the design of more inclusive and competitive coconut agribusiness

models, with potential relevance for similar tropical commodity systems.

MATERIALS AND METHODS

Study area and research design

This study was conducted in North Sulawesi Province, Indonesia, with a focus on two major coconut-producing districts: Minahasa Tenggara and Minahasa Selatan. These districts were selected purposively because they are important centres of coconut production and have been identified as pilot areas for the development of more integrated coconut agribusiness models, including closed-loop partnership initiatives.

The research adopted an applied, case-study design aimed at analysing the structure and performance of the coconut agribusiness supply chain and exploring the potential implementation of a closed-loop model. The analysis was structured around two main dimensions in the primary production centres: (i) market aspects, including market channels and access conditions, and (ii) price incentives at the farm level. In addition, the study included a descriptive examination of farmer empowerment and opportunities to increase the scale of smallholder coconut farming within a closed-loop system.

Data sources and collection

The study used both secondary and primary data. Secondary data were obtained from relevant institutions at the provincial and district levels, including the Plantation Service, the Industry and Trade Service, the Central Statistics Agency, and the Chamber of Commerce and Industry (KADIN) of North Sulawesi. These data provided information on coconut production, trade flows, and the overall development of the coconut sector in the province.

Primary data were collected through structured questionnaires and direct interviews with key stakeholders in the coconut agribusiness supply chain in Minahasa Tenggara and Minahasa Selatan. Stakeholders included smallholder coconut farmers, local traders or collectors, micro, small and medium enterprises (MSMEs) engaged in coconut and by-product processing, and representatives of processing companies operating in the study area. The questionnaire instrument was prepared and validated through preliminary interviews with farmers and relevant stakeholders to ensure that the questions were clear and reflected the main elements of the emerging closed-loop model.

Additional qualitative information was gathered through interviews with officials in government agencies and local institutions, such as the district Plantation Service, Industry and Trade Office, village-owned enterprises (BUMDes), and financial institutions. These interviews helped to clarify policies, regulations, and support programmes that affect the coconut supply chain and the utilisation of coconut by-products.

An overview of the types of respondents and data sources used in the study is presented in Table 1.

Table 1 summarises the main groups of respondents and institutional sources that contributed information to the study in both districts. The table shows that the empirical basis of the analysis combines the perspectives of farmers, intermediaries, processors and MSMEs, as well as supporting institutions and official secondary data. This combination provides a comprehensive view of how the coconut supply chain operates and how a closed-loop model might be developed in the study area.

Fieldwork and data collection were carried out over an eight-month period, from March to October 2025, and included instrument preparation, preliminary validation, the main survey, and follow-up interviews.

Data analysis

The analysis combined qualitative and simple quantitative approaches. Qualitative analysis was used to map the full cycle of product flows along the coconut supply chain, identify the main actors and their roles, and describe the relationships and coordination mechanisms among them. Particular attention was given to the distinction between forward flows (from production through processing to final consumers) and reverse flows (from by-products and residues back into economic use), in order to identify existing and potential elements of a closed-loop system.

Table 1. Overview of data sources and respondents in the study

Category	Minahasa Tenggara	Minahasa Selatan	Description
Farmer respondents	Smallholder coconut farmers in main coconut-producing villages, selected purposively	Smallholder coconut farmers in coconut-producing villages, including those participating in partnership schemes, selected purposively	Qualitative sample of farmers representing typical production and marketing practices
MSME or processor actors	Local primary processors and traders involved in copra and basic coconut processing	Processing company or companies (for example PT Tropicana Coconut) and associated MSMEs that process primary products and by-products	Stakeholders linked to coconut processing and emerging closed-loop initiatives
Traders or collectors	Village and sub-district collectors who connect farmers with district traders and processors	Village collectors and traders operating alongside cooperatives, BUMDes and company off-takers in coordinated supply arrangements	Intermediaries that connect farmers with downstream markets and processors
Other stakeholders interviewed	District Plantation Service, Industry and Trade Office, local government officials and agricultural extension officers	District Plantation Service, Industry and Trade Office, BUMDes, financial institutions, local government officials and extension officers	Institutions that provide policy support, facilitation, and financial or technical services
Secondary data sources	Provincial and district Plantation and Industry Services, Central Statistics Agency, KADIN North Sulawesi	Same provincial and national institutions	Statistical data, sector reports and policy documents on coconut production and trade in the province

