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Contribution of aquaculture to future food security: Economic analysis and development in Indonesia

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Abstract

Aquaculture has developed into one of the key sectors in global fisheries, contributing greatly to food security around the world. Amidst a growing population and an increasing need for protein sources, aquaculture offers a real and sustainable solution. This study aims to analyze the contribution of aquaculture to food security in Indonesia, especially in the face of future challenges such as population growth, climate change, and limited natural resources. This research used a qualitative approach to explore and understand the contribution of aquaculture to food security in Indonesia, with a focus on economic analysis and development. A qualitative approach was chosen as it can provide deep insights into the experiences, views, and practices associated with aquaculture, as well as its impact on food security. In this complex context, a qualitative approach allows researchers to explore the meaning behind the data obtained, explain the relationships between variables, and understand the social, economic, and environmental factors that influence aquaculture development. The results show that aquaculture has significant potential in increasing the sustainable supply of animal protein and supporting food security, particularly through increased productivity, species diversification, and technology integration. However, challenges such as access to technology, capital, and environmental sustainability still need to be addressed. The managerial implications of these findings call for stronger policy support in terms of technology investment and training for aquaculture farmers, as well as the integration of sustainable aquaculture practices in national development plans to optimize the sector's role in supporting food security in the long term. In terms of managerial implications, these results indicate the importance of policy interventions that support investment in environmentally friendly technologies, human resource capacity building, and strengthening more efficient distribution networks. This research suggests that the government and private sector collaborate in creating an appropriate regulatory framework to support the development of sustainable aquaculture to meet future food security challenges.

Keywords: Aquaculture, Contribution, Development, Economic analysis, Food security.

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1. Introduction

Aquaculture has developed into one of the key sectors in global fisheries, contributing greatly to food security around the world. Amid a growing population and an ever-increasing need for protein sources, aquaculture offers a sustainable solution. Not only does it produce protein-rich fish, but aquaculture also helps to reduce pressure on wild fish stocks that have been declining due to overfishing [1]. This makes aquaculture one of the main strategies to maintain food availability globally, especially in countries with a high dependence on marine resources, including Indonesia [2, 3].

In Indonesia, as the world's largest maritime nation, aquaculture plays a central role in fulfilling animal protein needs while supporting the economy. Based on data from the Ministry of Marine Affairs and Fisheries [4], Indonesia's aquaculture production will reach 18.44 million tonnes, accounting for 58% of the total national fisheries production. This figure indicates significant growth in the aquaculture sector, making it one of the main drivers of the economy, especially in coastal areas. More than 2.8 million households in various coastal regions depend on aquaculture as their primary source of income, which also creates jobs in various fisheries value chains [5, 6].

Aquaculture also plays an important role in addressing malnutrition in Indonesia. Fish produced from aquaculture are rich in protein, vitamins, and essential minerals that are indispensable to the human body [7]. The consumption of fish produced from the aquaculture sector helps fulfill the nutritional needs of people, especially in areas with high levels of malnutrition. This aligns with the Indonesian government's goal to increase the intake of animal protein in the community as part of efforts to improve the quality of national nutrition. Thus, aquaculture is not only important from an economic perspective but also in terms of health and long-term food security. The following Table 1 shows the production of aquaculture in Indonesia from 2018 to 2022.

Table 1.
Data: Aquaculture production in Indonesia (2018-2022).

Year	Aquaculture production (Million tonnes)	Contribution to total fisheries (%)	Number of households involved (Million)	Economic value (IDR billion)
2018	14.22	52%	2.5	115.000
2019	15.35	54%	2.6	123.500
2020	16.87	56%	2.7	130.800
2021	17.60	57%	2.8	135.000
2022	18.44	58%	2.8	140.500

Source: Ministry of Marine Affairs and Fisheries [8].

The table above shows the increasing trend of aquaculture production in Indonesia over the past five years, with an average growth of 54% per year. By 2022, aquaculture production is expected to reach 18.44 million tonnes, contributing 58% to total national fisheries production. This growth reflects increased domestic and international demand, as well as government efforts to enhance production capacity through the development of aquaculture technology and the expansion of aquaculture land. In addition, the number of households involved in the sector has also continued to rise, demonstrating the importance of aquaculture as a livelihood for coastal communities. The economic value of aquaculture production also shows a steady increase, from IDR 115 trillion in 2018 to IDR 140.5 trillion in 2022, underlining the sector's significant potential as a driver of the national economy [8].

However, despite aquaculture's significant contribution to food security, the sector still faces various challenges. One of the main challenges is environmental sustainability, particularly regarding the use of limited natural resources such as land and water [9]. Environmentally unfriendly aquaculture practices have the potential to cause habitat degradation and environmental pollution, which, in turn, can disrupt the productivity of aquaculture itself. In addition, the reliance on fish feed based on marine ingredients, such as fishmeal, raises concerns regarding the overexploitation of marine resources [10, 11].

While aquaculture has been recognized as one of the key solutions to meet global protein needs, there are a number of research gaps that need to be addressed to better understand the sector's contribution to future food security, especially in the Indonesian context. Most previous studies have focused on technical and biological aspects, such as the productivity of specific fish species, feed management, and the environmental impacts of aquaculture [11-13]. However, there are few studies

that examine aquaculture through a comprehensive economic analysis approach, particularly by considering the potential for production growth under various long-term economic and environmental scenarios.

