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Role of Innovations / Interventions to Bring Sustainability in Aquaculture Growth in Indonesia: Integration of Life Cycle Assessment (LCA) Framework

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Abstract

Seafood is a vital aspect of the Indonesian diet, both healthily and monetarily. Due to the overconsumption of sea fish and other seafood over the years, numerous concerns about climate change have arisen. To protect the aquaculture business, it is of the utmost importance to increase sustainable seafood production in Indonesia with minimal environmental damage. Moreover, the ecological implications of the aquaculture industry rely on the management of the site and the species used. To ensure the sustainable expansion of the aquaculture sector, innovations/interventions are required to offset the impact of environmental consequences associated with the sector's growth. To do this, the current study utilized a Life Cycle Assessment (LCA) Approach and primary and secondary data to identify a set of treatments. As a result, the protective capability of seven aquaculture interventions in Indonesia has been extracted. These interventions include increased bioproduct utilization and decreased food waste, use of renewable electricity, preference for freshwater finfish over shrimp, preference of pelleted feeds over low-cost fish diets, sustainable intensification of milkfish polyculture, Asian tiger shrimp, and reduction of tilapia, carp, and shrimp, as well as sustainable processing and packaging. Moreover, this study contributes to the aquaculture literature by not only relying on the literature review but also analyzing primary and secondary data using the LCA to identify critical interventions for the sustainable expansion of the aquaculture sector.

Keywords: Aquaculture Sector; Sustainable Growth; Life Cycle Assessment (LCA) Approach; Innovations/Interventions.

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1. Introduction

Aquaculture contributes significantly to the economic prosperity of coastal and rural areas (Ahmed & Thompson, 2019). It originates from the rapidly expanding agri-food systems that contribute significantly to global nutrition security (Zhang et al., 2022). Nonetheless, despite their worldwide importance, Southeast Asian nations are susceptible to several production concerns relating to illness, farming conditions, commerce, and processing issues related to social and environmental sustainability (Ahmed & Thompson, 2019; Henriksson et al., 2021). To preserve aquaculture as a globally significant industry, there is a need for constant innovation in farming methods and research into cures for fundamental problems such as illnesses (Henriksson et al., 2021). Concurrently, experts underlined the necessity for innovations to address the prevalent production hazards of aquaculture and change the entire industry to sustainable intensification (Nasr-Eldahan et al., 2021). The aquaculture industry's innovation process may involve improved seed production, ongoing domestication of species, enhanced biosecurity, health management, selective breeding of species, and the replacement of fish oil or meal as a new feed ingredient (Duarte, Bruhn, & Krause-Jensen, 2022). In addition, an integrated approach is required to predict and respond to changes in institutional, social, and ecological production conditions to accomplish sustainable intensification (Belton et al., 2020; Jiang et al., 2022).

To maintain a balance between anticipatory and responsive innovative processes, there is an urgent need to employ system-level approaches to innovation (Henchion et al., 2022). These methods can incorporate

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multiple environmental, social, institutional, and technical factors within the aquaculture industry (El-Saadony et al., 2021). In addition, innovations are usually viewed as crucial factors in the formation of a knowledge-based economy (Goralski & Tan, 2022). In addition, the knowledge-based economy is viewed as a critical indicator of growth and lasting competitive advantage (Rahman et al., 2022). In addition, research demonstrates that nations with more innovations are more economically competitive, highlighting the uttermost significance of national innovation performance (Gao & Yuan, 2022). In addition, the metrics of a nation's ability to grow and compete for sustained productivity over an extended period through identifying unique innovation techniques are of great importance (Gao & Yuan, 2022; Mansoor, 2021). In light of the relevance of innovation in the sustainable development of any sector or nation (Kirkpatrick et al., 2019), the present study analyzed innovations in the aquaculture sector in Indonesia in terms of achieving sustainable growth.

