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Realizing Low-carbon and Climate-resilient Development on Aquaculture

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aquaculture production supports food security, and it is an important commodity for Indonesia's exports. Climate change determines the sustainability of aquaculture production. Low-carbon development is an effort to control the impact of climate change from a mitigation standpoint, while climate-resilience development is an adaptation. In order to realize sustainable aquaculture in a broad and long dimension and in line with the Sustainable Development Goals (SDGs), it is necessary to develop a low-carbon and climate-resilience development strategy. A descriptive analysis was carried out on a review of published literature to develop the concept of low-carbon and climate-resilience development in aquaculture. The keywords used in the literature search are

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the impact of climate change on aquaculture, low-carbon development, climate-resilience development, and achievement of the SDGs in aquaculture. The research that has been published mostly discusses the potential Green House Gas emissions (GHG) from aquaculture activities, is still very limited and explains efforts to mitigate and adapt aquaculture to climate change. Efficiency and use of alternative energy sources, increased productivity, feed efficiency and effectiveness, effluent management, disease control and water quality management, and superior seeds can be applied in low-carbon emission development. Meanwhile, climate-resilience development that can be implemented includes the implementation of Integrated Multi-Tropical Aquaculture (IMTA) and Regional Integrated Multi-Tropical Aquaculture (RIMTA), closed systems, and Recirculating Aquaculture Systems (RAS), as well as ponds that integrate mangroves.

Keywords: Climate change; mitigation; adaptation; SDGs.

1. INTRODUCTION

As stated in Law No. 17 of 2007, Indonesia's long-term development goals are to realize a beautiful and sustainable Indonesia in line with the Sustainable Development Goals (SDGs). There are 17 agendas to be achieved in the SDGs by 2030. The 13th Agenda of the SDGs is climate action or efforts related to climate change, which consists of 2 (two) sides: mitigation and adaptation. Nationally, two action plans have been established: the National Action Plan for Reducing Greenhouse Gas Emissions called RAN GRK and the National Action Plan for Climate Change Adaptation called RAN API. The RAN GRK is a set of efforts to mitigate climate change, while the RAN API is an effort to reduce the risk of climate change impacts through adaptation activities. In its implementation, it is known as Low Carbon Development (PRK) as part of the implementation of the RAN GRK and Climate Resilience Development (PBI) as part of implementing the RAN API.

Most SDGs targets are relevant to aquaculture development; in their implementation, EAA (Ecosystem Approach to Aquaculture) contributes significantly to achieving 17 SDG goals [1]. Sustainable aquaculture development and contributing to the achievement of SDGs can be achieved with a blue economy approach [2]. The main challenge of aquaculture governance is to ensure effective measures for environmental sustainability, economic growth, entrepreneurship, and relevance to social aspects. The emphasis on space planning developed as part of EAA brings EAA closer to blue growth [3]. FAO has promoted blue growth since 2014 as the management of aquatic resources with a cohesive approach that aligns with the environmental management principles, integrated and socio-economically sensitive. Ecosystem approaches to aquaculture, climate change, habitat restoration, protected areas, and regulation and control of invasive species are part of the blue growth initiative [4].

Climate change is an environmental phenomenon in the form of changes in the pattern and intensity of climatic elements over a very long period [5]. Earth's climate is very complex; changes in one component can trigger changes in other components in the short and long term [6]. The form of change is related to changes in weather habits or the distribution of weather events [7]. The main cause of climate change is global warming. The acceleration of global warming results from increasing concentrations of greenhouse gases (GHG) in the Earth's atmosphere, which causes the greenhouse effect [8,9]. Human activities can also change the Earth's climate and drive climate change through global warming [10]. Climate change occurs through interactions between climate elements over tens to millions of years. A few decades ago, many parties still questioned the existence of this climate change phenomenon. However, with the development of science and a long series of studies, climate change is scientifically proven. Empirically, the impact of climate change is increasingly real and felt. Climate change will impact the ocean, land, and air layers [11].

