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TOWARDS SUSTAINABLE COASTAL FINANCE: THE ROLE OF ESG IN BLUE BOND ELIGIBLE SEAWEED AQUACULTURE

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Abstract

Seaweed aquaculture in coastal areas is a strategic sector supporting Indonesia's maritime economic resilience. However, its sustainability remains challenged by ecological pressures, limited access to financing, and a lack of widespread adoption of sustainability-oriented business practices. This study examines the contribution of Blue Bonds to the sustainability of seaweed aquaculture systems, with particular attention to the mediating role of Environmental, Social, and Governance (ESG) indicators. An explanatory quantitative approach was employed using Partial Least Squares Structural Equation Modeling (PLS-SEM), based on survey data from 100 seaweed farmers in South Sulawesi. The findings indicate that Blue Financing positively influences sustainable seaweed farming practices. However, there is insufficient evidence to support a significant mediating effect of ESG, suggesting that ESG principles have yet to be fully integrated at the farmer level. The effectiveness of blue financing is still heavily influenced by institutional capacity and cross-sectoral support. To optimize ESG's role as a transformative catalyst, strategies such as institutional strengthening, adoption of adaptive technologies, and cross-sectoral policy interventions are crucial. This study offers both theoretical and practical contributions to the development of a more contextual and applicable Blue Finance framework for sustainable marine sector development in Indonesia.

Keywords: Blue Bond; ESG; Seaweed Aquaqulture; Maritime Economic.

INTRODUCTION

Indonesia, the world's largest archipelagic nation, is endowed with abundant marine and fisheries resources, particularly in the aquaculture subsector. With an estimated aquaculture potential of approximately 17.91 million hectares, the sector is considered strategic for promoting sustainable maritime economic growth (Alamsyah, 2023). Its economic value is estimated to exceed USD 250 billion annually (KKP, 2024). According to the (FAO, 2024), Indonesia ranked third globally in aquaculture production in 2022 after China and India contributing approximately 7% of total global output. Domestically, production has followed a positive growth trajectory, increasing from 16.97 million tons in 2023 to 17.17 million tons in 2024, signaling the sector's vital role in national food security, coastal livelihoods, and the advancement of maritime-based MSMEs. However, Indonesia's aquaculture development continues to face structural and environmental constraints that challenge its sustainability. Critical issues include climate change, disease outbreaks, coastal ecosystem degradation, and limited access to modern, efficient cultivation technologies. One of the most pressing barriers is the lack of financing options for small-scale producers. Inability to provide collateral, coupled with high perceived business risks and low financial literacy among stakeholders, limits credit distribution. Consequently, many farmers persist with inefficient traditional methods that often worsen environmental degradation (Riany et al., 2023).

To address these challenges, the Blue Economy and Blue Finance approaches have gained growing attention as integrated and sustainable development frameworks. The Blue Economy emphasizes the responsible use of marine resources to support economic growth while preserving ecosystem integrity and improving the welfare of coastal communities. Complementing this approach, Blue Finance serves as a financing mechanism designed to support sustainable ocean-related projects through instruments such as Blue Bonds, blended finance, and investments guided by Environmental, Social, and Governance (ESG) principles (Choudhary et al., 2021). However, the implementation of Blue Finance in Indonesia remains constrained by several key barriers, including the limited recognition of the marine sector's contributions in national development planning, the absence of standardized investment criteria for sustainable marine projects, and the low efficiency and inclusiveness of financial markets (Sumaila et al., 2021). On the fiscal side, the national budget (APBN) can only cover approximately 20–25% of the estimated USD 1.6 trillion financing needs of the marine sector (Kusumawardhani et al, 2023). Therefore, integrating Blue Finance into national development policy, strengthening governance, and creating incentives for private sector participation has become increasingly urgent (Shiiba et al., 2022a).

Seaweed farming is one of the most strategic aquaculture subsectors in supporting the coastal economy of Indonesia. This commodity not only serves as a primary income source for coastal households but also contributes to various industrial sectors, such as food, pharmaceuticals, and cosmetics. Furthermore, it plays a significant ecological role in blue carbon absorption. According to data from the Ministry of Marine Affairs and Fisheries (KKP), Indonesia is the world's largest producer of aquaculture-based seaweed, with a high concentration of production in eastern regions such as South Sulawesi, East Nusa Tenggara, and Maluku. Despite its potential, the sector continues to face sustainability challenges such as limited market access, global price fluctuations, inadequate post-harvest technology, and environmentally unsound farming practices.

