# THE OPTIMIZATION STRATEGY OF FISHERY WASTE IN SUMENEP REGENCY AS A VALUE-ADDED PRODUCT BASED ON THE CIRCULAR ECONOMY

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## ABSTRACT

The fisheries sector in Sumenep Regency plays a vital role in food security and the local economy, but generates substantial waste, including fish heads, bones, viscera, and skins. Most of these residues are discarded into the sea or landfills, creating environmental burdens and economic losses. This study aims to formulate a strategy for optimizing fishery waste based on circular economy principles using a sequential explanatory mixed-methods approach. The quantitative phase employed multiple linear regression to examine the effects of business duration, technology, and average catch on waste utilization. Results indicate that technology significantly influences utilization ($p < 0.01$), whereas business duration and catch volume are not significant. The qualitative phase, involving in-depth interviews and focus group discussions, reinforced these findings by revealing that limited access to simple processing technologies, weak market linkages, and inadequate regulations remain the main obstacles. Nevertheless, respondents recognized the potential of fish waste to be converted into organic fertilizer, animal feed, fish oil, and collagen. This study concludes that appropriate technology, market access, and regulatory as well as multi-stakeholder collaboration are crucial for implementing a circular economy model in Sumenep's fisheries sector. The practical implication suggests strengthening community capacity and policy support to advance sustainable fishery waste valorization.

Keywords : Fishery Waste; Circular Economy; Appropriate Technology; Sumenep; Mixed Methods

## *ABSTRAK*

*Sektor perikanan di Kabupaten Sumenep memainkan peran penting dalam ketahanan pangan dan perekonomian lokal, tetapi menghasilkan limbah yang cukup besar, termasuk kepala, tulang, jeroan, dan kulit ikan. Sebagian besar residu ini dibuang ke laut atau tempat pembuangan akhir (TPA), sehingga menimbulkan beban lingkungan dan kerugian ekonomi. Penelitian ini bertujuan untuk merumuskan strategi optimalisasi limbah perikanan berbasis prinsip ekonomi sirkular menggunakan pendekatan metode campuran eksplanatori sekuensial. Tahap kuantitatif menggunakan regresi linier berganda untuk menguji pengaruh durasi usaha, teknologi, dan rata-rata hasil tangkapan terhadap pemanfaatan limbah. Hasil menunjukkan bahwa teknologi berpengaruh signifikan terhadap pemanfaatan ($p < 0,01$), sedangkan durasi usaha dan volume tangkapan tidak signifikan. Tahap kualitatif, yang melibatkan wawancara mendalam dan diskusi kelompok terfokus (FGD), memperkuat temuan ini dengan mengungkapkan bahwa keterbatasan akses terhadap teknologi pengolahan sederhana,* *lemahnya keterkaitan pasar, dan regulasi yang tidak memadai tetap menjadi kendala utama. Meskipun demikian, responden menyadari potensi limbah ikan untuk dikonversi menjadi pupuk organik, pakan ternak, minyak ikan, dan kolagen. Studi ini menyimpulkan bahwa teknologi tepat guna, akses pasar, serta kolaborasi regulasi dan multipihak sangat penting dalam penerapan model ekonomi sirkular di sektor perikanan Sumenep. Implikasi praktisnya adalah penguatan kapasitas masyarakat dan dukungan kebijakan untuk memajukan valorisasi limbah perikanan yang berkelanjutan.*

*Kata Kunci : Limbah Per*ikanan; Ekonomi Sirkular; Teknologi Tepat Guna; Sumenep; Metode Campuran

## INTRODUCTION

The fisheries sector in Indonesia, particularly in coastal regions such as Sumenep Regency, East Java, plays a key role in national food security and economic development. Sumenep, a central area for fish production, makes a significant contribution to both local consumption and national supply chains. However, the sector's productivity is accompanied by an important issue: a substantial volume of fishery waste, including fish bones, shells, skins, and internal organs, is generated. These by-products, often underutilized or discarded, contribute to environmental pollution and inefficient resource utilization, underscoring the need for improved management practices (Gill et al., 2025).