Implementing PRK and PBI is part of a commitment to achieving sustainable development goals or SDGs, especially the 13th Agenda (climate action). Indonesia's commitment to achieving SDGs is outlined in Presidential Regulation (Perpres) Number 59 of 2017 concerning implementing the Achievement of Sustainable Development Goals. This Presidential Regulation mandates the achievement of SDGs through the participation of all stakeholders. PRK and PBI initiatives are listed in the national development priorities in the

2020-2024 National Medium-Term Development Plan (RPJMN) document (Perpres 18/2020), which is part of National Priority (P.N.) 6 "building the environment, increasing disaster resilience and climate change". There are 3 Priority Activities (K.P.) in P.N. 6 related to efforts to control climate change: K.P. 1: recovery of pollution and damage to natural resources and the environment, K.P. 2: increasing climate resilience, and K.P. 3: low carbon coastal and marine. The national Agenda in efforts to control climate change consisting of PRK and PBI is outlined in the National Determined Contribution (NDC) and Enhance NDC. NDC is a national commitment to address global climate change to achieve the Paris Agreement's goals for the United Nations Framework Convention on Climate Change (UNFCCC).

As an integral part of national development, aquaculture development needs to participate in realizing low-carbon development (PRK) and climate-resilience development (PBI) to achieve long-term sustainability [2]. From existing research, it can be concluded that irresponsible aquaculture and not applying good aquaculture practices (GAP) impact the environment, including climate change [8,12]. Instead, climate change will determine the viability and sustainability of aquaculture [13]. Climate change causes disruption of the function of ecosystems to absorb carbon, and the impact of climate change causes increasing global warming, thus the cycle continues, which ultimately has extreme consequences for life [14]. For this reason, aquaculture needs to anticipate and minimize the impact of climate change. Furthermore, to be able to contribute to mitigation and formulate aquaculture that is adaptive to climate change, it is necessary to map issues, problems, and challenges of its implementation so that policy and strategy recommendations can be formulated.

2. METHODOLOGY

Descriptive analysis is used to develop strategies to achieve low-carbon and climate-resilience development in aquaculture. Descriptive analysis is the collection, processing, presentation, and interpretation of quantitative data or percentages that can be presented in tables or graphs [15]. Descriptive analysis aims to convert a set of data that is still raw data into information in a form that is easier to understand. It can use schemes, bar charts, pie charts, histograms, ogives, and others in its presentation.

Desk studies are conducted on secondary data consisting of published research and books, reports, regulations, and laws related to low-carbon development and climate resilience. The keywords used in the literature search are the impact of climate change on aquaculture, low-carbon development, climate-resilience development, and achievement of the SDGs in aquaculture. A systematic review is a comprehensive and fact-balanced policy-making approach [16]. A conceptual model needs to make a policy recommendation. System thinking is used to formulate conceptual models of sustainable shrimp pond farming related to climate change. Based on the literature, the review is also formulated as an alternative strategy for low-carbon and climate-resilience development in aquaculture.

3. RESULTS AND DISCUSSION

3.1 Potential Carbon Emissions and Climate Change Impacts on Aquaculture

The rise and rapid growth of aquaculture, in addition to creating a source of economic growth and improving community welfare, also has the potential to cause several environmental problems. The potential for environmental problems occurs in aquaculture activities that are not by regulations and recommended technology [17]. Carbon emissions are among the potential environmental problems associated with aquaculture development [17,18]. The potential for carbon emissions is mainly in aquaculture that uses considerable energy, such as intensive technology shrimp farming, and those that require large areas of land and convert natural ecosystems, such as traditional/extensive technology shrimp farming in ponds [17,18]. Aquaculture carbon emissions are also related to commercial feed use, and globally these potential emissions were approximately 0.49% of anthropogenic GHGs in 2017 [19].