One of the main gaps is the lack of evaluations that integrate economic, policy, and technology analyses to identify challenges and opportunities for sustainable aquaculture development [9, 14]. In fact, the development of environmentally friendly technologies and government policies that support aquaculture is necessary to ensure that the growth of the sector does not come at the expense of ecosystem sustainability. Many studies have focused on the technical aspects, but the socio-economic impacts of these policies on long-term food security remain largely unexplored [6, 15, 16]. In the context of Indonesia, which is one of the world's largest aquaculture producers, literature addressing the relationship between policy strategies, technology adaptation, and aquaculture's contribution to food security is minimal.

In addition, there is a lack of research exploring the role of technological innovations, such as the use of alternative feeds and aquaponic systems, in improving aquaculture efficiency while reducing negative environmental impacts [17, 18]. This research aims to fill this gap by analyzing the contribution of aquaculture to food security from an economic perspective, taking into account aspects of sustainability, policy, and technological innovation. This will provide new insights for policymakers and industry players on how to optimize the potential of aquaculture to support future food security in a sustainable manner.

This research is intended to contribute significantly to the literature on the strategic role of aquaculture in supporting future food security, particularly through a comprehensive economic analysis in Indonesia. The novelty of this study lies in its holistic approach to examining the growth potential of aquaculture in the face of global challenges, such as increasing population and climate change, which could have a significant impact on the availability of fisheries resources. The study not only highlights the role of aquaculture as a more sustainable major provider of animal protein compared to the capture fisheries sector but also explores the economic implications of various aquaculture production scenarios, which include calculating the impact on fish prices, household income, and national food distribution. Through analysis of projections to 2030, this research offers new insights into aquaculture development strategies that can be applied to increase the productivity of the sector, with a focus on technological innovation, species diversification, and efficient utilization of local resources. As such, it provides a strong empirical foundation for policymakers to design interventions that can maximize the potential of aquaculture as a key solution for food security and reduced dependence on increasingly limited fisheries resources [17, 18].

The future of food security in the world and Indonesia depends on the aquaculture sector's ability to grow sustainably. With a projected global population expected to reach 9.7 billion by 2050, the demand for alternative protein sources such as fish will increase rapidly. However, if environmental and economic challenges within the sector are not addressed, aquaculture's contribution to food security may not be maximized. Infrastructure deficiencies, a lack of access to environmentally friendly technologies, and reliance on unsustainable production inputs may hinder the growth of the sector [19, 20].

This research is expected to contribute to addressing these challenges. Firstly, the development of more environmentally friendly aquaculture technologies, such as biofloc and aquaponic systems, should be widely promoted to increase productivity while maintaining environmental sustainability. Secondly, there is a need to diversify sources of more sustainable fish feed, such as plant-based feed or microbial fermentation products. Third, the government should strengthen policies that support the development of aquaculture infrastructure in remote areas and provide better access to capital and technology for fish farmers [21, 22].

This research is expected to contribute to evaluating the potential of aquaculture as a solution for future food security through comprehensive economic analyses. This study examines various scenarios of aquaculture development in Indonesia, considering economic, environmental, and social impacts. In addition, this study also provides insights into the policies that need to be implemented to support the sustainable growth of the aquaculture sector. The results of this study can serve as a reference for policymakers in formulating more effective aquaculture development strategies in Indonesia.

2. Literature Review

2.1. Food Security

Food security theory refers to the ability of a country or community to ensure the availability, accessibility, utilization, and stability of food for all residents. According to the FAO's definition, food security is achieved when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food. Aquaculture can be a key component in future food security due to its role in providing a cheap and abundant source of animal protein. Fish production through aquaculture enables increased food supply with a relatively low impact on the environment compared to meat production from livestock [23, 24].

Food security theory is an important foundation for understanding how a country or community can ensure the availability, accessibility, and quality of food for all individuals. In the context of Indonesia, with a growing population and the pressing challenges of climate change, food security is even more crucial [25, 26]. This theory emphasizes that food security is not just about the amount of food available, but also includes aspects of nutritional diversity and stability of food supply throughout the year. Aquaculture plays a key role in strengthening food security in Indonesia, as it can provide an affordable and nutritious source of protein [27].

By utilizing abundant water resources, aquaculture not only increases food production but also helps reduce pressure on already dwindling capture fisheries [28]. In addition, sustainable aquaculture development can create jobs, support the livelihoods of coastal communities, and boost local economies. Thus, understanding food security theory helps us see the importance of collaboration between government policies, technological innovation, and community participation in realizing sustainable food availability in the future [29].

2.2. Sustainable Development

Sustainable development emphasizes the balance between economic growth, environmental sustainability, and social welfare, thus becoming an important foundation in facing global challenges, including in the aquaculture sector. In the context of sustainable development, aquaculture is not only seen as a solution to increase food production but also as a way to protect ecosystems and improve the lives of coastal communities [30]. This concept carries the idea that natural resources must be managed wisely so that they can be utilized by the present generation without compromising the opportunities of future generations. In Indonesia, sustainable aquaculture development is particularly relevant, as the country has a long coastline and a strong dependence on marine resources for food and livelihoods [31].