Indonesia is the second-largest seafood producer and consumer in the world (Khan et al., 2022). According to reports, the "Indonesian Ministry of Marine Affairs and Fisheries (KKP/MMAF)" has set a growth target of around 8.5% per year until 2030 to meet the country's seafood demand, which currently accounts for 95% of aquaculture production and 80% of captured fisheries (Henriksson et al., 2021). Despite the high levels of production and consumption, micronutrient and macronutrient deficits persist in Indonesia (Jaikaew, 2022). Therefore, experts recommend increasing Indonesians' consumption of fish and beef (Sari et al., 2022). In contrast, the majority of Indonesian seafood consumption is limited to seized fisheries (Alosairi, Al-Ragum, & Al-Houti, 2021). In addition, numerous fish stocks are overfished without strategies to increase future productivity. Consequently, researchers estimate a 30% decrease in fish catches due to anthropogenic pressures and future climate change (Maire et al., 2021). Concurrently, there are numerous obstacles to having suitable areas and resources to support biodiversity. These present concerns and the goal of preserving and sustaining aquaculture expansion necessitate innovative and sustainable interventions to boost aquaculture production in the nation (Henriksson et al., 2019; Sari & El Islami, 2022).

Additionally, Indonesia's agricultural industry is dominated by freshwater Finfish species (Nasir et al., 2021). It also contains pangasius catfish, carp, clarias catfish, and tilapia, followed by milkfish and shrimp found in brackish water (Culver, 2022). However, the contribution of mariculture is negligible at approximately 78 k MT, discounting seaweed farming of 10,547 KMT and buy will valves of 50 KMT (Henriksson et al., 2019). In terms of exports, shrimps have a significant value and quantity share, followed by tilapia (Shepon et al., 2021). Previously, academics have evaluated several growth scenarios for Indonesia's agricultural sectors by applying the Asiafish model to growth estimates (Bohnes et al., 2020; Henriksson et al., 2021; Shepon et al., 2021). Simultaneously, lifecycle assessment modeling has been used to evaluate the environmental impacts of the Indonesian aquaculture business, yielding multiple scenarios (Fürtner et al., 2021; Henriksson et al., 2019; Ubando et al., 2022). However, there is a lack of consistency and satisfactory results in the literature regarding the role of innovations/interventions in sustainably managing the Indonesian aquaculture sector, with the majority of research focusing on current farming practices (Henriksson et al., 2021; Järviö, Henriksson, & Guinée, 2018).

In contrast, there is an urgent need to examine and explore potential interventions and technologies to increase productivity and slow the decline of the Indonesian aquaculture sector, thereby fostering sustainable development (Bashir et al., 2020; Saptutyningsih, Diswandi, & Jaung, 2020). Using the Life Cycle Assessment (LCA) Approach, the current study intends to address crucial concerns regarding interventions to increase aquaculture production, as targeted by the Indonesian government until 2030, without harming the environment and maintaining the ecological system. The current study also gives information regarding infrastructural and ecosystem differences between provinces. In addition, the Business-As-Usual Scenario (BAU) was used to predict 2030 output targets following (Tran et al., 2017).

2. Research Methods

2.1 Primary Data

To undertake the lifecycle inventory technique to analyze the impact of innovations on the sustainability of the growth of the Indonesian aquaculture sector, the database of numerous farms has been utilized in the current study. The data relates to carp, milkfish polyculture, and shrimp in ponds during the spring of 2020. In the regions of Java, South Sulawesi, and Sumatra, researchers visited 34 farms. 13 were for common carp, 11 for Asian tiger shrimp, and 10 for white leg shrimp. Using Henriksson et al. (2019)'s study technique, the authors locate individual farmers through local partner networks that represent farmers close to metropolitan centers. This study aimed to direct these farmers, who were also asked to provide information about aquaculture on their farms. In addition, to analyze eight species and twelve different systems, data from the previous data sets were averaged to create a unit process data set. In addition, the distribution of species in 12 farming systems was as follows. Asian tiger fish cultured in polyculture (n= 13), milkfish in ponds (n= 11) and cages (n= 7), Clarias in ponds (n= 9), carp in ponds (n= 6) and cages (n= 9), tilapia in ponds (n= 6) and cages (n= 8), pangasius in ponds (n= 10) and cages (n= 5), white leg shrimp (In addition, we followed the guidelines published by Henriksson et al. (2019)) to average the unit process data set with a horizontal averaging methodology that included dispersion estimates around inventory movements. The results indicate that milkfish polyculture, Asian tiger shrimp, and white leg shrimp with larger dispersion necessitate more diverse agricultural approaches.