Potential carbon emissions in aquaculture areas come from land conversion, carbon conversion from energy use during operation [17], water-air interface fluxes [20,21], emissions from organic matter from aquaculture waste [22], emissions from pond areas that are being drained [23] or ponds that are not operational or idle [24], and effluent which reaches the natural ecosystem around the aquaculture area [25,26]. Carbon emissions from land conversion, for example, mangrove ecosystems, consist of loss of carbon storage in the form of biomass [27], loss of carbon sequestration ability [28,29], and release of gases trapped in the bottom substrate [30;31].

The potential for greater carbon emissions during the production process is found in aquaculture activities that use intensive technology and commercial feed. The amount of carbon emissions depends on feed conversion ratio, feed efficiency and effectiveness, and composition for fish feed formulations that differ between aquaculture species. N_2O. The intensity of carbon emissions in aquaculture is still smaller than the production of terrestrial livestock such as sheep and goats, this is due to the absence of enteric CH_4 combined with high fertility and low feed conversion ratio in aquaculture [20]. Even the earthen shrimp ponds that applied traditional technology in southeastern China are found as a CO_2 sink but a source of CH_4 [32].

On the other hand, the accumulation of carbon gas emissions along with other greenhouse gases drives global warming due to the effect of greenhouse gases; global warming causes climate change [33,34,35,36]. Aquaculture is an activity highly dependent on environmental quality (water, soil, and air), so it is greatly affected by climate changes and environmental parameters [37]. Among aquaculture problems, such as shrimp ponds, are related to and triggered by climate change [17,38,39]. Climate change negatively affects aquaculture businesses' sustainability [17,20,40]. The effect of climate change on aquaculture can be direct or indirect. The indirect influence of climate change on aquaculture relates to all ecosystems and habitats in the sea, coastal, and terrestrial [41].

The impacts of climate change related to aquaculture are sea level and temperature rise, changes in monsoon patterns, extreme climate and water stress, exacerbation of eutrophication and stratification of static waters, increased incidence and impact of disease outbreaks [42]; coastal flooding, drought, acidification, salinity changes, and storm surge [41]. Aquaculture problems that arise as a result of climate change above are a decrease in growth rates due to environmental stress due to water quality parameters that are outside the optimum range [42], increased mortality due to declining fish/shrimp conditions, and increased disease outbreaks [41]; potential difficulties in managing water in and out for ponds that rely on tides; damage to aquaculture facilities and construction due to extreme waves, as well as the potential for sinking aquaculture areas due to sea level rise.

The potential contribution of aquaculture carbon emissions and climate change impacts differs from other animal protein production, and the ecological costs of each commodity and aquaculture system are also different [42]. For this reason, mitigation strategies must be formulated by implementing Low Carbon Development (PRK) and adaptation strategies by implementing Climate Resilience Development (PBI) in aquaculture.

