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Regular Research Article

Sustainable Value Chain Mapping of Downstream Aquaculture Fishery Products Based on Blue Economy

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Abstract: This study examines the sustainability of downstream aquaculture value chains in Cirebon's coastal area within a blue economy framework. Using a sequential explanatory mixed-methods design, quantitative data from 190 value chain actors across four sub-districts were collected through structured surveys measuring five sustainability dimensions (economic, social, environmental, technological, and institutional) with 42 indicators, followed by qualitative validation through 20 in-depth interviews and 4 focus group discussions. Value chain analysis reveals that processing stages capture the highest value addition (42.4%) while primary producers (farmers) receive only 24.2%, reflecting significant bargaining asymmetries. The aggregate sustainability score is 2.67 (Quite Sustainable), with social factors scoring highest (3.12) and technology scoring lowest (2.23). Correlation analysis reveals the strongest interdependence between the economic and technological dimensions ($r = 0.675$, $p < 0.001$). A SWOT-AHP strategic assessment involving 15 experts identifies integrated fisheries industrial cluster development as the foremost strategic priority for advancing sustainable aquaculture downstreaming. The study contributes a locally grounded multi-dimensional sustainability assessment framework adaptable to other Indonesian coastal regions.

Keywords: sustainable value chain; fisheries downstreaming; blue economy; aquaculture

1. Introduction

Indonesia, as the largest archipelagic country with a coastline of 108,000 kilometers, offers enormous opportunities for developing the blue economy, especially in fisheries and aquaculture [1]. However, in the last five years, the contribution of the fisheries and aquaculture sector to national GDP has remained limited to 3.6%, suggesting that the downstream potential of aquaculture products has not been optimally utilized [2]. FAO data for 2024 records remarkable achievements in the global aquaculture industry: production reached a record high of 130.9 million tons with an economic value of USD 312.8 billion, surpassing capture fisheries production of 94.4 million tons [3].

Studies conducted in coastal areas of the Java Sea, including around Cirebon, concluded that advances in environmentally friendly technology and improvements in human resource capabilities are crucial factors for ensuring sustainable growth [4]. The production system in Indonesia's coastal areas is still controlled by small-scale business actors, some of whom depend on subsistence economies. These changes in production patterns and livelihoods in the fisheries sector are like those in the mainland agricultural sector but receive much less research attention [5]. The World Economic Forum emphasizes that sustainable aquaculture must pursue four paths: improving livelihoods, healthy consumption patterns, protecting the environment, and governance reforms [6]. Research in Indonesia shows that seaweed cultivation can positively impact socio-economic conditions, though various risks require appropriate policy responses [2].

The digital revolution and technological innovation play a vital role in optimizing the

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fisheries value chain. Fishlog, as a community-based B2B platform, has improved the seafood supply chain throughout Indonesia through 40 operational locations with a management capacity of 3,000 metric tons of fish [7]. However, significant gaps remain in the integration of technology and information systems across the value chain [4]. In a study of 57 aquaculture systems worldwide using 88 sustainability indicators, it was found that economic, social, and environmental aspects are mutually supportive, although significant differences in sustainability levels exist between systems [8]. These findings confirm that the triple bottom line approach in aquaculture can be implemented practically [9].

In the context of value chain mapping, five key elements for building resilient and sustainable seafood supply chains have been identified: diversity in production systems, connectivity between actors, solid collaboration, continuous learning, and multi-stakeholder governance [10]. However, implementing these elements faces technical and institutional challenges, especially in developing countries. A study of aquaculture policies in Singapore and Norway found that feed production and use are the most significant contributors to environmental impact [11].

Despite extensive research, gaps remain. First, empirical studies on the implementation of the blue economy at the local level in Indonesia are very limited. Second, no universally applicable methodology exists for measuring the sustainability of the aquaculture value chain that comprehensively integrates all five dimensions (economic, social, environmental, technological, and institutional). Third, the impact of digital technology on the transformation of the fisheries value chain receives insufficient attention. Fourth, most existing research focuses on the national or global level, whereas implementation requires a deep understanding of local dynamics.

This research contributes to filling these gaps through several aspects: (1) proposing an integrated multi-dimensional framework that combines five sustainability dimensions within a single blue economy-based value chain analysis an integration that has been rarely applied to aquaculture at the sub-national level in developing countries; (2) adapting and applying FAO's FISH4ACP methodology to the specific context of Indonesia's blue economy, contributing to the limited but growing body of locally grounded applications; (3) providing local-level empirical evidence from Cirebon that may serve as a reference model for other coastal districts in Indonesia; (4) producing an applicative strategy with practical guidance for field actors; and (5) quantitatively identifying specific technology gaps (traceability system adoption at 13%, IoT monitoring at 15.8%) that serve as competitiveness bottlenecks, in contrast to previous predominantly descriptive research.

