

Integrating financial viability, value addition, and sustainability in household-based seaweed processing: a case study from coastal Indonesia

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Abstract. Seaweed processing offers significant opportunities to strengthen rural livelihoods by generating value-added products, particularly in coastal communities of developing countries. This study evaluates the financial viability, value-added distribution, and sustainability performance of household-based seaweed stick processing in Palabusa village, Southeast Sulawesi, Indonesia, using primary data from field observations, interviews, and enterprise records. Financial analysis confirmed strong economic feasibility, with a net annual profit of IDR 13.3 million, a revenue-cost (R/C) ratio of 1.44, and break-even thresholds well below actual production levels. Value chain analysis revealed a price increase of up to 7,900% from farm-gate to retail, though upstream farmers remained disadvantaged. Application of the Hayami method estimated value-added at IDR 138,000 per kilogram, with 36.2% allocated to labor and 25.1% to profit, indicating both profitability and distributive potential. Sustainability assessment produced a composite index of 78.33 ("Good"), dominated by economic strength but constrained by social and environmental factors. Sensitivity simulations showed that integrated interventions - credit access and improved waste management - could raise the index to 87.33 ("High"). This study is among the first to combine the Hayami method with a composite sustainability index and sensitivity-based policy scenarios in household-scale seaweed snack processing. Findings provide empirical and methodological contributions for policymakers and development agencies, highlighting the potential of micro-scale agroindustries to promote inclusive and sustainable coastal development.

Key Words: circular economy, coastal community development, financial viability, seaweed value chain, sustainability index.

Introduction. Seaweed has emerged as a strategic commodity for coastal economies due to its wide applications in the food, pharmaceutical, cosmetic, and bioenergy sectors (Nesic et al 2024). Indonesia ranks among the world's top producers, contributing over 9.6 million tons annually, with *Eucheuma cottonii* as the most dominant species thanks to its high carrageenan content and stable demand (Hermalena et al 2024). However, the majority of smallholder farmers continue to sell raw seaweed at low prices, with limited value addition and high dependence on volatile export markets (Nor et al 2020).

Recent research emphasizes the importance of moving beyond raw exports towards community-based processing of seaweed into higher-value products, which can enhance household incomes and strengthen local economic resilience (Chaofan et al 2022). Such initiatives also align with the United Nations Sustainable Development Goals (SDGs), particularly SDG 1 (No Poverty), SDG 8 (Decent Work and Economic Growth), and SDG 12 (Responsible Consumption and Production) (Atapattu et al 2024). Yet despite this potential, household-based processing remains underdeveloped, particularly in remote coastal areas where constraints such as limited technical skills, weak institutional support, and restricted market access persist (Rimmer et al 2021).

Technological advancements now enable the low-cost transformation of seaweed biomass into functional food products. Seaweed is rich in polysaccharides, polyphenols, proteins, and healthy lipids, offering nutritional and pharmacological benefits (Eladl et al 2024). Studies show that seaweed-based snacks can improve antioxidant properties, extend shelf life, and even provide health benefits such as lowering cholesterol and blood

sugar (Mohibullah et al 2023). However, from a value chain perspective, upstream actors - particularly farmers - often capture the smallest share of value, while downstream processors and retailers benefit disproportionately (Hermiatin et al 2022). Strengthening local processing capacity is therefore critical to improving bargaining power and fostering inclusive value chains (Bhandari 2025). The Hayami method offers a practical approach to assess value-added distribution across processing stages, yet its application to household-scale seaweed snack processing in Indonesia remains limited (Chen et al 2021).

Palabusa village in Southeast Sulawesi exemplifies a coastal community transitioning from raw seaweed sales to household-level processing of seaweed sticks - a locally marketed snack with higher profitability (Jayakody & Vanniarachchy 2024). While early evidence suggests positive income effects, there remains a lack of empirical data on financial feasibility, break-even performance, sustainability, and the policy conditions required to scale such initiatives (Umah 2025). Similar gaps are evident across Southeast Asia, where research often focuses on upstream production or large-scale industrial applications rather than household enterprises (Verissimo et al 2021).

To guide its analytical framework, this study draws on the Triple Bottom Line (TBL) perspective, which emphasizes a balance between economic viability, environmental sustainability, and social responsibility in agroindustrial systems (Narassima et al 2025). The TBL framework is complemented by circular economy principles that promote waste valorization, local resource loops, and shared value co-creation - particularly relevant for small-scale processing industries (Istanto et al 2025). These frameworks jointly support the development of sustainability indicators and the interpretation of value-added and waste management dynamics in household-based seaweed agroindustry systems.

This study advances the literature by integrating financial feasibility, value-added assessment (Hayami method), and a composite sustainability index into a single framework, applied to a household-scale seaweed snack enterprise. Moreover, the inclusion of sensitivity analysis to simulate policy interventions - specifically credit access and waste management - provides actionable insights for enhancing inclusive and sustainable micro-scale agroindustries. This integrated approach has not been previously applied in Indonesian seaweed processing and represents the key novelty of this research.

Material and Method

Research design and study site. This study adopts a qualitative case study design to examine the financial feasibility, value-added potential, and sustainability performance of household-based seaweed stick agroindustry. Conducted in Palabusa village, Baubau City, Southeast Sulawesi, Indonesia, the research was carried out during the period of January to March 2025, focusing on a coastal community recognized for its long-standing seaweed farming tradition and emerging small-scale processing activities.

Unlike most prior studies that focus solely on either financial analysis or sustainability indicators, this research employs a novel integrated framework that combines the Hayami value-added method, a composite sustainability index, and scenario-based sensitivity analysis. This methodological design enhances the capacity to capture not only the financial viability but also the distributive equity and long-term sustainability of household-based agroindustries.