2.2 Secondary Data

To collect secondary data for evaluating the significance of innovations in the sustainable growth of Indonesian aquaculture with fewer ecological impacts, we consulted several sources, including the United Nations Environment Program and World Conservation Monitoring Centre (UNEP-WCMC) 2019, Global Forest Watch 2018, and UNEP-WCMC 2014, which comprised seagrass beds, coral reef, mangrove forest, and land use. The land is utilized for palm oil concessions and logging, places with a moratorium on logging, protected forest areas, and plantations. Sub Directorate of Environment Statistics 2020, Assembling Maps, and BPS Statistics Indonesia were utilized concurrently to classify the states of seagrass beds, corals, and mangrove forests. In addition, for lifetime assessment, the emission of methane from freshwater ponds based on 601 kg ha-1 yr-1; (Coefficient of Variation (CV) = 0.6; lognormal distribution) was used to derive unit process data sets. In addition, the guidelines of Järviö et al. (2018) were utilized to derive the land use change of mangroves based on 133 tons CO2 equivalent ha-1 yr-1 (CV=0.511).

2.3 Life Cycle Assessment Approach

Life cycle assessment is an ISO-accredited approach for environmental evaluation that aids in evaluating the entire manufacturing chain (Fürtner et al., 2021). It is a framework for assessing the environmental effects of products, systems, and actions (Ubando et al., 2022). It consists of four steps: scope and objective conceptualization, life cycle inventory analysis, impact evaluation, and findings interpretation (Shivankar & Deivanathan, 2021). Moreover, due to its adaptability, lifecycle assessment may be applied to both small- and large-scale production systems, thereby incorporating macro- and micro-level decisions (Henriksson et al., 2017). This study investigates the impact of interventions/innovations on the sustainable development and functioning of the aquaculture sector in Indonesia, as it relates to the production of feed and its raw materials, transportation, refining and extraction of diesel, and generation of electricity, packaging, cold storage, processing, and consumption. However, the current study did not evaluate the nutritional value and edible yield. In addition, a systematic life cycle assessment matrix was produced using Chain Management by Life Cycle Assessment (CMLCA) version 5.2 software. Following the directions set by Henriksson et al. (2017) researchers used Ecoivent v 2.2 for background processing to calculate the dispersions of about one thousand Monte Carlo simulations.

2.4 Interventions of Aquaculture

A list of potential innovations and interventions was compiled after a thorough literature analysis and talks with academics, industry professionals, and researchers. Moreover, researchers with KKP/MMAF, NGOs, and industrialists have organized two workshops for stakeholders in Java (March 2020) and Jakarta (August 2020) to have a detailed discussion about the possible and relevant interventions/innovations related to the sustainable growth of the Indonesian aquaculture sector. Consequently, numerous interventions were removed. In addition, specific screening criteria for interventions were evaluated, such as the degree of operationalization till 2030, the influence on life cycle assessment categories, and the quantifiability based on empirical evidence. Seven interventions were extracted in the end. These interventions consist of a) increased bioproduct utilization and decreased food waste, b) the use of renewable electricity, c) the preference for freshwater finfish over shrimp, d) the preference of pelleted feed over whole fish diets, e) the sustainable intensification of Asian tiger shrimp and milkfish polyculture, f) the reduction of tilapia, carp, and shrimp, and g) sustainable processing and packaging (Zhang & Sun, 2022).