Amidst these challenges, the emergence of Blue Bonds as a sustainable financing instrument offers a new opportunity to address the funding gap in the aquaculture sector. This has sparked growing interest in evaluating the feasibility of seaweed farming projects through the lens of ESG principles, which are increasingly regarded as global standards for impact-based financing (Avramov et al., 2021). This study specifically explores the influence of ESG principles and the adoption of circular economy practices on the feasibility of seaweed aquaculture projects in securing Blue Bond financing. The novelty of this research lies in the integration of the ESG framework and circular economy into the discourse on cooperative-based aquaculture financing. Practically, this study provides data-driven guidance for preparing project proposals aligned with blue financing standards and theoretically contributes to the development of a sustainable finance framework in Indonesia's marine sector.

Langford et al., (2023), in a study by the Partnership for Australia-Indonesia Research (PAIR), investigated the sustainability and growth of the seaweed industry in South Sulawesi. According to KKP publications, Sulawesi Island is the largest seaweed-producing region in Indonesia, with nearly all of its provinces making significant contributions to national production. The seaweed industry holds substantial potential to support coastal economies, with thousands of households relying on this sector. While most current seaweed production is focused on carrageenan for the food industry, Indonesia processes relatively little of its own seaweed and primarily exports it as raw material, much of which is refined in countries such as China. China has made substantial investments in modern seaweed processing facilities, giving it a competitive edge in the global market. To unlock Indonesia's full potential, several areas must be improved: enhancing transparency and efficiency in the supply chain, strengthening research and development (R&D), providing technical support, and addressing the social and environmental impacts of marine space use. The PAIR report offers critical insights for policymakers in designing a sustainable seaweed industry strategy that meaningfully contributes to national economic growth.

TABLE.1 SEAWEED AQUACULTURE CONTRIBUTION REPORT
(10 Largest Seaweed Producing Regions)

No.	PROVINCE	AVERAGE PRODUCTION (2019-2023) - in tons	AVERAGE VALUE (2019-2023) - in rupiah
1	Sulawesi Selatan	3.656.062	10.004.678.929
2	Nusa Tenggara Timur	1.622.024	4.712.158.387
3	Sulawesi Tengah	777.127	3.357.280.576
4	Nusa Tenggara Barat	735.948	2.647.514.081
5	Jawa Timur	678.276	2.702.032.019
6	Kalimantan Utara	602.070	1.290.951.851
7	Maluku	405.844	1.555.915.369
8	Sulawesi Tenggara	344.939	1.692.767.678
9	Sulawesi Utara	264.431	792.782.959
10	Maluku Utara	97.777	576.750.013

Author Source (2025)

The table presents the average production and economic value of seaweed cultivation from 2019 to 2023 across ten key provinces in Indonesia. South Sulawesi ranks first, with the highest average annual production of 3,656,062 tons and a cumulative economic value of IDR 10.004 trillion over five years. This positions South Sulawesi as the leading province in terms of national contribution to seaweed cultivation. This dominance is not solely attributed to production volume, but also to supply chain efficiency and institutional support particularly through coastal cooperatives and relatively advanced logistics infrastructure compared to other regions. The data offers a geographical perspective on the contribution of each province to Indonesia's seaweed sector, measured in both tonnage and economic output. South Sulawesi emerges as a focal point for ESG-based Blue Finance project development due to its economic scale, skilled labor availability, and potential for integration with downstream processing and export-oriented programs.

Field observations further underscore the strategic role of coastal cooperatives in operationalizing Blue Finance. A case study from South Sulawesi illustrates how cooperatives function not only as economic entities, but also as catalysts for capacity building, technical assistance, and market access for seaweed farmers. Through cross-sectoral collaboration with academics, local governments, and development partners, these cooperatives have established a platform for inclusive, community-driven Blue Finance. This model offers a transformative pathway for bridging the financing gap and promoting sustainable aquaculture systems. In this context, the present study aims to examine how Blue Finance mechanisms can be effectively structured and implemented to support sustainable aquaculture in Indonesia. Theoretically, the study contributes to the growing body of literature on ESG and the Blue Economy. Practically, it offers actionable policy recommendations for government agencies, financial institutions, and local stakeholders to strengthen a more inclusive and resilient Blue Finance ecosystem.

In practice, integrating ESG principles into business strategies, risk management systems, and disclosure practices is critical to reinforcing the financial sector's role in transitioning toward a greener, more sustainable economy. However, the lack of standardized definitions, limited availability of ESG-related data, and an underdeveloped regulatory framework pose significant implementation challenges (Coleton et al., 2020). Folqué et al., (2021) highlight the importance of sustainable investment in managing ESG risks. They emphasize strategies such as impact investing and stakeholder engagement, which are considered more effective than negative screening in reducing ESG-related risks. Their study also underscores the necessity for accurate and transparent ESG data in guiding sound investment decisions. The impact investing approach is particularly relevant to the Blue Bond concept, as it targets investments that yield measurable positive outcomes for the environment and society. Blue Bonds, as sustainable financial instruments, can support seaweed-based projects that aim to reduce carbon emissions, conserve coastal ecosystems, and empower local communities. This conceptual alignment supports the development of an ESG-aligned Blue Bond investment model that adheres to the core principles of sustainability. As a form of thematic bond, Blue Bonds prioritize Environmental, Social, and Governance (ESG) objectives. These instruments require rigorous transparency in fund allocation and impact reporting to ensure that funded projects deliver tangible, long-term sustainable benefits (Halim, 2023).