The site was selected purposively as a representative case of community-level agroindustry innovation aimed at improving value capture from local marine resources.

Data collection. Primary data were obtained through direct field observation and semi-structured interviews with the owner and two workers of an active household seaweed stick production unit. This particular unit was selected due to its consistent operation since 2021 and its pioneering role in developing seaweed-based snacks within the community. Data collected included: raw material input and processing stages, labor utilization, operational costs and production volume and sales prices and revenue

records. Supporting documents such as daily logbooks and receipts were also reviewed to enhance data reliability. Complementary data were sourced from: local government planning and economic reports, Academic journals and grey literature and Statistical releases by the Ministry of Marine Affairs and Fisheries of Indonesia. These sources were used to contextualize findings, especially in value chain structure and sustainability dimensions.

Data validation. Triangulation techniques were employed to ensure the validity of collected information. Interview responses were cross-checked with observational notes, supporting documents, and feedback from local extension officers and village stakeholders. Financial estimates were verified through repeated consultation with the producer to minimize potential recall and response biases.

Analytical framework and procedures

Financial feasibility analysis. Key economic indicators were computed, including: total annual production costs (fixed + variable), annual revenue and net income, revenue-cost (R/C) ratio, break-even points (volume, revenue, and price).

Value added analysis (Hayami method). The Hayami value-added method was employed to measure processing contribution, using: gross value added (output value minus cost of raw materials), distribution of value added to labor wages and owner profits and value-added ratio (value added per unit of output).

Value chain mapping. A simplified value chain map was developed to trace product flows from farmers to final consumers. Stakeholder roles, benefits, and relational power disparities were identified, revealing opportunities for inclusive upgrading.

Sustainability performance assessment. Composite sustainability index was constructed based on three dimensions: economic: profitability, input efficiency; social: labor absorption, institutional access, credit inclusion; and environmental: waste management practices, resource use efficiency. Indicators were adapted from established sustainability frameworks for small-scale agroindustries and scored both qualitatively and quantitatively.

Sensitivity and scenario analysis. To simulate the impact of key interventions, three policy-relevant scenarios were analyzed: introduction of formal credit access, improved waste management system, and combined intervention (credit + waste). Each scenario's projected influence on economic, social, and environmental performance was assessed using a before-after simulation approach.

Research limitations. This study is subject to several limitations that should be acknowledged. First, the analysis is based on a single household enterprise in Palabusa village, which may constrain the generalizability of findings to other coastal communities or larger-scale operations. Second, financial data were primarily drawn from household records and self-reported interviews, which, despite triangulation, may involve recall biases and reporting inaccuracies. Third, the study covers a limited timeframe and does not capture seasonal or long-term fluctuations in production and market dynamics. These limitations are inherent to exploratory case study designs but do not diminish the contribution of this research. On the contrary, they highlight the need for follow-up studies with larger samples, longitudinal data, and comparative approaches across regions. Nevertheless, the integration of financial, value-added, and sustainability assessments in this case provides valuable empirical insights and methodological innovations that can inform future research and policy interventions in household-based agroindustries.

Results. The household-based seaweed stick enterprise in Palabusa village demonstrates strong financial viability under prevailing production conditions. As illustrated in Figure 1, production follows a straightforward household workflow - preparation, soaking, mixing, steaming, cutting, and packaging - characteristic of micro-scale coastal agroindustries that rely on basic equipment and family labor.

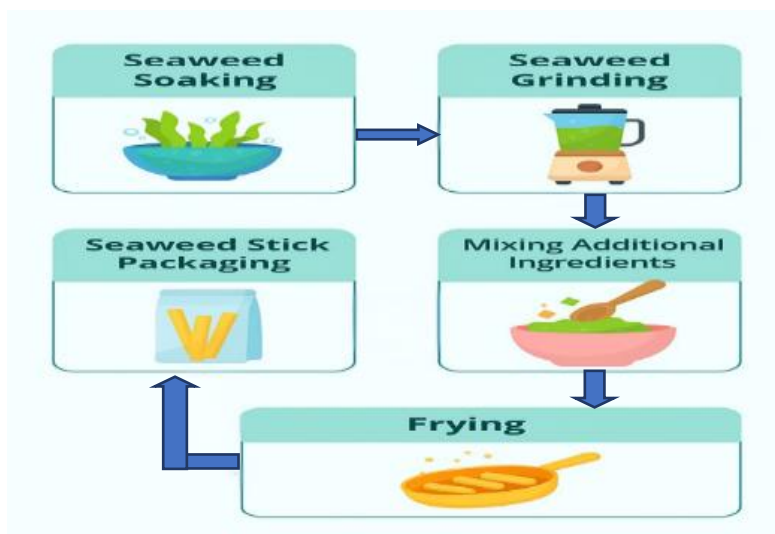


Figure 1. Processing flowchart of seaweed stick.

The cost structure is primarily driven by raw material inputs, followed by labor, fuel, and packaging (Figure 2). As shown in Table 1, annual output of 288 kg requires total operational costs of IDR 29,899,000, against revenues of IDR 43,200,000, yielding a net profit of IDR 13,301,000.

In addition to operating costs, capital requirements remain modest. As presented in Table 2, the total initial investment amounts to only IDR 2,145,000, covering essential equipment such as stoves, blenders, and sealing machines. This low entry barrier demonstrates the accessibility of seaweed stick processing for coastal households seeking additional income opportunities, while also explaining why household agroindustries are commonly adopted in resource-limited contexts.