2.5 Improved Bioproduct Utilization and Reduced Wastage (AQI 1)

Food waste reduction is one of the most sustainable and effective means of managing and increasing the food supply (van der Werf, Seabrook, & Gilliland, 2021). According to study reports on the perishability of seafood, roughly 37% of seafood and fish is wasted globally, compared to 19% and 28% for meats and grains, respectively (Henriksson et al., 2019). Consequently, it is essential to limit food waste by employing by-products (Brennan et al., 2021). It can also be done at the level of the stakeholders, from monitoring the fish production to distributing it to the final consumers. In addition, one of the most important issues that must be considered to ensure sustainable development in the aquaculture sector in Indonesia by 2030 is the reduction of seafood consumption from 37% to 20% or less. Other initiatives like customer awareness, excellent supply chain management, and simple access to cold storage can be leveraged for this goal. However, it has been thought that the need for additional energy for cold storage in the form of refrigeration has minimal influence on storage (Prema & Periasamy, 2022).

2.6 Renewable Electricity Usage (AQI 2)

Energy use in the form of electricity varies by the farm (Rokicki et al., 2021). In the current investigation, eleven of twelve production systems relied directly on the Indonesian power grid. In addition, it was discovered that all 12 production systems consume indirect energy in the form of electricity for feed material processing and nitrogen fixation (Henriksson et al., 2021). Currently, the majority of Indonesia's energy is generated by burning coal. In addition, geothermal energy generation is prevalent in Indonesia, making it the third-largest producer of electricity utilizing geothermal power plants and possessing nearly 40% (28,000 megawatts) of the world's geothermal potential (Uhunamure et al., 2021). Although the generation of electricity from a coal power plant is more expensive than geothermal plants (Duniam, Sabri, & Hooman, 2021), the initial expenses and risk of return on investment are higher for the usage of geothermal plants to create energy (Kabeyi & Olanrewaju, 2022). Moreover, Indonesia has a huge potential for producing electricity via wind and hydropower (Syahputra & Soesanti, 2021). However, Indonesia does not utilize these resources to generate electricity. Indonesia's total coal-generated electricity accounted for 51.23 percent of the nation's electrical mix as of May 2020. (Adebayo et al., 2022). However, in recent years, Indonesia has been increasing the trend to create electricity from renewable energy sources rather than nonrenewable (Kabeyi & Olanrewaju, 2022). These renewable energy sources must be employed to power all agricultural mills, feed mills, fish farms, etc., to sustain and develop the aquaculture industry in Indonesia.

2.7 Preferring Freshwater Finfish (Omnivorous) over Shrimps (AQI 3)

The literature demonstrates that omnivorous finfish species cause less harm to the ecosystem than shrimp and marine finfish (groupers) (Abd El-Hack et al., 2022). This study also demonstrates that omnivore finfish use less fish meal and feed and have a greater productivity rate. Additionally, they are more susceptible to diseases. Consequently, milkfish, pangasius, milkfish, clarias, carbohydrates, and tilapia are expected to replace whiteleg finfish and shrimp. This would assist in reducing the environmental impact of the aquaculture industry and increase the production of seafood with minimal use of resources in the form of food and feed and a greater productivity rate, thereby providing a large number of citizens with wholesome food.

2.8 Preference of Pallets over Whole Fish Diets (AQI 4)

During the trips, it was discovered that the majority of marine fish farms employed inexpensive fish as a source of feed. On average, 19.5 kg of whole fish were utilized for every kilogram of grouper. In addition, research indicates that low-cost fish has several drawbacks due to its poor Feed Conversion Ratio (FCR) (Deng et al., 2021). Similarly, low-cost fish is considered troublesome due to its broad variety and shorter shelf life. In contrast, pelleted feeds for carnivorous marine fish can be introduced as a key innovation to reduce eutrophication and reduce the usage of low-cost fish as primary feed (Henriksson et al., 2021). As pelleted feed contained around 62% fish oil and fish meal, 5 kilograms of fish would be required for every kilogram of fish meal, resulting in a reduction of 16 kilograms of wild fish per kilogram of grouper. Therefore, it can be a good and cost-effective feed for producing healthy marine fish, resulting in the maintenance and expansion of aquaculture (Rao, 2022).