Sumenep Regency—situated on eastern Madura, Indonesia—generates substantial fishery waste (heads, bones, viscera, scales), constituting an estimated 30–40 % of total catch weight. These by-products are often discarded, resulting in environmental burdens and lost economic potential. Existing waste valorization techniques (bioconversion, silage, composting) have been demonstrated in Indonesian studies. Still, no context-specific strategy has been developed for Sumenep that aligns circular economy principles with local realities.

This issue highlights a missed opportunity to extract value from what is traditionally considered waste. Within the framework of a circular economy, which emphasizes the sustainable use of resources, waste minimization, and closed-loop systems, fishery waste can be transformed into high-value products, including fishmeal, organic fertilizers, collagen, and bioactive compounds. Such innovations not only enhance environmental sustainability but also open new economic avenues, particularly for local communities, making them integral to the process (Suning et al., 2022).

Optimising fishery waste aligns with Indonesia's sustainable development goals, especially in the areas of responsible consumption and production, economic growth, and marine ecosystem conservation. Implementing circular economy strategies in Sumenep is a complex task that requires a multifaceted approach. This involves the adoption of appropriate technologies, strengthening policy frameworks, raising community awareness, and improving infrastructure for waste collection and processing. Stakeholder collaboration, particularly among local governments, fish processing industries, research institutions, and coastal communities, is critical in driving systemic chang (Yusuf et al., 2024).

Furthermore, the successful transformation of fishery waste into valuable products can contribute to job creation, improve public health through reduced environmental hazards, and enhance the economic resilience of the fishery sector. Case studies from other regions demonstrate that, with the right investments and training, small-scale processors and local entrepreneurs are not only key players but also the driving force behind waste valorisation, thereby creating a localised circular economy model (Wibowo et al., 2023).

In the context of Sumenep Regency, where the fishery sector remains central to livelihoods, the strategy for optimising fishery waste must be grounded in local realities while drawing on national and global best practices. This study aims to explore these strategic approaches, identify challenges and opportunities, and propose actionable recommendations that promote the development of a circular economy in the fisheries value chain, addressing an issue that requires immediate attention.

Based on the identified problem and significance, this study aims to develop a tailored strategy for optimising fishery waste in Sumenep Regency using circular economy principles. The specific objectives are to engage local stakeholders (fishermen, MSMEs, and local government) through participatory workshops to understand the barriers, opportunities, and preferences for valorisation pathways. To design a context-sensitive strategy that integrates technological, institutional, and market elements for transforming fishery waste into value-added products (e.g., larvae meal, compost, oil). To assess the expected economic feasibility and environmental benefits, we will incorporate indicators such as the WRI (waste reduction index), yield, and possible revenue models, as per comparable studies (Tirtawijaya et al., 2024).

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## LITERATURE REVIEW

This section reviews the current literature on circular economy approaches to fishery waste valorisation, relevant technologies, and industry practices globally and in Indonesia, emphasising their applicability to Sumenep Regency.

### Fishery Waste Valorisation in a Circular Economy Framework

Caruso et al. (2020) unveil the potential of fishery wastes as a vast reservoir of valuable biomolecules (e.g., collagen, enzymes, peptides, gelatine, hydroxyapatite), advocating for marine biorefinery models that enable zero-waste output and the comprehensive valorisation of all fish residues (Purnomo et al., 2024).

Similarly, a recent review in Bioresource Technology (2025) highlights the efficiency of biorefineries in integrating the extraction of high-value products—such as collagen, fish oil, and biofuels—with energy recovery within a single industrial process, thereby ensuring maximum resource efficiency and industrial sustainability (Gill et al., 2025).

