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Climate Risks and Opportunities of the Marine Fishery Industry: A Case Study in Taiwan

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Abstract: As climate change and extreme weather intensify, forecasting natural environmental changes involves high uncertainty and variation. Planned policy changes and the ability of fisheries to withstand these changes and impacts are major challenges in regard to addressing future climate hazards in Taiwan. Taiwan's geographic location is favourable for the marine fishery industry, which is an important primary industry and a source of animal protein for residents of Taiwan. Recently, both long-term climate change and extreme climate hazards have led to shocks in the marine fishery industry. The resulting instability of the industry directly affects the market supply of and demand for seafood. We conduct a case study of a marine fishery industry in Taiwan that incorporates social concern assessments of risk perception and judgements of risk acceptance through risk management processes. Furthermore, we incorporate stakeholder participatory processes to reduce the gap in awareness of adaptation and to increase the opportunity to reach consensus and develop an integrated risk management model that enables decision-makers to better meet the needs of society. These measures will enhance all parties' willingness to adapt and help achieve the goal of public-private collaboration in facing climate change challenges.

Keywords: marine fishery industry; stakeholder participatory processes; risk management; climate change; adaptation; fishery management



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1. Introduction

Since the Brazil UN Earth Summit proposed Agenda 21 in 1992, amid scientific and technological progress and rapid development in human socioeconomic activities, the ongoing democratization of developing countries, changes in the global population, and the transformation of social and economic structures, countries around the world have adopted the sustainable development goals (SDGs) as long-term development aims and key areas of governance [1,2]. The Paris Agreement passed by the UN in 2016 suggested that climate change would be the most challenging issue facing all countries in their efforts to safeguard food security and realize sustainable development. Furthermore, fluctuations in world fisheries' production in terms of output and monetary value will be critical to food security [3].

As a set of important international agreements, including the 2030 Agenda for Sustainable Development, Rio + 20, the Rome Declaration, and the Paris Agreement, has been signed and put into effect, the interplay between climate change, production, and supply and demand in the marine fishery industries has gradually become an important topic that has attracted global attention. The direct and indirect impacts of long-term environmental change and extreme weather events on the marine fishery production process and the uncertainty in global seafood supply and demand caused by production fluctuations have attracted the attention of international organizations. For example, the 2016 World Fisheries and Aquaculture Status Report published by the FAO noted that these changes would lead to structural changes in fishery sectors and increased fluctuations in production

and capacity around the globe, with complex impacts and uncertain pathways involving multiple facets, including the environment, catch species, fishing villages, and the economy [4–7]. Eventually, climate impacts and influences will translate to a high degree of uncertainty for marine fishery industry operators in their production process and will affect the overall supply and demand in the seafood market and overall food security (Ho et al., 2018). In the future, these climate hazards and the uncertainty and fluctuations in fisheries' production will bring about major changes in the global supply and trade of seafood and will potentially affect geopolitics and the economy. In particular, countries with domestic markets and economies that rely heavily on fishery industries may become major actors in safeguarding global food security and implementing the UN 2030 SDGs [6,8].

Taiwan is an island located in the subtropical climate zone, which is favourable for fisheries. The fishery industry has gradually become an important primary industry and a source of animal protein for the residents of Taiwan. According to the Fisheries Statistical Yearbook Taiwan, in 2018, the total output of fisheries and aquaculture in Taiwan was 1.0096 million metric tons (89.736 billion NTD) (Figures 1 and 2) [9]. According to the 2016 Food Supply and Utilization Yearbook, on average, seafood accounted for 6.99% of the daily per capita protein supply, and overall, seafood accounted for 16.33% of the supply of animal protein. The annual per capita consumption of seafood is approximately 26.42 kg [10]. However, Taiwan's fishery industry faces the same challenges as its global counterparts. Environmental changes resulting from both long-term climate change and extreme weather events have created shocks in the industry and brought uncertainty to production in terms of both output quantity and monetary value. Issues including increases in sea surface temperature (SST), changes in typhoon patterns, extremely heavy rainfall, changes in ocean current patterns, and production suitability have exposed fishery production to higher risks and increased its fragility, thereby heightening the risks to the associated marine fishery industry [8,11].

