International Journal of Sustainable Development and Planning
Vol. 21, No. 6, June, 2026, pp. 2735-2747
Journal homepage: http://iieta.org/journals/ijsdp

Sustainability Without Society? Evidence of Social Failure in Intensive Shrimp Aquaculture Systems

Aryani Rahmawati[1], Asep Awaludin Prihanto[2], Moh Khusaini[3], Anthon Efani[4*], Reny Tiarantika[1], Nur Aini Wahyuningsih[5]

[1] Department of Environmental Science, Graduate School, Universitas Brawijaya, Malang 65145, Indonesia
[2] Department of Fish Processing Technology, Faculty of Fisheries and Marine Science, Universitas Brawijaya, Malang 65145, Indonesia
[3] Department of Economics, Faculty of Economics and Business, Universitas Brawijaya, Malang 65145, Indonesia
[4] Department of Socio-Economic Fisheries and Marine Science, Faculty of Fisheries and Marine Science, Universitas Brawijaya, Malang 65145, Indonesia
[5] Program of Environmental Resource Management and Development, Graduate Program, University of Brawijaya, Malang 65145, Indonesia

Corresponding Author Email: anthonefani@ub.ac.id

https://doi.org/10.18280/ijsdp.210629

Received: 4 April 2026
Revised: 20 May 2026
Accepted: 27 May 2026
Available online: 30 June 2026

Keywords:
aquaculture sustainability, intensive shrimp farming, Multidimensional Scaling, social sustainability, Aquaculture Stewardship Council, coastal communities

ABSTRACT

This study aims to assess the sustainability of intensive shrimp aquaculture systems and identify structural imbalances across sustainability dimensions. A case study was conducted in Lombok, West Nusa Tenggara, Indonesia, using a quantitative–descriptive approach. Sustainability was evaluated through a multidimensional framework integrating environmental, economic, social, and technological–institutional dimensions. The analysis employed Multidimensional Scaling (MDS) using the Rapid Appraisal for Fisheries (RAPFISH) approach, complemented by Monte Carlo simulation and leverage analysis to ensure model robustness and identify sensitive attributes. The results indicate that the overall sustainability status is categorized as moderately sustainable, with an index value of 63.13. However, a significant disparity exists across dimensions. The technological–institutional, economic, and environmental dimensions show relatively strong performance, while the social dimension remains less sustainable with the lowest index score. Monte Carlo results confirm the stability of the model, with differences below 5%. Key sensitive attributes include mangrove habitat capacity, biosecurity management, community participation, and capacity building. The findings highlight that sustainability in intensive aquaculture systems is structurally imbalanced, where strong technical and economic performance is not accompanied by adequate social inclusion. This study implies the need for integrating participatory approaches and strengthening social dimensions to achieve comprehensive sustainability.

1. INTRODUCTION

Sustainability has become a central paradigm in global aquaculture development, driven by increasing demands for environmentally responsible production, economic viability, and social equity [1]. Intensive shrimp aquaculture, as one of the fastest-growing sectors in global food systems, is often portrayed as a success story of technological advancement and economic productivity [2-4]. However, this narrative frequently masks a critical question: can aquaculture systems truly be considered sustainable when social dimensions are neglected?

Existing sustainability frameworks emphasize the integration of environmental, economic, and social pillars as an indivisible foundation of sustainable development. In practice, however, aquaculture systems tend to prioritize biophysical efficiency and financial performance, often at the expense of social inclusivity [5]. Technological intensification has enabled higher survival rates (SR), improved feed efficiency, and increased profitability, yet these gains do not necessarily translate into equitable benefits for surrounding communities [6, 7]. This imbalance raises concerns about the legitimacy of sustainability claims in intensive aquaculture systems. This situation raises the possibility of structural breakdown, where the system appears sustainable based on aggregate indicators but still harbors significant social vulnerabilities.

Recent global certification schemes, such as the Aquaculture Stewardship Council (ASC), explicitly require compliance across all sustainability dimensions, with particular emphasis on community engagement, labor rights, and social accountability [8]. Unlike traditional assessments that allow trade-offs between dimensions, these standards adopt a non-compensatory approach, where failure in one dimension, especially the social dimension, can invalidate overall sustainability status. Consequently, the neglect of social aspects is not merely a secondary issue but represents a fundamental barrier to achieving globally recognized sustainability.

Despite the growing body of literature on aquaculture sustainability, empirical studies that systematically reveal structural imbalances across sustainability dimensions remain limited. Most assessments [9-11] focus either on environmental impacts or economic performance, while the social dimension is often underexplored or treated superficially [12]. In addition, there remains a lack of robust analytical approaches that integrate multidimensional evaluation with statistical validation to assess the stability and reliability of sustainability outcomes. Previous studies employing the RAP-BWAC approach have also demonstrated that the social dimension frequently represents the lowest-scoring component in aquaculture sustainability assessments in Indonesia [12]. However, most of these studies have continued to position the social dimension merely as a general assessment indicator, without explicitly examining how aggregate sustainability scores may obscure underlying structural social inequalities within large-scale corporate intensive aquaculture systems.

Furthermore, studies linking multidimensional sustainability evaluation outcomes with probable ASC-related sustainability gaps remain limited, particularly within the context of intensive shrimp aquaculture in Indonesia. As a result, an analytical gap persists between the achievement of aggregate sustainability indices and the social-institutional readiness of aquaculture systems to comply with global sustainability principles that are inherently non-compensatory. From this perspective, strong performance in the economic or technological dimensions does not automatically compensate for weaknesses in the social dimension.

To address these gaps, this study employs a Multidimensional Scaling (MDS) approach using the Rapid Appraisal for Fisheries (RAPFISH) framework, complemented by Monte Carlo simulation, to evaluate the sustainability status of intensive shrimp aquaculture systems across environmental, economic, social, and technological–institutional dimensions. This approach not only quantifies sustainability performance but also identifies sensitive attributes that exert the greatest influence on system sustainability. More importantly, it allows for the detection of structural disparities that are often overlooked in conventional assessments.

The findings of this study reveal a paradoxical condition in which strong economic and technological performance coexist with significant social failure [12-14]. While environmental management and production efficiency demonstrate relatively stable performance, the social dimension emerges as a critical weakness, characterized by limited community participation, inadequate capacity building, and minimal social responsibility initiatives [15-17]. This imbalance challenges the dominant assumption that improvements in technology and profitability inherently lead to holistic sustainability. This condition does not directly indicate a failure of ASC certification, but indicates the possibility of a relative gap in the sustainability criteria related to ASC, especially in the aspects of social engagement and participatory governance.

This study evaluates the sustainability performance of intensive shrimp aquaculture operations in Lombok, Indonesia, using a multidimensional RAPFISH-MDS framework that integrates environmental, economic, social, and technological-institutional dimensions. Unlike previous studies that primarily emphasised aggregate sustainability scores, this study specifically investigates structural imbalances across sustainability dimensions and examines their potential implications in relation to ASC-related sustainability expectations. While earlier Indonesian aquaculture studies similarly identified social sustainability as a vulnerable dimension, this study contributes by contextualising these findings within the setting of corporate-intensive shrimp farming and linking multidimensional sustainability outcomes to internationally recognised sustainability governance discourses.

2. THEORETICAL FRAMEWORK

Sustainability in aquaculture has evolved from a normative concept into a multidimensional analytical framework that integrates environmental integrity, economic viability, and social equity [18, 19]. Recent developments further extend this framework by incorporating technological and institutional dimensions as enabling factors that shape the effectiveness of sustainability implementation. However, a critical theoretical debate persists regarding the nature of relationships among these dimensions: whether they are substitutable or non-substitutable [12, 20]. In contemporary sustainability discourse, particularly within global certification systems such as the ASC, sustainability is increasingly conceptualized as non-substitutable, meaning that strong performance in one dimension cannot compensate for failure in another [8]. This perspective is important in understanding that economic and technological success in aquaculture does not necessarily reflect holistic sustainability if the social dimension still shows structural weaknesses.

Within this context, the political economy of aquaculture provides a critical lens to understand the structural imbalances embedded in intensive production systems. While technological intensification enhances productivity, efficiency, and profitability, it often simultaneously produces unintended social consequences, including marginalization of local communities, unequal distribution of benefits, and limited participation in decision-making processes [21, 22]. This phenomenon reflects a broader pattern of growth without equity, where economic gains do not necessarily translate into social well-being. As a result, social sustainability emerges not merely as a complementary dimension but as a critical indicator of whether development outcomes are inclusive and just.