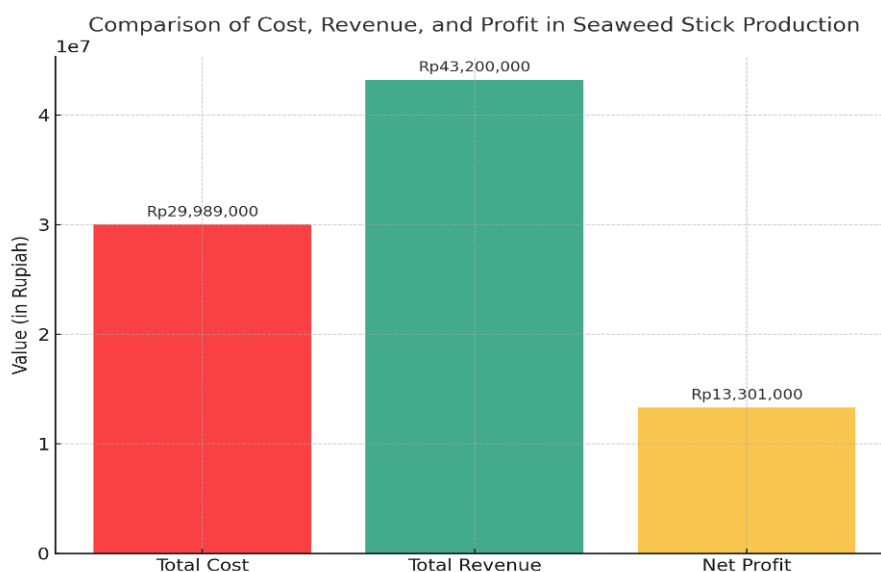


Figure 2. Comparison of cost, revenue, and profit in seaweed stick production.

Table 1

Cost structure of seaweed snack stick production

No.	Cost structure	Volume/unit	Cost per unit (Rp)	Total cost per period (Rp)	Total annual cost (Rp)
1.	Raw material:				
	Seaweed	2 kg	15,000	30,000	2,880,000
2.	Additional ingredients:				
	a. Rice flour	2.5 kg	12,000	30,000	2,880,000
	b. Sugar	0.5 kg	20,000	10,000	960,000
	c. Cheese	0.075 kg	267,000	20,000	1,920,000
	d. Eggs	2 pieces	2,000	4,000	384,000
	e. Salt as needed		1,000	1,000	96,000
	f. Margarine	0.2 kg	45,000	9,000	864,000
3.	Cooking oil	2 L	40,000	40,000	3,840,000
4.	Gas	3 kg	36,000	12,000	1,152,000
5.	Labor	2 workers	50,000	100,000	9,600,000
6.	Product packaging	30 pcs	1,500	45,000	4,320,000
7.	Marketing costs	1 month	50,000	50,000	600,000
8.	Depreciation costs				403,000
		Total cost			29,899,000

Source: Processed primary data, 2024.

Table 2

Details of investment costs for seaweed snack stick production

No	Cost component	Acquisition cost (Rp)	Residual value (Rp)	Economic life (years)	Depreciation value (Rp)
1.	Blender	500,000	150,000	5	70,000
2.	Pot	180,000	0	3	60,000
3.	Frying pan	170,000	0	3	56,667
4.	Spatula	35,000	0	3	11,667
5.	Oil strainer	55,000	0	3	18,333
6.	Large container	85,000	0	3	28,333
7.	Stove	500,000	150,000	5	70,000
8.	Weighing scale	120,000	30,000	5	18,000
9.	Standing pouch sealer	500,000	150,000	5	70,000
	Total	2,145,000			403,000

Source: Processed primary data, 2024.

The break-even point (BEP) analysis confirms financial resilience. The break-even revenue of IDR 19,162,048 is less than half of the actual revenue, while the break-even production volume of 127.75 kg is far below the realized output of 288 kg (Figure 3). Similarly, the break-even price of IDR 103,819 per kg remains comfortably under the prevailing market price of IDR 150,000 per kg. These margins highlight a strong financial cushion, consistent with the findings of Hassan et al (2013) in Kerala, India, where fisherwomen-based microenterprises producing cutlets, fish balls, and pickles achieved profitability with BEP levels significantly lower than their actual output, ensuring business continuity and income stability.

The enterprise's profitability is further reflected in its R/C ratio, which stands at 1.44 (Figure 4). This indicates that every IDR 1 invested generates IDR 1.44 in returns, or a 44% margin above cost. Ratios above 1.0 are considered financially feasible, and values exceeding 1.3 signal strong profitability. This finding is consistent with Mantri et al (2022), who reported similarly strong profitability in *Kappaphycus alvarezii* farming in India, with payback periods as short as 0.1-0.3 years. However, unlike farm-level cultivation, household snack processing such as in Palabusa remains more exposed to

input price fluctuations and limited production scale, which may constrain its ability to expand margins.