The research questions are formulated as follows: (1) What are the existing conditions of the downstream value chain of aquaculture products based on the blue economy in the coastal area of Cirebon? (2) What factors affect the sustainability of the downstream value chain of aquaculture products in Cirebon? (3) How can an appropriate sustainable value chain mapping strategy be developed for optimizing aquaculture downstreaming in Cirebon?

2. Materials and Methods

2.1. Materials

2.1.1. The Concept of Blue Economy in the Fisheries and Aquaculture Sector

The blue economy is recognized as an approach to managing marine resources that combines economic growth with environmental sustainability, encompassing fisheries, marine transportation, coastal tourism, renewable energy, marine biotechnology, and conservation [12]. The aquaculture sector makes an essential contribution to achieving the 2030 SDGs, especially in food security and nutrition [13]. However, ten social justice issues can arise from blue economy growth, including eviction of coastal communities, environmental pollution, destruction of traditional livelihoods, loss of access to marine resources, unfair profit distribution, negative cultural impacts, discrimination against women, human rights violations, and exclusion from decision-making [14].

A critical synthesis is that there is a tension between economic growth and social justice in the implementation of the blue economy. The World Bank emphasizes economic growth optimism [1], while Finkbeiner et al. warns of risks of social exclusion [14]. This research integrates both perspectives by measuring sustainability through a Triple Bottom Line that balances economic and social dimensions.

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2.1.2. Sustainable Value Chains in Aquaculture

Sustainability in the aquaculture value chain has evolved beyond economic profit to encompass environmental and social factors. Research on 57 aquaculture systems worldwide using 88 indicators shows that these three aspects are mutually supportive within global aquaculture, though significant sustainability differences exist between systems [8]. Norwegian aquaculture companies demonstrate a stronger orientation toward environmental and social sustainability than other industries [9]. Five key factors for building resilient seafood supply chains are: diversity in production systems, strong connectivity among actors, robust collaboration, continuous learning, and multi-stakeholder governance [10].

A critical synthesis is that the local context—regulations, markets, culture—strongly determines sustainability levels. Love et al. complemented this by identifying five key resilient supply chain elements: production diversity, stakeholder connectivity, information transparency, system adaptability, and multi-stakeholder collaboration [10]. This study draws on these elements in its analysis.

2.1.3. Downstreaming and Added Value of Fishery Products

Downstream processing of aquaculture products is crucial to increasing added value. Research on aquaculture policies in Singapore and Norway found that feed production and use are the most significant contributors to environmental impact [11]. Studies in The Gambia and Mali provide important lessons about the complexity of the fisheries value chain, underscoring that improving sustainability requires understanding how value chains operate [15]. Certification and eco-labeling studies found that certification schemes can change social and institutional relations in the fisheries industry [16]. A critical synthesis is that differences in approaches reflect the gap between developed [16] and developing country contexts [15]. This research integrates technology as an enabler and participation as a process, in line with FAO's FISH4ACP approach, which is both participatory and technology driven.

2.1.4. Value Chain Mapping and Technology

Value chain mapping in fisheries continues to evolve. A bibliometric analysis of 396 articles found that fisheries assessments have focused too heavily on ecological aspects alone [17]. FAO, through the FISH4ACP program, has developed a comprehensive value chain assessment methodology [3]. A critical synthesis is that mapping methodologies show a shift from eco-centric [17] to holistic, technology-enabled approaches [3]. This research integrates three perspectives: ecological considerations remain significant, socio-economic equity matters, and technology serves as an enabler.

2.1.5. Research Gaps and Opportunities

Key gaps include limited empirical studies of the blue economy at the local level in developing countries; no universal methodology for measuring the sustainability of aquaculture value chains; and insufficient attention to the impact of digital technology on the transformation of fisheries value chains. Future research should focus on developing frameworks that integrate economic, social, and environmental factors and involve local communities directly in the design and implementation of blue economy strategies.

2.1.6. Conceptual Framework

This study proposes an integrated conceptual framework linking three overarching constructs: the blue economy paradigm, sustainable value chain theory, and multi-dimensional sustainability assessment. The blue economy paradigm provides the normative foundation, emphasizing that the utilization of marine resources must balance economic productivity with environmental stewardship and social equity [1, 12, 14]. Sustainable value chain theory provides an analytical lens, drawing on Porter's value chain framework [18], adapted for agri-food contexts, which emphasizes value addition, actor linkages, and governance structures across the production, processing, distribution, and retail stages [10, 15].