The importance of the social dimension is further reinforced by the concept of Social License to Operate (SLO) and Legitimacy Theory. SLO refers to the level of acceptance or approval granted by local communities to industrial activities, which is essential for ensuring long-term operational stability [23, 24]. From the perspective of Legitimacy Theory, organizations are required to align their practices with societal norms, values, and expectations. Failure to address social concerns, such as inadequate community engagement, weak corporate social responsibility (CSR), and lack of capacity building, can result in a legitimacy gap that threatens both the continuity and credibility of operations [24]. Failure to build social legitimacy can create sustainability vulnerabilities, even when the system exhibits relatively high economic and technological performance.

Given the complexity of sustainability as a system of interdependent dimensions, robust analytical approaches are required to capture its multidimensional nature. The application of MDS through the RAPFISH framework provides a systematic method to evaluate sustainability across multiple dimensions simultaneously, while identifying sensitive attributes that exert significant leverage on system performance [25, 26]. The integration of Monte Carlo simulation further enhances analytical rigor by testing the stability and reliability of the results under conditions of uncertainty. This methodological approach aligns with systems thinking, which views sustainability as a dynamic and non-linear interaction among ecological, economic, social, and institutional variables.

Building upon these theoretical foundations (Figure 1), this study advances a conceptual proposition that sustainability without social inclusion represents a structurally flawed condition. In intensive shrimp aquaculture systems, high performance in environmental management, economic productivity, and technological capacity may create an appearance of sustainability; however, the absence of meaningful social integration manifested in low community participation, limited knowledge transfer, and weak social responsibility reveals a condition of *pseudo-sustainability*. Therefore, the social dimension is positioned as a central determinant that validates or invalidates sustainability claims. This integrated framework provides the basis for analyzing sustainability not only as a measurable outcome but also as a reflection of structural balance within the system, thereby offering a more critical and comprehensive understanding of sustainability in aquaculture.

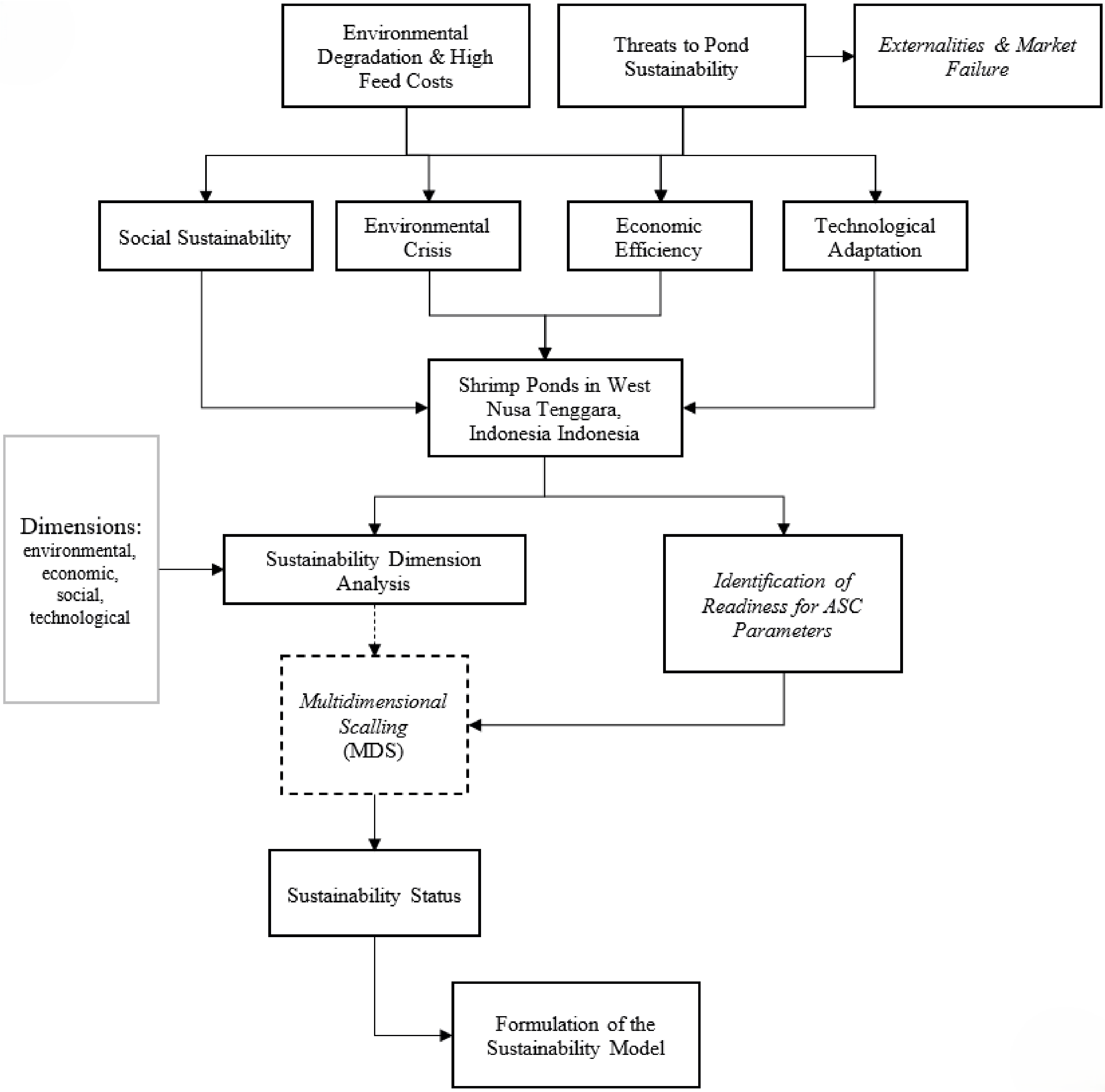


Figure 1. Theoretical framework

3. RESEARCH METHOD

This study employs a quantitative–descriptive approach to assess the sustainability of intensive shrimp aquaculture systems using a multidimensional framework. A case study design is applied to capture the complexity and context-specific characteristics of aquaculture practices in coastal areas.

3.1 Study area and data collection

The research was conducted in PT. Sumber Agromina Jaya, Lombok Island, West Nusa Tenggara, Indonesia (Figure 2), one of the major aquaculture production centers in the country. The province is recognized for its significant contribution to national shrimp production and its rapidly expanding aquaculture sector, particularly intensive shrimp farming systems [27]. Lombok represents a strategic case study due to its dual characteristics as both a high-productivity aquaculture region and a socially complex coastal system, where fisheries and aquaculture serve as primary livelihoods for local communities. This makes it an ideal setting to examine the interaction between economic performance, technological intensification, and social sustainability.

Data collection involved both primary and secondary sources. Primary data were obtained through structured interviews, expert judgment, and field observations involving key stakeholders, including farm managers, technical staff, and local community representatives. Secondary data were collected from institutional reports, scientific publications, and policy documents related to aquaculture development in the region.

A purposive sampling technique was used to select respondents with relevant expertise and experience in shrimp aquaculture management [28, 29]. Expert-based scoring was employed to evaluate qualitative sustainability attributes that are not directly measurable. The expert panel consisted of 12 specialists, including fisheries and environmental academics (4 experts), bureaucrats from the Marine and Fisheries Agency/local government institutions (3 experts), top management representatives of PT. Sumber Agromina Jaya (3 experts), and representatives from environmental non-governmental organizations (NGOs)/certification auditors (2 experts). This cross-sectoral composition was intentionally designed to minimize sectoral bias, thereby ensuring that the weighting assessment of MDS attributes remained objective and comprehensive. All expert respondents (100%) possessed more than 10 years of experience interacting with the aquaculture industry or coastal governance systems. This provides strong legitimacy that the determination of sustainability status was grounded in highly mature and valid expert judgment.

