International Journal of Entrepreneurship and Sustainability Studies, Vol. 5 No. 1 (2025) https://doi.org/10.31098/ijeass.v5i1.3044

Check for updates

Research Paper

System Thinking Approach to Fish Export Determinants in the Sustainable Blue Economy

Vita Sarasi[1*], Dina Yulianti[1], Deny Saefulhadjar[1], Oman Abdurahman[2], Desi Aswandari[3]

[1] Universitas Padjadjaran, Indonesia
[2] Bandung Polytechnic of Energy and Mining, Indonesia
[3] Airlangga University, Indonesia

Received : January 25, 2025	Revised : May 19, 2025	Accepted : June 12, 2025	Online : July 31, 2025

Abstract

Wakatobi holds considerable potential in the sustainable blue economy, particularly in the fisheries sector. However, only 6.4% of its annual capture fisheries potential has been utilized, despite recent export milestones. This study employed a qualitative methodology using a systems thinking approach to explore the key determinants influencing fish exports in Wakatobi. Data were collected through in-depth interviews, focus group discussions, and secondary sources, and were analyzed using causal loop diagrams (CLD) to map systemic interactions and identify leverage points. The findings revealed that outdated port infrastructure, insufficient cold storage, limited transportation access, and inadequate post-harvest handling were the main barriers to export readiness. Additionally, gaps in policy coordination and fisher training contributed to poor fish quality and limited market access. The study concluded that addressing these interconnected issues through integrated policies, investment in cold chain infrastructure, and capacity-building initiatives is critical for improving the competitiveness of Wakatobi's fishery exports. This research offers a systemic perspective for designing sustainable interventions that align economic growth with ecological preservation.

Keywords: *Blue Economy, Fish Exports, System Thinking, Qualitative Methodology, Sustainability*

INTRODUCTION

Wakatobi Regency, located in Southeast Sulawesi, Indonesia, consists of 97% marine territory and holds significant capture fisheries potential, reaching 18,855 tons per year (Marina, Sumarmi & Astina, 2020; Saediman et al., 2024). Despite this abundance, only 6.4% of the potential has been utilized, reflecting suboptimal marine resource management (Statistics Indonesia Wakatobi Regency, 2024). In October 2024, Wakatobi achieved a milestone by exporting 3,200 kilograms of live grouper to Hong Kong, signaling its initial participation in global seafood markets (Nuradzani et al., 2024; Wahyuni et al., 2021)

However, major structural challenges persist. Inadequate port facilities, limited cold chain infrastructure, and insufficient fish processing capacity contribute to post-harvest losses of 15–20%, which reduce both the quality and volume of exportable products (Maflahah et al., 2024; Zapata et al., 2023; Ariffien et al., 2024). Additionally, the lack of post-harvest training among fishers further compromises the value chain (Wardhani & Noviaristanti, 2023). These inefficiencies restrict Wakatobi's competitiveness in higher-value markets and limit economic returns. Figure 1 provides information on the quantity of exports from Wakatobi during the year 2023 regarding exports of some fish commodities.

Corresponding author's email: vita.sarasi@unpad.ac.id

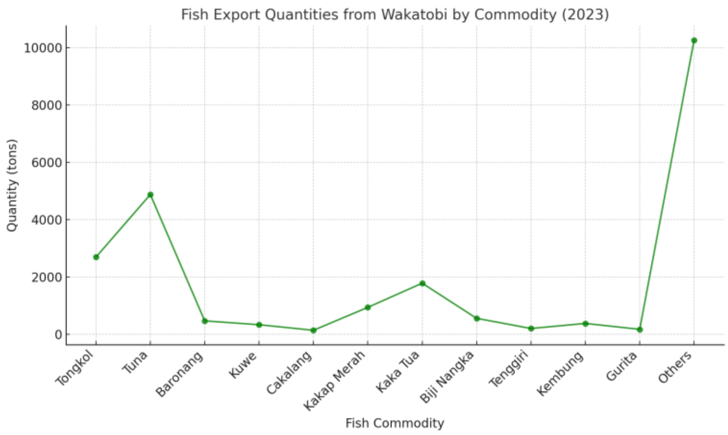

Figure 1. Fish Export Quantities from Wakatobi by Commodity 2023
Source: Wakatobi Regency in Figures (2024)

Data from 2023 show that Tuna (*Thunnus*) and Tongkol (*frigate tuna*) dominate fish exports, alongside Kakap Merah (*red snapper*) and Kaka Tua (*parrotfish*) (Das, 2023). Heavy reliance on a few species raises sustainability concerns and calls for diversification strategies. Strategic interventions are needed to balance species exploitation, enhance value addition, and ensure long-term ecological and economic resilience (Dirman et al., 2024).

Previous studies have largely addressed technical aspects of fisheries without analyzing the systemic interlinkages between infrastructure, human resources, policy frameworks, and market access. The application of a Systems Thinking approach, rarely used in the fisheries export context, offers a way to identify causal relationships and feedback loops that influence sustainability outcomes (Flamm & Braunsberger, 2022; Nguyen et al., 2011). This approach enables a more comprehensive understanding of how multiple variables interact dynamically over time, which is essential for designing effective and adaptive policy interventions.

Therefore, this study aims to identify and analyze the key determinants of fish exports in Wakatobi using a qualitative methodology grounded in a Systems Thinking approach. By mapping causal relationships and feedback loops, the study seeks to uncover leverage points that can inform strategic policy interventions. The ultimate goal is to offer integrated, system-based recommendations that enhance the competitiveness of Wakatobi's fishery products while promoting ecological sustainability in the broader context of the blue economy.

LITERATURE REVIEW

Post-Harvest Losses and Infrastructure Gaps

Post-harvest losses (PHL) remain a central challenge in the fisheries sector, particularly in developing countries. Studies indicate that up to 40–50% of harvested fish are lost due to inadequate infrastructure, poor cold chain systems, and lack of training in proper handling practices (Ahwireng et al., 2024; Gul et al., 2024). In the context of Sub-Saharan Africa, similar losses have been linked to outdated preservation methods and market inaccessibility (Bisht & Singh, 2024; Abelti & Teka, 2024). Infrastructure improvement, especially in cold storage and transportation, has been emphasized as a critical intervention to reduce PHL and improve product quality (Dsouza et al., 2023).

Barriers to Export and Governance Challenges

Export competitiveness is influenced not only by product quality but also by systemic barriers such as weak policy coordination, compliance difficulties, and market entry limitations. In

Indonesia and Bangladesh, for instance, ornamental and farmed fish exports are hindered by fragmented regulations and a lack of harmonization with international standards (Tarihoran et al., 2023; Alam et al., 2024). Successful export systems, such as Vietnam's pangasius industry, illustrate how coordinated policies and infrastructure investments can overcome such barriers (Emam et al., 2021). These findings underscore the importance of governance innovation and cross-sector collaboration in promoting sustainable fisheries exports (Nisar et al., 2024).

Environmental and Social Dimensions of Sustainability

Sustainable fisheries must also address environmental risks like overfishing, habitat degradation, and climate change impacts. Rising sea temperatures and resource depletion directly affect fish stock availability and disrupt market reliability (Komlatsky, 2024). Simultaneously, social dynamics, such as power imbalances and limited fisher participation in governance, have been found to hinder equitable resource distribution and co-management systems (Abu Samah et al., 2023). Effective sustainability, therefore, requires inclusive policies that integrate ecological, economic, and social dimensions.

Emerging Approaches in Fisheries Governance

Recent studies suggest that data-driven governance and systemic frameworks, including the use of Causal Loop Diagrams (CLD) and system dynamics modeling, can improve decision-making in complex fisheries environments (Nguyen et al., 2011; Stead, 2019; Olaoye et al., 2024). In the European context, machine learning and multivariate analyses are increasingly applied to optimize fleet segmentation and resource allocation (Valenza et al., 2024). These approaches allow for the identification of leverage points and feedback loops that can inform adaptive policies and sustainability-focused interventions.