Brakel et al., (2021) highlight the importance of utilizing and conserving marine genetic resources for sustainable seaweed aquaculture, a sector that is rapidly expanding, particularly in coastal nations such as Indonesia and the Philippines. Key challenges include limited understanding of seaweed genetic diversity and insufficient investment in breeding programs. The study emphasizes the role of selective breeding and genetic engineering techniques in enhancing seaweed resilience, adaptability, and genetic variation (Troell et al., 2023).

In the context of ESG and Blue Bonds, such breeding initiatives represent viable investment opportunities that align with sustainability objectives. Blue Bonds can be leveraged to finance research activities, breeding laboratories, and innovations in genetic resource management. These efforts have the potential to enhance the global competitiveness of Indonesia's seaweed industry while simultaneously conserving marine biodiversity and preserving coastal ecosystems. Despite the growing interest in sustainable finance, there remains a critical gap in comprehensive research assessing the feasibility of applying Blue Bonds as a financing mechanism for ESG-aligned projects in the seaweed sector. While Blue Bonds have emerged as a promising tool to mobilize capital for ocean-based sustainability initiatives, their application within specific community-based aquaculture contexts such as seaweed cultivation in Indonesia remains underexplored.

This study seeks to address this gap by developing and examining a tailored model of Blue Bond financing that integrates Environmental, Social, and Governance (ESG) principles into the operational and investment logic of seaweed aquaculture. Specifically, the research aims to investigate how the potential of Blue Bonds can be effectively optimized to finance seaweed farming initiatives that meet ESG criteria. It also explores the key drivers that influence investor confidence in such instruments, including the robustness of sustainability practices, ESG disclosure standards, and the perceived viability of projects within the broader blue economy framework.

Additionally, this research examines the mediating role of the blue economy itself in reinforcing the relationship between ESG performance, long-term sustainability, and the investment feasibility of Blue Bond-financed projects. In doing so, it seeks to clarify whether and how blue economy dynamics can amplify the impact of ESG factors on investor decisions and project success. By addressing these dimensions, this study makes a timely and significant contribution to the literature on sustainable finance, particularly within the context of coastal and aquaculture development. It not only provides theoretical insight into the interaction between ESG, blue economy policy, and thematic bonds, but also offers practical guidance for policymakers, financial institutions, and development stakeholders in designing inclusive, scalable, and context-specific blue financing frameworks. Ultimately, the findings are expected to support the establishment of stronger financial foundations for the sustainable transformation of Indonesia's coastal economies.

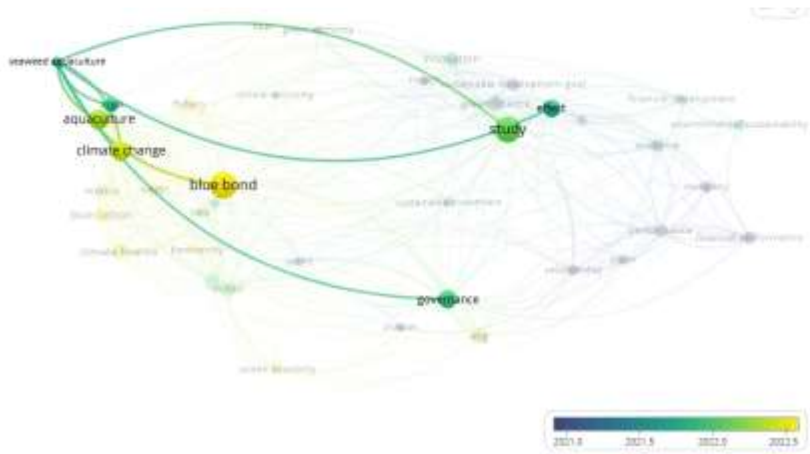

Figure 1. Conceptual Framework

Recent bibliometric analysis (see Figure 1) highlights “blue bonds,” “aquaculture,” “climate change,” and “governance” as prominent global research themes. However, terms such as “seaweed aquaculture” and “circular economy” appear less frequently and remain marginal in scope indicating a significant yet underexplored research gap. In particular, the integration of Environmental, Social, and Governance (ESG) principles and circular economy practices within smallholder-led seaweed farming systems has yet to be systematically investigated, especially in the context of eligibility for Blue Bond financing. This study addresses that gap by examining how ESG compliance and circular practices can collectively enhance the feasibility of community-based aquaculture projects under sustainable blue finance frameworks.