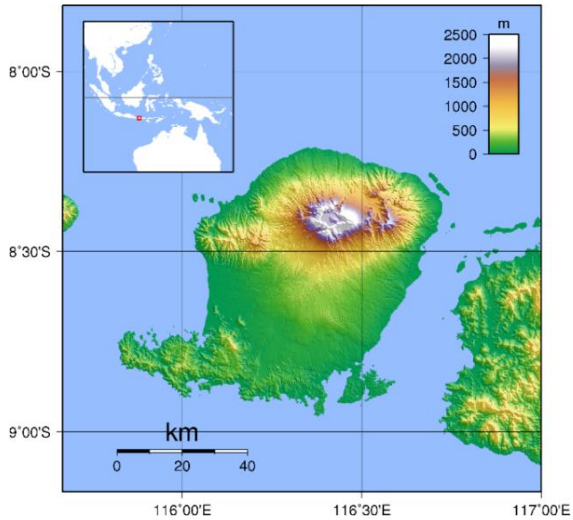


Figure 2. Research location

3.2 Sustainability assessment framework

The sustainability assessment was conducted using the RAPFISH framework, which applies MDS to evaluate system performance across multiple dimensions. The analysis includes four key dimensions: environmental, economic, social, technological and institutional (Table 1). Each dimension is represented by a set of attributes derived from field conditions, sustainability standards, and relevant literature. Scoring was conducted using an ordinal scale based on expert judgment.

Table 1. Research attributes

No.	Dimension	Attributes	Remarks	Source
1.	Ecology	1. Water Quality Management	Monitoring key parameters: pH, DO, ammonia, nitrite	[3, 30-33]
		2. Responsible Land Use	Compliance with RTRW and no conversion of critical habitats such as mangroves	
		3. Application of Biosecurity	Disease prevention, control, and containment protocols	
2.	Economy	1. Feed Conversion Ratio (FCR)	Biological and economic efficiency of feed use for production efficiency	
		2. Survival Rate (SR)	Percentage of shrimp that survive until harvest for production efficiency	
		3. Business Profitability	Investment feasibility analysis: (R/C Ratio)	
3.	Social	1. Community Participantion	Transparent communication mechanisms and prioritization of local workforce	
		2. Knowledge and Skill	Knowledge and skill of ponds, water quality, diseases, feed	
		3. Corporate Social Responsibility (CSR)	Structured contribution programs for local welfare	
4.	Technology–Institutional	1. Group Activity (Waste Management)	Integration of Local Institutions and Waste Management	
		2. Infrastructure	Application of systems such as RAS, Biofloc, or modern intensive ponds. Use of IoT sensors, automatic feeders, and real-time data analysis	
		3. Business Legality	Fulfillment of government regulations related to spatial planning, environment, and licensing	

3.3 Scoring protocol and expert

Sustainability attributes were assessed using an ordinal scale ranging from 0 to 3, where lower scores represented unsustainable conditions and higher scores indicated more sustainable conditions. The assessment was conducted using a scoring sheet developed based on the RAPFISH literature, aquaculture sustainability indicators, and the general principles embedded in the ASC standards. To ensure scoring consistency, all expert panel members were provided with the same assessment guidelines prior to the scoring process. In cases where substantial discrepancies occurred among evaluators, panel discussions were conducted to achieve a final consensus. This approach was applied to minimize subjective bias in the evaluation of qualitative attributes.

In the RAPFISH analysis, the GOOD and BAD reference points were used as ordination anchors to represent hypothetically the best and worst sustainability conditions, respectively. The UP and DOWN settings followed the standard RAPFISH procedure to maintain the stability of multidimensional ordination and to enable normalization of the sustainability index within a 0–100 scale range. The index was categorized into four levels: 0–25 (unsustainable), 26–50 (less sustainable), 51–75 (moderately sustainable), and 76–100 (highly sustainable) [34-36].

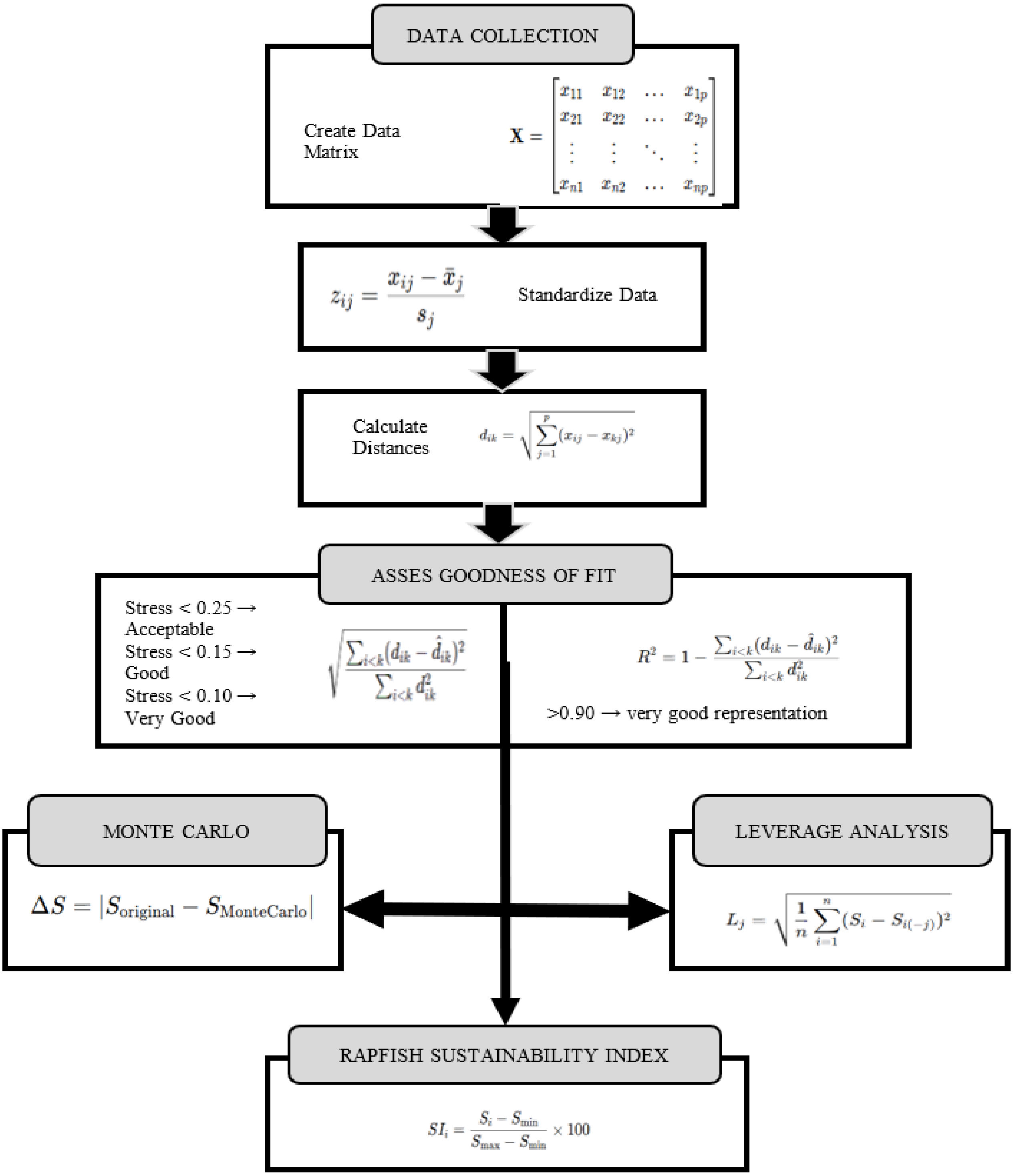


Figure 3. Data analysis

3.4 Data analysis

3.4.1 Multidimensional Scaling

MDS was applied using the RAPFISH approach to quantify sustainability performance across multiple dimensions (Figure 3). This method converts ordinal attribute scores into a multidimensional ordination space through an iterative optimization process that minimizes the discrepancy between observed dissimilarities and fitted distances [37, 38]. Technically, MDS seeks to minimize the stress function, which represents the goodness-of-fit between the distance matrix in the original attribute space and the reduced-dimensional ordination space [39]. The analysis was performed using a two-dimensional ordination to ensure interpretability and stability of results.

Each sustainability dimension (environmental, economic, social, and technological–institutional) was analyzed separately to generate dimension-specific indices, followed by a multidimensional aggregation to obtain the overall sustainability index. The resulting index values were transformed into a scale of 0–100 using linear interpolation, where higher values indicate better sustainability performance. The ordination results were further interpreted based on relative positioning, where systems located closer to the "good" reference point indicate higher sustainability status, while those closer to the "bad" reference point reflect lower sustainability performance.

3.4.2 Model validation

To evaluate the robustness and reliability of the MDS model, two key statistical indicators were used: stress value. The stress value measures the degree of distortion between the original dissimilarity matrix and the ordination results. A stress value of less than 0.25 indicates an acceptable fit, while values below 0.15 are considered highly reliable in representing the multidimensional structure.