The Gap and Rationale for System Thinking

Despite a rich literature on technical, environmental, and policy aspects of fisheries, there remains a lack of integrative studies that connect these variables within a unified systems perspective. Few studies have employed systems thinking to map the causal interdependencies affecting fish export performance, particularly in Indonesia's archipelagic and underdeveloped regions. This study addresses that gap by applying a qualitative systems thinking approach to analyze how infrastructure, governance, human capacity, and ecological sustainability interact within the fisheries export system of Wakatobi.

These strands of literature underscore the importance of integrating sustainability and blue economy principles into fisheries policy and export systems. This study positions itself at the intersection of these three domains, blue economy, sustainability, and fisheries governance, using a systems thinking approach to map dynamic relationships and identify leverage points for sustainable development.

RESEARCH METHOD

This study employed a Systems Thinking approach to understand the interlinked relationships affecting fisheries governance, post-harvest handling, and export readiness. Systems Thinking is particularly relevant for capturing the complex feedback structures and leverage points in fisheries systems, as recommended by Stead (2019) and Nguyen et al. (2011). The core analytical tool used in this research was the Causal Loop Diagram (CLD), which helps map dynamic interactions and system behavior over time.

Primary data collection was conducted between August and October 2024 in Wakatobi Regency. A total of 12 informants were selected through purposive sampling based on their knowledge of the fisheries export system. These included government officials, fishery experts, exporters, and community representatives. Informed consent was obtained before each interview and focus group discussion (FGD), ensuring participants' understanding of the study's aims, voluntary nature, and confidentiality. FGDs were held in two island clusters (*Wangi-Wangi and Kaledupa*), each with 6–8 participants comprising small-scale fishers and local processors. Secondary data were gathered from official reports. International sources included peer-reviewed scientific articles and global policy reports related to fisheries, trade, and sustainability. As the study involved no medical or psychological intervention, ethical clearance was not required, but all procedures adhered to ethical guidelines for social research.

To enhance methodological robustness, the study adopted a triangulation process, combining qualitative interviews and FGDs with quantitative validation. Thematic analysis was used to identify recurring patterns across stakeholder narratives, while quantitative data, such as post-harvest loss percentages, export volumes, and infrastructure indicators, were used to verify causal links. Key variables were mapped in the CLD using iterative loops to capture reinforcing and balancing dynamics, following techniques outlined by Flamm & Braunsberger (2022).

The resulting CLD was then validated through expert review and basic statistical testing (correlation and regression) to assess the strength and directionality of the proposed relationships. These steps allowed the identification of strategic leverage points for policy intervention, such as cold storage access, transportation networks, and training intensity. In addition, scenario simulations were conducted to explore the impact of changes in policy or infrastructure on fish export outcomes. The complete methodological flow, from data collection, triangulation, CLD development, to policy simulation, is summarized in Figure 2, serving as a visual guide for readers to follow the logic of the research design.

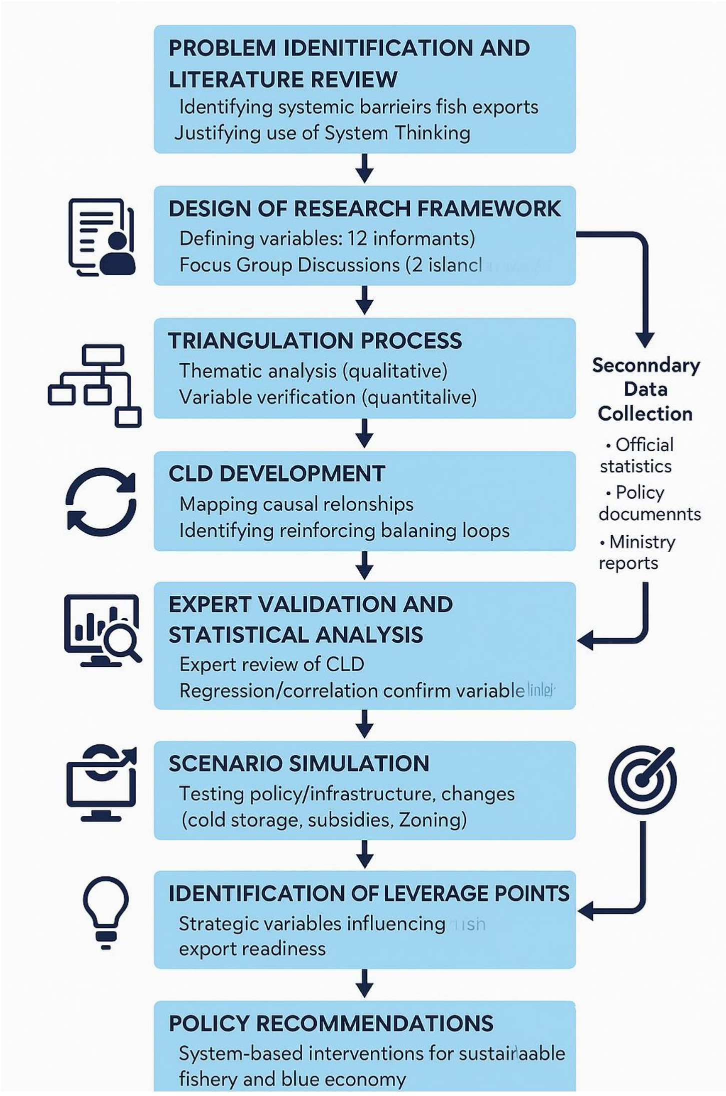

Figure 2. Flowchart of Research Methodology Step

Figure 2 presents the flowchart of the research methodology steps, visually summarizing the sequence from problem identification to policy recommendation. The process begins with a literature review and framework design, followed by primary data collection through expert interviews and FGDs, and secondary data compilation from official sources. These inputs undergo triangulation, thematic analysis, and quantitative validation, which inform the development of the Causal Loop Diagram (CLD). The CLD is then reviewed by experts and used in scenario simulations to assess the impacts of potential interventions. This structured flow enables a comprehensive understanding of systemic interactions and supports the formulation of integrated, system-based policy recommendations for sustainable fish export development.

The methodological framework illustrated in Figure 2 ensures a coherent flow from data collection to analysis, culminating in the formulation of system-based insights. Following this structured approach, the next stage of the study focuses on understanding the characteristics of key informants involved in the primary data collection. The findings and discussion begin with the profiles of respondents, which give critical context to understand the perspectives and experiences shaping the data presented in Table 1. The section describes key demographic and professional characteristics of respondents to ensure a comprehensive basis for analyzing their contributions to the study. From these profiles, the study has been able to establish the relevance and credibility of the insights gathered, thus forming the basis for subsequent analysis.

Table 1. Respondent Profiles

Expertise	Age	Experience (years)
Research in Electrical Engineering	55	25
Research in Fisheries Agribusiness	53	20
Fishing and Fish Export Management	48	15
Blue Economy Specialist	60	30

The profiles of respondents have shown a wide array of expertise with significant experiences spanning electrical engineering, fisheries, agribusiness, fish export management, and blue economy specialization. The age for the respondents ranged between 48 and 60 years, while their professional experiences ranged between 15 and 30 years. This clearly shows that the respondents have an in-depth understanding of both the technical and operational aspects of fisheries. The accumulated knowledge herein ensures a holistic understanding of sustainable fisheries management, particularly in matching technical innovation with economic and ecological objectives. In ensuring that the development of CLDs is robust, the study will incorporate various insights from several perspectives. Triangulation, as an approach, will merge data from diverse expertise and sources to further enhance the validity of identified systemic relationships. Specific triangulation sources are reflected in Table 2, demonstrating a deep base upon which to underpin the design and analysis of the CLD.