The five sustainability dimensions derive from the intersection of these constructs. The economic and social dimensions align with the Triple Bottom Line framework [19] and reflect the core blue economy objectives of growth and equity. The environmental dimension captures ecological stewardship, central to blue economy principles [12]. The technological dimension recognizes digitalization and innovation as critical enablers of value chain upgrading [4, 17]. The institutional dimension addresses governance,

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partnerships, and regulatory frameworks that shape value chain coordination and resilience [10, 14]. These dimensions are examined as interconnected components through correlation analysis, with relative importance assessed through expert-weighted scoring.

2.1.7. Indonesia's Context and Relevance

Indonesia, with its extraordinary potential in the blue economy, can learn from international experience. Best practices from Norway on aquaculture sustainability, along with various value chain mapping methodologies, can be adapted to Indonesia's specific conditions. The challenges identified in the international literature—social justice, environmental sustainability, and economic efficiency—are highly relevant. Research on sustainable value chain mapping in coastal areas, such as Cirebon, is fundamental to equitable and sustainable blue economy development.

2.2. Methods

2.2.1. Research Design

This study uses a mixed methods approach with a sequential explanatory design [20]. The quantitative stage uses structured surveys to measure value chain conditions and sustainability scores, followed by a qualitative stage that uses in-depth interviews and FGDs to provide a richer contextual understanding [21]. Research locations were purposively selected in four coastal sub-districts of Cirebon: Mundu, Losari, Gebang, and Pangenan, based on: (1) significant aquaculture production, (2) diversity of value chain business types, (3) downstream development potential, and (4) representativeness of Cirebon's coastal characteristics.

The analytical methods are sequenced coherently, addressing the three research questions progressively. First, value chain analysis (VCA) maps the existing structure, quantifying value addition and ROI at each stage (RQ1). Second, multi-dimensional sustainability scoring measures status across five dimensions using 42 weighted indicators. Third, multiple regression and Pearson correlation identify which dimensions most significantly influence overall sustainability and how they interrelate (RQ2). Fourth, qualitative interviews and FGDs explain, validate, and contextualize quantitative findings specifically eliciting stakeholder perspectives on why certain dimensions score low and what barriers constrain improvement. Fifth, SWOT analysis synthesizes findings from both stages, and AHP prioritizes strategies through expert judgment (RQ3). This sequential integration ensures that each method builds on the preceding one, with qualitative findings providing interpretive depth rather than functioning as a parallel strand.

2.2.2. Population and Sample

The research population includes all actors in the aquaculture value chain in Cirebon's coastal area. Stratified purposive sampling ensures representation across actor categories and business scales [22]. The sample distribution: farmers (95 people, 50%), processors (38 people, 20%), distributors (32 people, 17%), and retailers (25 people, 13%), reflecting the actual value chain structure. For qualitative data, 20 key informants were purposively selected based on: at least 5 years' experience in the fisheries industry, active value chain role, and in-depth local knowledge. Data saturation was achieved after the 15th interview, but interviews continued to 20 informants for validation [23].

2.2.3. Data Collection

Primary data were collected through three methods: (1) a structured questionnaire on a Likert scale of 1–5 measuring sustainability across five dimensions with 42 indicators; (2) in-depth interviews with 20 key informants using semi-structured guidelines covering operational aspects, economic performance, challenges, and expectations (60–90 minutes each, recorded with consent); and (3) four FGD sessions, each in one sub-district, with 8–12 participants representing various stakeholders. Secondary data from BPS, Marine and Fisheries Service, Department of Industry and Trade, scientific publications, and policy documents. Instrument validity was assessed through content validity with 5 experts, and trials with 30 respondents yielded Cronbach's Alpha of 0.87 (>0.70).

The 42 indicators are distributed as follows. Economic (10 indicators): profitability margins, ROI, capital access, market diversity, price stability, cost efficiency, income growth trend, revenue per unit production, value addition ratio, and economic resilience to shocks. Social (8 indicators): community participation, employment creation, income equity, gender

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inclusion in decision-making, skill development access, health and safety conditions, social cohesion, and welfare improvement. Environmental (9 indicators): water quality compliance (BOD/COD), adoption of waste treatment, feed conversion efficiency, biodiversity impacts, land-use sustainability, energy efficiency, pollution control, conservation practices, and climate adaptation. Technological (7 indicators): modern technology adoption, digital information system usage, traceability implementation, IoT monitoring, cold chain availability, processing technology sophistication, and quality control instrumentation. Institutional (8 indicators): organizational membership and activeness, formal partnership contracts, cooperative governance quality, regulatory compliance, coordination among actors, government support access, certification attainment, and stakeholder forum participation. Each indicator is scored 1–5; dimensional scores are calculated as the arithmetic means of constituent indicators.