The coefficient of determination (R^2) indicates the proportion of variance in the data that is explained by the model. Values approaching 1 (or 100%) suggest that the selected attributes adequately capture the variability of the system and that the model has strong explanatory power [40, 41]. Together, these indicators ensure that the MDS configuration accurately represents the underlying data structure and that the resulting sustainability indices are statistically valid and reliable for interpretation.

3.4.3 Monte Carlo simulation

Monte Carlo simulation was conducted to test the stability and sensitivity of the MDS results against uncertainties in the input data. This procedure involves repeated random perturbations of attribute scores within defined ranges to simulate potential variations arising from subjective judgment, data gaps, or measurement errors. Monte Carlo simulations were run for 3 iterations for each sustainability dimension, following common practice in the RAPFISH approach. The simulation results were then compared with the main MDS ordination to evaluate the stability of the sustainability index. The simulation generates a distribution of sustainability index values, which are then compared with the original MDS results. The absolute difference between the two results is used as an indicator of model stability. A difference of less than 5% is considered acceptable, indicating that the model is robust and not significantly affected by random errors or scoring inconsistencies [42, 43]. This step is critical in strengthening the credibility of the analysis, particularly in expert-based assessments where subjectivity may influence scoring outcomes.

3.4.4 Leverage analysis

Leverage analysis was performed to identify sensitive attributes that have the greatest influence on sustainability scores. This analysis uses the Root Mean Square (RMS) change in ordination when each attribute is systematically removed from the model. Attributes with higher RMS values indicate stronger leverage, meaning that small changes in these attributes can significantly alter the sustainability index [16]. Therefore, these attributes are considered critical control points within the system and serve as priority targets for management intervention and policy formulation. The identification of leverage factors allows for a more strategic approach to sustainability improvement by focusing on attributes that generate the highest impact, rather than addressing all variables equally.

4. RESULTS

4.1 Validity test (R^2 and stress value)

Validity testing is a key step that must be ensured before proceeding to the sustainability index. The feasibility of the MDS model needs to be tested using two main parameters: the stress value and the R^2. Furthermore, to test the scoring process's error rate, a Monte Carlo analysis is performed (Table 2).

Table 2. Result of validity test

Sustainability Dimension	Parameters	
	R^2 (%)	**Stress Value**
Environment	90.81	0.15
Economic	93.68	0.15
Social	93.53	0.15
Technology and Institutions	93.74	0.15

Based on the RAPFISH method [40], an analysis model is considered accurate and accountable if its stress value is less than 0.25 (< 25%) and its R^2 is close to 1 or 100%. Based on Table 2, all dimensions have a stress value of 0.15 (15%), which is far below the maximum threshold of 25%. Meanwhile, the R^2 value is in the range of 90.81% to 93.74%. This means that the attributes used in this model are perfectly able to explain 90% to 93% of the variation in the sustainability model of PT. Sumber Agromina Jaya's ponds. These results indicate that the RAPFISH-MDS approach applied to the PT. Sumber Agromina Jaya case study has a level of consistency and reliability capable of triggering multidimensional thinking at the company level.

4.2 Monte Carlo test

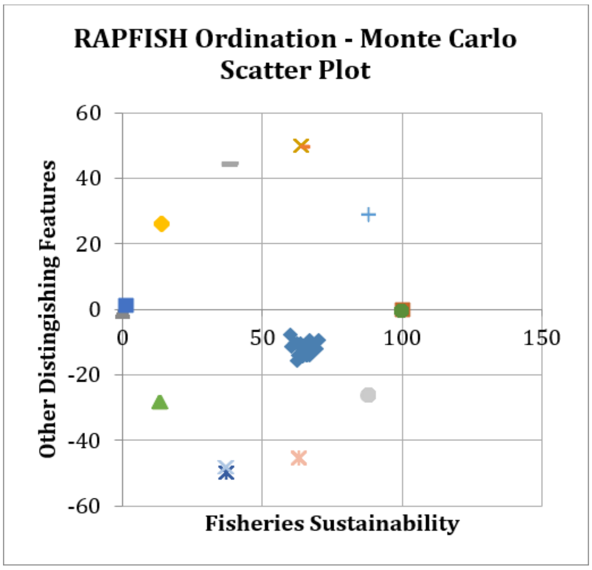
Monte Carlo analysis was conducted to evaluate the stability of the MDS results against potential errors arising from questionnaire input, scoring variability, and missing data. The acceptable difference between the RAPFISH score and the Monte Carlo simulation is less than 5%. Based on Table 3, the differences in sustainability index values across all dimensions are very small, ranging from 0.13% to 1.94%. This indicates that the expert judgments are highly consistent, the model is robust, and no significant outliers affect the results.

4.3 Sustainability status of shrimp pond management dimensions

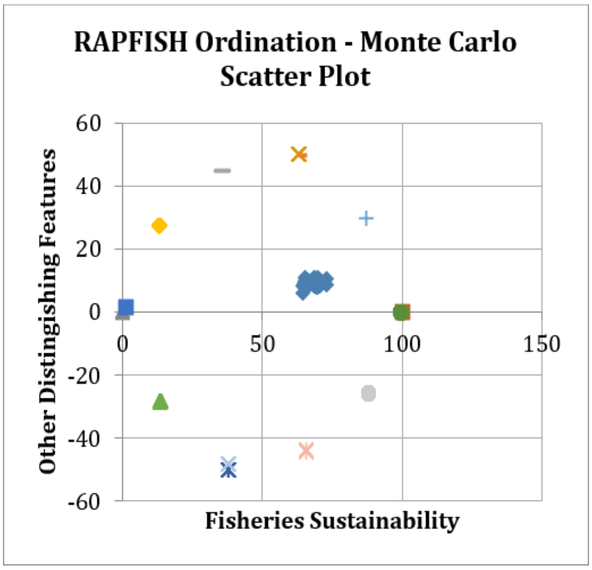
Sustainability status was evaluated using a composite index ranging from 0 to 100 (Figure 4). The sustainability categories are classified into four levels: 0–25 (unsustainable), 26–50 (less sustainable), 51–75 (moderately sustainable), and 76–100 (highly sustainable). Based on the overall (multidimensional) analysis, shrimp pond management at PT. Sumber Agromina Jaya Lombok Island achieved an average score of 63.13, which falls into the “moderately sustainable” category (Figure 5). However, a more detailed examination across dimensions reveals a critical structural imbalance. Three key operational dimensions demonstrate relatively strong performance, with the technological–institutional dimension achieving the highest score (69.85), followed by the economic dimension (69.76) and the environmental dimension (67.64). In contrast, the social dimension shows a sharp decline with a score of 45.28, placing it firmly in the “less sustainable” category.

Table 3. Result of Monte Carlo test

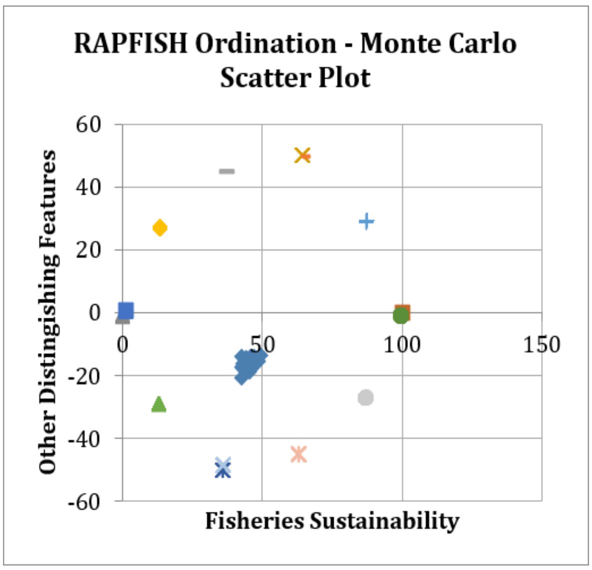
Dimensions of Sustainability	Sustainability Index		Difference (%)	Status
	Score RAPFISH	Monte Carlo		
Environment	67.64	65.70	1.94	Moderately Sustainable
Economic	69.76	68.62	1.14	Moderately Sustainable
Social	45.28	45.15	0.13	Less Sustainable
Technology and Institutions	69.85	68.80	1.05	Moderately Sustainable
Average		**63.13**		Moderately Sustainable