Table 2. Triangulation Source for CLD Development

Source	Key Variables	Application to CLD
Researcher in Electrical Engineering (Interview)	Port facilities (Macro), cold storage (Macro), transportation (Macro), export readiness (Macro)	Baseline variables for local infrastructure (Macro) and cold chain (Macro)
Researcher in Fisheries Agribusiness (Interview)	Cold storage facilities (Macro), transportation networks (Macro), and marine product diversification (Macro)	Integration of practical challenges into feedback loops (Macro)
Practitioner in Fish Export Management (Interview)	Ecological sustainability (Micro), cold storage (Macro), post-harvest handling (Micro)	Incorporating ecological and socio-economic feedback (Micro)
Specialist in Blue Economy (Interview)	Sustainability investments (Macro), marine resource stock (Macro & Micro), export volume (Macro), community welfare (Micro).	Sustainability investments (Macro), marine resource stock (policy-level) (Macro), export volume (Macro), Marine resource stock (community efforts) (Micro), community welfare (Micro)
Central Statistic Wakatobi (2024)	Marine biodiversity (Macro), fisheries production (Macro), infrastructure gaps (Macro)	Base variables for biodiversity (Macro) and marine resource dynamics (Macro)

Source	Key Variables	Application to CLD
Indonesian Maritime Policy	Maritime governance (Macro), sovereignty (Macro), policy integration (Macro)	Policy leverage points for governance loops (Macro)
Blue Economy Roadmap Jewel	Blue economy strategies (Macro), sustainable fisheries (Macro), aquaculture (Macro)	Strategic input for sustainability-oriented loops (Macro)
Ministry of Marine Affairs and Fisheries.	Resource management (Macro), tailored strategies (Macro), ecological preservation (Macro)	Tailored policy and governance interventions (Macro)
Ahwireng et.al. (2024); Abelti & Teka (2024).	Post-harvest losses (Micro), traditional methods (Micro), safety issues (Micro)	Feedback loops for addressing post-harvest losses (Micro)
Gul et al., (2024)	Food security (Macro), supply chain (Macro), sustainable practices (Macro)	Leverage points in supply chain efficiency (Macro)
Bisht & Singh (2024); Biondo & Burki (2020)	Cold chain systems (Macro), packaging (Macro), logistical improvements (Macro)	Cold chain nodes and system linkages (Macro)
	Dried fish value chains (Micro), socio-ecological analysis (Micro)	Socio-ecological feedback and fisheries value chain (Micro)
Nisar et al. (2024)	Export barriers (Macro), regulatory challenges (Macro), compliance (Macro)	Regulatory loops for export readiness (Macro)
Tarihoran et al. (2023)	Sustainability (Macro), ornamental fish industry (Macro), export challenges (Macro)	System dynamics for sustainability and export markets (Macro)
Sulanke et al. (2025)	Fleet segmentation (Macro), resource optimization (Macro)	Fleet management and resource allocation (Macro)
Stead (2019); Nguyen et al. (2011)	Systems Thinking (Macro), aquaculture policy (Macro), SDGs (Macro)	Policy integration for sustainable aquaculture (Macro)

The combined triangulation table brings together insights from expert opinions, questionnaire responses, and literature to pinpoint the key variables influencing fisheries governance and marine resource management. It highlights very important areas such as port infrastructure, cold storage, transportation networks, ecological sustainability, and export barriers, all from the perspective of their roles in systemic dynamics. These are basic variables that could be core to a CLD from which feedback loops concerning supply chain efficiency, policy integration, and socio-ecological balance may be analyzed. It constructs an integrated model that answers questions on interconnected challenges in fisheries management, and it is supportive of the creation of targeted and sustainable interventions. Figure 3 shows a Macro CLD of the Sustainable Fisheries System, depicting how key variables like supply chain efficiency, policy integration, and socio-ecological balance are connected through loops to address interlinked challenges and provide a focused, sustainable intervention.

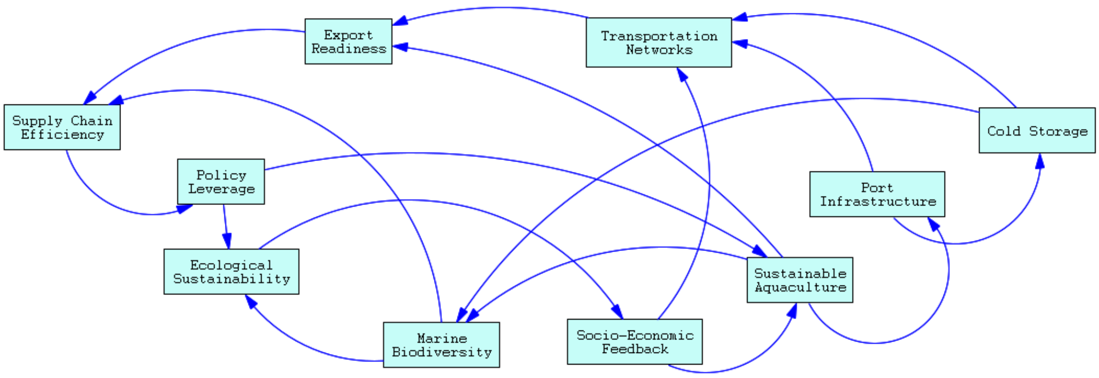

Figure 3. Macro CLD: Sustainable Fisheries System

The Macro-CLD maps the interdependence of key variables in sustainable fisheries, representing a dynamic system wherein infrastructure, ecology, policy, and socio-economic factors interact. Port infrastructure supports cold storage and transportation networks, enabling export readiness and enhancing supply chain efficiency. This efficiency facilitates policy leverage, which drives sustainable aquaculture practices, ultimately preserving marine biodiversity. Marine biodiversity fosters ecological sustainability, creating socio-economic feedback that reinforces sustainable aquaculture and benefits communities. It also secures a feedback-rich system wherein improvements in one area, say policy or infrastructure, will propagate across the system to reinforce ecological and economic resiliency. The macro-CLD displays systemic dynamics at regional and policy levels with the highlighting of critical variables in the forms of port infrastructure, cold storage, transportation networks, and supply chain efficiency (Sukiyono et al., 2023).

These are indeed interconnected variables whereby feedback mechanisms will be impacting marine biodiversity, ecological sustainability, and export readiness. The obvious illustration here is that improved port infrastructures ensure better cold storage capacities, transportation becomes easy, and it was assured of export readiness. The chain of better supply chain efficiency supports policy integration for further sustainable aquaculture investments (Mauli et al., 2023). There is a reinforcing feedback between sustainable aquaculture and marine biodiversity, with sustainable practices preserving biodiversity to ensure the availability of resources in the long run (Magambo et al., 2024). The macro CLD focuses on strategic interventions aimed at aligning infrastructure, policy, and ecological goals for sustainable governance of fisheries. Figure 4 gives a micro perspective to complement the macro view by providing the Micro CLD for a Sustainable Fisheries System, focusing on operational-level dynamics and specific interventions that drive day-to-day alignment of infrastructure, policy, and ecological practices toward sustainable fisheries governance.