2.2.4. Data Analysis

Quantitative data analysis uses several sequential methods. Value Chain Analysis calculates added value and ROI at each stage using Porter's value chain framework [18]. Added value is calculated as the difference between the output value and the input cost, while ROI is the ratio between profit and total investment. Multiple Regression Analysis identifies factors influencing sustainability. To avoid circularity between the dependent variable and its predictors, the regression model uses a stakeholder-assessed overall sustainability perception (Y) as the dependent variable, collected through a separate global assessment item in the questionnaire, rather than computing Y as the arithmetic composite of X1–X5. The model: $Y = \beta 0 + \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4 + \beta 5X5 + \varepsilon$, where X1–X5 are the five-dimensional sustainability scores, and ε is the error term. This specification allows the regression to test which dimensions most strongly predict actors' overall sustainability perception without tautological construction. Pearson Correlation Analysis measures interdimensional relationships: 0.00–0.19 (very weak), 0.20–0.39 (weak), 0.40–0.59 (moderate), 0.60–0.79 (strong), 0.80–1.00 (very strong).

Sustainability Dimension Weighting: The sustainability score is calculated as a weighted average of five dimensions, with weights determined through a structured expert judgment process using the Delphi method. A panel of 10 experts was purposively selected: 3 marine science academics, 3 fisheries industry practitioners, 2 government officials from the Marine and Fisheries Service, and 2 blue economy policy specialists. In the first round, experts independently allocated percentage weights with written justification; in the second round, aggregated results were shared, and experts refined allocations. Final consensus weights: economics (25%), social (20%), environmental (20%), technological (20%), institutional (15%). Economics received the highest weight, as experts consistently identified profitability and market access as the primary determinants of viability. Institutional received the lowest as it operates more as an enabling condition in the Cirebon context. Categories: <2.0 (Not Sustainable), 2.0–2.49 (Quite Sustainable–Low), 2.5–3.0 (Quite Sustainable–High), >3.0 (Sustainable).

Qualitative Data Analysis and Integration: Qualitative data from interviews and FGDs were analyzed using thematic content analysis with stages: (1) verbatim transcription, (2) thematic coding using NVivo 12, (3) categorization of themes, (4) interpretation and synthesis. Data triangulation compared findings across questionnaires, interviews, FGDs, and secondary data [19]. The qualitative findings serve three specific integrative functions: (a) explaining reasons behind low-scoring sustainability indicators, (b) validating quantitative patterns through stakeholder narratives, and (c) identifying contextual factors not captured by the survey instrument (e.g., informal power dynamics, cultural barriers to institutional participation).SWOT-AHP Strategic Analysis: The strategy is formulated using SWOT analysis, identifying Strengths, Weaknesses, Opportunities, and Threats [24]. Strategy priorities are determined using the AHP, involving 15 experts (5 academics, 5 practitioners, and 5 policymakers). The AHP process: (1) experts individually completed pairwise comparison matrices on Saaty's 1–9 scale; (2) individual matrices were aggregated using the geometric mean method; (3) priority vectors computed using the eigenvector method; (4) consistency verified through the Consistency

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Ratio (CR<0.10); (5) final priority weights derived from the aggregated matrix using Expert Choice 11 software.

3. Result

3.1. Existing Value Chain Conditions

Value chain analysis shows the structure of four main stages: production (farmers), processing, distribution, and retail, with unequal value-added distribution. Processing made the highest contribution (42.4%), followed by distribution (27.3%), production (24.2%), and retail (6.1%). Farmers, as primary producers, have a weak bargaining position, with an average ROI of only 16%, while distributors reach 34% and processors reach 24%. Table 1 and Figure 1 show the distribution.

Table 1. Aquaculture Value Chain Data

Stages of the Value Chain	Added Value (%)	ROI (%)	Number of Perpetrators
Production (Farmers)	24.2	16	95
Processing	42.4	24	38
Distribution	27.3	34	32
Retail	6.1	18	25

At the production stage, the average farm size is 0.8 ha with production of 2.4 tons/ha/season. Production costs are dominated by feed (48%), fry (22%), and labor (18%). Average selling prices are Rp 32,000/kg for milkfish and Rp 45,000/kg for tilapia, with profit margins of 18–22% and a harvest period of 4–5 months. Key challenges include feed price fluctuations, quality fry availability, climate change, and limited direct market access.

At the processing stage, 38 units operate with an average capacity of 500 kg/day, producing salted fish (45%), frozen fillets (28%), fish crackers (15%), and fermented products (12%). Added value reaches 42.4% through cleaning, cutting, salting, packaging, and storage. Technology remains relatively simple; only 23% have HACCP certification. At the distribution stage, 32 distributors cover local markets (45%), West Java (38%), and outside Java (17%). Traditional collector patterns dominate; only 13% use digital traceability, and cold chain coverage is minimal (18%), causing 15–20% post-harvest losses. The distribution margin is 27.3%, with an ROI of 34%. Retail comprises traditional markets (68%), modern stores (22%), and online (10%); consumer prices are IDR 55,000–65,000/kg (fresh) and IDR 70,000–95,000/kg (processed).