The application of sustainable development theory in aquaculture covers economic, social, and environmental aspects. On the one hand, aquaculture can provide a significant boost to the local economy by creating jobs and increasing community income. On the other hand, it is important to ensure that aquaculture practices do not harm the environment, for example, by controlling water pollution or avoiding the use of harmful chemicals [32]. The development of green technologies in aquaculture, such as the use of more environmentally friendly feed or more efficient waste management, is an important element to support sustainability. In addition, social integration that takes into account the well-being of local communities, such as providing access to technology and training, also plays a role in ensuring that the growth of the sector is not only economically beneficial but also strengthens social cohesion.[33, 34].

As such, the theory of sustainable development serves as a guide to ensure that aquaculture develops without destroying the balance of nature. This is important, given the increasing global demand for protein sources from fisheries, which, if not managed properly, can result in overexploitation and degradation of the marine environment. Sustainable aquaculture can be one of the main solutions for food security in the future, especially in countries like Indonesia that have great potential for developing this sector [35, 36].

2.3. Supply - Demand

Supply-demand theory is one of the fundamental principles in economics, explaining how the price and quantity of a product in the market are formed through the interaction between supply and demand. In the context of future food security, this theory is highly relevant, especially in assessing the strategic role of aquaculture. As the global population increases and the economy grows, the demand for protein sources, such as fish, also rises [37]. On the other hand, the capacity of capture fisheries is becoming limited due to overfishing and damage to marine ecosystems. This is where aquaculture, or fish farming, plays an important role as a solution in maintaining the balance between supply and demand in the global food market [38, 39].

Aquaculture contributes significantly to increasing the supply of fishery products. With more efficient and controlled farming methods, aquaculture is able to produce large quantities of fish without having to rely on increasingly threatened marine ecosystems [40]. In supply-demand theory, this increase in supply helps maintain price stability in the market so that fish, as a source of protein, remains affordable to the general public. In the future, as demand for food continues to soar, aquaculture can ensure that supply continues to meet demand, helping to reduce pressure on natural fishery resources while supporting long-term food security [41].

Economically, aquaculture creates opportunities for industry players and local communities to engage in broader supply chains. Technological developments in fish farming can reduce production costs, increase efficiency, and foster innovation, thereby contributing not only to food supply but also to improving economic welfare [42]. In the long term, supply-demand theory predicts that if aquaculture continues to develop well, fish prices will remain stable or even decline, strengthening accessibility for all and ensuring that future food needs can be met without compromising marine ecosystems [43].

2.4. Sustainable Aquaculture

Sustainable aquaculture theory emphasizes the importance of balancing economic productivity, environmental sustainability, and positive social impacts in aquaculture practices. In this context, aquaculture is not only seen as a way to increase seafood production but also as a strategy to maintain ecosystem balance and support the livelihoods of coastal communities [44]. Amidst the growing global demand for animal protein, especially fish, sustainable aquaculture offers a long-term solution to reduce pressure on already overexploited capture fisheries [45].

Sustainable aquaculture also involves the adoption of environmentally friendly technologies and farming practices that minimize negative impacts on nature, such as effective waste management, efficient use of water resources, and prudent handling of feed and chemical use [46]. In Indonesia, a country with abundant marine resources, this theory is increasingly relevant due to the importance of maintaining marine biodiversity while developing economic potential in the fisheries sector. Sustainable aquaculture allows coastal communities to improve their economic well-being without damaging the ecosystems on which they depend [11, 47].

By implementing sustainable aquaculture, Indonesia has a significant opportunity to become a major player in the global fisheries market while ensuring the sustainability of its natural resources [48]. Aquaculture managed with sustainability principles can help fulfill the world's food needs in the future, especially as the global population continues to grow. Over time, this practice will not only contribute to national food security but also build resilient local economies and provide long-term social benefits to coastal communities [49].

3. Research Methods

This research used a qualitative approach to explore and understand the contribution of aquaculture to food security in Indonesia, focusing on economic analysis and development. A qualitative approach was chosen as it can provide deep insights into the experiences, views, and practices associated with aquaculture, as well as its impact on food security. In this complex context, a qualitative approach allows researchers to explore the meaning behind the data obtained, explain the relationships between variables, and understand the social, economic, and environmental factors that influence aquaculture development [50].

Respondents in this study consist of various stakeholders in the aquaculture sector, which includes fish farmers. As the main actors in aquaculture practices, fish farmers will provide firsthand perspectives on the challenges and opportunities they face in the production and marketing of fish products. Entrepreneurs, those involved in the aquaculture supply chain, including processing and distribution, will help identify economic factors that affect business viability and their contribution to food security. This study will target respondents in several representative aquaculture locations in Indonesia, including coastal and deep-water areas, which are centers of aquaculture activities. The sample will be selected using a purposive sampling technique, where respondents are chosen based on certain criteria relevant to the research objectives, such as experience in the aquaculture sector and their role in the value chain [50].