### Technological Pathways & End- Use Applications

Several reviews highlight key valorisation pathways:

- Biopolymers for food packaging (e.g., gelatine, chitosan) show great promise. However, they are currently primarily at a lab or pilot scale, with challenges related to material performance, scalability, and regulatory compliance (Lionetto & Corcione, 2021).
- Enzymes derived from fishery and aquaculture waste—such as proteases, lipases, carbohydrases, and chitinases—are valuable in biotechnology and industry. The latest advancements in the field leverage AI/ML to optimise microbial production systems and yield, keeping the industry at the forefront of technological innovation (Khiari, 2024).
- Nutrient recovery (mainly nitrogen and phosphorus) from fish sludge and processing effluent offers potential for biofertilizer production. Importantly, agronomic trials have shown that these biofertilizers perform comparably to synthetic fertilisers, although concerns about salinity and microplastic contamination remain (Zhang et al., 2023).

**Systems-Level Approaches and Policy Dimensions**

Industrial ecology concepts, such as material flow management (MFM) and industrial symbiosis, underscore the importance of resource-sharing networks and integrated logistics. These practices are enlightening the industry about sustainable operations across facilities within a local Indonesian context (Suning et al., 2022).

**Regional Examples & Applicability to Sumenep**

Although region-specific studies in Indonesia remain sparse, Suning et al.'s case in Surabaya provides a useful policy model: through stakeholder engagement and strategic prioritisation, shrimp shell/head waste was identified as a target for conversion into value-added materials, such as chitosan, and feed inputs.

Elsewhere in Southeast Asia, a study by Kurniawan et al. (2025) reviews aquaculture sludge valorisation into biofertilizers for hydroponics, algae cultivation, and compost, indicating extensible methods applicable to coastal fish-processing residues in Sumenep (Kurniawan et al., 2025).

**Synthesis and Summary**

The literature collectively supports the following insights:

1. Marine biorefinery models enable the comprehensive valorisation of fishery by-products into high-value biomaterials (e.g., fish collagen for medical applications), biofuels (e.g., biodiesel from fish oil), enzymes (e.g., protease for detergent production), and chemicals (e.g., chitin for bioplastics) under zero-waste objectives.
2. Technologies such as enzymatic extraction, supercritical $CO_2$ processing, anaerobic digestion, and biopolymer production provide multiple output streams.
3. Circular ecosystem design, involving industrial symbiosis and MFM, enhances efficiency through closed-loop logistics and shared by-product management.
4. Policy frameworks and stakeholder collaboration are not only essential but also the backbone of the marine biorefinery industry, particularly at local levels, facilitating infrastructure development, technology transfer, and environmental safeguards.
5. Applications in Indonesia, particularly Sumenep, are underexplored but show promise based on analogous regional studies, inviting further exploration and research.

**Summary of Literature Review**

This review confirms a robust foundation of scientific evidence for circular economy-based valorisation of fishery waste. While much of the innovation remains at the lab or pilot stage, the emergence of scalable biorefinery frameworks and nutrient recovery techniques is a significant development. Localised studies in Indonesia, although limited, illustrate the critical role of policy and stakeholder mobilisation. They also highlight both the opportunities and challenges for implementing a circular economy strategy tailored to Sumenep Regency.

## RESEARCH METHODOLOGY

Method is a method of work that can be used to obtain something. While the research method can be interpreted as a work procedure in the research process, both in searching for data or disclosing existing phenomena (Zulkarnaen, W., et al., 2020).

### Rationale for Innovation

This study employs a quantitative-first, sequential mixed-methods framework, integrating Gujarati's lightweight, reduced-form regression modelling with participatory qualitative inquiry. This combination is seldom used in circular economy or fishery waste studies, yet it is straightforward and cost-effective.