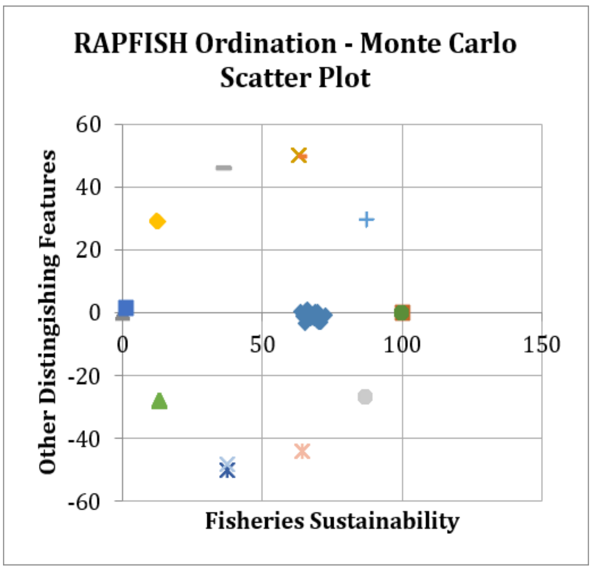
(a) Environmental



(b) Economic



(c) Social



(d) Technology and institutions

Figure 4. Sustainability index

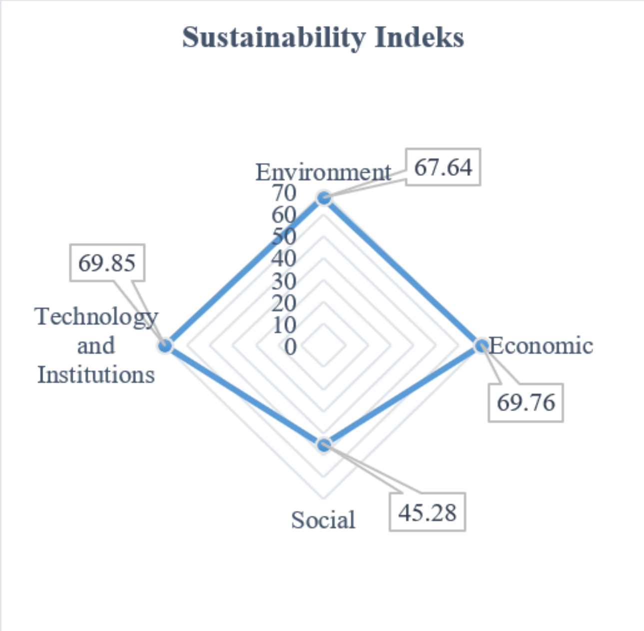


Figure 5. Sustainability status

These findings indicate that the company's operational and technological performance is relatively strong, but has not been fully accompanied by strengthening social aspects and community participation. Therefore, the results of this study are not intended as a formal audit of ASC certification compliance, but rather as an indication of possible sustainability gaps related to ASC, particularly in social aspects and participatory institutions. This structural imbalance confirms a fundamental principle of Sustainable Development Theory, where technological advancement and economic profitability have not been adequately integrated with social equity and community welfare (pro-poor and pro-job approaches) for the surrounding coastal communities [44-46].

The weak social dimension suggests a potential gap in ASC Principle 3, which emphasizes community engagement and respect for human rights. Failure to achieve balance across all dimensions represents a fundamental risk that threatens the company's SLO and may become a major barrier to accessing global markets that demand traceability and strict social compliance [47-49]. To address this gap and ensure alignment with ASC certification standards, several strategic actions are recommended:

1) Implementation of Participatory Social Impact Assessment (p-SIA): Conduct meaningful and participatory social impact assessments involving local communities, traditional leaders, and vulnerable groups (ASC Criterion 3.1).

2) Development of Proactive CSR Programs: Shift CSR from short-term charitable activities to structured capacity-building programs, such as providing basic aquaculture training for coastal youth to enhance local employment opportunities.

3) Establishment of a Formal Grievance Mechanism: Develop a transparent, accessible, and documented two-way communication channel for communities and workers to submit complaints, with clear timelines for response and conflict resolution.

4) Alignment with Human Rights Policies: Ensure that internal labor policies comply with legal standards, provide fair wages, guarantee occupational health and safety, and respect the fundamental rights of surrounding communities.

4.4 Sensitive attributes (leverage analysis)

Leverage analysis using the RMS method was conducted to identify the most sensitive attributes influencing sustainability in each dimension (Table 4). Higher RMS values indicate stronger leverage effects, meaning that improvements in these attributes can significantly enhance sustainability performance and reduce compliance gaps with international certification standards.

Table 4. The result of sensitive attributes

Sustainability Dimension	Sensitive Attributes
Environmental	Habitat Carrying Capacity (Mangroves) (18.38) Biosecurity and Disease Management (12.55) Use of Chemicals/Drugs
Economic	Survival Rate (SR) (7.32) Feed Efficiency (FCR) (5.93) Business Profitability (R/C Ratio) (4.94)
Social	Community Participation (10.29) Knowledge and Skills (8.97) Social Responsibility (6.06)
Technology and Institutions	Group Activity (Waste Management) (8.24) Infrastructure (6.54) Business Legality (4.79)

Environmental Dimension (Index: 67.64 – Moderately Sustainable)

The stability of the environmental dimension at PT. Sumber Agromina Jaya is largely determined by the company's ability to mitigate negative externalities; however, significant challenges remain in terms of habitat conservation. Based on leverage analysis, the most critical and sensitive attribute requiring immediate attention is Habitat Carrying Capacity/Mangroves (RMS 18.38). Field observations indicate that the company has not undertaken any conservation, restoration, or buffer zone development in the form of mangrove vegetation within the pond area. Within the framework of ASC certification, coastal ecosystem protection is considered a showstopper criterion (i.e., a critical non-compliance issue). ASC standards strictly prohibit the conversion of natural wetlands after May 1999 and mandate the restoration of critical habitats as a fundamental operational requirement (Criterion 2.2) [50].

The second most sensitive attribute is Biosecurity and Disease Management (RMS 12.55). Although farming operations are currently functioning well, the existing disease management system is considered suboptimal and largely reactive. Under ASC Principle 4 (Animal Health and Welfare), companies are required to implement a proactive, structured Veterinary Health Plan to prevent large-scale losses from pathogens and minimize animal stress. On the other hand, a highly positive finding is observed in the use of chemicals and drugs. Field practices confirm that the company has eliminated the use of prohibited chemical substances, particularly prophylactic antibiotics. Many countries have also implemented strict regulations prohibiting the use of prophylactic antibiotics [51, 52]. Although the use of prophylactic antibiotics has been widely restricted, alternative approaches such as probiotics, prebiotics, and other functional feed additives have been shown to enhance immune function, reduce stress, and prevent disease outbreaks without causing the negative impacts associated with chemical residues [53, 54]. This represents a significant strategic advancement, ensuring that shrimp products are free from harmful residues and directly complying with one of the strictest requirements (zero tolerance) in global food safety standards and ASC certification.

Economic Dimension (Index: 69.76 – Moderately Sustainable)

The economic resilience of PT. Sumber Agromina Jaya's shrimp farming system demonstrates strong performance, driven by production efficiency and financial stability. The most influential attribute in this dimension is the SR (RMS 7.32). Empirical evidence shows that the company consistently maintains high shrimp SR. This not only ensures sufficient harvest volumes to maximize revenue but also indirectly indicates that pond water conditions remain suitable for sustaining shrimp physiological well-being. This stability is further reinforced by Feed Conversion Ratio (FCR) efficiency (RMS 5.93), which is reported to be highly optimal [55, 56]. Efficient feed management generates a double dividend. Economically, it significantly reduces production costs, as feed accounts for more than half of total operational expenses. Ecologically, a low FCR implies minimal feed waste, thereby reducing organic pollution aligned with ASC requirements regarding the limitation of the Forage Fish Dependency Ratio (FFDR) to minimize nutrient discharge into coastal waters. The combination of biological productivity and operational efficiency ultimately strengthens the Business Profitability (R/C Ratio) (RMS 4.94). The company has demonstrated the ability to sustain profitability across multiple production cycles, indicating that economies of scale have been achieved and that the system is resilient to market fluctuations.

Social Dimension (Index: 45.28 – Less Sustainable)

The social dimension represents the critical bottleneck and the most significant challenge to sustainability at PT. Sumber Agromina Jaya. The low social index is primarily driven by weak Community Participation (RMS 10.29). Field observations reveal that local coastal communities are not meaningfully involved in operational decision-making processes [57]. This exclusion directly contradicts the core requirements of ASC Principle 3, which mandates the implementation of Participatory Social Impact Assessment (p-SIA) and inclusive stakeholder engagement mechanisms.