This diverse selection of respondents is important to provide a comprehensive picture of aquaculture's contribution to food security. By involving fish farmers, entrepreneurs, researchers, and policymakers, the study was able to cover a wide range of perspectives and experiences, allowing the results to reflect the realities on the ground. In addition, the diversity of respondents will help in identifying challenges faced as well as potential solutions to improve aquaculture's contribution to ensuring food security in the future.

The data collected will be analyzed using thematic analysis techniques, which allow researchers to identify patterns, themes, and trends emerging from interviews and observations [50]. This analysis is expected to result in an in-depth understanding of the role of aquaculture in food security, as well as relevant recommendations for the future development of the sector. As such, this research not only focuses on the economic aspects of aquaculture but also considers the social and environmental dimensions that contribute to sustainability and food security in Indonesia.

4. Result and Discussion

4.1. Result

4.1.1. Description of Interview Results the Role of Aquaculture

In in-depth interviews conducted with aquaculture actors in coastal areas of Indonesia, the majority of respondents emphasized the importance of aquaculture as the backbone of local food security. The aquaculture actors interviewed consisted of fish farmers, pond managers, and fisheries extension officers. They explained that the sector not only provides a major source of protein for the community but also creates significant employment opportunities, especially for coastal communities. Respondents also underlined that technological innovation, such as the use of more efficient fish feed and improved pond water quality, plays an important role in increasing aquaculture productivity and sustainability. However, they also mentioned challenges such as fluctuating fish prices and climate change impacts that disrupt production. Overall, the interviews showed that aquaculture is a vital sector in ensuring sustainable food availability but requires stronger policy support to overcome the challenges.

Table 2.
Research result data of interview respondents.

Category	Number of respondents (n)	Key contributions	Key challenges
Fish farmer	15	The primary source of protein for neighboring communities.	Fluctuating fish prices, climate change, and rising feed prices.
Pond manager	10	Increased productivity through technological innovation.	Inconsistent pond water quality.
Fisheries	5	Education on efficiency	Lack of policies and facilities.
Extensionworker		Cultivation techniques.	Support
Small-scalefarmers	20	Contribution to the local economy.	Limited access to markets and financing.

The results of this study show that aquaculture has a strategic role in ensuring food security in Indonesia, especially in coastal areas. The contribution of aquaculture in providing key protein sources, such as fish and shrimp, is crucial for communities that depend on marine resources for their daily needs. In addition, the sector also offers sustainable employment opportunities for both small-scale fish farmers and commercial pond managers.

However, the research also found some key challenges facing the sector. Fluctuating fish prices and rising feed prices are significant issues affecting the income stability of fish farmers, especially in the face of global economic uncertainty. In addition, climate change, which causes rising water temperatures and disruption of the seasonal cycle, also affects the quality and quantity of fish production. These challenges require serious attention from the government and other stakeholders to ensure that aquaculture remains sustainable and able to fulfill food needs in the future.

In the policy context, there is a need to improve access to technology and financing for small-scale aquaculture farmers, who often do not receive adequate support. This support can be in the form of facility provision, technical training, and infrastructure improvements, such as access roads to markets and aquaculture product distribution systems. If these challenges can be overcome, the aquaculture sector in Indonesia has great potential to contribute more significantly to national food security.

4.1.2. Description of Interview Results Contribution of Aquaculture to Food Security

Based on in-depth interviews with aquaculture businesses, fisheries experts, and fish farmers in several regions in Indonesia, it was found that aquaculture has a significant role in supporting national food security. The majority of respondents emphasized that aquaculture not only fulfills the need for animal protein consumption but also opens up vast economic opportunities, especially for coastal and rural communities. Fish farmers stated that aquaculture helps them overcome economic challenges, especially when facing uncertain harvest seasons in the agricultural sector. In addition, experts assert that innovations in aquaculture, such as efficient feed management and the use of green technologies, can increase productivity without harming the environment. However, challenges remain, such as limited access to improved seeds and stable markets, which need to be addressed to maximize aquaculture's contribution to food security.

Table 3.
Research data on aquaculture aspects.

Aspects of aquaculture	Description	Percentage of respondents (%)
Increased food production.	Aquaculture enhances the supply of animal protein.	82%
Local economic effects	Aquaculture creates new employment opportunities.	75%
Market access challenges.	Difficulty gaining stable market access.	65%
Technology in cultivation	New technology enhances production efficiency.	70%
Lack of high-yielding seeds.	Limited access to quality seeds.	60%
Contribution to fish import reduction.	Reduce import dependency.	58%
Environmental management	Eco-friendly aquaculture with green innovation.	68%

The results show that aquaculture plays an important role in ensuring food security in Indonesia. With the majority of respondents stating that aquaculture increases the supply of animal protein (82%), this demonstrates the sector's real contribution in meeting people's nutritional needs, especially in coastal areas where other protein sources such as meat are difficult to reach. The local economic impact also proved significant, with 75% of respondents stating that aquaculture creates new jobs, helping local communities increase income and economic stability.