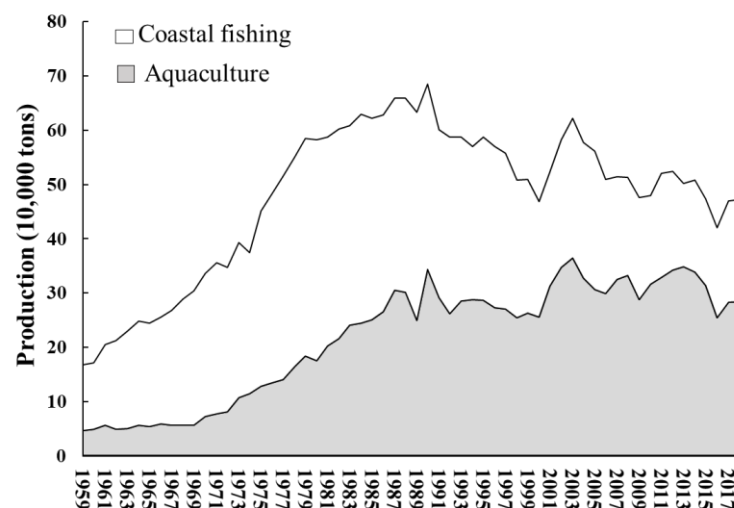


Figure 1. Coastal fishing and aquaculture production in Taiwan, 1953–2018. The data were obtained from the Fishery Agency, accessed on 25 May 2021.

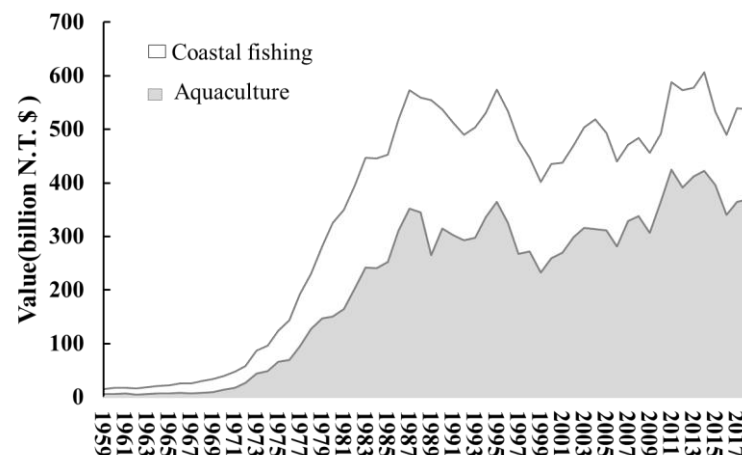


Figure 2. Coastal fishing and aquaculture production value in Taiwan, 1953–2018. The data were obtained from the Fishery Agency, accessed on 25 May 2021.

In October 2018, in accordance with the Summary for Policymakers “Global Warming of 1.5 °C” published by the IPCC and the Greenhouse Gas Emissions Reduction and Management Act, six major departments of the Executive Yuan developed the Action Plan for Carbon Emissions Reduction for Six Major Departments and established each department’s major policy direction and measures for responding to climate change. Under the greenhouse gas emissions reduction action plan, eight major policies were developed for the fishery industry, including implementing total greenhouse gas emissions control, developing green keys and green industries, establishing information channels, providing awards and subsidies, developing talent, enhancing public awareness and capacity for action, and reviewing regulations on greenhouse gas emissions. In terms of the greenhouse gas emissions control action plan, under the main theme of “strengthening the recycling and utilization of fishery energy resources,” “promoting environmentally friendly fishery operations, maintaining fishery production, and ensuring sustainable development” were set as the major adaptation policies, and two major action plans, the “plan for fishing boat acquisition and disposal” and the “plan for rewarding fishing moratorium,” were established [9]. To implement the policy goals, fishery agencies also developed related policies, legislation, and regulations, including the Agriculture Insurance Act, the Key Points of Natural Disaster Insurance Subsidy for Aquaculture and Fisheries, the Fisheries Act, the Enforcement Regulations of the Fisheries Act, and the Goods Stabilization Plan. Different adaptation policies and policy directions were established for different types of climate change risks.

In developing climate change adaptation policies, the extent to which the government and the public recognize policy issues, as well as the policy planning method and the choice of path, constitutes an important foundation for the actual implementation and evaluation of policies [8,12]. However, in most policy-making processes, there is a lack of consensus between the government and the public on the definition of the problem, starting with defining risk issues and setting targets. This lack of consensus leads to differences in risk perceptions and results that are expressed in extended arguments after risk evaluation or policy implementation. To improve the effectiveness and feasibility of management and adaptation policies, governments and international organizations around the world are encouraging the gradual involvement of stakeholders in the policy-making process [13–16]. This approach can resolve and reduce potential conflicts in policy implementation, enhance the climate resilience and adaptability of the entire system, and effectively achieve long- and short-term goals for climate change adaptation (Figure 3) [17–19].