The social issue becomes more complex when examining the Knowledge and Skills attribute (RMS 8.97). A significant human resource gap exists, where farm management and internal staff possess adequate technical competencies, while surrounding coastal communities exhibit low levels of education and technical knowledge. This disparity limits the company's ability to prioritize local workforce recruitment and often leads to social tensions. Ideally, this gap could be addressed through CSR initiatives (RMS 6.06). However, current contributions remain reactive and charitable in nature, such as temporary support for local health services (e.g., Posyandu funding). The absence of structured capacity-building or community empowerment programs indicates that the company has not yet generated meaningful economic spillover effects capable of improving the livelihoods of local and indigenous communities.

Technological and Institutional Dimension (Index: 69.85 – Moderately Sustainable)

The company's primary strength lies in the integration of production technology, although improvements are still required in institutional governance and administrative compliance. This is evident in the Group Activity and Waste Management attribute (RMS 8.24). Field findings reveal an interesting phenomenon: the low level of social conflict related to water pollution is not due to high community tolerance, but rather the effectiveness of technological adoption. The company operates an adequate wastewater treatment system and has designed an outfall that discharges directly into the sea without passing through densely populated settlements. This technological intervention has successfully minimized environmental degradation and complies with national effluent standards as well as ASC water quality criteria.

This environmental engineering success is supported by strong Infrastructure readiness (RMS 6.54). The company's facilities meet the standards of intensive aquaculture systems, including well-designed pond layouts, water reservoirs, wet–dry separation areas, employee housing, and centralized storage facilities. However, this technological advancement contrasts with the condition of Business Legality (RMS 4.79). Legal documentation, particularly environmental permits such as AMDAL or UKL-UPL, remains incomplete and requires immediate attention. Within international standards such as ASC, legal compliance (Principle 1) forms the foundation of sustainability. Without formal legal recognition from relevant authorities governing environmental and spatial planning aspects, all sustainability achievements may be considered illegitimate by third-party auditors [49, 58, 59].

5. DISCUSSION

The findings of this study reveal a fundamental paradox in intensive shrimp aquaculture systems of PT. Sumber Agromina Jaya, Lombok: strong performance in environmental, economic, and technological dimensions coexists with significant social failure. This condition challenges the dominant assumption in sustainability discourse that improvements in efficiency and productivity inherently lead to holistic sustainability outcomes. From a systems perspective, the results confirm that sustainability in aquaculture is inherently non-substitutable, as emphasized by standards such as the ASC. The relatively high scores in the economic (69.76) and technological–institutional (69.85) dimensions demonstrate that the system has achieved operational efficiency and technological maturity. These findings are consistent with the modernization theory of aquaculture, where intensification enhances productivity through improved feed management, disease control, and infrastructure development [7, 45].

However, the significantly lower score in the social dimension (45.28) indicates a structural imbalance that undermines the overall sustainability of the system. This imbalance reflects a classic case of "growth without inclusion", where economic gains are not equitably distributed among stakeholders, particularly local coastal communities. From a social sustainability perspective, weak community participation, limited stakeholder dialogue hinder public service to operations industry, which can increase the potential for social conflict and reduce a company's SLO [60-62].

Addressing these challenges requires participatory governance, a robust grievance system, and an integrated management approach to ensure social viability and long-term sustainability [62, 63].

This condition has critical implications when analyzed through the lens of SLO and Legitimacy Theory. The lack of social engagement and inclusivity may lead to a legitimacy deficit, which can threaten long-term operational stability despite strong economic performance [24]. In other words, the sustainability of the system is not only determined by technical efficiency but also by its ability to gain and maintain social acceptance.

In the technological and institutional dimensions, the most sensitive attributes include regulatory compliance, management digitalization, and local institutional integration. These results indicate that modernization of production technology has not been fully accompanied by strengthening institutional governance. This study found that the use of intensive production technologies such as automatic feeders, water quality sensors, and digital monitoring systems does increase operational efficiency, but has not automatically strengthened social participation mechanisms, institutional transparency, or integration with local institutions. This situation highlights a gap between technological improvements and institutional strengthening in intensive shrimp farming systems.

The leverage analysis further strengthens this argument by identifying key sensitive attributes that drive sustainability performance. In the environmental dimension, the absence of mangrove conservation represents a critical vulnerability, particularly given its status as a "showstopper" criterion in ASC certification. Similarly, in the social dimension, community participation and capacity building emerge as dominant leverage factors, indicating that improvements in these areas could significantly enhance overall sustainability. Another important insight is that technological advancement appears to partially mask underlying social issues. The effective use of wastewater treatment systems and infrastructure has minimized environmental conflict, but this does not necessarily reflect genuine social acceptance. Instead, it suggests that technological solutions may temporarily suppress visible conflicts without addressing their root causes. The results of this multidimensional assessment provide evidence of potential sustainability gaps related to the ASC, particularly in the areas of social participation, social responsibility, and institutional governance, which are conceptually linked to the ASC principles of social responsibility and aquaculture business governance. Therefore, this study can be used as an initial sustainability readiness assessment rather than a formal certification compliance evaluation.

6. CONCLUSIONS

This study assessed the sustainability of intensive shrimp aquaculture using a multidimensional approach integrating environmental, economic, social, and technological–institutional dimensions. The results indicate that the overall system falls within the moderately sustainable category, with an index value of 63.13. However, this aggregate performance conceals a critical structural imbalance among dimensions. The key finding of this study is the identification of the social dimension as the primary constraint to sustainability, with a significantly lower score compared to other dimensions. This confirms that sustainability cannot be achieved through technological advancement and economic efficiency alone, but requires meaningful integration of social inclusion, community participation, and equitable benefit distribution.

From a theoretical perspective, this study reinforces the concept of non-substitutable sustainability, where failure in one dimension, particularly the social dimension, cannot be compensated for by strengths in others. Practically, the findings highlight the urgency of addressing social gaps through participatory approaches, capacity-building programs, and institutional reforms aligned with global standards such as ASC. This study also demonstrates the effectiveness of combining RAPFISH-MDS, Monte Carlo simulation, and leverage analysis as a robust methodological framework for sustainability assessment. This study provides empirical evidence of probable ASC-related sustainability gaps, particularly in relation to community participation, social mechanisms, and the strengthening of coastal community capacity. Accordingly, the main contribution of this study lies in positioning the RAPFISH-MDS evaluation not merely as a sustainability index assessment tool, but also as an instrument for identifying social vulnerabilities that may affect corporate sustainability readiness within the context of international standards. However, this study has several limitations. The reliance on expert-based scoring may introduce subjectivity, although this was mitigated through Monte Carlo validation. Additionally, the case study approach limits the generalizability of the findings to other regions with different socio-ecological contexts. Future research should expand the scope by incorporating comparative studies across multiple regions, integrating longitudinal data, and exploring participatory evaluation methods that directly involve local communities in sustainability assessment processes.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to all respondents and stakeholders who contributed to this study, including aquaculture practitioners, local community representatives, and technical experts. This research was supported by institutional and academic collaboration that facilitated data collection and field observations in Lombok, West Nusa Tenggara, Indonesia. The authors also acknowledge the valuable input and constructive feedback provided by colleagues and reviewers, which significantly improved the quality of this manuscript.