Quantitative analysis was used in a descriptive manner to summarise key characteristics of the supply chain, such as volumes and types of coconut products handled, basic logistics characteristics (types of transport, logistics costs and travel time), and indicative patterns of price formation along the chain where data were available. These summaries supported the qualitative mapping of the supply chain and the assessment of market access and price incentives at the farm level.

The analysis of the closed-loop model proceeded in three main steps. First, the components of the closed-loop supply chain were identified and validated with stakeholders, distinguishing between the forward supply chain (production, distribution and consumption of primary coconut products) and the reverse supply chain (collection, processing and management of residues and by-products such as husk, shell and other materials that can be transformed into value-added products). Second, stakeholders involved in these flows were mapped, including farmers, traders or collectors, processing industries, MSMEs, distributors or off-

takers, retailers, consumers, logistics providers and government institutions. Third, information from these steps was synthesised to develop a prototype closed-loop supply chain configuration for coconut agribusiness in the study area, with a focus on its implications for market access and price incentives for farmers.

In addition, the study drew on concepts from agent-based modelling as an analytical framework to structure the understanding of interactions among actors in the coconut supply chain. Within this framework, the main agent types (farmers, processors, off-takers or distributors, consumers, logistics providers and government or financial institutions) were characterised in terms of their objectives, typical decision rules and interactions within forward and reverse flows. Rather than implementing a fully parameterised computational simulation, agent-based modelling concepts were used in this paper as a conceptual tool to organise the analysis of how changes in market conditions or policy interventions in a closed-loop setting could affect the overall behaviour of the system and the distribution of benefits among stakeholders.

RESULTS AND DISCUSSION

Closed-loop supply chain for coconuts in Minahasa Tenggara and Minahasa Selatan

The analysis confirms that the coconut supply chain in North Sulawesi is still dominated by smallholder farmers and a relatively long chain of intermediaries. In Minahasa Tenggara, the chain remains largely traditional, with farmers selling whole nuts to village collectors, who then sell to larger traders and processors or exporters. Local value addition is limited, and by-products such as husk and shell are mostly underutilised. As a result, value capture at the farm level is low and the elements of reverse flow and systematic feedback on quality have not yet been integrated into the supply chain.

In contrast, in Minahasa Selatan there are emerging forms of closed-loop supply chain arrangements. Farmer groups are linked to a processing company, such as PT Tropicana Coconut, under partnership schemes. Farmers supply coconuts that meet agreed standards of size and moisture content, and they receive technical assistance and training, including digital farming and financial record-keeping. Coconut husk is processed into cocopeat for export, while coconut water is fermented into liquid organic fertiliser, and shell is processed into charcoal and briquettes. These activities illustrate how forward and reverse flows can be connected to increase value addition and create a more circular system.

To provide an overview of the main actors involved in the coconut supply chain in both districts and their basic functions, Table 2 summarises the key categories and their roles.

Table 2 shows that both districts share a similar set of actors, but they differ in terms of how strongly these actors are connected and how much value is added locally. In Minahasa Tenggara, traders and collectors dominate the link between farmers and processors, with limited involvement of MSMEs and weak institutional coordination. In Minahasa Selatan, stronger links between farmers, processing companies and MSMEs have emerged, and supporting institutions play a more active role in facilitating closed-loop initiatives and farmer capacity building.