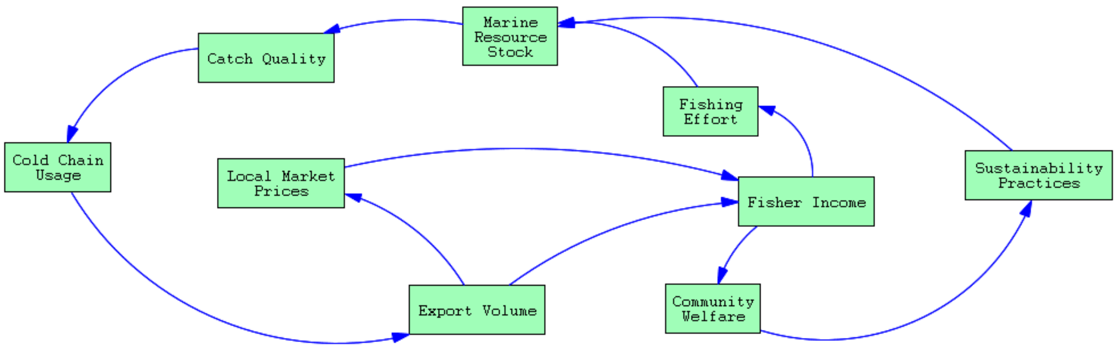

Figure 4. Micro CLD: Sustainable Fisheries System

The Micro CLD illustrates the complex feedback structure of local fisheries, balancing economic and ecological considerations. Fisher income is the driving force behind fishing effort, which in turn directly impacts the marine resource stock. Lower stock levels reduce catch quality, impacting cold chain usage and export volume, which in turn loops back into fisher income. Local market prices further drive income levels, impacting community welfare and encouraging sustainability practices. These practices contribute to replenishing the stock of marine resources, thereby closing the loop. This model emphasizes the crucial interaction among economic incentives, market dynamics, and ecological sustainability and thus requires a balanced intervention to assure long-term community welfare and resource preservation. The micro CLD represents the local and operational level of fisheries, focusing on individual and community-level variables such as fisher income, fishing effort, marine resource stock, and community welfare.

Key reinforcing feedback loops exist, like the interaction between the income of fishers and fishing effort; higher income begets more fishing, which, if not managed properly, will deplete the marine resource stocks. Catch quality and cold chain usage are critical variables that drive local market prices and export volume (Ariffien et al., 2024). Export volume, in turn, feeds into community welfare, which then drives sustainability practices. A balancing loop emerges as sustainability practices help maintain marine resource stocks, preventing overfishing and ensuring continued livelihoods. The micro CLD emphasizes the need for localized interventions in terms of training, subsidies, and community engagement to address the operational challenges. Integrating the macro and micro CLDs will provide a comprehensive framework of sustainable fisheries governance by linking policy-level strategies with operational dynamics at the grassroots level (Tezzo et al., 2021).

Key interface points, such as cold storage, transportation networks, export volume, and marine resource stock, bridge the two systems to ensure that macro-level infrastructure and micro-level community practices are aligned. For instance, the improvement in cold storage at the macro level enhances the efficiency of fishers at the micro level by reducing post-harvest losses and increasing the quality of exports (Abelti & Teka, 2024). This alignment underlines how infrastructure and policies can cascade into tangible benefits regarding fisher welfare and ecological sustainability. Feedback loops in the integrated CLD further manifest the dynamic interaction of the macro and micro systems.

Reinforcing loops, like improved cold storage, would increase export readiness, hence improving fishers' incomes while encouraging them to be more sustainable. These are somewhat offset by balancing loops, such as overfishing at the micro level, where macro policies will hopefully reduce it to ensure resource availability in the long term. This dynamic integration underlines that interventions should be done in tandem, with grassroots feedback informing regional policy for integrated achievement of ecological, economic, and social objectives. The integration of macro and micro CLDs has pointed out crucial interdependencies from systemic strategies and community-level action. With a focus on shared variables like transportation infrastructure and marine resource stock, policymakers could devise interventions to balance ecological health and economic growth by adopting a holistic approach; such practical solutions, scalable to fisheries management, could foster regional sustainability and community welfare accordingly (Figure 5).

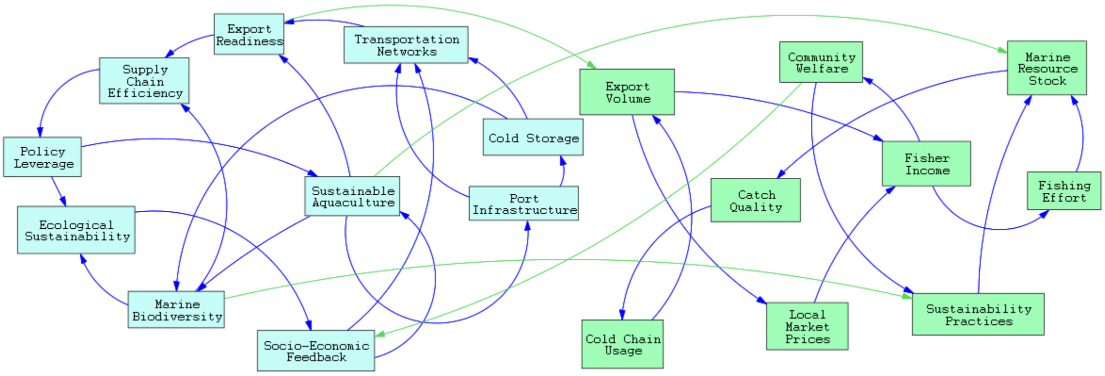

Figure 5. Integrated Macro–Micro Causal Loop Diagram (CLD) of Fish Export Determinants within the Blue Economy Framework

The fully integrated CLD connects macro and micro systems through direct and interface relationships, creating a comprehensive model of sustainable fisheries. Examples of macro elements that directly relate to micro-level variables include infrastructure and policy leverage to ecological sustainability, influencing fisher income, marine resource stock, and community welfare. Interface connections, such as export readiness linking to export volume and socioeconomic feedback connecting to community welfare, ensure that high-level policies translate into localized impacts. This integration underlines the interdependence of economic, ecological, and social factors, while flagging the need for interventions that are coordinated across scales to enhance sustainability, improve livelihoods, and maintain ecological balance. The enhanced Policy-CLD structure will be based on this understanding to create a systemic framework that connects policy-level strategies with operational and community-level dynamics in response to these interdependencies. It illustrates visually how such relationships spotlight key leverage points and feedback loops for actionable insights into achieving sustainable fisheries management (Figure 6).

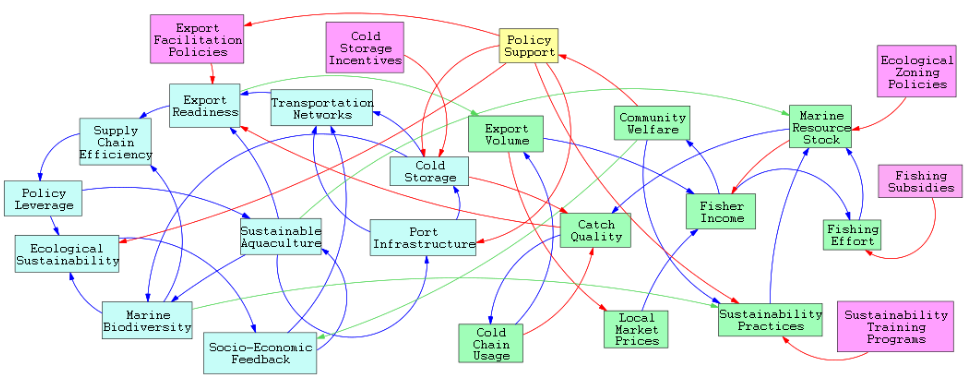

Figure 6. CLD enhanced with policies

The policy-enhanced CLD integrates macro, micro, and policy variables that present a comprehensive model of sustainable fisheries management. Policy interventions, such as fishing subsidies, ecological zoning, and export facilitation, directly act on key variables like fishing effort, marine resource stock, and export readiness, creating feedback loops that impinge on fisher income, sustainability practices, and community welfare. Macro-micro interactions in, for example, cold storage related to cold chain usage and export volume, harmonize infrastructure and market dynamics. Policies towards sustainability training at the enterprise level improve ecological balance, while export policies make it competitive in the market. This would point out how relevant policies bridge macro-level infrastructure with the micro-level livelihood and underline the need for articulate strategies toward ecological preservation, economic growth, and community resilience.