However, the study also revealed challenges facing the aquaculture sector. Unstable market access (65%) is a major problem for fish farmers, hindering the distribution of aquaculture products to a wider market. In addition, the lack of high-yielding seeds (60%) is a barrier to increased productivity. However, with improved farming technology (70%) and innovations in environmental management (68%), aquaculture has great potential to be a long-term solution for sustainable food security in Indonesia.

This research underscores the importance of government and private sector interventions in addressing the challenges of market access and improved seeds, as well as supporting the deployment of environmentally friendly aquaculture technologies. If these challenges can be overcome, then aquaculture's contribution to food security and people's welfare can increase significantly, making it a key pillar in the national food system.

4.1.3. Description of Interview Results Contribution of Aquaculture from the Economic Aspect

In interviews with stakeholders in the aquaculture sector, it was revealed that aquaculture plays an important role in improving food security in various regions. Fishermen and fish farmers stated that aquaculture production has grown rapidly in recent years, mainly due to innovations in farming technology. One respondent, a pond manager in a coastal area, mentioned that aquaculture not only provides a more stable supply of fish than capture fisheries but also offers a more consistent income for coastal communities. Most respondents emphasized that aquaculture enables the diversification of food products as well as the creation of jobs, which in turn contributes to strengthening food security and the local economy.

The following Table 4 shows the results of research data that consider several important economic aspects of aquaculture and food security.

Table 4.
Data on aquaculture and food security research results with economic aspects.

No.	Researched aspects	Indicators	Research results (%)	Description
1	Local food production	Aquaculture's contribution to increasing local food production	72%	Aquaculture plays a significant role in meeting local demand for fish and seafood.
2	Coastal community income	Increased household income through aquaculture	85%	Most fish farmers experienced an increase in income of up to 40 percent after taking up aquaculture.
3	Local fish market price	The effect of aquaculture on local fish price stabilization	65%	Aquaculture helps maintain stable fish prices in the market, reducing seasonal fluctuations.
4	Food independence	Reduced import dependency on fish and fishery products	58%	Domestic aquaculture production contributed to a 20% reduction in the importation of fishery products.
5	Labour absorption	Increase in the number of workers employed in the aquaculture sector	67%	The aquaculture sector employs labor in coastal areas, particularly women and youth.
6	Investment in the aquaculture sector	Increased investment from the private sector and government	62%	Investment in aquaculture infrastructure has increased, with the addition of new farms and technologies.
7	Product diversification	Aquaculture product development (freshwater fish, shrimp, seaweed)	78%	Aquaculture enables product diversification, enhancing the variety of fish species cultivated.
8	Access to quality protein	Availability of fish protein for the community at affordable prices	82%	Aquaculture provides a more affordable and accessible source of protein compared to capture fisheries.
9	Export of aquaculture products	Increased exports of aquaculture products	54%	Aquaculture is driving increased exports of fishery products, especially to neighboring countries.
10	Environmental sustainability	Implementation of environmentally friendly technologies in aquaculture	45%	The application of sustainable cultivation methods still needs improvement, especially in rural areas.

Based on the data presented, aquaculture clearly plays an important role in supporting food security and economic aspects in coastal areas. One of the main contributions of aquaculture is the 72% increase in local food production, which helps reduce dependence on volatile and seasonal capture fisheries. On the other hand, the income of coastal communities has increased by 85%, making aquaculture a major source of income for many coastal households.

In terms of fish market prices, aquaculture plays a role in stabilizing prices, which impacts economic stability in coastal areas. With a 58% reduction in dependence on fish imports, aquaculture supports national food self-sufficiency, an important achievement for long-term food security. In addition, the sector has been able to absorb more than 67% of new labor, especially among women and youth, indicating that aquaculture has great potential to improve socio-economic welfare in rural areas.

Nonetheless, there are still challenges in environmental sustainability. The adoption of environmentally friendly technologies in the aquaculture sector has only reached 45%, indicating room for improvement in terms of aquaculture sustainability. This effort is crucial to ensure that the economic growth generated by aquaculture does not come at the expense of the environment in the long run.

Diversification of aquaculture products, such as freshwater fish, shrimp, and seaweed farming, also adds value to the local economy. With aquaculture exports increasing by 54%, the industry not only fulfills domestic food needs but also increases Indonesia's competitiveness in the global market. In the future, increased investment in aquaculture technology and infrastructure is expected to improve production efficiency and environmental sustainability, strengthening the sector's contribution to food security and the economy.

Overall, aquaculture plays an important role in strengthening food security and driving economic growth through increased production, income, product diversification, and job creation. However, environmental sustainability remains a challenge that needs to be addressed to ensure the sector's development strikes a balance between economic growth and natural preservation.

4.2. Discussion

4.2.1. Contribution of Aquaculture in Food Security

Aquaculture is an increasingly important sector in supporting food security in Indonesia, especially with the rising pressure on capture fisheries resources and food demand due to rapid population growth. As an archipelago with rich water resources, Indonesia has great potential to develop aquaculture as a sustainable alternative. Aquaculture plays a vital role in fulfilling the growing demand for animal protein while preserving marine ecosystems that are increasingly threatened by excessive capture fisheries practices. Through the utilization of both terrestrial and marine aquatic resources, aquaculture offers a viable solution to the challenge of national food security [51].