Forward supply chain structure

The forward supply chain, covering the movement of coconuts from production to processing and final markets, exhibits distinct characteristics in each district. In Minahasa Tenggara, marketing channels are mainly based on individual transactions between farmers and village collectors. Prices are negotiated informally, and

farmers have limited information about downstream markets. Quality standards are basic and often not enforced, which contributes to quality deterioration during storage and transport and leads to a significant share of non-standard coconuts.

Table 2. Main actors and functions in the coconut supply chain in the study area

Actor category	Typical role or function	Minahasa Tenggara (status)	Minahasa Selatan (status)
Smallholder farmers	Production of coconuts; basic on-farm sorting and drying	Sell whole nuts individually to village collectors; limited farmer organisation; low value addition at farm level	Some farmers organised in groups or cooperatives; participate in partnership schemes; apply agreed quality standards and receive training
Village collectors	Purchase coconuts from farmers, carry out initial sorting and aggregation	Key intermediaries and main channel connecting farmers with district traders and processors	Still active but share their role with cooperatives or village enterprises and company off-takers in more coordinated arrangements
District traders	Bulk aggregation and transport of coconuts and copra to processing industries or inter-district markets	Important actors in moving products to processors and exporters; relationships with farmers mostly based on spot trade	Operate alongside direct delivery channels from farmer groups to processing companies
Processing industry	Processing coconuts into copra, oil and other products	Processors are generally located outside villages; linkages with farmers mostly indirect through traders	Presence of processing companies such as PT Tropicana Coconut with more direct linkages to farmer groups and local processors
MSMEs	Processing by-products (husk, shell, coconut water and other residues) into value-added products	Only limited or emerging initiatives; most by-products remain underutilised	Active MSMEs or farmer groups processing husk into cocopeat and coir products, and shell into charcoal or briquettes
Retailers	Sale of coconut products to final consumers in local and regional markets	Retailers sell fresh coconuts, copra-based products and simple derivatives in local markets	Retailers sell traditional coconut products and some value-added products from processing industries and MSMEs
Supporting actors	Government agencies, village-owned enterprises, financial institutions, logistics services and extension	Local government and extension provide basic support; coordination for closed-loop initiatives is still limited	Government agencies, village-owned enterprises, financial institutions and extension or research bodies support pilot closed-loop projects and farmer training

Table 2. Average Wind Speed in Coconut-Based Agroforestry in Ongkaw Village, Sinonsayang District

In Minahasa Selatan, partnership schemes between farmer groups and processors create more coordinated forward supply chains. Farmers follow agreed standard operating procedures for production and harvesting, and coconuts are delivered to collection points before being transported to processing facilities. Processors define quality criteria, such as size and moisture content, and provide training and feedback to farmers. These arrangements contribute to more stable market access and a clearer alignment between production and processing requirements.

Key differences in the forward supply chain characteristics are summarised in Table 3.

Table 3. Key characteristics of the forward coconut supply chain by district

Aspect	Minahasa Tenggara	Minahasa Selatan
Dominant marketing channel	Farmers mostly sell whole nuts to village collectors, who then sell to district traders and processors or exporters	Farmers and farmer groups deliver coconuts through cooperatives, village enterprises or company off-takers to processing companies and markets
Type of transactions	Mostly informal and based on spot transactions at the farmgate	Combination of spot and semi-formal or contractual arrangements within partnership schemes
Coordination with processors	Limited; processors largely interact with traders and collectors rather than directly with farmers	Stronger; processors work directly with farmer groups and designated off-takers under agreed quality and delivery arrangements
Quality standards	Basic grading; quality deterioration during storage and transport is common; standards weakly enforced	More specific quality requirements, for example regarding nut size and moisture content; standards communicated and monitored within partnerships
Value addition at village level	Minimal; activities largely limited to harvesting and simple copra production	Some local value addition through improved sorting, drying and initial processing activities linked to company processing
Access to market information	Farmers rely mainly on information provided by traders and collectors, with limited transparency	Improved access through processor communication, partnership-based training activities and, in some cases, use of digital tools

Table 3 highlights how the move from a predominantly trader-driven system in Minahasa Tenggara towards more coordinated partnerships in Minahasa Selatan changes the nature of forward supply chains. In particular, stronger coordination with processors and clearer quality standards in Minahasa Selatan provide a foundation for integrating closed-loop practices, whereas the more fragmented structure in Minahasa Tenggara constrains such integration and maintains farmers' dependence on intermediaries.