For incorporating targeted policies into the framework for fisheries management, such critical leverage points align systemic strategies with localized needs. For example, fishing subsidies address fishers' income and might aim to increase it through an increase in fishing effort. In the absence of safeguards, this leads to the over-exploitation of marine resource stocks. To this end, subsidies need to be coupled with ecological zoning policies and sustainability training programs so that economic benefits are not realized at the expense of environmental degradation. This balance creates a system where short-term gains align with long-term ecological and economic goals. Ecological zoning is an important strategy toward marine biodiversity conservation, thereby stabilizing resource availability. Zoning creates separate areas for fishing and conservation to ensure sustainable use of resources while considering the livelihood of fishers. However, these policies need good enforcement mechanisms and collaboration among stakeholders to ensure compliance. Success depends on community-level involvement to create buy-in and accountability, especially in regions where fishing involves a core livelihood activity (Bennett et al., 2024).

Cold storage incentives significantly enhance post-harvest quality, reducing losses and improving export readiness. These policies have a trickling effect, improving export volume and enhancing local market competitiveness. However, their success depends on infrastructure investments and access to reliable energy. Meeting these fundamental needs will help make cold storage facilities accessible to small-scale fishers, closing the gap between policy intent and operational practice. Export facilitation policies simplify export procedures and provide tax incentives, enhancing global market positioning for fisheries products. These policies improve fisher income and community welfare, creating a positive feedback loop that drives economic growth. However, alignment with international standards and regulatory compliance is essential for maximizing these opportunities. Policymakers must also ensure that these regulations do not disadvantage small-scale fishers, who often lack the resources to meet stringent export requirements.

Along with these policies, sustainability training programs foster environmentally friendly practices among fishers. This reduces environmental degradation, replenishes marine resource stocks, and builds balancing loops to counteract the increased fishing effort caused by subsidies. For added value, training should be both localized and inclusive, concerned with specific needs within the fishing communities. Coupled together in a systemic framework, governance of fisheries can achieve a balanced development in economic growth, community welfare, and ecological sustainability. This balance would necessitate a clear-cut strategy that should guide the implementation and assure the relevance of the policies to macro and micro objectives. To validate these methods, data-driven insights are crucial to their effectiveness and consistency with real economic and ecological outcomes. Statistical analysis plays a very important role in providing important evidence on how key variables interact and thereby shows patterns and trends that inform policy decisions. Further, this data supports identification of trade-offs between economic growth and sustainability and gives a backdrop against which to evaluate long-term impacts (Figure 7).

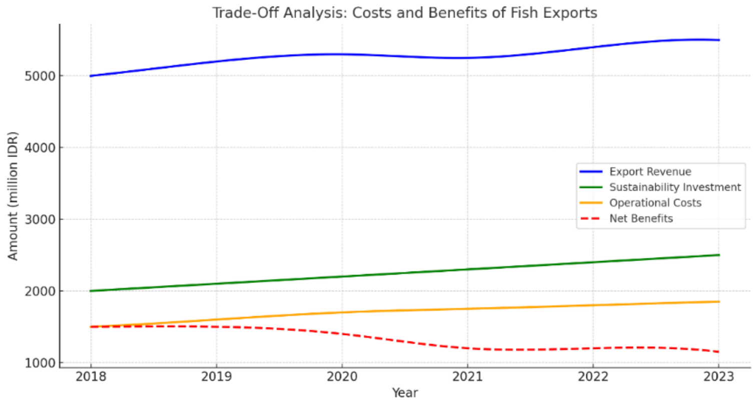

Figure 7. Trade-Off Analysis: Costs and Benefits of Fish Exports
Source: Blue Economy Roadmap, 2023

The percentage analysis shows that 60-65% of the total economic value is contributed by export revenue, indicating that Wakatobi is dependent on the international demand for its products. Sustainability investments are growing at an annual growth rate of 4.5% and now represent 25-30% of revenue, reflecting a high commitment to resource sustainability. Operational costs stand at 25-28%, which indicates efficient management, but net benefits have declined from 40% in 2018 to 32% in 2023, influenced by increased sustainability spending. This trend underlines the trade-off between short-term profits and long-term ecological and economic resilience and, by showing the systemic interplay of revenue, costs, and sustainability efforts, confirms the findings from the CLD and triangulation. These insights provide a basis for integrating policy variables into the model that strategic interventions are necessary to address these trade-offs and foster sustainable fisheries management.

It is with the integration of policy variables that targeted interventions become highlighted for fostering sustainable fisheries. Policies aimed at facilitating subsidies for fishing and exports directly enhance fishing effort, export readiness, and fisher incomes while incentivizing ecological balance through zoning and sustainability training programs. These are the means that make sure that investments in macro-level infrastructure, such as cold storage and transportation networks, actually align with improved cold chain usage, better quality catches, and more export volumes. Linking community welfare with policy support, such interventions feed back into a self-sustaining circle of social and ecological benefits.

For such policy intervention to achieve the greatest impacts, multi-stakeholder collaboration among the government, fishers, and the private sector is key. There is a need to ensure regular monitoring and evaluation mechanisms that can determine how the policy is working, especially regarding the goal of resource stock conservation and community welfare. For investment in eco-friendly technology, emphasis would be placed on energy-efficient cold storage and sustainable fishing tools. Such diversification of marine-based products can add value to the economy at the local level and reduce overdependence on single export commodities. Finally, policies must involve fishers as active participants to ensure ownership and compliance, strengthening the link between policy objectives and practical outcomes. By integrating sustainability into economic strategies, this approach creates a feedback loop that reinforces long-term growth, aligning seamlessly with the CLD simulation's emphasis on linking ecological preservation to economic advancement.

The simulation based on CLD stresses the need for feedback that links sustainability to economic growth. Wakatobi will be able to strengthen its position in the production of premium-quality fisheries in world markets by linking cold storage efficiency, targeted market expansion, and ecological zoning policies. Such an integrated strategy not only reduces risks across different scenarios but also provides strong, long-term benefits to the regional economy and sustainability endeavors. In all, this is visualized in Figure 8, which highlights scenario-based simulations of cold storage, PHL reduction, premium market growth, return on investment (ROI) from ecological zoning policy, and fisher training as examples of how these mechanisms interactively work together to foster sustainable fisheries development.

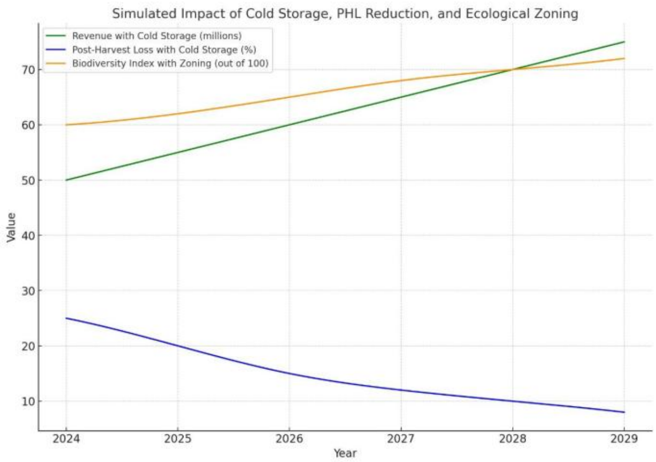

Figure 8. Simulation: Impacts of Cold Storage, PHL Reduction, Premium Market Growth, and ROI from Ecological Zoning Policies and Fisher Training

The implementation of cold storage technology has significantly increased fishermen's income, rising from IDR 50 billion in 2024 to IDR 75 billion in 2029, a 50% growth over six years. This indicates that the technology enables fishermen to access premium markets better, thereby enhancing the value of their products. At the same time, the post-harvest loss (PHL) rate has drastically decreased from 25% in 2024 to just 8% in 2029, representing a 68% reduction. This decrease reflects improved management efficiency, ensuring that the quality of harvested products is maintained until they reach consumers. Positive impacts are also evident in the sustainability of marine ecosystems. The biodiversity index increased from 60 in 2024 to 72 in 2029, showing a 20% improvement. The ecological zoning policies implemented successfully protect marine resources and maintain a healthy ecosystem, supported by fishermen training that encourages sustainable fishing practices. Overall, the combination of cold storage, ecological zoning, and fishermen training provides balanced economic, social, and environmental benefits. Income increases, losses decrease, and the environment remains preserved, creating sustainability that supports the long-term welfare of fishing communities. This positive synergy highlights the importance of integrating economic, social, and environmental strategies, as illustrated in Figure 9, which simulates the combined impacts of cold storage, post-harvest loss reduction, premium market growth, and sustainable policies on production and export outcomes.