### Quantitative Component: Gujarati- Style Cross-Sectional Regression

Drawing from Gujarati's approach in *Essentials of Econometrics*, the quantitative phase will:

- Collect cross-sectional data from fish processors and MSMEs in Sumenep: waste inputs (kg/day), yield outputs, technology use, labour, and revenue from vaporized products.
- Use simple OLS regression models (avoiding complex matrix algebra) to estimate how key predictors (e.g., technology type, scale of operation, local support) impact vaporisation efficiency (recovery yield per kg waste).
- Include diagnostic tests easily accessible at a beginner level—e.g., tests for multicollinearity (VIF), heteroscedasticity (White or Breusch- Pagan), and specification errors (Ramsey RESET)—all clearly explained in Gujarati's text.

This quantitative modelling requires only basic software, such as Excel, EViews Student version, or SPSS, without advanced statistical capabilities, making it practical for field researchers.

### Qualitative Component: Grounding and Interpretation

Following quantitative estimation, the qualitative phase involves:

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- Conducting semi-structured interviews with key stakeholders (farmers, processors, local officials, NGO representatives) to explore the why behind statistical relationships—e.g., why specific predictors are significant, barriers to uptake, local perceptions of vaporisation practices.
- Holding focus groups and co-design workshops to validate regression findings and collaboratively interpret results in the local context.

**Integration of Methods**

- Leaf- out triangulation: regression coefficients provide directional understanding (e.g., larger MSME scale → higher yield), while interviews explain mechanisms (e.g., access to crusher machines reduces manual losses).
- Iterative feedback loop: qualitative insights may refine quantitative specifications (e.g., adding dummy variables for access to extension services) and vice versa.

**Strengths and Ease of Use**

- Low technical barrier: Gujarati's approach is accessible to researchers without a deep econometric background—no need for panel/time-series, instrumentation, or advanced mathematics.
- Novel in field application: Few waste valorisation studies employ econometric regression informed by local predictors; combining this approach with participatory qualitative methods is especially rare.
- Action-oriented: Regression identifies statistically significant factors influencing success; interviews and workshops build a strategy grounded in stakeholder realities.

**Ethical Considerations & Validity**

- Standard ethical protocols (informed consent, anonymity, data protection) will be followed.

Validity will be reinforced through: (a) regression robustness checks (Gujarati's diagnostic procedures), and (b) credibility gained from stakeholder validation during workshops.

## RESULT AND DISCUSSION

**Multiple Linear Analysis**

For testing the research hypothesis, the researcher in this case employs a data analysis tool known as multiple linear regression analysis shown in table 1.

The multiple linear regression function is as follows:

Tobacco farmers' income =

$$-0.104300 - 3.654742 + 0.132433 + 8.764137 + \mu$$

Where:

Y: Fish Waste
X1 Length of Effort
X2 : Technology
X3: Average Fish Turnover

After obtaining the results of the calculation carried out with EViews 12, the Adjusted R-squared value is 0.186881, which means that the variables of Business, Technology, and Fish Acquisition collectively affect Fish Waste in the Sumenep district by 18%. At the same time, the remaining variation is attributed to other variables not accounted for in this regression model.

**Partial Test**

Variable Length of Effort (X1)

Based on the comparison of these values, Ho was accepted, and H1 was rejected. Therefore, it can be stated that the variable of business length does not have a significant effect on Fishery Waste in Sumenep Regency.

Technology Variables (X2)

Based on the comparison of the scores, Ho was rejected and H1 was accepted. Technological variables have a significant impact on Fishery Waste in Sumenep Regency.

Variable Average Fish Catch (X3)

Based on the comparison of these values, Ho was accepted, and H1 was rejected. So the variable of fish acquisition does not have a significant effect on Fishery Waste in Sumenep Regency which can be seen in Table 2.

**Simultaneous Tests**

Table 3 shows that the Prob Level (F statistic) is 0.005709 using an α rate of 0.01 or 1% so H0 is rejected and H1 is accepted. Therefore, it can be concluded that independent variables consist of Business Length (X1), Technology (X2), and Average Fish Catch (X3). Together (Simultaneously) has a significant effect on the dependent variable, namely Fish Waste in Sumenep Regency.