Reverse flows and utilisation of coconut by-products

A core element of the closed-loop model is the utilisation of by-products and residues through reverse flows. Field observations show that in Minahasa Tenggara, most by-products, such as husk and shell, are either discarded or used only for low-value purposes, such as household fuel. Coconut water from copra production is frequently wasted, and other biomass components are rarely processed into higher value products.

In Minahasa Selatan, the situation is more dynamic. Sabut kelapa (coconut husk) that arises during copra production is collected and processed into cocopeat and

coir rope, with some products destined for export markets such as Japan. Coconut shell is processed into charcoal and briquettes, while coconut water is utilised for the production of liquid organic fertiliser. These activities not only reduce waste but also create additional income opportunities for farmers and local MSMEs.

The main types of by-products, their current utilisation and potential value-added products are summarised in Table 4.

Table 4. Coconut by-products, current utilisation, and potential value-added products

By-product type	Current utilisation in Minahasa Tenggara	Current utilisation in Minahasa Selatan	Potential value-added products	Main actors involved or potential actors
Husk	Often left in the field or used as low-value household fuel; no organised commercial collection	Collected and processed as raw material for cocopeat and coir rope in enterprises linked to partnership arrangements	Cocopeat, coir fibre products, mulching material, growing media	Farmers, MSMEs, cooperatives or village enterprises, processing companies
Shell	Used mainly as household fuel or discarded; no structured commercial utilisation	Processed into charcoal and briquettes as part of emerging MSME and processor activities	Charcoal, briquettes, potentially activated carbon	MSMEs, processors, local traders
Coconut water	Frequently discarded during copra production; occasionally used informally as animal feed	Partially processed into liquid organic fertiliser; remaining volume still underutilised	Beverage products, fermentation products, liquid organic fertiliser	MSMEs, farmer groups, processing companies
Other biomass	Leaves, fronds and other residues used only in a limited way, for example as occasional fuel or mulch	Similar limited use, with some interest in composting and organic fertiliser production	Compost, organic fertiliser, animal feed	Farmers, MSMEs, farmer groups and village-level initiatives

Table 4 illustrates that the potential for reverse flows is substantial in both districts but is more actively realised in Minahasa Selatan. The use of husk and shell for cocopeat, coir products and charcoal or briquettes demonstrates how residues can be integrated into the value chain and how the closed-loop concept can be operationalised through MSMEs and farmer-based initiatives. In Minahasa Tenggara, these opportunities remain largely untapped, reinforcing the conclusion that the closed-loop model is still at an early stage of implementation.

Toward a closed-loop supply chain configuration

Based on the mapping of forward and reverse flows in the two districts, a prototype closed-loop supply chain configuration for coconut agribusiness can be outlined. In this configuration, smallholder farmers remain the primary producers, but their linkages to processing industries and MSMEs are strengthened and by-products are systematically collected and processed.

Figure 1 illustrates the main stages of the proposed closed-loop supply chain in Minahasa Tenggara, starting from coconut production, harvesting and product processing, and continuing through market distribution. The lower part of the figure depicts the reverse flow, in which husk and

shell are transformed into derivative products and final goods, which are then utilised and generate feedback to farmers and processors. This configuration summarises how forward and reverse flows can be integrated to increase value addition and reduce waste in the local coconut agribusiness system.