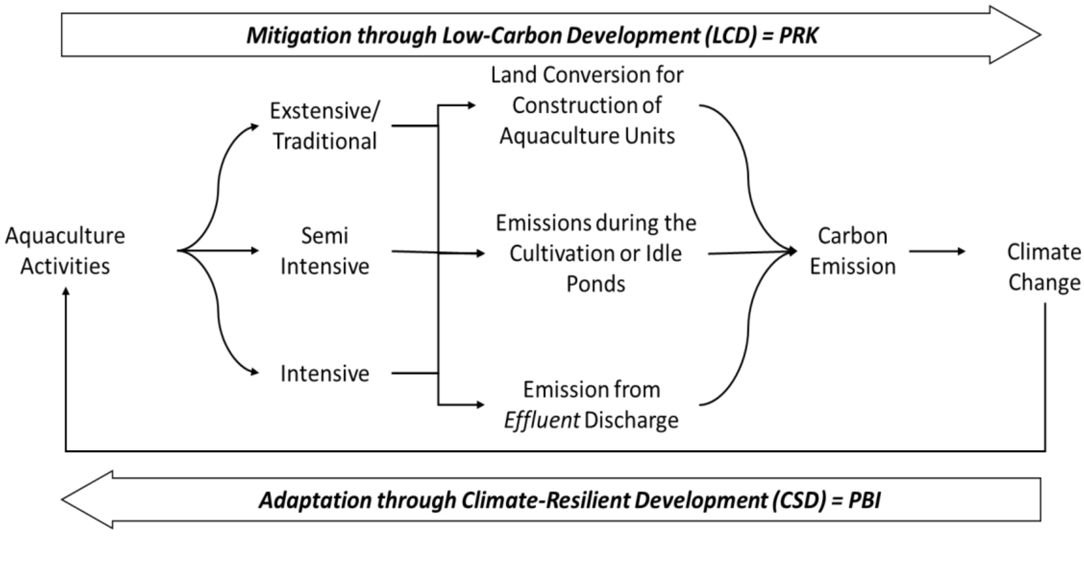

Fig. 1. Strategy scheme for mitigating potential carbon emissions and adapting to climate change impacts on aquaculture

3.2 Conceptual Model of Sustainable Aquaculture in Climate Change Perspective

Mitigation and adaptation efforts must be formulated to consider the impact of climate change on aquaculture and the survival of life on Earth. PRK and PBI have been implemented in priority sectors contributing to emission reduction; currently, mangroves as blue carbon ecosystems are included in the FOLU (Forest and Other Land Use) sector in NDC (National Determination Contribution) and enhance NDC. Existing research has identified and inventoried emission sources and potential carbon sequestration and storage in aquaculture areas. PRK and PBI in aquaculture development are carried out by minimizing emission sources, optimizing carbon absorption and storage, and anticipating the impact of climate change on production continuity and the realization of SDGs.

In general, efforts that can be made to realize sustainable aquaculture include spatial planning and arrangement of aquaculture areas, control and supervision of spatial use, environmental control and supervision, application of eco-labelling, implementation of PRK and PBI, and aquaculture technology engineering. Spatial arrangement is intended to harmonize activities in an area, especially those adjacent, and impact each other. The arrangement of aquaculture areas is carried out considering the carrying capacity of the environment, carbon dynamics, and social communities [18]. Strengthening regulations and the capacity of local governments to control and supervise the use of space and the environment need to be improved [17]. The engineering of shrimp farming technology in ponds is carried out to minimize potential GHG emissions such as efficient use of energy and the use of low-emission alternative energy and optimize carbon absorption and storage, optimize phytoplankton populations and composition, and apply Integrated Multi Tropic Aquaculture (IMTA) [17,18,43].

Research on shrimp farming in ponds and its relation to climate change is a widely publicized aquaculture activity. Integrated management of coastal areas is expected to balance the community's welfare, shrimp farmers, and the environment, especially mangrove ecosystems. A healthy mangrove ecosystem can support the productivity of shrimp ponds, providing income protection, contributing to food and social security, and reducing greenhouse gas emissions. Analysis of the relationship between low-carbon and climate-resilience shrimp ponds for environmental policy formulation begins with problem mapping using system thinking (Fig. 2).