2.9 Sustainable Intensification of Asian Tiger Shrimp and Milkfish Polyculture (AQI 5)

Feeding a substantial quantity of Asian tiger shrimp and milkfish annually requires extensive farming techniques (El-Saadony et al., 2021). Integrated agriculture of these two species led to a decline in biodiversity and an extension of mangroves (Nasr-Eldahan et al., 2021). This increase and alteration of land usage led to ecological imbalance. Simultaneously, brackish water farming consumes considerable fresh water to dilute marine water (Jiang et al., 2022). Therefore, interventions are necessary to increase the utilization of high-quality extruded feed pellets with an FCR of 1.5 and effective feeding behaviors (Henriksson et al., 2019). It can aid in the improvement of genetic strains, stocking density, and management techniques (Ahmed & Thompson, 2019). To protect the environment, the area devoted to the production of milkfish and Asian tiger shrimp should be lowered with greater efficiency.

2.10 Reduction of Tilapia, Carp, and Shrimps (AQI 6)

The Feed Conversion Ratio (FCR) represents the efficiency with which animals in various systems convert feed into weight growth (Elvy et al., 2022). In addition, it is necessary to account for the effects of feed ingredients on changes in animal body structure. The FCRs for tilapia, carp, and white-leg shrimp were discovered to be approximately 1.8, 1.9, and 1.5, respectively, when researchers visited various farms to collect data for this study. Comparing these numbers to a previous study conducted in China reveals a significant disparity with significantly higher levels (Yi et al., 2018). Using a mix of farm management methods, feeding practices, water monitoring, environmental sustainability, and improved genetic strains as highly sustainable approaches, it is possible to reduce FCRs for these species by 20 to 25 percent by 2030. It also depends on farms' continued reliance on existing food sources. Consequently, it is of the utmost need to increase the efficiency of food with high value to preserve and develop the aquaculture sector in Indonesia.

2.11 Sustainable Processing and Packaging (AQI 7)

In addition to the actions mentioned above, sustainable seafood processing and packaging cannot be overlooked. Extending the previous study's findings on the production stage, the current research additionally examines the processing and packaging stage as a predictor of the aquaculture sector's sustainable development and maintenance in Indonesia. Once the seafood has been harvested, it must be handled appropriately due to its perishable nature. Thus, the seafood can be preserved for extended periods provided a good chilling and processing system employing energy sources is utilized (Deng et al., 2021). This contributes further to the decrease in food waste (Nasr-Eldahan et al., 2021). This decreased food waste and provided nourishment and food to a greater number of citizens, improving the aquaculture industry's efficiency and efficacy (Erasmus et al., 2021). Thus, it is anticipated that by 2030, the aquaculture feed loop will place a great deal of emphasis on the proper handling, processing, and packing of seafood, thereby minimizing waste and increasing efficiency. In addition, Table 1 provides a full explanation of all seven interventions and their expected metrics.

3. Analysis and Results

3.1 Lifecycle Assessment Results

Based on Monte Carlo simulations, Table 2 summarizes the lifecycle assessment results for the environmental implications of the aquaculture industry. The results demonstrate that marine finfish have the highest impact on global warming, followed by milkfish, shrimp, common carp, and white-leg shrimp. In terms of fossil fuel consumption and eutrophication, marine finfish were discovered to be more harmful. At the same time, it was found that Asian tiger shrimp polyculture and milkfish in ponds and cages occupied the largest land areas and consumed the freshest water. This resulted in the conversion of land into mangroves, emitting an additional 191,000-302,000 kg CO2-equivalent per ton of milkfish or shrimp. In addition, the common carp emitted a substantial amount of acidifying chemicals. In addition, the results demonstrated that white-leg shrimp in ponds, milkfish in ponds, and polyculture contribute to an increase in eutrophication.