Stakeholders and feedback loops in the closed-loop model

The closed-loop model for coconut agribusiness in North Sulawesi involves multiple stakeholders, each contributing to production, processing, marketing, financing and support functions. In the empirical context of the study, the key stakeholders and their roles within the closed-loop system can be described as in Table 5.

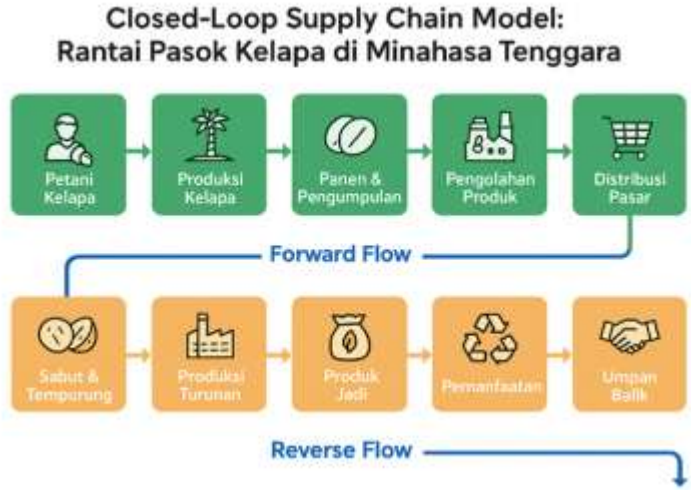

Figure 1. Conceptual closed-loop supply chain model for coconut agribusiness in Minahasa Tenggara

Table 5. Main stakeholders and roles in the closed-loop coconut supply chain

Stakeholder	Main role in the closed-loop model
Coconut farmers	Produce coconuts according to agreed standards and schedules under partnership arrangements
Cooperatives or farmer groups (Gapoktan)	Provide production inputs, organise farmers, collect and bulk output, and negotiate with off-takers
Processing companies or off-takers	Process coconuts and by-products into primary and secondary products, and organise marketing
Financial institutions and village-owned enterprises (BUMDes)	Provide financing for production inputs, processing equipment and local processing units
Extension services and research institutions	Provide technical assistance, training and innovation in cultivation and processing practices
Local government	Develop regulations, facilitate infrastructure and support market access and coordination

Table 5 emphasises that the effectiveness of the closed-loop model depends not only on production and processing activities but also on the presence of strong organisational and institutional arrangements. Farmer groups

and cooperatives are central to aggregating supply and negotiating with processing companies, while village-owned enterprises and financial institutions provide the capital needed for investment in processing and logistics. Extension and research bodies, together with local government, facilitate feedback loops through training, quality monitoring and policy support, helping to improve productivity and ensure that farmers benefit from their participation in the supply chain.

Market access and price incentives for farmers

Evidence from the study indicates that the structure of the supply chain has important implications for market access and price incentives at the farm level. In the traditional supply chain configuration observed in Minahasa Tenggara, farmers often face a long chain from farm to processor or exporter, with multiple layers of collectors and traders. This structure tends to weaken farmers' bargaining position, as they depend heavily on local collectors for immediate cash needs and have limited access to information about downstream prices and market conditions. As a result, farmgate prices are often relatively low and volatile.

In Minahasa Selatan, the closer integration of farmers with processing companies under closed-loop partnership schemes provides an opportunity for improved price incentives. Contractual or semi-formal arrangements, combined with technical assistance and clear quality standards, can stabilise market access and reduce uncertainty about demand. Moreover, the utilisation of by-products for cocopeat, charcoal, briquettes and liquid organic fertiliser offers additional income streams. While detailed quantitative data on price changes and income effects are still limited, the qualitative evidence suggests that the closed-loop model has the potential to enhance value capture at the farm level and to reduce farmers' dependence on village collectors.

The relative value position of different actors in the chain, based on their role and typical cost and revenue structure, can be summarised in a qualitative way as shown in Table 6.