This research contributes to the growing body of literature on sustainable blue finance by offering an empirical and practical framework for aligning inclusive aquaculture systems in Indonesia with global ESG and sustainability standards. Unlike prior studies that often treat ESG and Blue Bonds as separate policy discourses or focus solely on large-scale marine conservation efforts, this study emphasizes their intersection at the micro level specifically within smallholder-driven seaweed farming communities. The study’s key finding that ESG does not significantly mediate the relationship between Blue Economy financing and project feasibility further underscores a critical implementation gap. It reveals that while ESG frameworks exist at the policy level, they are not yet adequately operationalized at the community level, which calls for deeper institutional support and cross-sectoral interventions. From a literature perspective, four critical gaps can be identified. First, most studies on Blue Bonds focus on macroeconomic or sovereign-level financing, such as marine infrastructure or national conservation programs, with limited exploration of small-scale, community-based aquaculture systems. This is a pressing issue in Indonesia, where over 80% of aquaculture producers are smallholders operating outside formal capital markets. Second, while ESG has become a dominant metric in sustainable investing, its practical application in coastal aquaculture particularly among seaweed cooperatives remains underdeveloped. There is limited knowledge on how ESG criteria can be adapted and integrated into the daily operations and financing structures of such entities. Third, there is a lack of integrated models that connect circular economy principles (e.g., waste minimization, regenerative production) with ESG compliant Blue Bond frameworks. This intersection is especially promising for seaweed, given its low ecological footprint and multi-sectoral utility. Fourth, bibliometric analysis reveals that research on “seaweed aquaculture” is still fragmented and lacks conceptual alignment with broader themes of sustainable finance and marine governance in Southeast Asia.

To address these gaps, this study delivers several key contributions. First, it presents one of the first empirical investigations into the feasibility of Blue Bond financed projects in smallholder seaweed aquaculture using data from 100 farmers in South Sulawesi. Second, it develops a multidimensional framework that incorporates ESG indicators and circular economy concepts into the evaluation criteria for Blue Bonds, bridging financial feasibility with ecological and social value. Third, it applies Partial Least Squares Structural Equation Modeling (PLS-SEM) to test ESG's mediating role, revealing the disconnect between sustainability frameworks and ground-level implementation. Fourth, the study offers practical policy recommendations, particularly the use of coastal cooperatives as institutional vehicles to facilitate ESG-compliant project aggregation, reduce financial risk, and improve access to Blue Finance. Fifth, by focusing on South Sulawesi a region with the highest national seaweed production the study provides contextual relevance and offers a scalable model that can be replicated in other coastal areas across Indonesia and the Global South. In sum, this study not only addresses a scholarly blind spot but also presents a grounded, locally relevant approach for enhancing the effectiveness and inclusivity of Blue Bond instruments in supporting sustainable seaweed aquaculture.

LITERATURE REVIEW AND HYPOTHESIS FORMULATION

LITERATURE REVIEW

2.1. Blue Economy and Seaweed Aquaculture

The ocean economy commonly referred to as the Blue Economy encompasses all economic activities that are directly or indirectly linked to the ocean. This includes a diverse range of sectors such as fisheries, aquaculture, marine biotechnology, coastal tourism, maritime transport, and ocean-based renewable energy. The Blue Economy presents numerous opportunities for socio-economic advancement and the sustainable diversification of coastal livelihoods (Mathew et al, 2021). It also includes emerging sectors driven by marine science and technology, as well as initiatives in environmental protection and ecosystem restoration. As a sustainable development paradigm, the Blue Economy emphasizes the responsible utilization of ocean and coastal resources to achieve a balanced approach to economic growth, social equity, and the conservation of marine ecosystems (World Bank, 2023). Similar to the broader concept of the Green Economy of which it is a subset the Blue Economy advocates the sustainable use of natural capital while minimizing adverse impacts on marine environments. Investing in a sustainable Blue Economy reflects a growing recognition of the ocean's economic and ecological value, as well as the urgent threats posed by climate change, overexploitation, and marine pollution (Katharine Thoday, 2023).

Indonesia, with its abundant marine resources and strong performance in aquaculture particularly seaweed has the potential to become a global leader in sustainable ocean-based industries. However, unlocking this potential requires innovative financial mechanisms. Blue Economy Financing refers to targeted financial strategies that mobilize public and private capital to support marine-based activities that are environmentally responsible and socially inclusive (Katharine Thoday, 2023). In the Indonesian context, such financing mechanisms are increasingly seen as critical to bridging the funding gap in the marine and fisheries sector gaps that cannot be covered by the national budget alone (Kusumawardhani et al, 2023).