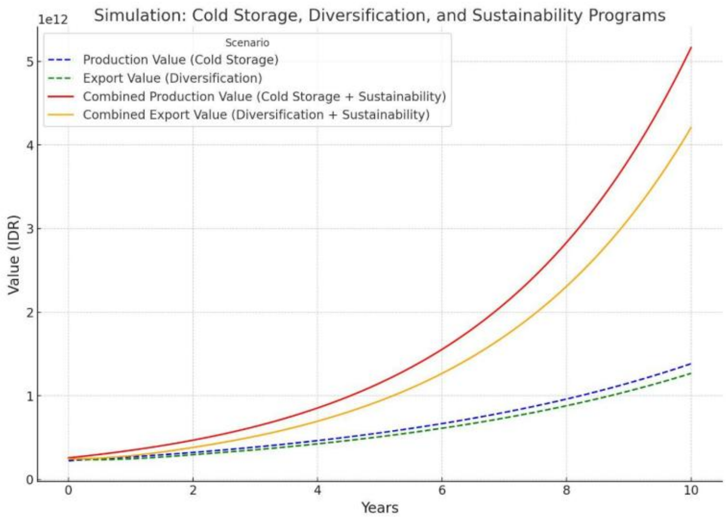

Figure 9. Simulation: Cold Storage, Market Diversification, and Sustainability on Fishery Production and Exports

A holistic approach, combining cold storage, market diversification, and sustainability, shows significant impacts on fishery production and exports in Wakatobi across three scenarios. In the optimistic scenario, with strong market growth at 15% per year and with maximum implementation of sustainability initiatives, production value increases to nearly 3.74 times its original value, or increases by 274%, while export value grows to 3.32 times, or up by 232%. The most probable scenario, with medium market growth of 10% per year, shows more than a doubling of production value to 2.5 times higher, an increase of 150%, while export value doubles, an increase of 100%. Even in the pessimistic scenario, assuming slower market growth of 5% annually and limited policy support, production value increases to 1.8 times higher, an 80% increase, while export value rises by 50%, underlining the robustness of these strategies. This integrated approach not only secures immediate economic benefits but also lays a strong foundation for sustainable development, aligning perfectly with the phased implementation process outlined in the roadmap to enhance and sustain fish exports.

The roadmap to enhance and sustain fish exports is focused on a phased implementation process-balancing immediate economic gains with sustainability in the long term. In the first two years, efforts focus on strengthening infrastructure through modern cold storage and improved transportation networks, while also implementing ecological zoning and fishing quota policies. By year four, energy-efficient technologies, digital supply chain systems, and market certifications for sustainable products are introduced. Diversification of products and markets follows by year six, with the launch of value-added goods and expansion into alternative markets. Long-term strategies include continuing the updating of policies, monitoring stocks of marine resources, positioning Wakatobi as an internationally recognized leader in sustainable fisheries by year ten, to ensure ecological preservation while fostering economic resilience (Figure 10).

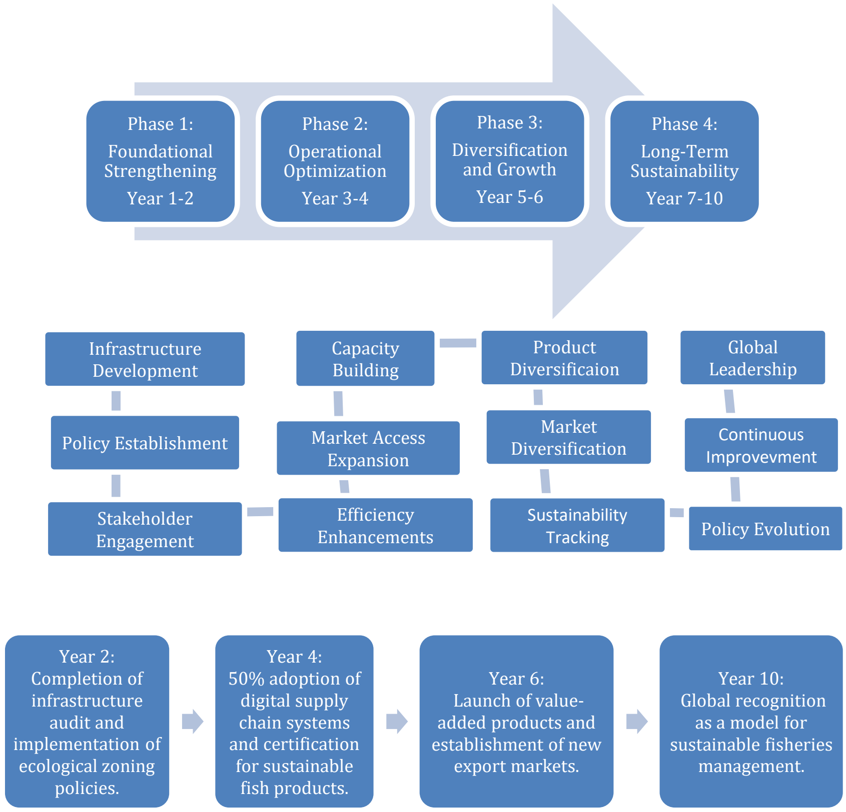

Figure 10. Fish Export Roadmap Flowchart

To validate these strategies, data-driven insights are essential to measure their effectiveness and align them with real-world economic and ecological outcomes. Statistical analysis provides crucial evidence for understanding how key variables interact, revealing patterns and trends that inform policy decisions. Furthermore, this data allows the identification of trade-offs between economic growth and sustainability, and thus lays a foundation for evaluating long-term impacts shown in Figure 11.

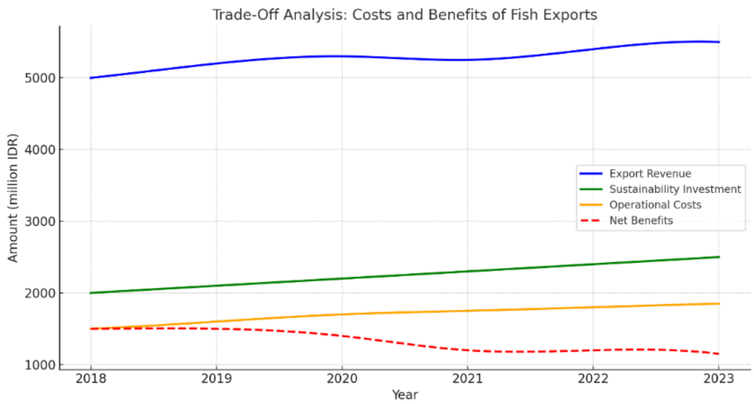

Figure 11. Trade-Off Analysis: Costs and Benefits of Fish Exports
Source: Blue Economy Roadmap, 2023

The percentage analysis highlights that export revenue contributes 60-65% of the total economic value in Wakatobi, emphasizing its reliance on global demand. Sustainability investments, growing at 4.5% annually, now represent 25-30% of revenue, showcasing a strong commitment to resource preservation. Operational costs remain stable at 25-28%, reflecting efficient management, but net benefits have declined from 40% in 2018 to 32% in 2023, driven by increased sustainability spending. This trend reveals the trade-off between short-term profits and long-term ecological and economic resilience, hence validating the findings of the CLD and triangulation through the systemic interplay of revenue, costs, and sustainability efforts. The integration of policy variables into this insight illustrates the need for strategic interventions in these trade-offs for sustainable fisheries management.