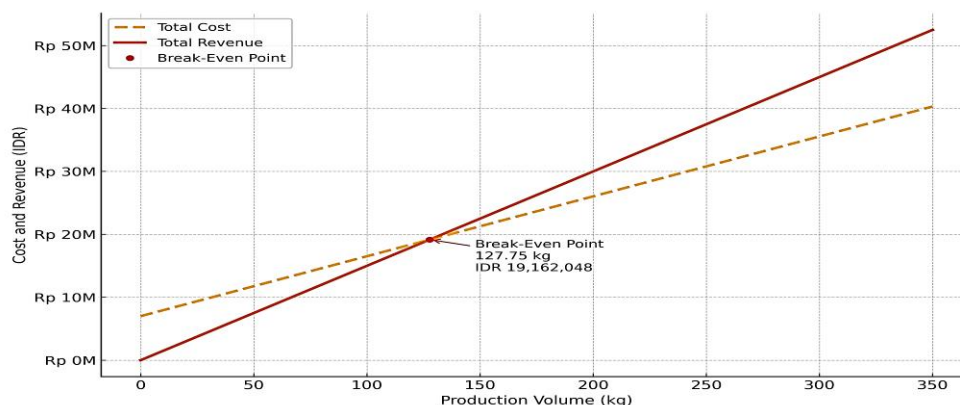


Figure 3. Break-even analysis of household-scale seaweed stick production in Palabusa village.

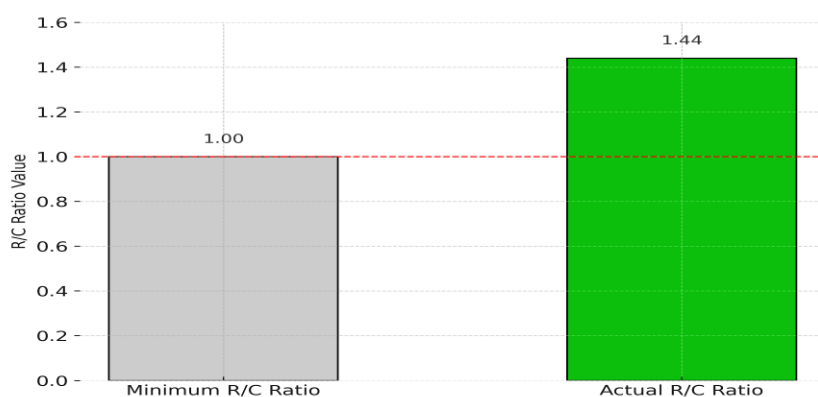


Figure 4. Comparison of actual and break-even revenue-cost (R/C) ratios in household seaweed stick processing.

Comparable studies on fisherwomen-based enterprises in Kerala, India (Hassan et al 2013) also revealed profitability above break-even levels, but with greater vulnerability to market volatility when institutional support was weak. These parallels suggest that while high R/C ratios indicate short-term financial resilience, long-term viability in microenterprises depends critically on access to collective marketing structures, credit facilities, and stable supply chains.

From a theoretical perspective, these results confirm the economic pillar of the TBL framework, demonstrating that household-based seaweed stick processing contributes to financial sustainability and local economic resilience (Narassima et al 2025). Nonetheless, the modest absolute profit margin indicates vulnerability to input price shocks and scale limitations. To strengthen financial viability, institutional support such as access to microfinance, training, and collective marketing could be pivotal. Additionally, integrating circular economy strategies - such as reusing seaweed residues for compost or animal feed - can reduce production costs and expand value creation, as successfully demonstrated in the tapioca industry (Istanto et al 2025).

Value addition analysis. The contribution of household-based seaweed stick processing to local income generation is assessed using the Hayami value-added method. As shown in Table 3, gross value added reaches IDR 138,000 per kilogram of output, equivalent to 61.3% of total product value. Of this, 36.2% is distributed as labor income, while 25.1% accrues to the owner as profit. This ratio exceeds that of cassava chip agroindustries in Thailand, which typically range between 45 and 55% (Chancharoenchai & Saraithong 2022), indicating that marine-based snack innovations can provide stronger profitability margins compared to conventional crop-based products. Despite this, the distribution of

benefits remains uneven. Owner profit shares surpass labor wages, echoing findings from fisherwomen-led processing enterprises in Kerala, India (Hassan et al 2013), where entrepreneurs consistently captured higher margins while workers earned modest but stable incomes. This persistent inequity underscores the importance of institutional mechanisms - such as cooperatives or revenue-sharing schemes - to promote more balanced outcomes.

Table 3

Cost structure, production and revenue of seaweed snack stick processing business in Palabusa village, BauBau City, 2024

<i>Variable</i>	<i>Value</i>
I. Output, input, and price	
1. Output (kg)	3
2. Raw material (kg)	2
3. Labor (Person-day).	2
4. Conversion factor	1.5
5. Labor coefficient	1
6. Output price (Rp/kg)	150000
7. Labor wage (Rp/(person-day))	50000
II. Revenue and profitability	
8. Raw material price (Rp/kg)	15000
9. Contribution of other inputs (Rp/kg)	72000
10. Output value (Rp/kg)	225000
11. a. Value added (Rp/kg)	138000
b. Value added ratio (%)	61.3
12. a. Labor income (Rp/kg)	50000
b. Labor share (%)	36.2
13. a. Profit (Rp/kg)	88000
b. Profit rate (%)	63.8
III. Remuneration for production factor owners	
14. Margin (Rp/kg)	210000
a. Direct labor income (%)	23.80
b. Contribution of other inputs (%)	34.28
c. Entrepreneur's profit share (%)	41.90

Source: Processed primary data, 2024.

Based on the calculations presented in Table 3, the seaweed snack stick processing enterprise in Palabusa demonstrates strong financial performance driven by value-added processing at the household level. The operation generates a value added of IDR 138,000/kg with a profit rate of 63.8 percent, indicating high economic efficiency. Moreover, the share of labor income reaching 36.2 percent suggests that the activity contributes meaningfully to local livelihoods, while the margin distribution shows a balanced contribution between labor, input costs, and entrepreneurial profit. These results highlight the economic relevance of small-scale agroprocessing in strengthening household income and expanding market opportunities for seaweed-based products.