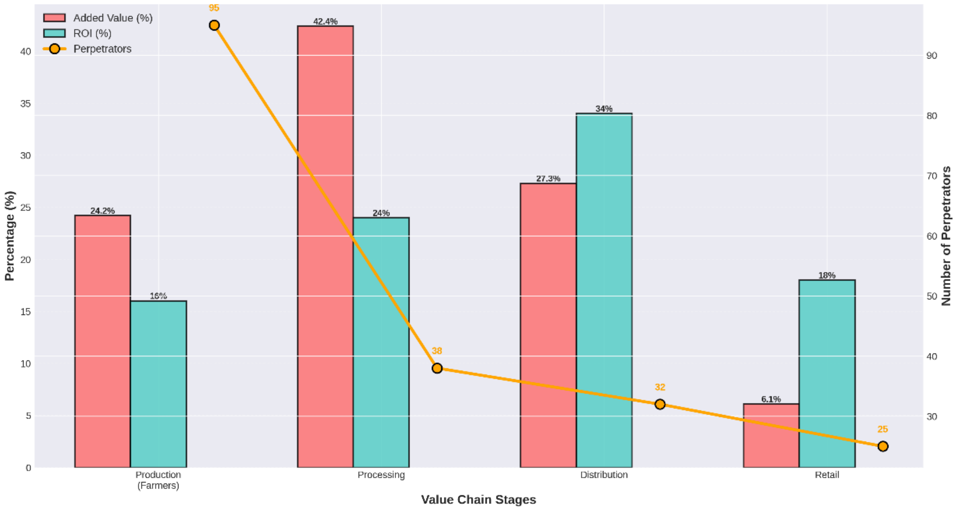

Figure 1. Aquaculture Value Chain: Comprehensive Overview

The concentration of value addition at the processing stage (42.4%) and the low share captured by farmers (24.2%) reveal a structural bargaining asymmetry rooted in several interconnected factors. Qualitative interviews illuminate the mechanisms behind this imbalance. Farmers typically lack storage facilities and must sell immediately, reducing

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negotiating leverage. Processors control access to preservation technology, market channels, and quality certification—all of which confer pricing power. Spot-market transactions dominate (72% of farmer sales), and farmers lack knowledge of downstream prices while processors possess more complete market intelligence. Only 28% of farmers have formal contracts. These findings extend Nurdin et al.'s [25] observations on power asymmetries in tuna value chains, highlighting how technology deficits and information asymmetries specifically reinforce bargaining disadvantages at the production stage.

3.2. Sustainability Factors

The overall sustainability score was 2.67 in the Quite Sustainable (High) category. Social achieved the highest score (3.12), indicating high community participation and positive welfare impact. The technological dimension scored lowest (2.23), indicating low adoption of modern technology and digital systems. Table 2 and Figure 2 show scores by dimension.

Table 2. Sustainability Score by Dimension

Dimensions	Score	Category	Weight (%)
Economy	2.54	Quite Sustainable	25
Social	3.12	Sustainable	20
Environment	2.48	Quite Sustainable	20
Technology	2.23	Quite Sustainable	20
Institutional	2.98	Quite Sustainable	15
Average	2.67	Quite Sustainable	100

The economic dimension (2.54) showed strong profitability but constrained capital access: 62% of respondents reported difficulty accessing banking credit due to inadequate collateral. The social dimension (3.12) recorded the best achievements: community participation in fisheries (84%), job creation (78%), and income improvement (72%), though a gender gap persists with only 34% women in decision-making. The environmental dimension (2.48) shows concerning conditions: declining water quality at some sites, with BOD and COD exceeding standards, and only 38% of farmers implementing adequate waste treatment. Pollution from organic waste and feed residues is the main problem. The technological dimension (2.23) recorded the lowest scores: modern technology adoption (23%), information system use (33%), and traceability application (13%).