REFERENCES

[1] Bethel, B.J., Buravleva, Y., Tang, D. (2021). Blue economy and blue activities: Opportunities, challenges, and recommendations for The Bahamas. Water, 13(10): 1399. https://doi.org/10.3390/w13101399

[2] Nguyen Thanh, B., Le Van Thuy, T., Nguyen Anh, M., Nguyen Nguyen, M., Nguyen Hieu, T. (2021). Drivers of agricultural transformation in the coastal areas of the Vietnamese Mekong Delta. Environmental Science & Policy, 122: 49-58. https://doi.org/10.1016/j.envsci.2021.04.010

[3] Zhang, Y.Q., Yao, N., Zhang, C.T., et al. (2022). Genetic analysis of survival in Penaeus japonicus exposed to

white spot syndrome virus. Aquaculture, 559: 738424. https://doi.org/10.1016/j.aquaculture.2022.738424
[4] Devadas, S., Zakaria, Z., Mohamed Din, M.S., et al. (2025). Knowledge, attitudes and practices on antimicrobial use and antimicrobial resistance among shrimp aquaculturists in Peninsular Malaysia. Preventive Veterinary Medicine, 239: 106513. https://doi.org/10.1016/j.prevetmed.2025.106513
[5] Hernández-Sain, A., Palacios, E., Soto-Rodriguez, S.A., Osuna-Ruiz, I., Rojas-Hernandez, P.G., Hernández, C. (2025). Seaweed potential as nutraceutical and functional food ingredient in shrimp aquaculture. Animal Feed Science and Technology, 330: 116540. https://doi.org/10.1016/j.anifeedsci.2025.116540
[6] Tufa, R.A., Noviello, Y., Di Profio, G., et al. (2019). Integrated membrane distillation-reverse electrodialysis system for energy-efficient seawater desalination. Applied Energy, 253: 113551. https://doi.org/10.1016/j.apenergy.2019.113551
[7] Agya, B.A., Agyemang, P., Anokye, K. (2025). Beyond silos: An integrated AI-blockchain framework for sustainable aquaculture in Ghana. Smart Agricultural Technology, 12: 101576. https://doi.org/10.1016/j.atech.2025.101576
[8] Samerwong, P., Toonen, H.M., Oosterveer, P., Bush, S.R. (2020). A capability approach to assess aquaculture sustainability standard compliance. PLoS ONE, 15(1): e0227812. https://doi.org/10.1371/journal.pone.0227812
[9] Colt, J., Tetreault, J., Fogle, R.L. (2024). Development and standardization of physical, operational, and performance metrics for aquaponics. Reviews in Fisheries Science & Aquaculture, 32(4): 562-578. https://doi.org/10.1080/23308249.2024.2353578
[10] Henriksson, P.J.G., Banks, L.K., Suri, S.K., Pratiwi, T.Y., Fatan, N.A., Troell, M. (2019). Indonesian aquaculture futures—Identifying interventions for reducing environmental impacts. Environmental Research Letters, 14: 124062. https://doi.org/10.1088/1748-9326/ab4b79
[11] Sinner, J., Newton, M., Barclay, J., et al. (2020). Measuring social licence: What and who determines public acceptability of aquaculture in New Zealand? Aquaculture, 521: 734973. https://doi.org/10.1016/j.aquaculture.2020.734973
[12] Tamrin, T., Schaduw, J.N.W., Wantasen, A.S., Sambali, H., Abdullah, T. (2025). Rapid appraisal of brackishwater aquaculture (RAP-BWAC) for assessing sustainable development of brackishwater aquaculture in coastal areas. Ocean & Coastal Management, 269: 107822. https://doi.org/10.1016/j.ocecoaman.2025.107822
[13] Dasari, D., Dong, C.D., Singhania, R.R., Tambat, V.S., Piechota, G., Patel, A.K. (2025). Harnessing microalgae for sustainable aquaculture and mariculture: Marine pollution mitigation and circular economy strategies. Marine Pollution Bulletin, 219: 118292. https://doi.org/10.1016/j.marpolbul.2025.118292
[14] Cozzolino, M., Salomone, R., Ricca, B., Gulotta, T.M. (2025). Circular economy in aquaculture: An Italian survey to understand perceptions, challenges and options for transition. Marine Policy, 176: 106660. https://doi.org/10.1016/j.marpol.2025.106660
[15] Zhang, Q.S., Wang, X.L., Wong, L.L., Liu, S.K., Li, M., Wang, G.Q. (2025). Enhancing safety in aquaculture with nanostructures: Hazard detection and elimination. Engineering, 58: 273-290. https://doi.org/10.1016/j.eng.2025.07.044
[16] Gill, J.M., Hussain, S.M., Ali, S., et al. (2025). Optimizing aquaculture sustainability: Microalgae-based co-culture systems for aquaculture wastewater treatment and pollution reduction. Algal Research, 92: 104430. https://doi.org/10.1016/j.algal.2025.104430
[17] Ngoc Thuy, N.T., Ha, P.T.M., Thao, N.T.P., et al. (2025). Therapeutic potential of Phyllanthus spp. in sustainable aquaculture: A phytopharmacological perspective. RSC Advances, 15(49): 41432-41446. https://doi.org/10.1039/d5ra07594g
[18] Gudbrandsdottir, I.Y., Oddsson, G.V., Stefansson, H., Olafsdottir, G., Bogason, S.G. (2025). Towards a systems perspective in policy design: An analysis of how the endogenous feedback structure of the Norwegian salmon aquaculture industry impacts policy outcomes. Aquaculture, 598: 742045. https://doi.org/10.1016/j.aquaculture.2024.742045
[19] Johnson, T.R., Beard, K., Brady, D.C., et al. (2019). A social-ecological system framework for marine aquaculture research. Sustainability, 11(9): 2522. https://doi.org/10.3390/su11092522
[20] Formenti, L. (2022). Assessing transparency in fisheries subsidies: A notification-driven analysis. Marine Policy, 136: 104152. https://doi.org/10.1016/j.marpol.2020.104152
[21] Efani, A., Muntaha, A., Lestariadi, R.A., Tirta, E.Y.W. (2022). Does financing source affect productivity and efficiency in tuna fishing business? In Modeling Economic Growth in Contemporary Indonesia, pp. 237-252. https://doi.org/10.1108/978-1-80262-431-120221015
[22] Rastogi, M., Kolur, S.M., Burud, A., et al. (2024). Advancing water conservation techniques in agriculture for sustainable resource management: A review. Journal of Geography, Environment and Earth Science International, 28(3): 41-53. https://doi.org/10.9734/jgeesi/2024/v28i3755
[23] Johnson, B.B., Rickard, L.N. (2022). Sense of place and perceived community change in perceived impacts of and cooperation with local aquaculture development in the US. Journal of Environmental Psychology, 84: 101882. https://doi.org/10.1016/j.jenvp.2022.101882
[24] Alexander, K.A. (2022). A social license to operate for aquaculture: Reflections from Tasmania. Aquaculture, 550: 737875. https://doi.org/10.1016/j.aquaculture.2021.737875
[25] Wiyanto, D.B., Harahab, N., Rudianto, Sartimbul, A. (2020). Cultural heritage conservation of “the United State Army Transport (USAT) Liberty” shipwreck site as a sustainable scuba diving ecotourism. International Journal of Conservation Science, 11(4): 931-944.
[26] Pitcher, T.J., Preikshot, D. (2001). RAPFISH: A rapid appraisal technique to evaluate the sustainability status of fisheries. Fisheries Research, 49(3): 255-270. https://doi.org/10.1016/S0165-7836(00)00205-8
[27] Husni, S., Yusuf, M., Nursan, M., Fr, A.F.U. (2022). Study of household welfare level of crab fishermen using fisherman exchange rate (FER) indicators in East Lombok. IOP Conference Series: Earth and Environmental Science, 1107(1): 012112. https://doi.org/10.1088/1755-1315/1107/1/012112

[28] Jana, J., Hammidah, H., Chand, R., Haselkorn, J. (2024). Community spirit and local wisdom: Strengthening character education through the Ngarot tradition in social studies learning. Journal of Social Knowledge Education, 5(1): 9-20. https://doi.org/10.37251/jske.v5i1.888

[29] Etikan, I., Musa, S.A., Alkassim, R.S. (2015). Comparison of convenience sampling and purposive sampling. American Journal of Theoretical and Applied Statistics, 5(1): 1-4. https://doi.org/10.11648/j.ajtas.20160501.11

[30] Ocktovian, H., Nasmia, N., Serdiati, N. (2024). Different feeding frequency on growth and feed conversion ratio of vaname shrimp (Litopenaeus vannamei). Jurnal Ilmiah Kelautan dan Perikanan, 5(3): 324-335. https://doi.org/10.21107/juvenil.v5i3.27168

[31] Faidatun, N., Susanto, R., Wisnumurti, A. (2023). Desa tuksongo borobudur sebagai bentuk pengembangan wisatayang berkelanjutan. Jurnal Ilmiah Multidisiplin, 2(7): 2892-2900. https://doi.org/10.56799/jim.v2i7.1768

[32] Hariawansyah, F.A., Widyorini, N., Ain, C. (2019). Kelimpahan makrozoobentos berdasarkan stratifikasi salinitas dari hulu – hilir sungai siangker semarang macrozoobentos abundance based on salinity stratification from upstream - lower siangker River Semarang. Management of Aquatic Resources Journal (MAQUARES), 8(2): 56-62. https://doi.org/10.14710/marj.v8i2.24227