Nevertheless, the financial indicators alone cannot fully capture the broader implications of this enterprise. Further examination is needed to understand how these economic outcomes relate to institutional, social, and sustainability dimensions. By linking the Hayami analysis with theoretical perspectives and previous studies, the discussion can provide deeper insights into how household-based seaweed processing contributes to community development, employment potential, and value chain upgrading. Rimmer et al (2021) emphasize, seaweed-based enterprises in Indonesia often face institutional and market barriers that limit broader community spillovers. Strengthening cooperative structures, market linkages, and access to training is therefore essential to enhance the distributive reach of such enterprises.

From a theoretical perspective, the findings reflect both the economic and social pillars of the TBL. Economically, the enterprise secures strong margins that ensure financial viability. Socially, more than one-third of value added flows to labor, indicating meaningful livelihood contributions (Narassima et al 2025). However, the absolute number of workers engaged remains small, constraining broader employment impact.

There is also potential to enhance value added through circular economy strategies. By valorizing seaweed residues - for example, processing them into animal feed, compost, or bioplastic materials - households could diversify income streams while reducing waste disposal costs. This approach has proven effective in Indonesia's tapioca industry (Istanto et al 2025) and could be replicated in seaweed agroindustries. Overall, the Hayami analysis confirms that household-based seaweed stick enterprises generate substantial value added and distribute it in ways that support profitability and local livelihoods. Yet scaling up these benefits requires enabling policies that foster cooperative marketing, institutional coordination, and sustainable resource use.

In addition to financial outcomes, the social dimension of household processing is closely linked to family and gender roles. In Palabusa, production is typically managed within households, with women often responsible for key stages such as preparation, mixing, and packaging. This reflects broader patterns in South and Southeast Asian microenterprises, where women's labor underpins value-added processing but is frequently undervalued (Hassan et al 2013).

The limited labor absorption observed in this case (two workers) further constrains wider community spillovers. Without stronger institutional support - such as gender-sensitive training programs, cooperatives, or shared ownership models - household processing risks reinforcing existing gendered divisions of labor rather than transforming them. Addressing gender equity is therefore essential not only for distributive fairness but also for enhancing the social pillar of sustainability.

Value chain mapping and stakeholder roles. Analysis of the seaweed stick value chain reveals a strong concentration of value at downstream nodes, while upstream actors - particularly farmers - capture disproportionately low returns. As shown in Figure 5, the farm-gate price of dried seaweed in Palabusa is only IDR 18,000 per kilogram, whereas the retail price of seaweed sticks reaches IDR 150,000 per kilogram. This wide gap illustrates a fragmented chain in which farmers, despite supplying the raw material, secure only a small share of the final value.

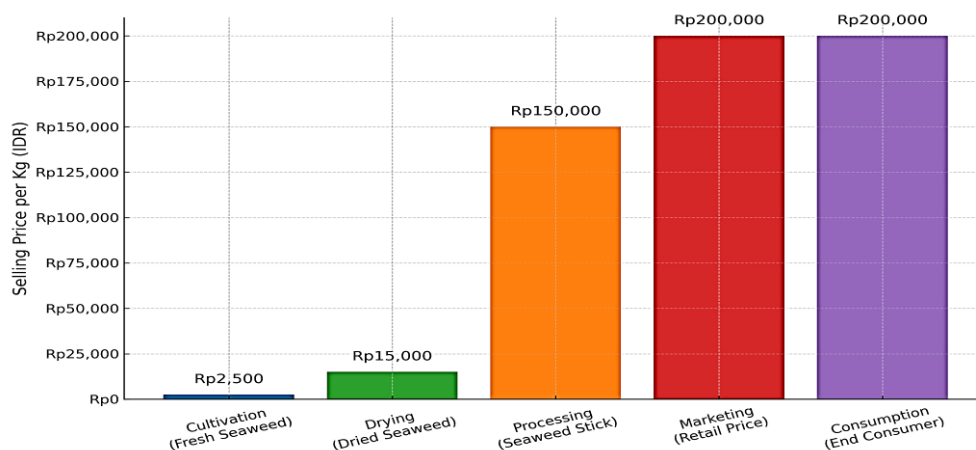


Figure 5. Progressive increase in selling price per kilogram along the seaweed stick value chain, from cultivation to final consumer.

The distribution of margins further underscores these disparities. As depicted in Figure 6, household processors capture the largest share of margins due to value addition, while farmers and small traders receive limited benefits. Retailers also secure significant margins because of direct consumer access and control over pricing. These asymmetries mirror findings from other small-scale agroindustries. For instance, Hassan et al (2013)

observed that in fisherwomen-based processing in Kerala, entrepreneurs retained substantially higher value shares than labor. Similarly, Chanchaoenchai & Saraithong (2022) found that cassava chip producers in Thailand were disadvantaged in value distribution due to limited bargaining power and weak institutional coordination.