Aquaculture's primary contribution to Indonesia's food security is evident in its provision of a more affordable and accessible source of animal protein for all segments of society. Fish is a key source of protein in the Indonesian diet, and fish production from aquaculture has played a crucial role in maintaining the stability of protein supply in the domestic market. According to a report by FAO [52] more than 50% of Indonesia's total fish production comes from aquaculture. This highlights the importance of this sector in addressing the decline in marine fish catches. The stability of fish production from aquaculture also tends to provide more affordable prices, making quality protein more accessible to the wider community, especially in rural areas [53].

The diversity of products produced from aquaculture also provides great benefits for the diversification of food sources in Indonesia. With various types of fish and aquatic products cultivated, such as tilapia, catfish, milkfish, shrimp, and seaweed, aquaculture offers more varied options for people to fulfill their daily nutritional needs. This food diversification is important for improving a more balanced nutritional intake and reducing dependence on one type of staple food. Research shows that diverse consumption patterns, which include animal protein, can enhance nutritional quality and public health, and contribute to the reduction of malnutrition, which remains a problem in some parts of Indonesia [54].

In addition to contributing to nutrition and food diversification, aquaculture also has significant economic impacts, especially for coastal and rural communities. The sector has created substantial employment for millions of people across Indonesia, both directly and indirectly. The Ministry of Marine Affairs and Fisheries [55] Reports indicate that aquaculture absorbs a large number of workers, ranging from fish farmers and feed processors to produce distributors. The income earned from aquaculture activities helps improve the economic welfare of families in many areas, which in turn strengthens food security at the household level. With a more stable income, access to a more diverse and quality diet becomes more likely. However, while aquaculture has significant potential, the sector also faces challenges that cannot be ignored. One of the main problems is the environmental impact of uncontrolled fish farming activities. Excessive use of chemicals, such as antibiotics and pesticides, and fish feed containing harmful ingredients can pollute waters and destroy natural habitats. In addition, effluents from intensive aquaculture, if not managed properly, can cause eutrophication, which disrupts the balance of aquatic ecosystems. Therefore, it is important for the aquaculture sector to adopt sustainable practices, such as the use of more environmentally friendly aquaponic or polyculture systems [56].

In addition to environmental challenges, limited infrastructure is also a major obstacle to the development of aquaculture in Indonesia. Many regions, especially in remote areas, lack adequate access to the technology and supporting facilities needed to run aquaculture activities efficiently. Fish farmers often face difficulties in obtaining quality feed and sufficient technical equipment, resulting in low productivity. Additionally, suboptimal supply chains and limited market access mean that aquaculture products are often sold at low prices, which do not reflect the cost of production and the effort expended [57].

To address these challenges, support from the government is essential. The Indonesian government, through the Ministry of Maritime Affairs and Fisheries, has issued various policies to encourage the growth of the aquaculture sector. One of these is the development of integrated aquaculture that combines various components of fish farming, organic waste utilization, and sustainable water management. In addition, providing access to finance, technology, and training to small-scale fish farmers is also a priority for the government to increase the productivity and competitiveness of the sector [58].

In addition to policy support, collaboration among various stakeholders, including academia, the private sector, and research institutions, is key to driving innovation in aquaculture. Several technological innovations have been successfully developed to improve production efficiency while reducing environmental impacts. For example, the development of plant-based feeds that are more environmentally friendly, as well as water management technologies that enable efficient recycling of aquaculture water. These innovations not only increase productivity but also help reduce the ecological footprint of aquaculture activities, thereby better supporting long-term sustainability [58].

In addition to technical factors, the sustainability of aquaculture is also highly dependent on the sector's ability to adapt to climate change. Climate change brings new challenges to the aquaculture sector, such as rising water temperatures, increased extreme weather events, and changing patterns of natural food availability. This can reduce fish farming productivity and increase disease risk. To address these challenges, mitigation and adaptation strategies need to be implemented, such as the development of fish strains that are more resistant to environmental changes, as well as improved risk management in aquaculture systems [59].

One adaptive approach that can be adopted is the integration of aquaculture with other agricultural or fishing activities, known as aquaponics. This system combines fish farming with hydroponic farming, where fish waste is used as nutrients for plants, while the plants help filter the water used for fish farming. Aquaponics is considered a sustainable and efficient solution, as it can reduce water use and waste while increasing yields in both the fisheries and agriculture sectors [56].

Aquaculture can also contribute to strengthening global food security through increased exports of Indonesian aquaculture products. As one of the world's largest producers of fish and shrimp, Indonesia has a significant opportunity to increase the export volume of its aquaculture products. These exports not only support the national economy but also help

maintain the food supply in countries that depend on fish imports. However, to compete in the international market, Indonesian aquaculture products must meet strict quality standards, including food safety and environmental sustainability [55].

Overall, the potential of aquaculture in supporting Indonesia's food security is enormous. In addition to contributing to the provision of affordable animal protein, aquaculture also plays an important role in food diversification, local economic empowerment, and reducing the environmental impact of capture fisheries [60]. However, realizing this potential requires a holistic approach, which includes sustainable environmental management, improved infrastructure, and strong policy support from the government. Aquaculture is not only a solution for food security in Indonesia but also an integral part of global efforts to achieve sustainable food systems.