The integration of policy variables underlines the critical role targeted interventions play in fostering sustainable fisheries. Policies such as fishing subsidies and export facilitation directly enhance fishing effort, export readiness, and fisher income, while incentivizing ecological balance through zoning and sustainability training programs. These measures ensure that macro-level infrastructure investments, such as cold storage and transportation networks, are indeed aligned with micro-level economic outcomes like increased usage of cold chains, better-quality catches, and higher export volumes. By linking community welfare to policy support, these interventions reinforce a feedback loop where the social and ecological benefits drive long-term sustainability.

The depth of the impact of such policies necessitates multi-stakeholder collaboration among governments, fishers, and the private sector. Regular monitoring and evaluation mechanisms should be implemented to measure policy effectiveness, particularly in terms of resource stock preservation and community welfare. Besides, investment in eco-friendly technology, such as energy-efficient cold storage and sustainable fishing gear, is needed. Diversification of marine-based products can also add value to local economies and reduce reliance on single export commodities. Finally, policies have to involve fishers as active participants to ensure ownership and compliance, hence strengthening the link between policy objectives and practical outcomes. This approach ensures balanced economic growth, ecological preservation, and community resilience. This approach provides the framework for analyzing the findings and discussion that highlight its effectiveness in achieving sustainable and impactful outcomes.

FINDINGS AND DISCUSSION

Cold Storage as a Strategic Leverage Point

Cold storage emerged as a central leverage point in both macro and micro CLDs due to its direct impact on product quality, post-harvest losses, and export readiness. Expert input and triangulated data consistently identified inadequate cold storage as a bottleneck in reaching premium export markets. Similar findings were observed by Bisht & Singh (2024) and Ariffien et al. (2024), emphasizing that cold chain infrastructure plays a decisive role in improving export competitiveness. Investment in cold storage was shown to enhance the efficiency of supply chains, particularly when combined with fisher training and policy incentives. This aligns with Flamm & Braunsberger's (2022), assertion that infrastructural nodes act as reinforcing points in systemic models. Therefore, addressing cold storage inadequacies not only raises income but also triggers positive socio-economic feedback loops that contribute to long-term sustainability.

Balancing Economic Incentives and Sustainability

The findings indicate that economic growth policies, such as fishing subsidies and export incentives, can be double-edged. While they elevate fisher income and improve export volume, unregulated implementation risks accelerating resource depletion. This supports the warning from (Tezzo et al., 2021), who emphasize the need to couple economic incentives with ecological safeguards. In this study, the CLD simulation demonstrated that ecological zoning and sustainability training can serve as balancing loops that prevent overfishing and resource exhaustion. Such integration of policies at the macro level with behavioral change at the community level creates a harmonized approach that enhances both biodiversity and long-term profitability. Furthermore, this dynamic shows how policy design must internalize ecological thresholds and not merely pursue short-term economic gains.

Export Facilitation and Inclusiveness in Policy Design

Export policies were shown to significantly improve export volume and international positioning, yet access remains unequal among fishers. This reflects the structural disadvantages faced by small-scale operators, as also discussed by Alam et al. (2024). Interview responses emphasized the need for inclusive capacity-building programs that align smallholders with global standards. Without such alignment, there is a risk of deepening inequality in value distribution, undermining the goal of community welfare. The research supports policy recommendations that integrate export facilitation with simplified compliance mechanisms, market linkage support, and inclusive training. This ensures that macro-level export growth translates into community-level welfare gains.

Integrated Dynamics in Macro-Micro CLDs

The integration of macro and micro CLDs revealed crucial interfaces such as cold storage, marine resource stock, and export volume. Improvements in infrastructure (macro) were shown to affect fisher income and sustainability practices (micro), confirming the reinforcing and balancing loops mapped in the CLD. These findings support Stead (2019) and Mauli et al. (2023), who emphasize that infrastructure-policy alignment is key to adaptive governance in marine systems. Moreover, scenario simulations (Figures 8–9) showed that the combination of cold storage investment, sustainability training, and ecological zoning yielded optimal results in production growth, biodiversity index, and export value, even in pessimistic growth scenarios. This validates the robustness of the integrated systemic approach used in this study.

Trade-Offs and Strategic Implications

Quantitative analysis revealed that while export revenues contribute 60–65% of Wakatobi's economic value, sustainability investments are steadily increasing. However, a decline in net benefits from 40% in 2018 to 32% in 2023 (Figure 11) suggests a trade-off between profitability and long-term resilience. This echoes the findings of Nisar et al. (2024) and Bennett et al. (2024) that emphasize the importance of aligning short-term economic goals with environmental investments. The simulation models and CLD structures collectively suggest that policies must be adaptive and based on feedback mechanisms to remain effective across changing ecological and market dynamics.

CONCLUSIONS

This study fulfilled its objective of identifying key determinants of fish exports in Wakatobi by applying a qualitative Systems Thinking approach. Through the development of macro and micro Causal Loop Diagrams (CLDs), the study demonstrated how infrastructure, particularly cold storage, policy design, and sustainability training, interact as leverage points within an integrated system. The findings confirm that export readiness is not solely a matter of production capacity but emerges from the dynamic interaction between economic incentives, ecological balance, and community participation. Practical implications from this research point to the need for multi-level interventions that harmonize infrastructure development with regulatory coherence and behavioral change at the grassroots level. Policymakers are encouraged to adopt feedback-informed strategies, such as combining fishing subsidies with sustainability training and ecological zoning, to ensure that economic growth is aligned with long-term resource preservation. This study also emphasizes the value of system-based modeling for guiding adaptive governance in the fisheries sector, particularly under the framework of a sustainable blue economy.

LIMITATION & FURTHER RESEARCH

Despite offering rich insights, this study has limitations that should be addressed in future research. First, the analysis is context-specific, relying on expert interviews and secondary data from Wakatobi, which may limit its generalizability to other regions. Second, the use of static CLDs does not allow for dynamic simulations that can quantify long-term impacts of policy interventions over time. Future research should incorporate system dynamics modeling to test policy scenarios under changing ecological and market conditions. Expanding the research to include comparative case studies across different coastal regions could improve external validity and offer broader policy lessons. Additionally, integrating innovative tools such as agent-based modeling or market-based instruments (e.g., blue carbon credits) could enrich the analytical depth and support more actionable, cross-sectoral recommendations. Addressing these areas will contribute to more robust and scalable solutions for sustainable fisheries governance.

REFERENCES

Abelti, A. L., & Teka, T. A. (2024). Intervening fish post-harvest losses to narrow the gap between demand and supply: A review on magnitude of fish post-harvest losses in some Sub-Saharan African countries. *Aquaculture, Fish and Fisheries, 4*(2), Article e168. https://doi.org/10.1002/aff2.168

Abu Samah, A., Maruf, A., Ahmad, N., & Hamsan, H. (2023). Patron-client relationships and transformative capacity: A case study of Bajau fishers in Wakatobi, Indonesia's response to climate change. *Journal of Marine and Island Cultures, 12*(3), Article 18. https://doi.org/10.21463/jmic.2023.12.3.18

Ahwireng, A. K., Bavinck, M., Onumah, E. E., Pouw, N., & Nunoo, F. K. E. (2024). Post-harvest travels of marine fish: How small fish food systems variously support food security and nutrition in coastal and inland cities in Ghana. *Tijdschrift voor Economische en Sociale Geografie, 115*(3), 418–438. https://doi.org/10.1111/tesg.12626

Alam, M. M., Haque, M. M., & Santi, M. (2024). Barriers to the export of farmed Pangasius and Tilapia from Bangladesh to the international market: Evidence from primary and secondary data. *Aquaculture Journal, 4*(4), 293–315. https://doi.org/10.3390/aquacj4040022