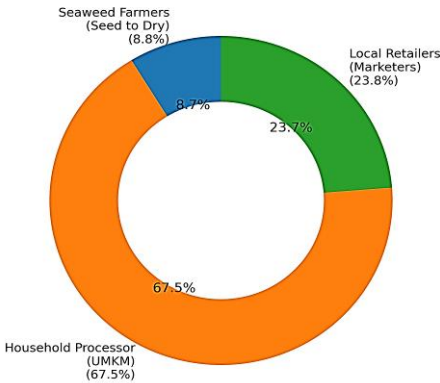
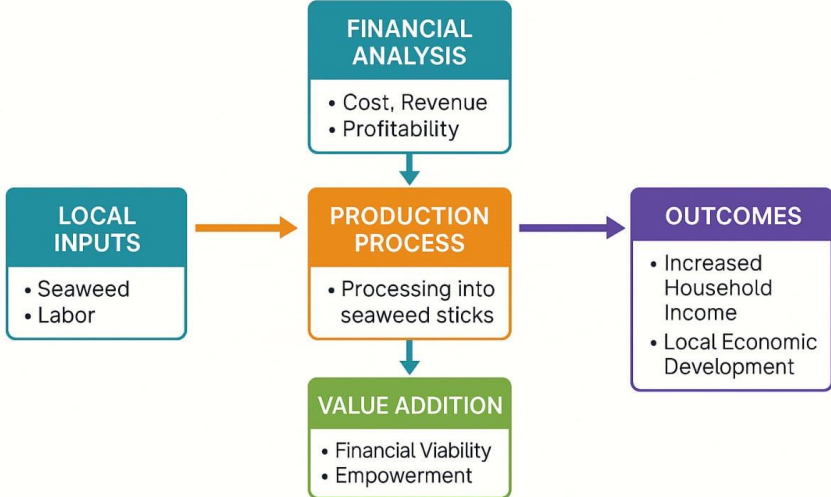


Figure 6. Distribution of value-added margins per actor in the seaweed stick value chain.

Stakeholder mapping (Figure 7) confirms the central role of household processors, who link upstream farmers to downstream consumers. Yet the limited scale of household operations restricts spillover benefits to the broader community. As noted by Rimmer et al (2021), seaweed aquaculture and processing in Indonesia contribute significantly to livelihoods and community well-being, but impacts are often constrained by institutional fragmentation, inadequate infrastructure, and the absence of formalized cooperatives. Without coordinated upgrading, household processors risk remain confined to local markets with limited scalability.



Conceptual Model of Household-Based Coastal Agroindustry Development

Figure 7. Flowchart of the household-scale seaweed stick value chain in Palabusa village.

From a theoretical perspective, these findings highlight both opportunities and vulnerabilities in the value chain. Economically, household processors capture significant value, aligning with the economic pillar of the TBL (Narassima et al 2025). Socially, however, unequal margin distribution reflects a weak social pillar, as upstream farmers remain marginalized and lack bargaining power. Unless corrective interventions are introduced, household agroindustries risk reinforcing rather than reducing inequalities.

Upgrading strategies are therefore essential to rebalance the chain. Strengthening farmer-processor cooperatives could improve price negotiation and ensure more

equitable distribution. Building partnerships with retailers and integrating local processors into broader markets may also enhance competitiveness. Evidence from Mantri et al (2022) demonstrates that profitability in seaweed farming and processing increases significantly when combined with organizational upgrading. Moreover, adopting circular economy strategies, such as valorizing processing by-products into animal feed or compost, could expand value creation while reducing environmental externalities, thereby strengthening the environmental pillar of TBL (Istanto et al 2025).

In sum, the mapping of the seaweed stick value chain demonstrates both the potential of household-based processing to capture and retain value locally, and the structural limitations that prevent fair distribution to upstream actors. Sustainable upgrading - through institutional coordination, cooperative models, and circular practices - will be critical to ensure that seaweed agroindustries contribute not only to profitability but also to inclusivity and resilience.

Sustainability analysis. The sustainability assessment of household-scale seaweed stick processing in Palabusa, based on the TBL framework, reveals asymmetrical performance across dimensions. The economic pillar scored the highest (93.33/100, "High"), while the social (66.67/100) and environmental (70.00/100) pillars were both categorized as "Good." The resulting composite sustainability index was 78.33/100, placing the enterprise within the "Good" category overall (Table 4).

Table 4

Sustainability scores of the seaweed stick agroindustry

<i>Dimension</i>	<i>Score (0-100)</i>	<i>Category</i>
Economic	93.33	High
Social	66.67	Good
Environmental	70.00	Good
Composite	78.33	Good

The sustainability assessment presented in Table 4 indicates that the household-based seaweed stick agroindustry in Palabusa exhibits an overall sustainability status categorized as Good, with a composite score of 78.33. However, this aggregate score conceals a pronounced imbalance among the three sustainability dimensions, reflecting asymmetric development pathways within the enterprise system.

The economic dimension achieved the highest score (93.33), classified as High, underscoring the strong financial foundation of the enterprise. This performance is primarily driven by favorable profitability indicators, stable market demand, and efficient input utilization, as evidenced by the high R/C ratio and substantial value-added margins reported earlier. Such dominance of the economic pillar is characteristic of emerging household agroindustries, where immediate income generation often constitutes the primary motivation for adoption. From a Triple Bottom Line perspective, this result confirms that the enterprise is economically sustainable in the short to medium term, providing a solid basis for livelihood resilience.

In contrast, the social dimension recorded a moderate score of 66.67 (Good), revealing structural limitations that constrain broader social benefits. Limited labor absorption, weak institutional linkages, and the absence of formal cooperative arrangements reduce the enterprise's capacity to generate inclusive growth. Although labor income accounts for a meaningful share of value added, employment opportunities remain restricted to a small number of household members, thereby limiting spillover effects at the community level. Moreover, the reliance on informal arrangements and the lack of access to formal credit institutions further weaken social sustainability by constraining opportunities for scaling and collective upgrading.

The environmental dimension, with a score of 70.00 (Good), reflects partial sustainability performance. While seaweed-based processing inherently benefits from low chemical input use and renewable raw materials, environmental management practices at the household level remain basic. Waste residues from processing are not

systematically valorized, and disposal practices rely largely on conventional methods. This indicates that environmental sustainability is not yet integrated as a strategic component of enterprise management but remains a secondary consideration, potentially becoming a constraint if production intensity increases.