[33] Elegbede, I.O., Al Jufaili, S.M., Jolaosho, T.L., et al. (2025). Health-related dimensions of fishers for sustainable commercial fisheries in the Atlantic Gulf of Guinea: Ecological and social assessments. One Health, 20: 100972. https://doi.org/10.1016/j.onehlt.2025.100972

[34] Alvi, N.N., Nurhasanah, I.S., Persada, C. (2018). Evaluasi keberlanjutan wisata bahari pulau pahawang kabupaten pesawaran. Plano Madani: Jurnal Perencanaan Wilayah dan Kota, 7(1): 59-68. https://doi.org/10.24252/jpm.v7i1.4242

[35] Chaliluddin, M.A., Sundari, S., Rizwan, T., et al. (2023). RAPFISH: A rapid appraisal technique to evaluate the sustainability status of pelagic fisheries in North Aceh Waters. Jurnal Penelitian Pendidikan IPA, 9(7): 5603-5609. https://doi.org/10.29303/jppipa.v9i7.3841

[36] Burhanis, Alaudin, Fadhillah, R., et al. (2024). Size frequency, sustainability index of the yellowfin tuna (Thunnus albacares) landed in PPI Ujong Baroh, West Aceh, Indonesia. Egyptian Journal of Aquatic Biology and Fisheries, 28(1): 1601-1612. https://doi.org/10.21608/ejabf.2024.341740

[37] Rosmala, F., Bambang, A.N., Purnaweni, H. (2021). Leverage factors at red brick production centers in Sinar Tanjung Village, Banjar City, West Java Province. IOP Conference Series: Earth and Environmental Science, 799(1): 012013. https://doi.org/10.1088/1755-1315/799/1/012013

[38] Harahab, N., Riniwati, H., Utami, T.N., Abidin, Z., Wati, L.A. (2021). Sustainability analysis of marine ecotourism management for preserving natural resources and coastal ecosystem functions. Environmental Research, Engineering and Management, 77(2): 71-86. https://doi.org/10.5755/j01.erem.77.2.28670

[39] Wardana, I.M., Sukaatmadja, I.P.G., Ekawati, N.W., Yasa, N.N.K., Astawa, I.P., Setini, M. (2021). Policy models for improving ecotourism performance to build quality tourism experience and sustainable tourism. Management Science Letters, 11(1): 595-608. https://doi.org/10.5267/j.msl.2020.9.007

[40] Kavanagh, P., Pitcher, T.J. (2004). Implementing Microsoft Excel software for RAPFISH: A technique for the rapid appraisal of fisheries status. Fisheries Centre Research Reports, 12(2): 1-75.

[41] Adiga, M.S., Ananthan, P.S., Kumari, H.V.D., Ramasubramanian, V. (2016). Multidimensional analysis of marine fishery resources of Maharashtra, India. Ocean & Coastal Management, 130: 13-20. https://doi.org/10.1016/j.ocecoaman.2016.05.008

[42] Gayat, E., Resche-Rigon, M., Mary, J.Y., Porcher, R. (2012). Propensity score applied to survival data analysis through proportional hazards models: A Monte Carlo study. Pharmaceutical Statistics, 11(3): 222-229. https://doi.org/10.1002/pst.537

[43] Liu, Z.F., Huang, M., Zhu, Q.B., Qin, J.W., Kim, M.S. (2023). Evaluating performance of SORS-based subsurface signal separation methods using statistical replication Monte Carlo simulation. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 293: 122520. https://doi.org/10.1016/j.saa.2023.122520

[44] Wang, W.K., Feng, L.Y., Zheng, T., Liu, Y. (2021). The sustainability of ecotourism stakeholders in ecologically fragile areas: Implications for cleaner production. Journal of Cleaner Production, 279: 123606. https://doi.org/10.1016/j.jclepro.2020.123606

[45] Billing, S.L. (2018). Using public comments to gauge social licence to operate for finfish aquaculture: Lessons from Scotland. Ocean & Coastal Management, 165: 401-415. https://doi.org/10.1016/j.ocecoaman.2018.09.011

[46] Zahedi, S. (2019). Sustainable development theory: A critical perspective and an integrative model. Journal of Economics and Sustainable Development, 10(21): 43-52. https://doi.org/10.7176/jesd/10-21-05

[47] Ido, A. (2023). Antimicrobial use in ecolabel certified and non-certified yellowtail (Seriola quinqueradiata) aquaculture in Japan. Aquaculture Reports, 31: 101647. https://doi.org/10.1016/j.aqrep.2023.101647

[48] Haque, M.M., Alam, M.M., Hoque, M.S., et al. (2021). Can Bangladeshi pangasius farmers comply with the requirements of aquaculture certification? Aquaculture Reports, 21: 100811. https://doi.org/10.1016/j.aqrep.2021.100811

[49] Zhen, S.H., Ren, Y.J., Duric, I. (2026). Does message framing affect sustainable seafood consumption? Evidence from eye-tracking experiments on ASC and organic-labeled products. Aquaculture, 620: 743928. https://doi.org/10.1016/j.aquaculture.2026.743928

[50] Wakamatsu, H., Miyata, T. (2021). Effects of radioactive safety information on consumer fears of radioactive contamination from oyster products in Japan. Marine Policy, 126: 104401. https://doi.org/10.1016/j.marpol.2021.104401

[51] Salas, R.G., Del Río, M.M.V., Concepción, I.P. (2021). Intensive use of prophylactic antibiotics in aquaculture: A growing problem for human and animal health. Universidad y Sociedad, 13(S2): 204-210. https://www.scopus.com/pages/publications/85116122872.

[52] Ljubojević Pelić, D., Radosavljević, V., Pelić, M., et al. (2024). Antibiotic residues in cultured fish: Implications for food safety and regulatory concerns. Fishes, 9(12):

484. https://doi.org/10.3390/fishes9120484
[53] Mustafa, S.A., Al-Faragi, J.K. (2021). Supplementation of feed additives on aquaculture feeds: A review. International Journal of Pharmaceutical Research, 13(1): 561-567. https://doi.org/10.31838/ijpr/2021.13.01.097
[54] Rudoy, D., Meskhi, B., Olshevskaya, A., et al. (2025). Analysis of edaphic factors on the role of probiotics in the development of sustainable and productive aquaculture. Fishes, 10(9): 457. https://doi.org/10.3390/fishes10090457
[55] Ai, C.X., Leng, X.J., Luo, Z., Zhou, Z.G., Ai, Q.H. (2025). A review of the latest advances in aquaculture nutrition research. The Journal of Nutrition, 155(10): 3267-3290. https://doi.org/10.1016/j.tjnut.2025.08.009
[56] Raza, B., Zheng, Z.M., Yang, W. (2024). A review on biofloc system technology, history, types, and future economical perceptions in aquaculture. Animals, 14(10): 1489. https://doi.org/10.3390/ani14101489
[57] Bibeau, J., Meilleur, R., St-Jean, É. (2024). To formalize, or not to formalize, business incubators' networks: That is not the question. Technovation, 130: 102904. https://doi.org/10.1016/j.technovation.2023.102904
[58] Vandergeest, P., Unno, A. (2012). A new extraterritoriality? Aquaculture certification, sovereignty, and empire. Political Geography, 31(6): 358-367. https://doi.org/10.1016/j.polgeo.2012.05.005
[59] Davis, R.P., Boyd, C.E. (2021). A comparison of the technical efficiency of Aquaculture Stewardship Council certified shrimp farms to non-certified farms. Current Research in Environmental Sustainability, 3: 100069. https://doi.org/10.1016/j.crsust.2021.100069
[60] Eriksen, K., Mikkelsen, E. (2024). What affects the level of local social acceptance of salmon farming in Norway? Aquaculture, 588: 740926. https://doi.org/10.1016/j.aquaculture.2024.740926
[61] Ho, T.Q., Do, H.L. (2026). Production performance and risk in shrimp farming: The role of social trust belief. Aquaculture, 612: 743167. https://doi.org/10.1016/j.aquaculture.2025.743167
[62] Joffre, O.M., Klerkx, L., Khoa, T.N.D. (2018). Aquaculture innovation system analysis of transition to sustainable intensification in shrimp farming. Agronomy for Sustainable Development, 38: 34. https://doi.org/10.1007/s13593-018-0511-9
[63] da Silva, H.J.H., Pierri, N. (2022). The shrimp farming resumes in Brazil (2012–2020): Dismantling of environmental regulations and new socio-environmental impacts. Desenvolvimento e Meio Ambiente, 60: 182-205. https://doi.org/10.5380/dma.v60i0.80348