In particular, the seaweed industry, which is largely dominated by smallholder farmers, stands to benefit significantly from Blue Finance. It can facilitate access to capital for upgrading cultivation practices, adopting sustainable technologies, and strengthening cooperative-based business models. This is particularly important in Indonesia, where small-scale producers often face structural barriers such as the lack of collateral and limited financial literacy (Riany et al., 2023). When implemented through inclusive institutions such as coastal cooperatives, Blue Economy Financing holds transformative potential not only to empower grassroots communities but also to contribute to marine ecosystem restoration.

2.2. Blue Bonds as a Sustainable Financial Instrument

Blue Bonds are debt instruments issued to mobilize funding for projects that support the sustainability of marine and coastal ecosystems. These bonds are specifically designed to finance initiatives such as marine resource conservation, habitat protection, and climate change mitigation and adaptation in coastal areas (Roth,et.al, 2019). As a thematic extension of green and sustainability bonds, Blue Bonds provide a targeted mechanism for channeling investment into ocean-related projects critical to achieving the Sustainable Development Goals (SDGs), particularly SDG 14: Life Below Water (Katharine Thoday, 2023).

Blue Bonds require a structured framework that includes clear criteria for the use of proceeds, measurable impact indicators, and transparent ESG-based reporting in accordance with international standards such as those set by the (ICMA, 2021). According to (Shiiba et al., 2022), Blue Bonds can play a pivotal role in bridging the financing gap in marine and coastal sectors by leveraging private investment aligned with national sustainability and climate targets. In the context of seaweed aquaculture, Blue Bonds offer the potential to finance sustainable cultivation systems, ecosystem restoration, research and development, and the establishment of inclusive, community-based value chains. However, the effectiveness of Blue Bond implementation depends on the presence of bankable projects, compliance with ESG standards, and the capacity to demonstrate verifiable environmental and social outcomes (Avramov et al., 2022).

More broadly, sustainable finance refers to investment and financial management practices that incorporate environmental, social, and governance considerations into decision-making processes. Unlike conventional finance, which prioritizes short-term returns, sustainable finance emphasizes long-term value creation by integrating ESG risks and opportunities (Coleton et al., 2020). As awareness of climate change and corporate responsibility grows, sustainable finance is gaining traction as a mainstream approach. Nevertheless, its further development requires regulatory support, standardization in impact assessment, and broader integration into global financial markets (Cunha et al., 2021).

2.3. ESG (Environmental, Social and Governance) Integration in Aquaculture

The concept of ESG (Environmental, Social, and Governance) serves as a critical framework in the financial sector for evaluating sustainability related risks and opportunities in investment decision-making. ESG encompasses three core dimensions environmental responsibility, social equity, and governance accountability which collectively provide a comprehensive measure of a company's or project's long-term sustainability and its broader impact on society and the environment (Klerk, 2023). Within the context of the blue economy, ESG principles function as essential benchmarks for assessing the investment readiness and sustainability of projects, particularly those in marine and coastal sectors. In aquaculture, environmental criteria refer to minimizing habitat destruction, reducing pollution, promoting biodiversity conservation, and adopting climate-resilient practices. The social dimension includes community engagement, equitable labor practices, and the empowerment of small-scale producers. Governance indicators relate to transparency, regulatory compliance, traceability, and institutional accountability (Folqué et al., 2021b).

Despite the rising relevance of ESG in global investment portfolios, its practical application in smallholder aquaculture systems such as seaweed farming in Indonesia remains underdeveloped. Several studies indicate that limited ESG integration at the grassroots level can undermine project viability, even when sustainable finance instruments like Blue Bonds are available (Coleton et al., 2020). This highlights the need to understand the mediating role of ESG in improving project bankability and ensuring that Blue Bond financed initiatives align with sustainability goals.

ESG is more than a theoretical construct; it is a measurable framework increasingly used by credit rating agencies and investors to evaluate organizational performance across these three dimensions. The framework involves a wide array of indicators, including carbon emissions, labor rights, stakeholder engagement, and managerial transparency. However, the absence of a globally standardized definition of ESG presents a challenge. Rating agencies often apply their own methodologies, leading to inconsistencies in ESG scoring and assessment (Berg & Madsen, 2020). In the context of Blue Bonds, ESG compliance is vital to ensure that funded projects meet rigorous sustainability standards. ESG criteria help ensure that investments do not result in environmental degradation or social exclusion, but instead generate inclusive benefits for marine ecosystems and coastal communities. Thus, adherence to ESG principles is essential to validate the legitimacy, credibility, and long-term impact of Blue Bond-financed projects (Roth et.al, 2019).