**Coefficient of Determination (R2)**

From the regression results in table 4, the Adjusted R-square was obtained value of 0.186881 was obtained, indicating a significant relationship between the five independent variables (length of business, technology, and average fish acquisition) and Fishery Waste in Sumenep Regency. This means that the model explains 16.86% of Sumenep Regency's Fishery Waste, while the remaining 83.14% is explained or influenced by other variables that this model does not analyze.

**Classic Assumption Test**

**Normality Test**

Based on the table 5, the Jarque-Bera value is 0.807697, while the Probability value exceeds $\alpha = 0.01$ (1%) at 0.667745. Therefore, it can be concluded that the data is distributed normally.

**Multicollinearity Test**

Based on the table, it is concluded that there is no multicollinearity, as evidenced by each variable. Significant, because the matrix correlation value is smaller than 0.9, so it can be concluded that there is no problem of multicollinearity in the regression model.

**Heteroskedasticity Test**

Based on the table, it can be seen that the value of Chi-Square is calculated to be greater than the critical value with a certain degree of confidence, namely $\alpha = 1\%$, then there is no heteroscedasticity problem. It shows that R-squared has an R-squared probability of 0.4937, greater than the alpha value of 0.01, so there is no heteroskedasticity.

**Narrative Analysis**

**Waste**

Most of the respondents stated that fishery waste is still not appropriately managed. A common practice that occurs is to dispose of waste directly into the ocean, landfill, or to sell a small part to collectors.

*"Every day there is the rest of the head and stomach of the fish. Usually it is immediately thrown into the sea because we do not know how to process it,"* (Respondent, Fisherman, Bluto).

*"If collectors are coming, it will be sold cheaply. Otherwise, it will be thrown away,"* (Respondent, Market Trader, Gapura).

This condition highlights that knowledge and practices of waste management remain limited, and there has been no consistent application of innovation at the community level.

Most respondents still dispose of fishery waste in the sea or landfills due to the lack of a clear utilisation system. However, there are a few variations of the answer:

Respondent 1 (Fisherman, Bluto): *"I usually throw the contents of fish bellies into the sea because I do not know how to process them."*

Respondent 2 (Trader, Gapura): *"If a collector comes, I sell my fish head cheaply, but it is often wasted."*

Respondent 3 (MSMEs, Saronggi): "*I tried to make chicken feed from leftover fish, but the results were not optimal."*

**Types of Waste**

Respondents identified that the most common waste generated was fish heads, bones, stomach contents, and shells. This waste is the most significant residue of daily treatment activities.

*"In the market, there are mostly fish heads and shells left. It is all just garbage,"* (Respondent, Small Processor, Saronggi).

This shows the potential for abundant raw materials that can actually be further processed into value-added products.

Respondents mentioned that the waste that is most often produced is fish heads, stomach contents, bones, and shells.

Respondent 4 (Small Processor, Ambunte *): Most of the waste is leftover fish heads and shells. The amount can reach sacks."*

Respondent 5 (Trader, Trunks): *"The bones and stomach contents are the hardest to remove; the smell is powerful."*

**Potential Waste Utilization**

Some respondents have realized that fish waste has the potential to be processed into organic fertilizers, animal feed, collagen, and fish oil.

*"If fertilizer can be made, it must be good. The problem is that many farmers in our village need cheap fertilizer,"* (Respondent, Fisherman, Dungkek).

*"I have heard in other areas that fish waste can be used as animal feed. If there is training, I want to try it,"* (Respondent, MSMEs, Saronggi).

This awareness indicates new business opportunities at the local level, although implementation is still not optimal.

Although most of it is still disposed of, respondents are aware of the opportunities for waste utilization.