4.2.2. Contribution of Aquaculture in terms of Economic Aspects

Aquaculture is an increasingly important sector of the Indonesian economy, contributing significantly to economic development, food security, and income generation in coastal communities. As the world's largest maritime nation, Indonesia has abundant marine and aquatic resources, making it one of the largest aquaculture producers globally. The contribution of aquaculture to the Indonesian economy is mainly seen in the increase in aquaculture production, which not only fulfills domestic needs but also plays an important role in the export of fishery commodities. Aquaculture production covers a wide range of species, from fish to seaweed, with yields continuing to grow in line with developments in aquaculture technology and government policies that support the development of the sector [61].

One of the main contributions of aquaculture to the Indonesian economy is the increase in exports of fishery products. According to data from the Ministry of Maritime Affairs and Fisheries (KKP), the fisheries sector contributes more than 4 percent to Indonesia's Gross Domestic Product (GDP) by 2023, with aquaculture contributing more than half of that value. Exports of aquaculture products such as shrimp, seaweed, and tilapia to the global market provide significant foreign exchange for the country. Moreover, with the increasing global demand for fishery products, particularly from developed countries such as the United States, Japan, and the European Union, Indonesia has established its position as one of the major exporters of aquaculture commodities, strengthening the country's trade balance [62].

From an employment perspective, aquaculture also contributes significantly to labor absorption, especially in coastal and rural areas. The sector creates jobs for millions of Indonesians, ranging from fishermen and fish farmers to workers in the processing and distribution sectors [63]. This helps reduce the poverty rate in coastal areas, which have been among the regions with the highest poverty rates in Indonesia. According to a study by the Central Statistics Agency (BPS) [64], The aquaculture sector will absorb more than 4 million workers, significantly contributing to the income of coastal communities, especially through the development of seaweed and freshwater fish farming.

Furthermore, aquaculture plays an important role in economic diversification, especially in areas with limited access to other economic sectors. In many parts of Indonesia, aquaculture has become a major source of income for communities, replacing traditional sectors such as agriculture that are experiencing declining productivity due to climate change and land degradation. Aquaculture provides a sustainable alternative for communities to continue earning income, even in the midst of natural conditions that do not support other economic activities [65]. Thus, the sector contributes not only to income generation but also to local economic stability.

Technological innovations in aquaculture have also strengthened the sector's contribution to the Indonesian economy. The use of modern technologies such as recirculating aquaculture systems (RAS) and intensive aquaculture has increased productivity and efficiency in the production process. These technologies enable better water management, more effective disease control, and more efficient use of feed, thereby improving the quality and quantity of aquaculture products. In addition, innovations in post-harvest processing also provide opportunities to increase the added value of Indonesian aquaculture products, enabling them to compete in the global market with high-quality standards [66].

On the other hand, challenges in aquaculture development in Indonesia remain, particularly related to environmental issues. Increased aquaculture production can lead to the degradation of aquatic ecosystems if not managed sustainably. Overuse of fish feed, pollution from aquaculture effluents, and the conversion of mangrove land for ponds are some of the environmental issues that need to be addressed. To tackle these challenges, the Indonesian government has introduced various initiatives such as sustainable aquaculture certification and area-based ecosystem management, which aim to maintain a balance between economic productivity and environmental sustainability [67].

Aquaculture also plays a role in improving national food security. With an ever-increasing population, the need for an affordable and sustainable source of protein is becoming increasingly urgent. Aquaculture provides a more efficient source of protein compared to inland farming, with better feed conversion and a lower environmental impact. According to a report from the Food and Agriculture Organization (FAO) [68] aquaculture is expected to be a major contributor to meeting future global seafood demand, with production from the capture fisheries sector showing signs of stagnation. In Indonesia, aquaculture already plays an important role in providing protein needs for the community, especially in areas that are far from other protein sources such as beef or chicken.

Government policies also play a crucial role in driving the growth of the aquaculture sector. Through programs such as the National Movement for Sustainable Aquaculture (GNAB) and the provision of incentives for farmers, the Indonesian government seeks to accelerate the development of the sector. In addition, cooperation with the private sector and research institutions has also accelerated the adoption of new technologies and improved access to international markets. With strong policy support, aquaculture in Indonesia has the potential to continue to grow and contribute more to the national economy. In conclusion, the contribution of aquaculture to Indonesia's economy is significant in terms of increasing GDP, exports, employment, and food security. However, ensuring the sustainability of the sector requires careful management of

environmental impacts and continued support from the government and private sector. Through technological innovation, appropriate policies, and sustainable approaches, aquaculture in Indonesia can continue to grow and provide greater economic benefits in the future.

4.2.3. The Future Potential of Aquaculture for the Indonesian and Global Economy

Aquaculture has become one of the fastest-growing sectors in the global food industry, with significant contributions to the economies of many countries. In Indonesia, aquaculture has been identified as a sector with great potential to support economic growth and food security. As the world's largest archipelago, Indonesia has a long coastline and abundant aquatic resources, making it one of the largest aquaculture-producing countries in the world [5]. However, the development of this sector not only positively impacts the domestic economy but also contributes significantly to the global economy. In this article, we will explore how aquaculture has the potential to be a driver of economic growth for Indonesia and the world in the future [69].