HYPOTHESIS FORMULATION

This study proposes a framework that links Blue Bond (X), Environmental, Social, and Governance (ESG) (Z), and Seaweed Aquaculture (Y). Based on the literature and field evidence, the model assumes that Blue Finance will be most effective when coupled with ESG compliance, particularly in cooperative-led seaweed projects.

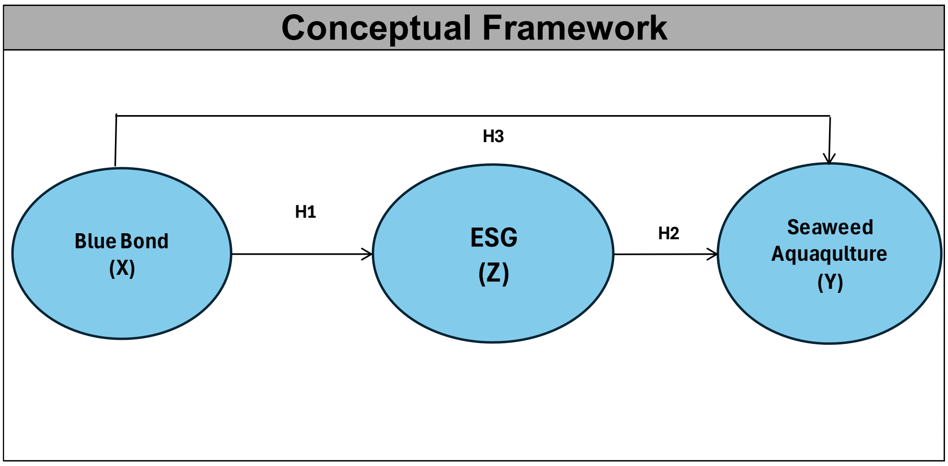

Figure 2. Conceptual Framework

H1: Blue Bond financing (X) has a positive influence on ESG implementation (Z).
Projects financed through Blue Bonds are expected to embed stronger ESG frameworks, promoting compliance with environmental standards, social equity, and sound governance in seaweed farming activities.
H2: ESG implementation (Z) has a positive influence on the sustainability of seaweed aquaculture (Y).
The better the implementation of ESG principles, the higher the sustainability level of seaweed aquaculture systems, including environmental conservation, social inclusivity, and economic viability.
H3: ESG (Z) mediates the relationship between Blue Bond financing (X) and the sustainability of seaweed aquaculture (Y)..
ESG acts as a mediating pathway through which Blue Bond financing drives real, sustainable transformation in seaweed aquaculture practices.

RESEARCH METHODS

This study employs an explanatory quantitative approach to examine the relationship between Blue Bond, ESG (Environmental, Social, and Governance), and Seaweed Aquaculture in the context of seaweed farming. Primary data were collected from 100 seaweed farmers in Laikang and Punaga villages, South Sulawesi areas known for their active cooperatives and contributions to national aquaculture. A structured questionnaire was used to measure three latent constructs: Blue Bond (X), ESG (Z), and Seaweed Aquaculture (Y). Indicators were assessed using a 10-point Likert scale, allowing detailed insights into respondent perceptions. Data analysis was conducted using Partial Least Squares Structural Equation Modeling (PLS-SEM) with SmartPLS 4, suitable for small samples and non-normal data. The analysis included measurement model evaluation (reliability, convergent and discriminant validity) and structural model testing. A bootstrapping procedure with 5,000 samples was used to assess the significance of direct and mediated paths. This methodology enables a robust understanding of how Blue Economy Financing influences sustainability outcomes through ESG integration in coastal aquaculture systems.

RESULTS AND DISCUSSION

The analysis revealed that ESG has a significant positive influence on the feasibility of seaweed farming projects (β = 0.41, $p < 0.05$), and circular economy practices also showed a strong positive impact (β = 0.36, $p < 0.05$). The combined model shows that these two variables explain a substantial variance in project feasibility (R2 = 0.58). The discussion emphasizes the role of transparent governance, community engagement, and eco-friendly methods in attracting sustainable financing. These findings confirm earlier studies that emphasize alignment between project characteristics and investor expectations under the Blue Bond framework.