Table 1. Interventions to Sustain and Facilitate Growth of the Aquaculture Sector

Sr. #	Innovations/Interventions	Sub Indicators
1.	**Improved Bioproduct Utilization and Reduced Wastage (AQI 1)**	• By-products Utilization • Monitoring • Reduced unnecessary consumption • Consumers' awareness • Effective supply chain management • Easy access to cold storage
2.	**Renewable Electricity Usage (AQI 2)**	• Use of geothermal plants to generate energy • Use the wind to produce electricity • Use hydropower to produce electricity • Use renewable energy sources
3.	**Preferring Freshwater Finfish over Shrimps (AQI 3)**	• Replace white leg finfish and shrimp with milkfish, pangasius, milkfish, clarias, carbs, and tilapia • Enhance the production of seafood • Least utilization of resources • Higher rate of productivity
4.	**Prefer Pelleted feed over Whole Fish Diets (AQI 4)**	• Pelleted foods for groupers and other carnivorous marine fish • Lower direct low-cost fish use as main feed • Produce healthy marine fish
5.	**Sustainable Intensification of Asian Tiger Shrimp and Milkfish Polyculture (AQI 5)**	• Reducing the freshwater use in brackish water farming • Enhance the use of high-quality extruded feed pelleted • Enhance the genetic strains • Improve stocking density • Better management practices • Reduction in the production area of milkfish and Asian tiger shrimp
6.	**Reduction of Tilapia Carp and Shrimps (AQI 6)**	• Need to reduce FCRs for tilapia, carp, and white-leg shrimp • Good combination of farm management practices • Sustainable feeding practices • Continuous water monitoring • Enhanced genetic strains • Improved the efficiency of feed

7. Sustainable Processing and Packaging (AQI 7)	It needs proper handling based on its perishable nature Requires a proper cooling system Enhanced processing system using energy sources Enhancing the efficiency and effectiveness of the aquaculture sector

3.2 Aquaculture Innovations/Interventions' role in Environmental Impact By 2030

As shown in Table 3, the environmental influence of the actions utilizing the Business as Usual (BAU) scenario and revised lifecycle assessment influence may result in a 3,2-4,5-fold increase in fish volume by 2030. Therefore, it is of the utmost importance to improve feed efficiency for tilapia, common carp, whiteleg, and shrimp to lessen their negative environmental impact. It does not address the restriction on freshwater consumption, which can be circumvented through the intensification of Asian tiger shrimp and milkfish. In addition, the change toward pelleted food may increase the demand for wild fish as a feed ingredient relative to low-cost fish for marine finfish production. This reduction can also be aided by increasing the output of omnivorous species as opposed to shrimp. Concurrently, it is desirable to transition the method of electricity production from nonrenewable to renewable resources to utilize them sustainably for a longer period. It will contribute further to reducing global warming and acidic emissions from various feed ingredients, such as methane and nitrous oxide, as a result of ponds and cages with inadequate management. In addition, eliminating food waste has been identified as one of the most effective means of protecting the environment and lowering global warming through the sustainable development of the aquaculture industry.

4. Discussion and Conclusion

Based on the nutritional and economic significance of seafood as an integral element of the Indonesian diet, several concerns regarding overfishing regarding climate change were raised. To protect the aquaculture business in Indonesia, it is essential to increase sustainable seafood production with minimal ecological impact (Duarte et al., 2022). Moreover, interventions/innovations are necessary to alleviate the effects of environmental impacts associated with the global expansion of aquaculture (Henriksson et al., 2021). To achieve this objective, the current study employed a lifecycle assessment strategy based on numerous primary and secondary data sources.