Overall, the sustainability profile depicted in Table 4 illustrates a system that is economically robust but socially and environmentally underdeveloped. This imbalance suggests that without targeted interventions, the long-term sustainability trajectory of the agroindustry may be compromised despite its strong financial performance. Strengthening institutional support, expanding access to finance, and integrating circular economy practices - particularly waste valorization - are therefore essential to harmonize the three sustainability pillars and transition the enterprise from a "Good" to a "High" sustainability category. These findings reinforce the argument that economic success alone is insufficient to ensure sustainable agroindustrial development at the household scale

Figure 8 provides a visual representation of these results through a radar diagram. The figure illustrates the wide gap between the economic pillar and the comparatively compressed lines for social and environmental attributes. This graphical asymmetry reinforces the quantitative evidence that household-based seaweed processing remains economically robust but socially and environmentally underdeveloped. This asymmetry between dimensions provides the basis for comparing Palabusa's sustainability profile with other agroindustrial cases globally.

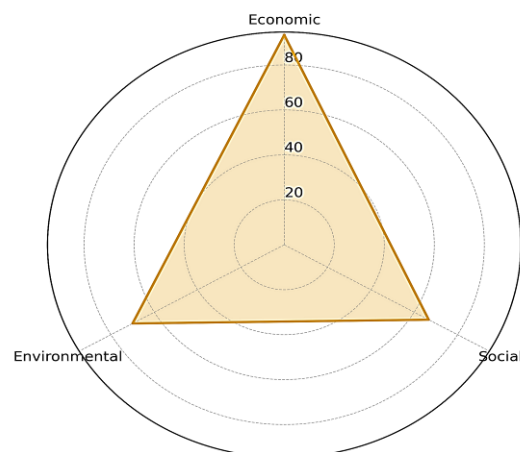


Figure 8. Radar chart of sustainability dimensions (0-100).

These findings are consistent with patterns reported in other Indonesian agroindustries, such as tapioca processing, where profitability tends to outpace social inclusion and waste valorization (Istanto et al 2025). In contrast, European seaweed industries demonstrate more balanced sustainability outcomes, supported by stronger institutional coordination and environmental regulations (Jueterbock et al 2025). This divergence highlights the decisive role of governance and policy contexts in shaping sustainability trajectories, beyond enterprise-level practices.

Environmental performance in Palabusa remains modest despite positive contributions from seaweed cultivation, such as carbon sequestration and low chemical input use (Waqas et al 2024). Reliance on conventional waste disposal without by-product utilization represents a structural weakness that may escalate as production scales. Similar trade-offs have been documented in smallholder food enterprises globally, where short-term economic imperatives often outweigh environmental considerations (Jueterbock et al 2025).

The social pillar also reflects systemic limitations. Although women play a central role in processing stages such as preparation, mixing, and packaging, their contributions remain undervalued and undercompensated. This pattern aligns with broader evidence from South and Southeast Asia, where women's labor sustains value-added processing

yet receives limited recognition (Hassan et al 2013). Without gender-sensitive interventions, cooperatives, and equitable revenue-sharing mechanisms, household processing risks perpetuating rather than alleviating inequalities.

In summary, the sustainability assessment highlights a strong economic foundation but weaker social and environmental performance. Embedding circular economy practices, strengthening institutional coordination, and promoting gender equity will be essential for elevating household-based seaweed processing from “good” to “high” sustainability and ensuring long-term resilience.

Sensitivity analysis. Sensitivity analysis was conducted to evaluate strategies for improving sustainability performance. Three scenarios were simulated: (i) access to formal credit, (ii) improved waste management, and (iii) a combined intervention incorporating both measures (Table 5).

Table 5

Comparison of sustainability scores under baseline and scenarios

<i>Condition</i>	<i>Economic</i>	<i>Social</i>	<i>Environmental</i>	<i>Composite index</i>	<i>Category</i>
Baseline	93.33	66.67	70.00	78.33	Good
Scenario 1: access to formal credit	93.33	83.33	70.00	83.33	High
Scenario 2: improved waste management	93.33	66.67	83.33	82.33	High
Scenario 3: credit + improved waste	93.33	83.33	83.33	87.33	High

As shown in Table 5, the baseline condition scored 78.33 on the composite sustainability index, classified as “Good”. The economic dimension was dominant (93.33), while social (66.67) and environmental (70.00) dimensions were weaker.

Under Scenario 1, the introduction of credit access raised the social score to 83.33, lifting the composite index to 83.33 (“High”). This underscores the role of financial inclusion in strengthening social resilience and enabling enterprise expansion, consistent with evidence from rural empowerment studies (Singh et al 2024).

Scenario 2, which introduced improved waste management, increased the environmental score to 83.33 and produced a composite index of 82.33 (“High”). These results demonstrate the potential of low-cost ecological innovations - such as converting residues into compost or animal feed - to mitigate environmental risks while generating new value streams, in line with evidence on waste valorization in agri-food systems (Waqas et al 2024).

The most significant effect occurred in Scenario 3, where credit and waste management were combined. Both social and environmental scores rose to 83.33, raising the composite index to 87.33 - the highest among all conditions. This synergy illustrates that integrated institutional and environmental interventions can strengthen all three TBL pillars simultaneously: economic efficiency, social inclusion, and environmental sustainability. Similar conclusions have been drawn from composite index approaches to agro-industrial upgrading (Magrini 2022). Figure 9 illustrates these trends graphically, showing that while the baseline index was “Good” (78.33), individual interventions lifted the score above 82, and the combined intervention pushed it to 87.33 (“High”).