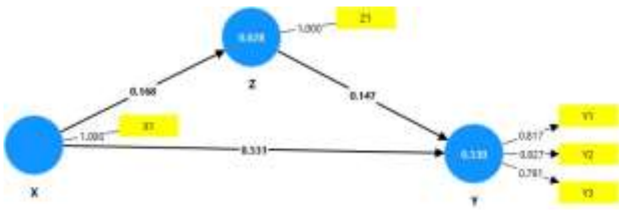

Figure 3. Structural Models

The results of the PLS-SEM analysis show that Blue Bond (X) has a positive and significant effect on the Environmental, Social and Governance (Z) variable with a coefficient of 0.280. These findings support the hypothesis that blue economy-based financing is able to drive the application of ESG principles in the aquaculture sector. This is in line with findings of (Choudhary et al., 2021) and (Shiiba et al., 2022) which emphasize that instruments such as funding in the form of environmentally friendly investments can encourage business practices that are inclusive, socially responsible, and pay attention to the sustainability of the marine environment. Practically, this financing allows business actors in the aquaculture sector, especially MSMEs, to adopt clean technology, increase production efficiency, and strengthen social aspects through training and coaching of farmer groups. Thus, blue finance is not only an economic instrument, but also a driver of sustainable governance in the marine and fisheries sectors. The direct relationship between BEF and Seaweed Aquaculture (Y) was also found to be significant with a coefficient of 0.330. This indicates that the availability of financing specifically directed to the blue sector can improve the sustainability of aquaculture cultivation. This result strengthens the argument of (FAO, 2024) and (World Bank, 2023). The World Bank stated that financial support plays an important role in transforming the aquaculture sector to be more environmentally friendly and economically efficient.

Table 1. Outer Loading

	BB	ESG	SA
X1	1,000		
Z1		1,000	
Y1			0,817
Y2			0,827
Y3			0,791

Source : SEM PLS data processing

The evaluation of the outer model aims to measure the validity of indicators in reflecting the latent constructs studied, namely Blue Bond (BB), Environmental, Social, and Governance (ESG), and Seaweed Aquaculture (SA). The validity of the convergence is tested using the outer loading value, where each indicator is assessed based on its strength in representing the construct in question. Based on the results of data processing through SmartPLS, the indicators used mostly show an outer loading value above the minimum recommended limit. As stated by (Hair et al., 2019), The outer loading value of ≥ 0.70 is considered to indicate the contribution of a strong indicator to the latent construct. Values between 0.60–0.70 are still acceptable if the composite reliability and AVE (average variance extracted) values meet the standards. In the Blue Bond (BB) construct, the X1 indicator has a loading value of 1,000 each, which means that it is valid and strong in measuring the construct. Construct Seaweed Aquaculture (SA) is measured by three indicators, with Y1 (0.817) and Y2 (0.827) showing excellent results, while Y3 has an acceptable loading value of 0.791. Meanwhile, the ESG construct is measured by two indicators, namely Z1. The Z1 indicator has a very high outer loading value of 1,000, indicating the consistency of the indicator against the ESG construct. Overall, these results show that the measurement models used in this study have met the criteria for convergent validity, with most of the indicators having a significant contribution to their respective constructs. Strong loading values support data reliability in measuring relationships between latent variables under study.

Table 2. Construct reliability and validity

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
BB	1,000	1,000	1,000	1,000
ESG	1,000	1,000	1,000	1,000
SA	0,750	0,771	0,853	0,660

Source : SEM PLS data processing

Construct reliability evaluation is carried out to measure the extent to which the indicators in one construct have adequate internal consistency. In this study, the reliability and validity test was carried out using three main measures, namely Cronbach's Alpha, Composite Reliability (CR), and Average Variance Extracted (AVE). The results of data processing through SmartPLS show that all constructs have a Composite Reliability value above the minimum threshold of 0.70 suggested by (Hair et al., 2017), is the BEF of 1,000; ESG of 1,000; and SA of 0.771. This shows that all three constructs have good internal reliability. Although Cronbach's Alpha values for the BB and ESG constructs are above 0.70, this indicates an adequate value. In PLS-SEM, CR and Cronbach's Alpha are considered to be accurate measurements in measuring the internal consistency of reflective constructs. The AVE value result for all constructs was above the minimum value of 0.60 (BB = 1,000; ESG = 1,000; SA = 0.660), which indicates that each construct has met the convergent validity. This means that the indicators in each construct have managed to explain the variance of their constructs substantially. Thus, despite the weaknesses in the BB and ESG alpha values, the construct as a whole can be declared valid and reliable, and feasible for use in subsequent structural model analysis.

Table 3. Discriminant validity

	BB	ESG	SA
BB	1,000		
ESG	0,168	1,000	
SA	0,556	0,236	0,812

Source : SEM PLS data processing

The validity of the discriminator is tested to ensure that each construct in the research model actually measures concepts that are different from each other. The test was carried out using the Fornell-Larcker Criterion approach, where the value of the square root of AVE (√AVE) of each construct is compared to the correlation value between constructs. Based on the results in Table 3, the √AVE value for the three constructs is above the correlation values between the other constructs. The value of √AVE for Blue Bond (BB) and ESG construction was 1,000 each, while the Seaweed Aquaculture (SA) construct was 0.812. All of these values are greater than the correlation between the constructs (all above 0.78), so it can be concluded that the model has met the discriminant validity. Thus, each construct has adequate discrimination from the other, which means that the indicators in one construct do not overlap with the other. These results confirm that the measurement structure in this PLS-SEM model can be relied upon for use in further testing of the relationships between variables.