Respondent 6 (Fisherman, Dungkek): *"If fertilizer can be made, it will be very beneficial for farmers here."*

Respondent 7 (MSMEs, Saronggi): *"I want to try to make animal feed, but there needs to be training."*

Respondent 8 (Small Processor, Bluto): *"I heard that the waste could be fish oil, but we don't know how."*

**Support needed**

Respondents emphasized the need for support from the government and other parties. The most commonly mentioned forms of support are:

1. Fisheries Waste Treatment Training.
2. Market access for derivative products.
3. Affordable and straightforward technology.

*"If there is training on how to make fertilizer or feed from waste, there must be many people who are interested. But now there has never been,"* (Respondent, Small Processor, Ambunten).

*"The problem is not only that it can be made, but there must also be buyers. So market access is important,"* (Respondents, Market Traders, Bars).

Respondents emphasized the need for facilities to process waste. The most common forms of inclusion are training, simple technology, and market access.

Respondent 9 (MSMEs, Saronggi): *"If there is training on how to process waste, many are interested in participating."*

Respondent 10 (Trader, Gate): *"The important thing is that there are buyers. If the product does not sell, it is useless."*

**Key Challenges**

From the analysis, the biggest challenges in the utilization of fishery waste are:

- **The market** → have difficulty selling products.
- **Regulations** → lack of supporting policies.
- **Technology** → limitations of processing tools.

*"If the product exists, but no one buys it, it is useless. That's our main problem,"* (Respondent, Fisherman, Gate).

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*"The regulations are not clear. The government should be able to make rules that support MSMEs who process waste,"* (Respondent, MSMEs, Saronggi).

Limited, and a lack of regulation.

Respondent 11 (Fishermen, Sticks): *"Products from waste may be made, but the market does not exist yet."*

Respondent 12 (MSMEs, Saronggi): *"Processing machines are expensive, we cannot afford to buy them ourselves."*

Respondent 13 (Fisherman, Ambunten): "*There are no clear rules from the government to manage fishery waste."*

**Discuss**

The results of the questionnaire show that the use of fishery waste in Sumenep Regency is still minimal. Most respondents admitted that garbage, including fish heads, bones, stomach contents, and shells, is generally disposed of directly into the sea or landfill. At the same time, a small part is sold to collectors. This condition indicates a low level of innovation and public awareness in the processing of waste into value-added products. These findings align with the study by Gill et al., (2025), which highlights that without technological and policy interventions, waste management practices often result in discharges that create an environmental burden.

Nevertheless, there is awareness among respondents about the economic potential of fishery waste. Some mention that waste can be used to make organic fertilizers, animal feed, collagen, and fish oil. This realization presents opportunities for the transition to a marine-based circular economy model, as outlined by Purnomo et al., (2024), that fish biomass has the potential as raw materials for collagen, enzymes, and environmentally friendly biopolymers.

However, this opportunity is hampered by various factors. In terms of technology, the primary concern is the limitation of simple tools to process waste into new products. This is reinforced by the regression analysis in this study, which shows that technology has a significant effect on waste treatment capabilities. These findings are consistent with Khiari (2024), who emphasizes that the development of biotechnology-based enzymes and technologies from fish waste requires continuous research support and technology transfer.

In addition, the market is a significant challenge. Many respondents emphasized that although products from waste can be produced, without market guarantees, the results are not sustainable. This market challenge aligns with the findings of Zhang et al. (2023), which indicate that although organic fertilizers and biofertilizers derived from fish waste exhibit good agronomic performance, their commercialization is hindered by limited distribution access and consumer skepticism.

In terms of policy, respondents considered that government regulations and support were inadequate. In fact, various studies Suning et al., (2022) emphasized that regulatory support, incentives, and collaboration between stakeholders largely determine the success of a fisheries-based circular economy. Without structural support, waste treatment efforts by fishermen and MSMEs will be challenging to survive.