Ariffien, A., Sudirman, I., & Juniati, A. T. (2024). The influence of sustainable captured fish supply chain management on the quality of sea-caught fish exports. *Ilomata International Journal of Management, 5*(1), 320–339. https://doi.org/10.52728/ijjm.v5i1.1041

Bennett, M., March, A., & Failler, P. (2024). Blue economy financing solutions for the fisheries and aquaculture sectors of Caribbean island states. *Fishes, 9*(8), Article 305. https://doi.org/10.3390/fishes9080305

Biondo, M. V., & Bürki, R. (2020, May). *Regulating the trade in marine ornamental fish: The case of Indonesia*. Workshop on Marine Ornamental Fishes, Brisbane, Australia. Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Bisht, A., & Singh, S. P. (2024). Postharvest losses and management of horticultural produce: A review. *Journal of Scientific Research and Reports, 30*(3), 305–320. https://doi.org/10.9734/jsrr/2024/v30i31881

Das, J. (2023). Blue economy, blue growth, social equity and small-scale fisheries: A global and national level review. *Studies in Social Science Research, 4*(1), 38–50. https://doi.org/10.22158/sssr.v4n1p38

Dirman, E. N., Harahab, N., Semedi, B., & Rachmansyah, A. (2024). Analysing factors influencing the sustainable fishing port model in East Java Province, Indonesia. *Journal of Water and Land Development*, (61), 139–149. https://doi.org/10.24425/jwld.2024.151561

Dsouza, A., Mishra, A. K., & Webster, S. (2023). Vertical coordination and post-harvest losses: Implications on food loss. *Applied Economic Perspectives and Policy, 45*(1), 460–486. https://doi.org/10.1002/aepp.13210

Emam, M. A., Leibrecht, M., & Chen, T. (2021). Fish exports and the growth of the agricultural sector: The case of South and Southeast Asian countries. *Sustainability, 13*(20), Article 11177. https://doi.org/10.3390/su132011177

Flamm, R. O., & Braunsberger, K. (2022). Systems thinking to operationalize knowledge-to-action in fish and wildlife agencies. *Conservation Science and Practice, 4*(9), Article e12774. https://doi.org/10.1111/csp2.12774

Gul, S., Shafiq, U., Mir, S. A., Iqbal, G., & Lone, H. Q. (2024). Enhancing global food security through sustainable fisheries and aquaculture: A comprehensive review. *Asian Journal of Agricultural Extension, Economics & Sociology, 42*(10), 60–70. https://doi.org/10.9734/ajaees/2024/v42i102563

Komlatsky, G. (2024). Aquaculture—Driver of the fisheries industry. *E3S Web of Conferences, 541*, Article 03006. https://doi.org/10.1051/e3sconf/202454103006

Maflahah, I., Asfan, D. F., & Omar, E. N. (2024). Design of the compliance of halal assurance system criteria for smoked fish processing in small and medium enterprises (SMEs) in Bangkalan Regency. *BIO Web of Conferences, 146*, Article 01054. https://doi.org/10.1051/bioconf/202414601054

Magambo, E., Nyamwesa, A., Mgulunde, A., & Magasi, C. (2024). Factors affecting succession planning in family-owned fish trading SMEs in Mwanza City, Tanzania. *International Journal of Research in Business and Social Science, 13*(2), 84–97. https://doi.org/10.20525/ijrbs.v13i2.3094

Mauli, S., Thow, A.-M., Mulcahy, G., Andrew, G., Ride, A., & Tutuo, J. (2023). Opportunities to strengthen fish supply chain policy to improve external food environments for nutrition in the Solomon Islands. *Foods, 12*(4), Article 900. https://doi.org/10.3390/foods12040900

Nguyen, N. C., Graham, D., Ross, H., Maani, K., & Bosch, O. (2012). Educating systems thinking for sustainability: Experience with a developing country. *Systems Research and Behavioral Science, 29*(1), 14–29. https://doi.org/10.1002/sres.1097

Nisar, U., Zhang, Z., Wood, B. P., Ahmad, S., Ellahi, E., Ul Haq, S. I., ... Fathi Abd-Allah, E. (2024). Unlocking the potential of blockchain technology in enhancing the fisheries supply chain: An exploration of critical adoption barriers in China. *Scientific Reports, 14*(1), Article 10167. https://doi.org/10.1038/s41598-024-59167-4

Nuradzani, D., Hadiroseyani, Y., Effendi, I., & Budiardi, T. (2024). Ornamental fish marketing at Laladon Ornamental Fish Exchange, Bogor, West Java. *Jurnal Syntax Transformation, 5*(9), 1122–1132. https://doi.org/10.46799/jst.v5i9.1001

Olaoye, O., Ojebiyi, W., & Adenika, O. (2024). Assessment of socio-demographic predictors of fish farmers' access to formal credit sources in Ogun West Senatorial District, Nigeria. *The Philippine Journal of Fisheries*, 95–108. https://doi.org/10.31398/tpjf/31.1.2021-0029

Saediman, H., Yana, W. O., Hidrawati, H., Yunus, L., Alwi, L. O., Alam, S., & Mboe, I. S. (2024). Economic analysis of flying fish roe harvesting: The case of Wakatobi fishers operating in the Aru Islands, Maluku Province. *BIO Web of Conferences, 112*, Article 11002. https://doi.org/10.1051/bioconf/202411211002

Statistics Indonesia (BPS) Wakatobi Regency. (2024). *Wakatobi Regency in figures 2024*.

Stead, S. M. (2019). Using systems thinking and open innovation to strengthen aquaculture policy for the United Nations Sustainable Development Goals. *Journal of Fish Biology, 94*(6), 837–

844. https://doi.org/10.1111/jfb.13970

Sulanke, E., Rubel, V., Berkenhagen, J., & Bernreuther, M. (2024). Amending the European fishing fleet segmentation based on machine learning and multivariate statistics. *Fisheries Research, 281*, 107190. https://doi.org/10.1016/j.fishres.2024.107190

Sukiyono, K., Rhomdon, M. M., Nabiu, M., & Windirah, N. (2023). Risk management in micro, small, and medium enterprises: An empirical analysis of SMEs dried fish in Bengkulu Province. *Jurnal Ilmiah Perikanan dan Kelautan, 15*(1), 106–120. https://doi.org/10.20473/jipk.v15i1.38409

Tarihoran, A. D. B., Hubeis, M., Jahroh, S., & Zulbainarni, N. (2023). Competitiveness of and barriers to Indonesia's exports of ornamental fish. *Sustainability, 15*(11), Article 8711. https://doi.org/10.3390/su15118711

Tezzo, X., Bush, S. R., Oosterveer, P., & Belton, B. (2021). Food system perspective on fisheries and aquaculture development in Asia. *Agriculture and Human Values, 38*(1), 73–90. https://doi.org/10.1007/s10460-020-10037-5

Valenza, G., Zoppelletto, A., & Fazio, G. (2024). Family SMEs and managerial approaches to sustainability in the blue economy. *Journal of Management & Organization, 30*(3), 521–544. https://doi.org/10.1017/jmo.2023.32

Wahyuni, D., Nazaruddin, Amalia Frastika, S., & Budiman, I. (2021). Performance measurement of tempeh crackers supply chain management using halal criteria on SCOR model. *E3S Web of Conferences, 332*, Article 04002. https://doi.org/10.1051/e3sconf/202133204002

Wardhani, D. K., & Noviaristanti, R. (2023). Post-harvest handling training for fishery MSMEs as a strategic effort to strengthen the fishery product value chain. *Journal of World Science, 2*(2), 163–168. https://jws.rivierapublishing.id/index.php/jws/article/view/502

Zapata, N. R. J., Sarmiento, J. A. C., & Cruz, M. B. (2023). Development of smart food value chain intervention models for the milkfish industry in Region 1, Philippines. *Asian Journal of Agriculture and Development, 20*(1), 87–108. https://doi.org/10.37801/ajad2023.20.1.6