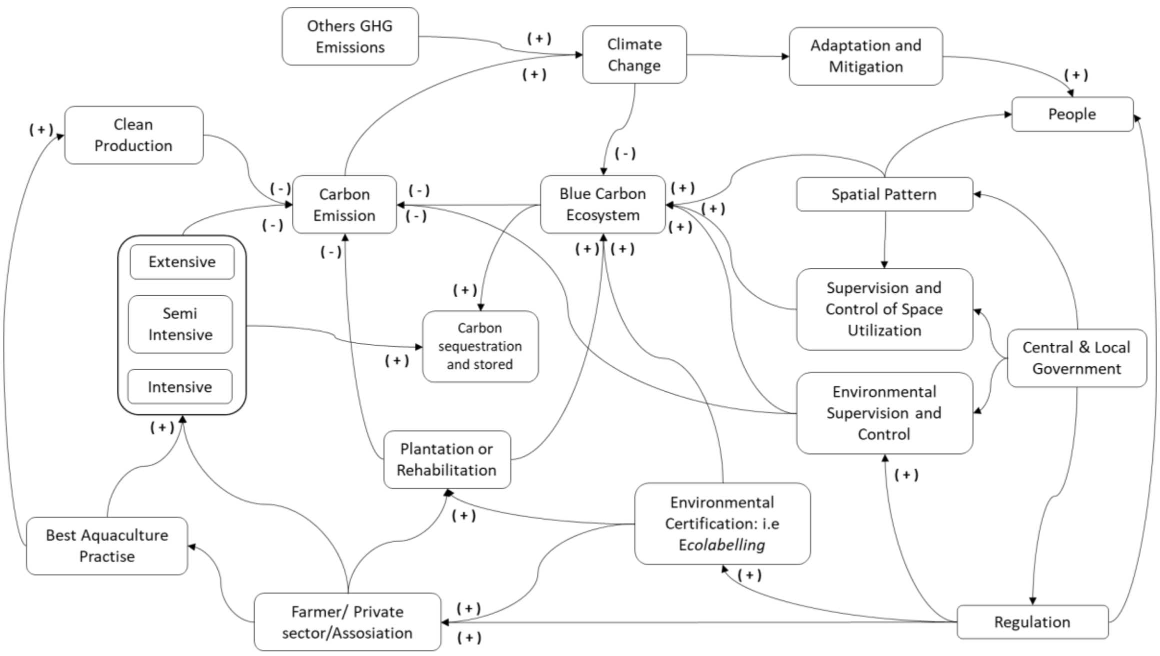

Fig. 2. System Thinking of sustainable shrimp pond farming related to climate change

Fig. 2 schematically explains the problem of shrimp farming in ponds at shrimp farming areas. From various literature, the greatest potential for greenhouse gas emissions in shrimp farming areas is some ponds that convert mangroves due to the loss of the ability to absorb CO_2 and carbon storage in the form of biomass and gases in the mangrove bottom substrate. Shrimp farming in ponds also has the potential to cause emissions. The greatest potential comes from using energy for peddling wheels, pumps, lighting, and pond activities. On the other hand, mangrove ecosystems are also effective absorbers of organic matter, so the existence of mangrove ecosystems will help the environment neutralize/purify wastewater from shrimp farming activities in ponds. On the other hand, the potential for carbon absorption and storage during shrimp farming is ponded as the study's results [44]. Low-carbon semi-intensive and intensive shrimp farms are closely related to GHG reduction in the energy sector while low-carbon traditional/extensive shrimp ponds are closely related to GHG reduction in the FOLU sector [17].

Increasing productivity and land area while considering land suitability and carrying capacity can achieve production exceeding the predetermined target [20,21]. At the same time, land designated as mangrove protection can be restored to its function as a provider of environmental services, including supporting the continuity and sustainability of shrimp farming activities in ponds. With the arrangement of the area, aquaculture engineering, good fish farming practices, and the use of alternative energy sources during the shrimp farming process in the pond, the source side will be minimized, and the sink side can be improved [43].

3.3 Low Carbon Development Strategy for Aquaculture

Based on the potential emissions, efforts to mitigate climate change by reducing the potential for emissions and maximizing the potential for carbon absorption in shrimp farming activities in ponds can be carried out, including efficient use of energy during the cultivation process, including through the conversion of the use of electrical energy and fuel to renewable energy sources such as wind power and solar energy; optimization of water quality management during the cultivation process, including phytoplankton population and composition; effluent management of ponds in reservoirs and sewers, including the Integrated Multi Trophic Aquaculture (IMTA) model; maintaining inundated land ponds during non-production; enforcement of rules on areas designated as mangrove areas; processing waste from shrimp farming in collaboration with the Regency / City Government and increased land productivity and use of quality production inputs [18].