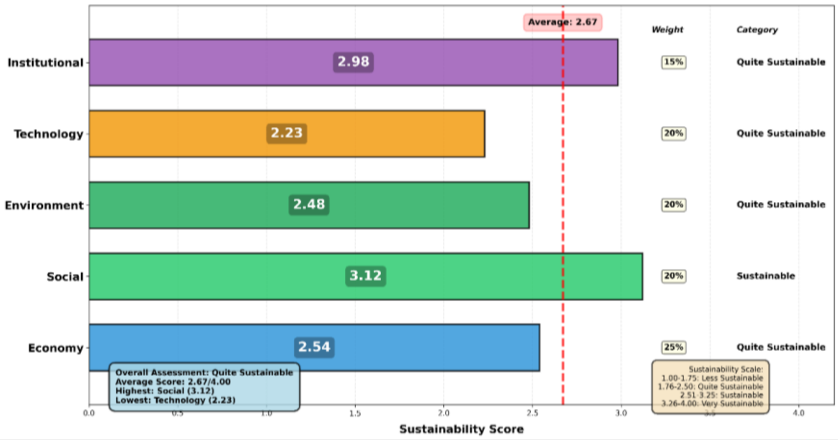

Figure 2. Sustainability Assessment by Dimension

The institutional dimension (2.98) shows a relatively strong organizational presence but limited effectiveness: only 42% of organizations actively carry out routine activities, and formal partnerships account for 28%. Qualitative findings reveal four underlying factors: (1) cooperatives lack professional management capacity in accounting, marketing, and governance; (2) trust deficits between upstream and downstream actors constrain partnership formation farmers expressed skepticism about whether contracts genuinely protect their

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interests, while processors cited supply reliability concerns; (3) fragmented government coordination across agencies (Marine and Fisheries Service, Department of Industry and Trade, local government) creates inconsistent policy implementation; (4) information asymmetries reduce collective bargaining effectiveness even within cooperatives. Government support in training, mentoring, and market facilitation remains suboptimal and insufficiently targeted to these specific constraints.

Table 3. Correlation Matrix Between Dimensions of Sustainability

Dimensions	Economy	Social	Environment	Technology	Institutional
Economy	1.000	0.523	0.412	0.675	0.487
Social	0.523	1.000	0.456	0.398	0.534
Environment	0.412	0.456	1.000	0.367	0.423
Technology	0.675	0.398	0.367	1.000	0.445
Institutional	0.487	0.534	0.423	0.445	1.000

Multiple regression analysis identified five factors influencing sustainability perception: $Y = 0.342 + 0.278X1 + 0.245X2 + 0.156X3 + 0.198X4 + 0.189X5$ ($R^2 = 0.742$, $p < 0.001$). Technology is the most dominant factor ($\beta=0.278$, $p<0.001$), followed by economic ($\beta=0.245$, $p<0.001$), institutional ($\beta=0.198$, $p<0.01$), social ($\beta=0.189$, $p<0.01$), and environmental ($\beta=0.156$, $p<0.05$). The strongest correlation: economic-technological ($r=0.675$, $p<0.001$), indicating that technology investment directly improves economic performance. Strong correlations also exist between social-institutional ($r=0.534$, $p<0.001$) and social-environmental ($r=0.456$, $p<0.001$) dimensions. Table 3 and Figure 3 present the correlation matrix.

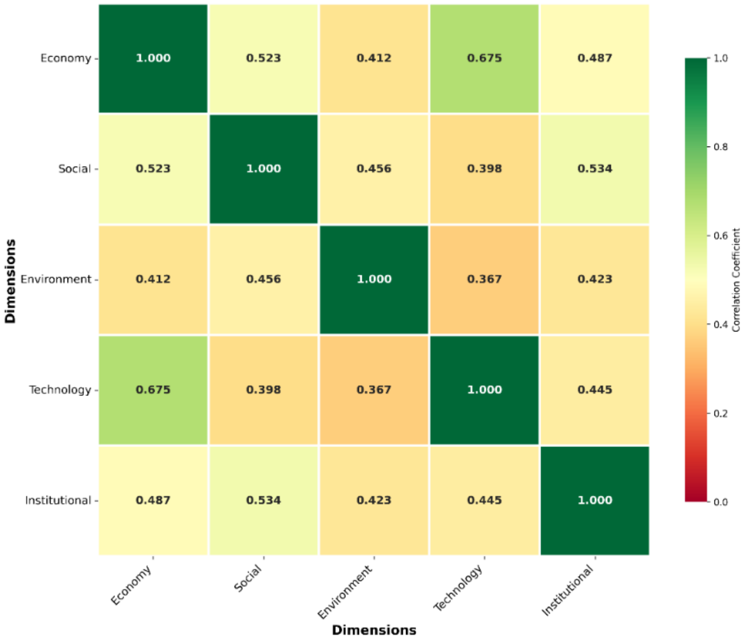

Figure 3. Correlation Matrix Between Dimensions of Sustainability

3.3. Sustainable Value Chain Mapping Strategy

Based on SWOT and AHP analysis involving 15 experts, five priority strategies were formulated. The aggregated consistency ratio was 0.067 (<0.10), confirming acceptable judgment consistency. Key strengths: abundant fishery resources, local government support, and community aquaculture experience. Key weaknesses: limited technology adoption, constrained access to capital, and minimal cold chain infrastructure. Key opportunities: high market demand, national blue economy policies, and digital technology development. Key threats: climate change, competition from imported products, and fluctuations in feed prices. Table 4 and Figure 4 show the strategy priorities.