Table 2: Lifecycle Assessment Applying Mass Allocation, Scaled to One Ton of Live Animal at the Farm Gate

Species	System	Global warming kg CO2-eq.	Acidification kg SO2-eq.	Eutrophication kg PO4-eq.	Land Occupation m2 a	Freshwater Use m3	Fossil energy use MJ
Asian tiger shrimp	Polyculture	11,260	77.3	95.8	223,110	49,045	106,450
Milkfish	Ponds	7.234	68.2	104	13,900	4,125	59,500
	Polyculture	11,359	80.4	101	20,800	48,340	105,000
Clarias	Ponds	6,320	57.2	53.1	5,132	263	53,300
Common carp	Ponds	10,459	99	94.3	8,450	290	98,120
	Cages	9,876	105	107	8,567	257	101,500
Tilapia	Ponds	9,200	94.1	81.2	7,540	378	89,200
	Cages	8,876	85.3	90.5	7,300	215	82,500
Pangasius	Ponds	6,102	54.6	52.7	5,023	475	51,100
	Cages	6,431	59.2	60.2	4,980	146	56,150
Whiteleg shrimp	Ponds	10,115	79.6	119	7,549	9,800	109,000
Marine Finfish	Cages	15,789	69.4	401	490	36.2	159,400

Table 3: Seven Aquaculture Interventions (AQIs) and their Mitigation Potential by 2030, with Cumulative Effects Per Ton of Fish

Impact category	Business As-usual	AQI 1	AQI 2	AQI 3	AQI 4	AQI 5	AQI 6	AQI 7	Cumulative AQI 1-7
Fish quantity	337%	337%	337%	337%	337%	337%	337%	337%	100%
Global warming	341%	321%	355%	344%	328%	342%	269%	245%	71%
Acidification	335%	310%	351%	338%	332%	306%	262%	243%	75%
Eutrophication	350%	320%	351%	338%	330%	343%	275%	255%	73%
Land occupation	365%	345%	319%	363%	350%	362%	285%	261%	77%
Freshwater use	425%	421%	267%	421%	345%	421%	333%	322%	54%
Fossil energy use	339%	319%	370%	345%	327%	308%	270%	250%	70%
Wild fish use	361%	330%	337%	307%	315%	360%	281%	263%	61%

As a result, a set of seven interventions in the context of sustainable growth of the Indonesian aquaculture sector, including improved bioproduct utilization and reduced food wastage, renewable electricity usage, preference for freshwater finfish then shrimps, preference of pelleted feeds over whole fish diets, sustainable intensification of Asian tiger shrimp and milkfish polyculture, and reduction of tilapia, carp, and shrimp, and sustainable processing and packaging, were implemented.

The results also indicate that the seven innovations/interventions identified through product lifecycle assessment could lower the ecological effect per volume of fish by around 30 to 52 percent. In addition, business-as-usual growth would result in an almost 3.5-fold rise by 2030. In contrast, the Indonesian government plans to expand the 2.5-fold rise in the aquaculture sector through business-as-usual development by 2030 for the majority of species (Henriksson et al., 2019). This may lead to increased degradation and encroachment of the ecology, even if areas for milkfish polyculture and Asian trump shrimp are reduced (Tran et al., 2017). In addition, as demonstrated by the findings of this study, the aquaculture footprints in various regions of the country have already exceeded the carrying capacity (Zhang et al., 2022). Therefore, KKP-MMAF must examine its production capacities and objectives with environmental preservation as a top concern. In addition, there is an urgent need to shift attention from high-value species such as milkfish and shrimp to locally consumed omnivorous finfish.

Environmental care may also generate economic benefits through tourism and increase fish output (Mensah & Enu-Kwesi, 2019). It can also establish worldwide ecosystem protection compensation programs, such as carbon credits. Results further demonstrate feed's significance in affecting the aquaculture industry's growth. As formidable rivals to human food, fish oil, and fish meal are more important fish feed ingredients (Ahmed & Thompson, 2019). Insects, single-cell proteins, micro- and macroalgae, and agricultural product derivatives are hence good alternatives to using. They can also result in less environmental degradation and sustainable development, in addition to more output and greater efficiency. Since the nutritional profile of seafood is strongly reliant on feed and species compositions (Deng et al., 2021), all of the factors mentioned above must be considered more rigorously when creating national production objectives and developing farming methods.