In summary, the sensitivity analysis confirms that household-based seaweed processing in Palabusa is financially viable but constrained socially and environmentally. Well-targeted interventions - particularly when integrated - substantially enhance sustainability outcomes. These findings reinforce the need for policies that simultaneously promote financial inclusion, capacity building, and circular economy innovations, consistent with global recommendations for sustainable seaweed industry development (Jueterbock et al 2025).

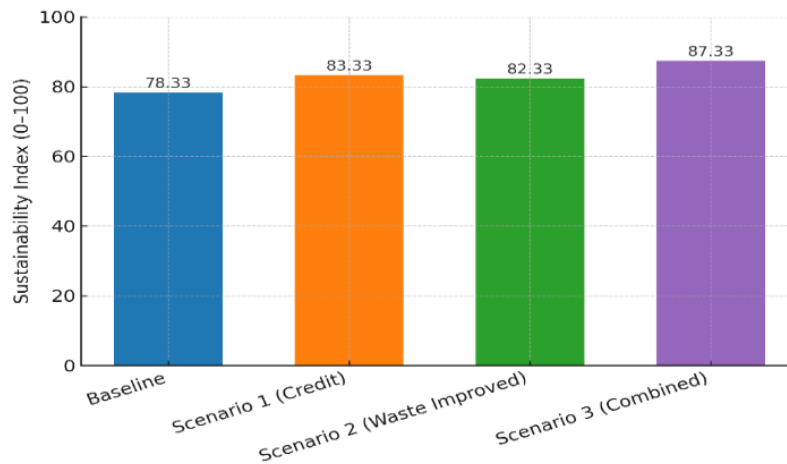


Figure 9. Comparison of sustainability index (baseline vs improvement scenarios).

Policy implications. The findings of this study indicate that while household-scale seaweed agroindustries demonstrate strong economic viability, their long-term sustainability is constrained by institutional and environmental barriers. Addressing these limitations requires integrated policy interventions that move beyond production efficiency to tackle systemic challenges such as financial exclusion, weak technical capacity, limited waste management, and fragmented market access.

Financial inclusion is a critical priority. Many household processors remain excluded from formal banking systems due to lack of collateral or credit history. Community-based financial mechanisms - such as cooperatives, rotating savings groups, or village credit unions - can serve as intermediaries to reduce lender risk and expand access to working capital (Singh et al 2024; Bennett et al 2025). By aggregating borrowers and enhancing financial literacy, these institutions can facilitate enterprise expansion and technological upgrading.

Capacity building is equally important. Training in bookkeeping, pricing strategies, packaging, and digital marketing can improve efficiency and competitiveness. Local governments, vocational training centers, and NGOs should collaborate to provide modular, low-cost training tailored to small-scale food processors. Certification schemes and branding initiatives may further enhance product quality assurance and consumer trust.

Environmental interventions must address the limited waste management capacity of household units. Policies promoting waste valorization - for example, converting seaweed residues into compost, animal feed, or biodegradable packaging - would reduce environmental risks while generating new value streams. Micro-grants, fiscal incentives, and technical assistance could support adoption. These approaches align with circular economy principles increasingly recommended for small-scale agroindustries (Waqas et al 2024).

Inclusive value chain development should also be prioritized. Cooperative marketing models, participation in local trade fairs and digital platforms, and access to geographical indications (GI) or community-based branding can improve income stability and bargaining power. Strengthening traceability and quality assurance systems will be essential for building consumer confidence in community-based products.

Finally, institutional coordination is necessary to ensure that these interventions are mutually reinforcing. Cross-sectoral alignment among the ministries of marine affairs, cooperatives, environment, and industry would provide a coherent roadmap for household-scale agroindustry development. Such a roadmap should integrate finance, training, environmental regulation, and market access into a unified framework.

While rooted in the context of Palabusa village, these policy implications are scalable to other coastal communities across Indonesia and similar developing regions. By integrating economic empowerment with institutional support and ecological innovation, policy frameworks can transform household-based seaweed agroindustries into drivers of resilient, inclusive, and sustainable coastal livelihoods.

Conclusions. This study advances the analysis of micro-scale agroindustries by integrating Hayami value-added analysis, a composite sustainability index, and sensitivity-based policy simulations within a single framework. Unlike previous studies that examined economic feasibility, value chains, or sustainability in isolation, this approach offers a novel methodological contribution that can be replicated in other smallholder contexts.

Empirical findings from Palabusa village confirm that household-based seaweed stick processing is financially viable, operating well above its break-even point with a favorable R/C ratio. Value chain mapping highlights significant disparities in benefit distribution, with downstream actors - particularly processors and retailers - capturing the largest margins. The sustainability assessment indicates strong economic performance but weaker social and environmental outcomes, while sensitivity simulations demonstrate that integrated interventions - combining credit access, capacity building, and ecological innovation - can raise overall sustainability.

The study also emphasizes the critical but often undervalued role of women in household-based seaweed processing. Women contribute substantially to production yet continue to face inequitable benefit distribution, underscoring the need for gender-sensitive training, cooperative structures, and inclusive market mechanisms.

In conclusion, this research contributes both empirical evidence and methodological innovation. By combining economic, social, and environmental perspectives with scenario-based interventions, it provides theoretical advancement and practical policy guidance for scaling resilient, inclusive, and sustainable coastal agroindustries in Indonesia and comparable developing regions.

Conflict of interest. The authors declare that there is no conflicts of interest.

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