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Table 4. Priorities of Sustainable Value Chain Mapping Strategies

Priorities	Strategy	AHP Weight	Score
1	Development of Integrated Fisheries Industry Cluster	0.312	5
2	Development of Digital Traceability System	0.245	4
3	Institutional Strengthening of Cooperatives and Partnerships	0.198	3
4	Diversification of High-Value Processed Products	0.156	2
5	Cold Chain Infrastructure Development	0.089	1

Strategy 1: Integrated Fisheries Industry Cluster (0.312). Creating a mutually supportive business ecosystem combining production, processing, and distribution within a single estate to improve logistics efficiency, facilitate technology transfer, and strengthen actor linkages. Indicative components include aquaculture production zones with recirculating aquaculture systems (RAS), modern processing facilities, cold-storage distribution zones, and supporting facilities (quality control laboratories, R&D centers, and training facilities). Based on preliminary estimates from comparable cluster developments and stakeholder consultation, the indicative investment is approximately IDR 125 billion under a Public-Private Partnership, with target outcomes of a 35% increase in value addition and the creation of 500 jobs over 3 years. These projections are indicative and require validation through a detailed feasibility study.

Strategy 2: Digital Traceability System (0.245). Implementing blockchain and IoT technologies for value chain transparency: product QR codes with complete information from farmers to consumers, integrated digital platforms, IoT sensors for real-time monitoring of water quality, feed, and storage conditions, and mobile applications. This would facilitate export market access requiring sustainability certification and reduce information asymmetry. Indicative investment is approximately IDR 15 billion, with projected selling price increases of 15–20% for certified products, based on comparable Southeast Asian implementations.

Score: 5 = Highest Priority (Priority 1), 1 = Lowest Priority (Priority 5)

Figure 4. Priority Strategy for Sustainable Value Chain Mapping

Strategy 3: Institutional Strengthening of Cooperatives and Partnerships (0.198). Strengthening collective bargaining through cooperative revitalization: capacity-building in management, accounting, and marketing; facilitating capital access through subsidized business loans; developing protective partnership contracts; and establishing a Fisheries Value Chain Forum for coordination. The nucleus-plasma model can be adapted by processors that provide market guarantees, production inputs, and technical guidance to

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plasma farmers.

Strategy 4: Diversification of High-Value Processed Products (0.156). Developing high-added-value derivative products: surimi, fish gelatin for pharmaceutical and cosmetic industries, omega-3 supplements with export potential, and ready-to-eat products (fish burgers, nuggets, sausages). This requires R&D collaboration with universities, food safety certification (BPOM, Halal MUI), attractive branding and packaging, and market penetration through e-commerce and modern retail.

Strategy 5: Cold Chain Infrastructure Development (0.089). Building an integrated cold chain system to reduce post-harvest losses from 15–20% to below 5%: cold storage at production sites, refrigerated trucks for transportation, cold distribution centers, and blast freezer facilities for quick freezing. Funding is proposed through a Public-Private Partnership scheme with government and private components.

4. Discussion

4.1. Value Chain Structure and Efficiency Analysis

Cirebon's aquaculture value chain exhibits highly uneven value distribution, mirroring observations by Silva et al. (2022) regarding developing economies [11] and Nurdin et al. (2024) on power asymmetries [25]. Beyond describing this distribution, the asymmetry persists because processors control three critical resources: preservation technology, market access, and quality certification. Farmers operating at an average of 0.8 ha lack volume to justify individual investment, creating a structural dependency that spot-market transactions reinforce rather than mitigate. The 28% formal contract rate indicates insufficient governance mechanisms for equitable value redistribution. Addressing this requires not merely improving farmer productivity but restructuring the institutional and informational architecture of the chain, consistent with value chain governance theory [18] and developing country evidence [15, 25].

4.2. Multidimensional Sustainability Assessment

The 2.67 overall score leaves substantial room for improvement. Social sustainability scored highest (3.12), likely reflecting the strong community bonds typical of Indonesia's coastal zones—mutual support networks, collective decision-making, and dense social ties documented by Brugere et al. (2019) [26]. This social capital already exists to support development strategies requiring cooperation.