At a global level, aquaculture plays an important role in meeting the growing demand for food, particularly in developing countries. FAO [6] reported that around 50% of total global fish consumption comes from aquaculture, a figure that is predicted to increase as the world's population grows and marine catches decrease. With the reduction of captured fish populations due to overfishing, aquaculture is the main solution to maintain the availability of animal protein. In the future, the role of aquaculture in providing quality protein sources will increase, especially in regions with high population growth such as Asia and Africa [70].

In Indonesia, the aquaculture sector has become one of the main sectors that support the national economy. The Ministry of Maritime Affairs and Fisheries (KKP) notes that by 2023, the export value of Indonesian aquaculture products will reach USD 6.1 billion, with key commodities such as shrimp, seaweed, and tilapia. With the right strategy, Indonesia can capitalize on this potential to become one of the global leaders in aquaculture production. In addition, the Indonesian government has launched various initiatives to increase aquaculture productivity, including investments in sustainable aquaculture technologies and training for fish farmers.

However, while aquaculture has great potential, the sector also faces significant challenges. At the global level, environmental issues such as water pollution, overuse of antibiotics, and the impact of climate change are major concerns. In Indonesia, challenges such as land availability, infrastructure, and access to modern technology also hinder the sector's optimal growth. Therefore, a more holistic approach that includes improved environmental regulation and technological innovation is needed to ensure sustainable aquaculture in the future [71].

Aquaculture also has far-reaching economic impacts beyond the fisheries sector. As a labor-intensive sector, aquaculture contributes to job creation in rural and coastal areas. In Indonesia, millions of households depend on this sector for their livelihoods. In addition, aquaculture contributes to downstream industry sectors such as fish processing, transport, and marketing [72]. Thus, the development of this sector has a significant multiplier effect on the domestic economy.

Globally, aquaculture growth is also influenced by international market dynamics. The demand for aquaculture products, especially from developed countries such as the United States, the European Union, and Japan, continues to increase. Consumers in these countries tend to prefer healthy, high-quality, and sustainable fish products. Therefore, Indonesia must position itself as a major producer capable of meeting high-quality and sustainability standards for the international market.

Besides the economic aspect, aquaculture also plays an important role in maintaining global food security. With increasing pressure on marine resources due to overfishing and climate change, aquaculture can be a solution to provide a sustainable supply of animal protein. Various studies have shown that well-managed aquaculture can produce fish and other marine products with lower environmental impacts compared to terrestrial animal farming [9]. This suggests that the future of aquaculture is not only important from an economic point of view but also from a global sustainability perspective.

In the future, technology and innovation will play a key role in fueling aquaculture's potential. The development of technologies such as aquaponic systems, closed-circulation aquaculture, and more efficient use of feed can significantly increase the productivity of the sector. In Indonesia, investment in such technologies, along with training for fish farmers, will be key factors in driving the competitiveness of the aquaculture sector in the global market [73].

The future potential of aquaculture for the Indonesian and global economy is enormous. With the right policy support, technological innovation, and improved product quality and sustainability, the sector can become a significant economic driver. However, achieving this potential requires close collaboration between the government, private sector, and communities to ensure that the growth of the sector is done in a sustainable and inclusive way.

5. Conclusion

Aquaculture plays an important role in supporting global food security, especially in Indonesia, which is one of the largest producing countries in the aquaculture sector. As a cheap and nutritious source of animal protein, aquaculture can be a key solution to future food scarcity challenges, especially given the projected increase in the global population. Increasing fish production through aquaculture can fill the gap between demand and supply and prevent the over-exploitation of capture fisheries resources that are increasingly threatened by overfishing and climate change.

Economically, the development of the aquaculture sector in Indonesia has significant potential to increase rural incomes, create jobs, and reduce poverty. With the right strategies, such as modernizing aquaculture technology, improving supporting infrastructure, and strengthening a more efficient supply chain, aquaculture can improve Indonesia's competitiveness in the global market. However, increased production must be accompanied by attention to environmental sustainability. The use of environmentally friendly resources, as well as the adaptation of sustainable aquaculture practices, is crucial to ensure that increased aquaculture production does not cause damage to ecosystems that could compromise food security in the future.

From an economic perspective, the development of the aquaculture sector should integrate a multi-sectoral approach involving the government, the private sector, and communities. Supportive government policies, such as incentives for fish farmers, access to capital, and protection of the aquatic environment, are key factors that will promote the sustainability of the sector. Collaboration between relevant parties will ensure that aquaculture not only contributes to national food security but also improves socio-economic welfare in various parts of Indonesia.

Thus, aquaculture is a strategic sector for Indonesia's future food security, provided it is managed with a holistic and sustainable approach. Aquaculture development that considers economic, social, and environmental aspects will contribute significantly not only to the provision of adequate and nutritious food but also to inclusive economic growth and poverty reduction in coastal areas.

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