Furthermore, the results of the questionnaire also show the urgent need for training, simple technology, and market access. This is consistent with the findings of Kurniawan et al., (2025) in the Southeast Asian aquaculture sector, that the success of waste valorisation is highly dependent on building the capacity of local communities and supporting infrastructure. Thus, the fishery waste optimization strategy in Sumenep must focus on capacity building, the provision of appropriate technology, and integration with local and national markets.

Overall, the results of this study show that although awareness of the potential utilization of fishery waste has begun to emerge, market, technological, and regulatory challenges still dominate. Therefore, the implementation of the local circular economy model by involving multi-stakeholder collaboration (government, MSMEs, universities, and NGOs) is a strategic step to optimise the utilisation of fishery waste in Sumenep Regency. This model not only has the potential to increase people's incomes but also reduces environmental burdens and supports the achievement of the Sustainable Development Goals (SDGs).

**Integration of Quantitative and Qualitative Findings**

Regression analysis showed that the technology variable had a significant effect on the utilisation rate of fishery waste ($p < 0.01$). In contrast, the variables of length of effort and average catch were not substantial. These findings are consistent with qualitative results, where respondents emphasised the limitations of simple tools and high costs as the main obstacles. Respondents stated:

*"The processing machine is expensive, we cannot afford it ourselves."* (Respondent, Saronggi MSMEs).

Thus, from both quantitative and qualitative perspectives, technology has proven to be a key factor in the optimisation of fishery waste. This is in line with Khiari (2024), who emphasises the importance of simple technology transfer to encourage the fisheries bio-economy.

**Market Challenges and Regulation**

Qualitative findings reveal that Market Access has become the dominant obstacle. Respondents repeatedly asserted that without a clear market, waste utilisation cannot be sustainable. This strengthens the analysis o fZhang et al. (2023), which states that the commercialisation of biofertilizers and fishery waste derivative products is still hampered by consumer hesitancy and limited distribution.

In addition, respondents highlighted the lack of regulation that supports MSMEs that process waste. In fact, the literature Suning et al. (2022) emphasises that the success of the circular economy is greatly influenced by the existence of incentive policies, quality standards, and supporting infrastructure.

**Utilisation Potential and Economic Opportunities**

Respondents are aware of the great potential of fishery waste to be processed into organic fertilisers, animal feed, fish oil, and collagen. These findings support the international literature (Caruso et al., 2020; Gill et al., 2025), which emphasised that fish waste is a reservoir of valuable biomolecules (proteins, collagen, bioactives) that can be treated through *the marine biorefinery* model.

However, there is still a gap between public awareness and implementation capabilities. As stated by respondents: *"If fertiliser can be made, it will be beneficial. But we do not know how."* (Respondent, Dungkek Fisherman).

This shows that the technical capacity of the community needs to be strengthened so that economic opportunities can be realised.

**Multi-Party Support and Collaboration**

The support that respondents needed the most was waste treatment training, appropriate technology, and market access. This condition confirms that the waste optimisation approach must be based on multi-stakeholder collaboration. Local governments are expected to play the role of regulators and facilitators, NGOs and universities as training and research providers, and MSMEs and fishermen as the leading actors in implementation.

These findings reinforce the study of Kurniawan et al. (2025), which shows that the success of bio-circular in the Southeast Asian aquaculture sector is highly dependent on strengthening local capacity and collaborative networks.

**Theoretical and Practical Implications**

Theoretically, the results of this study enrich the literature on the circular economy in the fisheries sector, especially in the context of Indonesia's coastal areas, where there is still a lack of empirical studies. In practical terms, these results indicate that:

Simple technologies (e.g., shredders, household-scale fermentation) need to be adopted immediately. Market access must be strengthened through regulations, product branding, and distribution networks. Collaboration between actors is the foundation of sustainability, involving the government, MSMEs, academics, and the community.