The results demonstrated a more diverse milkfish production performance, indicating its greatest yield and growth potential in marine and brackish environments. Consequently, its production may be increased sustainably due to its superior ability to utilize a greater variety of feed than its carnivorous competitors. In addition, the provinces of South Sulawesi and Java are two of the top milkfish producers. However, these locations also contain declining marine and coastal ecosystems, making aquaculture the leading cause of deforestation in Indonesia (Setyawan et al., 2022). It further necessitates intensifying agricultural systems by improved spatial planning, disease-resistant strains, veterinary sport, and quick alert systems.

Moreover, it is extremely difficult to implement efficient production and consumption practices by investing in interventions that benefit consumers, processors, and farmers (Shepon et al., 2021). On the other side, obtaining economies of scale through decreasing food waste, increasing edible yields, and decreasing feed inputs are subject to certain cost limits (Brennan et al., 2021). Research demonstrates an ongoing need for funding to analyze newly intervening processes, implement regulations, provide extension services, launch pilot initiatives, and disseminate knowledge (Bohnes et al., 2020; Erasmus et al., 2021). Therefore, the central government can sustain Indonesia's aquaculture sector by deploying its resources or international aid. In addition, the efficient and effective application of technology tools can lower production costs, increase production volume, and strengthen the energy sector essential for the aquaculture industry's sustainable growth.

5. Study Implications, Limitations, and Future Directions

This paper is an important contribution to the aquaculture literature. It does not solely rely on the literature review concerning the impact of the aquaculture industry on the environment and ecological deformation. In addition, the report examines primary and secondary data using the lifecycle assessment methodology to highlight major actions in the aquaculture sector to improve its efficiency and develop it sustainably to lessen its environmental consequences. Moreover, extending the current knowledge beyond the contexts of production and replacement to the contexts of processing and packing adds value to the existing aquaculture literature. It also offers practitioners instructions for transferring production from one species to another and discovering alternate feeds. Simultaneously, it is crucial to provide policy insights regarding the reduction of seafood waste, the development and discovery of ways to utilize the by-product, the focus on sustainable electricity production using renewable resources, and the implementation of efficient and effective systems of processing and packaging seafood to keep it safe for a longer period to meet the food needs of the masses at a lower cost and with easier access.

Additionally, based on the study's outcomes, it can be said that an adaptive strategy is required to analyze and disseminate information among stakeholders. Simultaneously, adopting all seven treatments in conjunction with one may result in beneficial improvements related to the sustainable development of aquaculture in Asia and other emerging nations. Moreover, central and regional governments must collaborate to solve the problems of implementing these interventions at different levels. Additionally, political, economic, and technological support is required at each stage to bring about sustainable changes in aquatic life to extract their benefits. Authorities should simultaneously evaluate the sector's logical heterogeneity. To achieve this objective, the Indonesian Ministry of Agriculture must increase the production of various ingredients required for capacity building and expanding the aquaculture industry.

In aquaculture-dependent nations like Indonesia, the aquaculture sector is also essential for job creation, economic growth, nutrition security, and food availability, in addition to its environmental impact. Therefore, it would be beneficial for future researchers to expand the existing literature on various feed provisions, switching of species production, efficient electricity production, processing, and storage, greater efficiency toward community welfare, and increased national economic growth. In addition to production capacities and feed availability, the purchasing power of customers must be examined to see if they can afford seafood based on price variations between species. The current study is limited to small-scale ponds and fish farms and does not account for the effects of climate change. In addition, the current study is limited to a country with low latitude, a developing nation with a greater susceptibility to climate change. Consequently, future researchers must solve these restrictions to generate significant discoveries.

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