The low technology score (2.23) warrants deeper interpretation. Qualitative interviews revealed three interconnected barriers: (1) a financial barrier—upfront costs of digital systems, IoT monitoring, and traceability infrastructure exceed small-scale actors' investment capacity, with no appropriate financing instruments available; (2) a capability barrier—many actors, particularly older farmers, lack digital literacy, and available training programs insufficiently address this gap; (3) a perceived relevance barrier—actors selling predominantly into local traditional markets see limited return on technology investments since buyers do not require traceability or digital documentation. These findings suggest that technology adoption must be bundled with financing mechanisms, capacity-building, and market-access interventions to be effective.

While the institutional dimension (2.98) appears relatively favorable, the underlying data reveals concerning patterns. The 42% active organization rate and 28% formal partnership rate indicate largely nominal rather than functional institutions. Governance constraints include fragmented regulatory authority across agencies, inconsistent enforcement of quality standards, and limited government capacity for sustained extension services. The social-institutional correlation (r=0.534) suggests that strengthening governance could leverage existing social capital, but only if reforms address the specific trust deficits and coordination failures identified in the qualitative analysis.

4.3. Strategic Priorities and Implementation Pathways

The integrated cluster's top ranking (0.312) reflects current blue economy thinking, stressing collaboration and connectivity over isolated efforts. Love et al. (2023) identified several cluster value-creation mechanisms: knowledge transfer is more readily facilitated when firms operate in proximity, shared infrastructure becomes economically viable, and collective bargaining power increases substantially [10]. Cirebon's existing geographic concentration and

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actor networks, though imperfect, provide favorable preconditions for this strategy.

4.4. Research Implications and Contributions

Theoretical Contributions: This research contributes a framework integrating five interconnected sustainability dimensions for blue economy contexts, revealing synergistic dynamics missed by single-dimension analyses. The comprehensive approach shows these dimensions influence each other in ways that create synergies visible only through integrated examination. Practical Implications: Sustainable aquaculture development requires coordinated intervention across multiple dimensions simultaneously, not narrow programs addressing isolated problems. The strategic framework offers evidence-based priorities: cluster development, digital systems, and institutional capacity building emerge from examining where constraints are most significant and efforts most likely to produce results.

4.5. Limitations and Future Research Directions

Several limitations should be acknowledged. First, this cross-sectional study constrains causal inference associations between sustainability factors cannot be interpreted as causal without longitudinal evidence. Second, geographic scope is limited to four Cirebon sub-districts; replication in other coastal regions would strengthen external validity. Third, sustainability scoring relies on self-reported perceptions, which may be subject to response bias, though triangulation mitigates this concern. Fourth, expert-derived dimension weights are context-specific and may not apply universally.

Future research should pursue longitudinal designs to track intervention effects, comparative studies across multiple coastal regions to assess the transferability of the framework, objective sustainability metrics alongside perception-based measures, and investigations of the causal mechanisms underlying the economic-technology nexus.

4.6. Synthesis

A comprehensive assessment reveals that Cirebon’s aquaculture value chain is paradoxically positioned. Real potential exists: deep social capital, reasonable market access, and generational production knowledge. Yet the sector faces substantial obstacles—structural inefficiencies and significant technology gaps. The 2.67 score reflects this tension. Social aspects (3.12) indicate strong community foundations; technology (2.23) signals a critical weakness. This pattern suggests targeted interventions could drive significant improvements precisely because social infrastructure exists to support adoption and implementation.

5. Conclusions

Empirical Findings. The existing conditions show an unequal distribution of value added, with processing contributing 42.4% while farmers receive only 24.2%, reflecting weak bargaining positions and suboptimal coordination. Technology gaps and weak cold chain infrastructure result in 15–20% losses and limit access to the premium market. The overall sustainability score of 2.67 (Quite Sustainable) shows considerable variation: social scores highest (3.12) and technology lowest (2.23). Technology is the most influential factor ($\beta=0.278$) and shows the strongest interdimensional correlation with the economic dimension ($r=0.675$), confirming that technology investment directly enhances economic performance.

Practical Implications. Sustainable aquaculture development in Cirebon requires coordinated, multi-dimensional interventions rather than isolated sectoral programs. The strong economic-technology correlation implies that technology investment should be bundled with market access and financing mechanisms. Institutional weaknesses, particularly low formal partnership rates and limited organizational effectiveness represent critical enabling conditions that must be addressed alongside technical interventions.

Policy Recommendations. Five priority strategies, with integrated industrial cluster development as the top priority, are proposed to optimize downstreaming in aquaculture. These complementary strategies are mutually reinforcing successful cluster implementation would facilitate the adoption of traceability, strengthen institutions, encourage product diversification, and justify investment in the cold chain. This aligns with blue economy principles, integrating economic growth, social well-being, and environmental sustainability. Investment figures and targets are indicative and require

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validation through detailed feasibility studies.

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