**Conclusion of the Discussion**

The mixed method approach in this study provides a comprehensive overview: quantitative emphasises the significance of technological factors, while qualitative deepens understanding of market challenges, regulations, and support needs. With a circular economy-based strategy, the use of fishery waste in Sumenep has the potential to not only reduce pollution but also open up new economic opportunities, increase the income of fishermen and MSMEs, and support the achievement of the SDGs.

## CONCLUSION

This study confirms that the fisheries sector in Sumenep Regency has great potential in circular economy-based waste management, but its utilization practices are still very limited. Quantitative analysis shows that technology is the most significant factor in optimizing fishery waste, while the length of business and average catch do not have a significant effect. Qualitative findings reinforce this, where limited access to simple technology, weak market access, and a lack of regulations and policy support are the main obstacles.

Although most waste is still disposed of directly into the sea or landfills, local businesses are aware of the opportunities to utilize waste into value-added products such as organic fertilizer, animal feed, fish oil, and collagen. However, this awareness has not been matched by technical capabilities, infrastructure, or market guarantees.

Therefore, the strategy for optimizing fishery waste in Sumenep must focus on strengthening community capacity through training and mentoring, providing simple and affordable appropriate technology, and improving market access through regulation, product branding, and distribution networks. In addition, multi-stakeholder collaboration between the government, academics, NGOs, businesses, and fishermen is essential to ensure sustainability.

The implementation of this circular economy-based strategy has the potential not only to increase the income of fishermen and MSMEs but also to reduce the environmental burden and support the achievement of the Sustainable Development Goals (SDGs).

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## GAMBAR, GRAFIK DAN TABEL

Table 1. Multiple Linear Regression

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| Long Term of Effort | -0.104300 | 0.099525 | -1047977 | 0.3001 |
| Technology | -3.654742 | 1.151751 | -3.173026 | 0.0027 |
| Average Fish Turnover | 0.132433 | 0.075819 | 1.746709 | 0.0874 |
| C | 8.764137 | 1.817521 | 4.822027 | 0.0000 |
| R-squared | 0.236664 | | | |
| Adjusted R-squared | 0.186881 | | | |

Table 2. Partial Test

| Dependent Variable | Independent Variables | Coefficient | Std. error | Prob. | Conclusion/Results of the T Test | |
|---|---|---|---|---|---|---|
| Fishery Waste | Length of Time (X1) | -0.104300 | 0.099525 | 0.3001 | Insignificant | Accepting H0 Resisting H1 |
| | Technology (X2) | -3.654742 | 1.151751 | 0.0027 | Significant | Reject H0 Accept H1 |
| | Average Fish Catch (X3) | 0.132433 | 0.075819 | 0.0874 | Insignificant | Accepting H0 Resisting H1 |

Table 3. Simultaneous Tests

| | |
|---|---|
| F-statistic | 4.753932 |
| Prob(F-statistic) | 0.005709 |

Table 4. Coefficient of Determination (R2)

| Type | R-squared | Adjusted R-squared |
|---|---|---|
| 1 | 0.236664 | 0.186881 |

Table 5. Normality Test

| Type | Jarque-Bera | Probaility |
|---|---|---|
| 1 | 0.807697 | 0.667745 |

Table 6. Multicollinearity Test

| | (X1) | (X2) | (X3) |
|---|---|---|---|
| (X1) | 1 | 0.035194 | 0.133145 |
| (X2) | 0.035194 | 1 | -0.018510 |
| (X3) | 0.133145 | -0.18510 | 1 |

Table 7. Heteroskedasticity Test

| Heteroskedasticity Test: Breusch-Pagan-Godfrey | | | |
|---|---|---|---|
| F-statistic | 0.812251 | Prob. F(3.46) | 0.4937 |
| Obs *R-Square | 2.515397 | Prob. Chi-Square (3) | 0.4425 |
| Scaled explaned SS | 1.896087 | Prob. Chi-Square (3) | 0.5943 |