a. **Efficient energy use and development of alternative energy sources during cultivation**. It includes converting electrical energy and fuel to renewable energy sources such as wind and solar. Efficient use of energy can impact less operational costs and increased efficiency. At times, the farmer operating the peddle wheel will need fuel or electrical as a source of energy. Optimization of operations using a peddle wheel will impact shrimp cultivation yields and profitability.
b. **Optimization of water quality management during the cultivation process**: Aquaculture requires a clean environment and ideal water parameters, arrangement of aquaculture areas and irrigation systems that differ between inlet and outlet water so that clean water and dirty water are not mixed, so as not to cause stress on aquaculture commodities. Each aquaculture unit needs to have a wastewater treatment system so as not to degrade environmental quality. Aquaculture technology innovation during production can increase productivity, and efficient use of resources such as water use can increase the competitiveness of aquaculture production.
c. **Management of effluent (wastewater) in reservoirs and sewers,** among others, can apply the IMTA model. The IMTA system is expected to reduce waste problems and trigger the development of species with low tropical levels but with high nutrition (source: aquaculturecelebes.com). An active role and public awareness of the importance of protecting the environment are urgently needed. The government is obliged to impose rules on all of the industry and the community so as not to dispose of waste into the waters of rivers, beaches, and seas. The government also needs to regulate good disposal so that the waste does not pollute the water area.

d. **Increasing land productivity and using quality production inputs**, land conversion is the largest source of emissions from traditional/extensive aquaculture activities. For this reason, increasing productivity with technological improvements and using production inputs such as feed, seeds, and quality fish medicine can reduce the potential carbon emissions from aquaculture activities.
e. **Keep earthen ponds inundated during non-production periods,** and improve pond construction, such as elevating the embankments and pond beds to facilitate water exchange. Shrimp ponds that are not inundated have greater CO_2, CH_4, and N_2O emissions than inundated ponds [24]. It is possible because the bottom substrate of the pond, rich in organic matter, is exposed directly to sunlight.
f. **Enforcement of rules in areas designated as mangrove areas,** to overcome problems related to rule enforcement requires cooperation between the government, the community, and the private sector. Deforestation of mangroves by various human activities causes CO_2 emissions [45,46], i.e shrimp ponds that convert mangroves and traditional/extensive technology (productivity around 250 kg per ha) in the Mahakam Delta have the potential to cause emissions of 1,603 kg CO2-equivalent for every 1 kg of shrimp produced [46], and Mangroves converted to shrimp ponds caused a loss of more than 75.5% of carbon in Sri Lanka's Puttalam Lagoon [13].
g. **Waste management,** the waste problem is in line with the population and economics growth rate, which will increase the consumption level and ultimately increase the amount of waste more and more. To overcome the waste problem in the aquaculture area, pond communities can create integrated landfills located some distance from residential areas by implementing the 4Rs, namely replace, reduce, reuse, and recycle. Of course, it also makes a separate trash can between organic and inorganic.

The above strategies are mostly relevant to the 3rd policy of the marine and fisheries blue economy road map, namely the development of aquaculture in the sea, coastal and land. The achievement of each item strategic key element of the marine and fisheries blue economy policy has been targeted at five-year periods until 2045 [47]. All of the above low-carbon aquaculture development strategies are in line with good aquaculture principles, except for the use of new and renewable energy sources. Currently, the use of new and renewable energy sources in aquaculture is still very limited, due to the huge investment costs needed.

The energy sector's emission reduction targets have been outlined in the Updated Nationally Determination Contribution (NDC) [48], and also explained in the Indonesia Long-Term Strategy for Low Carbon and Climate Resilience (LTS-LCCR) [49] as well as efforts to achieve the zero-sum emission target by 2060 [50]. The targeted supply of new and renewable energy in 2050 in Indonesia will reach 275.2 - 477 MTOE [51]. So, it is expected that along with the development of science and technology, especially in the use of new and renewable energy sources, it is hoped that it will be cheaper and easier and can be implemented in aquaculture activities.