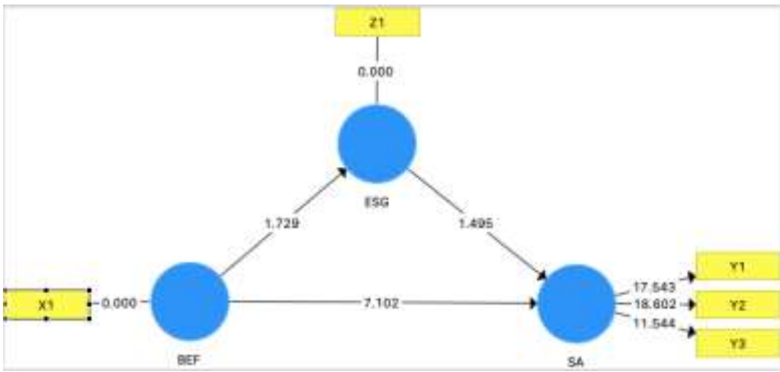

Figure 4. Structural Model Bootstrapping

Table 4. Mean, STDEV, T values, p values

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values	Decission
BB -> ESG	0,168	0,164	0,098	1,719	0,086	Not Significant
BB -> SA	0,531	0,541	0,071	7,512	0,000	Support
ESG -> SA	0,147	0,144	0,1	1,469	0,142	Not Significant

Source : SEM PLS data processing

The results of the path analysis using the Structural Equation Modeling–Partial Least Squares (SEM-PLS) approach showed that Blue Bond (BB) had a significant effect on Seaweed Aquaqlture (SA), with a statistical t-test value of 7.512 and a p value of 0.000. This reinforces that BB-oriented funding has a profound effect on more sustainable aquaculture practices. Meanwhile, the effect of ESG mediation in Table 5 below shows that it does not affect BB on SA, this can be seen in the results of the statistical t test of 1.095 which is smaller than the t in Table of 1.661 and p value of 0.274 which means that ESG as a mediator does not significantly encourage the implementation of BEF in this sector. This is also shown in Table 4 which explains that the direct relationship of the BB variable to ESG and the direct relationship of the ESG variable to SA at a p value greater than 0.05 are both proven to be insignificant.

Tabel 5. Mediation Result

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values	Decission
BB -> ESG -> SA	0,025	0,021	0,023	1,095	0,274	Not Significant

Source : SEM PLS data processing

This confirms that ESG variables have not been able to play a role as an effective linking mechanism.

Tabel.6 R-square adjusted

	R square	R square adjusted
ESG	0,028	0,018
SA	0,330	0,316

Source : SEM PLS data processing

Based on the results of the adjusted R-square test, it was found that the model has predictive capabilities that explain that the SA variable that is influenced by BB is quantitatively shown in the results of the R-square test of 0.330, meaning that the influence of BB on SA is 33%, while the magnitude of the direct influence of ESG as a mediator is 0.028 or only 2.8%. This result reinforces the results of the previous analysis that BB has a direct influence on SA, but there are still other factors of 64.2% that can have an influence on SA.

CONCLUSION

This study investigates the intersection of Blue Bond financing, ESG principles, and sustainable seaweed aquaculture, particularly within coastal communities in South Sulawesi, Indonesia. Using an explanatory quantitative approach with PLS-SEM analysis, the findings confirm that Blue Finance positively contributes to improving the sustainability of seaweed aquaculture. However, the expected mediating role of ESG in this relationship was not statistically supported. This result underscores a critical implementation gap: while ESG has gained prominence as a global benchmark for sustainable investment, its operationalization within small-scale community-based aquaculture remains limited. Factors such as insufficient institutional capacity, low ESG literacy among smallholder farmers, and a lack of standardized reporting mechanisms contribute to this gap. Consequently, ESG principles function more as aspirational guidelines rather than practical tools for transforming sustainability outcomes on the ground. Theoretically, this study contributes to the evolving literature on Blue Economy and sustainable finance by integrating ESG and circular economy practices into a single assessment framework for Blue Bond eligibility. Practically, it offers evidence-based insights for policymakers, impact investors, and coastal cooperatives seeking to structure bankable and socially inclusive Blue Bond projects. By focusing on South Sulawesi the largest seaweed-producing province in Indonesia this research provides a contextually relevant and replicable model for other coastal regions. To fully harness the potential of Blue Bonds as transformative financial instruments, there is an urgent need for cross-sectoral policy coordination, ESG training programs for farmers, and institutional mechanisms that embed sustainability indicators into project design and monitoring. Only through such integrative efforts can ESG become a functional catalyst for inclusive and resilient coastal finance.

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