Table 6. Indicative value position along the coconut supply chain

Actor	Product form	Indicative position in value chain	Main cost components	Approximate margin or value added (qualitative)
Farmer	Whole nuts	Lowest price level at the farmgate	Production costs, harvesting, basic handling and local transport	Low; constrained by dependence on collectors and limited on-farm value addition
Village trader	Whole nuts (sorted)	Intermediate level between farmgate and processor prices	Purchase price from farmers, local aggregation, transport, basic sorting	Moderate; gains arise from aggregation and better market information but depend on competition and transaction costs
Processor or MSME	Processed coconuts and by-products	Higher value level due to transformation of raw materials	Raw material costs, labour, energy, processing equipment, packaging, compliance costs	Higher; value added created through processing, branding and quality improvement
Retailer	Final products to consumers	Highest unit price level at the end of the chain	Purchase price from processors or wholesalers, marketing, retail overheads	Variable; margins depend on product type, branding strategy and target market segment

Table 6 indicates that the bulk of value addition occurs at the processing and retail stages, rather than at the farm level. The closed-loop model aims to shift some of this value back towards farmers and rural communities by involving them more directly in quality-controlled production, by-product processing and more organised marketing arrangements. Strengthening farmer organisations, supporting MSMEs and ensuring transparent and fair contractual relations between farmers and off-takers are therefore essential for translating the closed-loop concept into concrete improvements in market access and price incentives.

CONCLUSION

This study analysed the coconut agribusiness supply chain in North Sulawesi Province, with a particular focus on the potential implementation of a closed-loop model in Minahasa Tenggara and Minahasa Selatan Districts. The findings show that while both districts share a similar set of actors along the supply chain, they differ significantly in terms of coordination, value addition and utilisation of by-products. In Minahasa Tenggara, the supply chain remains largely conventional and trader-driven, with limited local processing and minimal integration of by-products. In Minahasa Selatan, partnership schemes between farmer groups, processing companies and MSMEs have begun to create more coordinated and circular arrangements, especially through the utilisation of husk, shell and coconut water for value-added products.

The results highlight that the forward supply chain in Minahasa Selatan is more strongly linked to processing industries through semi-formal or contractual arrangements, clearer quality standards and more systematic feedback to farmers. These features provide a foundation for closed-loop practices and can improve market access and price incentives over time. In contrast, the more fragmented and informal structure observed in Minahasa Tenggara constrains the development of closed-loop initiatives and maintains farmers' dependence on village collectors, which limits their ability to capture a higher share of value.

The analysis of reverse flows and by-product utilisation confirms that there is substantial potential for integrating closed-loop elements into coconut agribusiness. Activities such as processing husk into cocopeat and coir products, shell into charcoal and briquettes, and coconut water into liquid organic fertiliser demonstrate how residues can be transformed into additional sources of income and contribute to waste reduction. However, these opportunities are still unevenly realised across locations and require supportive institutional arrangements, investment and capacity building to be scaled up.

From a policy and management perspective, the study suggests that promoting a closed-loop coconut supply chain requires more than technical processing options. Strengthening farmer organisations, cooperatives and village-owned enterprises, supporting MSMEs involved in by-product processing, and facilitating transparent and fair partnerships between farmers and processing companies are essential steps. Local government, extension services and financial institutions have an important role in providing infrastructure, training and tailored financial products to support these developments.

The study is mainly exploratory and relies on qualitative and descriptive quantitative evidence, so its conclusions should be interpreted with this limitation in mind. Future research could build on these findings by incorporating more detailed quantitative analysis of price dynamics, income effects and environmental benefits of closed-loop practices. Modelling approaches, including fully implemented agent-based simulations, could also be used

to assess alternative policy and market scenarios and to estimate the potential impacts of different closed-loop configurations on farmers, MSMEs and processors. Despite these limitations, the study provides a useful empirical basis and conceptual framework for understanding how closed-loop supply chain principles can be applied to coconut agribusiness under smallholder conditions in Indonesia and similar tropical commodity systems.

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