3.4 Aquaculture Climate Resilience Development Strategy

The impact of climate change tends is increase; the effort that can be made is to slow its rate and simultaneously increase adaptability to minimize the impact. Efforts that are needed are to find alternative commodities and varieties that are adaptive to changes in environmental parameters due to climate change and aquaculture engineering to minimize environmental influences on cultivation systems such as closed systems and recirculating aquaculture systems. The increase in population leads to competition for resource use, environmental pressures, and climate change, as well as efforts that can be made for adaptation and sustainability of aquaculture [12].

Specifically, the impact of climate change will differ on freshwater, brackish, and marine aquaculture activities, and the impact of climate change will also differ from each location [42]. The efforts to adapt aquaculture technology engineering to deal with environmental pressures and climate change impacts above are integrated aquaculture rice-fish farming [12], and aquaculture associated with mangroves or sylvo-fishery.

a. **The selection of commodities that are adaptive to emerging changes and those** that are tolerant of changes in salinity are needed in aquaculture areas affected by seawater intrusion. Commodities that are adaptive to non-fish protein sources must be developed to anticipate declining catches due to climate change [42].
b. **IMTA (Integrated Multi Tropical Aquaculture),** developing multi-species commodities can reduce the risk of business failure due to climate change [41]. Aquaculture commodities of low tropical species will increase production along with the increase in phytoplankton and zooplankton populations due to eutrophication [42] to tolerable levels.
c. **RAS (Recirculating Aquaculture System),** a recirculation cultivation system, can minimize water intake from outside the system to reduce the risk of extreme changes in water quality parameters and minimize the entry and spread of disease-causing pathogens in the cultivation unit. Aquaculture that uses blue-green water efficiently has better resilience to the impacts of climate change [52].
d. **Construction engineering of cultivation units.** It is needed for the safety of marine aquaculture; it is necessary to develop technology and construction cultivation units that can anticipate the impact of extreme weather [42].
e. **Effectiveness of irrigation canal management.** To ensure adequate quality and quantity of water supply, well-managed irrigation canals are needed. Irrigation facilities in cultivated areas can improve adaptability to the impacts of climate change [41]. Participatory irrigation management is an approach that is seen as effective. Cultivators and local communities are involved in the channel management process.
f. **Governance and institutions** In addition to the technical aspects above, it is also necessary to pay attention to policy aspects, including strengthening governance and institutions. Among them that need to be strengthened, according to [42], are the development and process of technology transfer, zoning and monitoring of aquaculture areas, and aquaculture insurance. Supported by multi-disciplinary research and development and strong collaboration among all relevant stakeholders such as cultivators, business actors, financing institutions, research institutions, and government and non-government organizations [41].

Most strategies to realize aquaculture that is resilient to climate change are also relevant to 3rd policy of the marine and fisheries blue economy road map, namely the development of aquaculture in the sea, coastal and land. The target of five-year period until 2045 for each of the key strategic items has been outlined on the marine and fisheries blue economy roadmap [47].

4. CONCLUSION

Aquaculture contributes to climate change through potential carbon emissions, on the other hand aquaculture is affected by the direct and indirect impacts of climate change. The number of contributions of aquaculture to carbon emissions is different for each technology applied. Most strategies to realize low-carbon and climate-resilient aquaculture development are in line with the best aquaculture principles, except for the use of new and renewable energy and governance and institutions. So special efforts are needed related to the use of new and renewable energy as well as improving governance and strengthening aquaculture institutions.

To streamline efforts to realize low-carbon and climate-resilience development, strengthening governance and institutions needs to be carried out in terms of mitigation and adaptation. Consumer awareness of low-carbon products will encourage the implementation of low-carbon development, including aquaculture. On the other hand, awareness of farmers and business actors on climate change's impacts will encourage climate-resilience development.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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