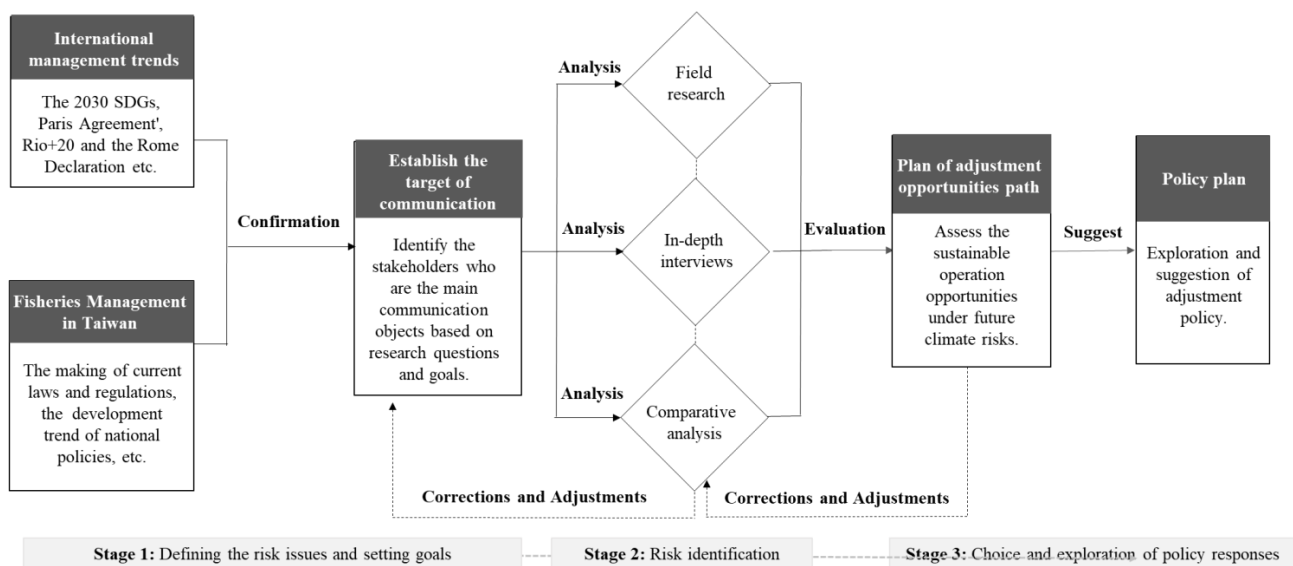


Figure 3. Climate risk assessment process and stakeholder participatory cooperation.

Fishers in local fishing villages and related industries play a critical role in climate change adaptation. In the face of long-term climate change and imminent extreme weather events, local fishing villages are subject to immediate and direct impacts and risks. When facing the impact and variations of climate change, the strategies of local fishing villages and marine fishery industry operators for coping with and adjusting to long- and short-term fluctuations in fisheries and marine fishery production—in terms of quantity and monetary value—and the differences in their choices of adaptation policies determine the fragility, degree of risk, ability to adapt, and industry resilience of local fishery communities. These factors are also key in regard to determining whether supply and demand in the fisheries sector are stable [9,18].

This study aims to achieve the goals discussed above and fill the existing research gap by providing more scientific evidence for future research and international fishery management. Specifically, the study has three goals:

- (1) To provide information about stakeholders' perceptions of climate change adaptation as well as their risks and behaviours during long-term climate change and imminent extreme weather events and to develop a stakeholder participation mechanism that will be adopted in the process of planning for climate change adaptation.
- (2) To provide users with appropriate adaptation options and potential financial opportunities. We suggest different adaptation options that may give rise to potential opportunities and financial interests that will likely benefit fishery agencies, operators, and coastal communities in Taiwan and other countries with similar industry patterns. We also expect the suggested options to fill the research gap in this field.
- (3) To propose two different approaches to promote climate education for the general public and for stakeholders to enhance public awareness of and identification with issues related to climate and the fishery sector.

2. Integrated Framework for Climate Change Risk Management in the Marine Fishery Industry

2.1. Defining the Scope of the Study

For this research, we set Taiwan's marine fishery industry as the object of study. We adopt the risk management process in response to climate change with a rolling revision process proposed by the Task Force on Climate-Related Financial Disclosures (TCFD) and The Taiwan Climate Change Projection and Information Platform Project (TCCIP) of the Financial Stability Board as the research framework [20]. We also incorporated appropriate stakeholder participatory processes into the research at different stages.

2.2. Evaluation Method and Process

2.2.1. Step 1: Defining the Risk Issues and Setting Goals

Based on the goals of the 2050 SDGs, to mitigate the possible impact of climate change on the marine fishery industry and to realize the goals of food security and sustainable development, we sorted the key topics into four major categories: the environment, ecology, the fishing community and the economy, and production stability. We employ both top-down and bottom-up evaluation methods to examine issues at different management levels. In accordance with the key topics and the research gap, the following issues are included in the study:

- (1) Confirm stakeholders' awareness of climate risks, their issues of concern, and their attitudes towards risk and the impact of historical climate change or extreme weather events on the stability of marine fishery production.
- (2) Verify the adequacy of the existing management system and adaptation capacity to support resilience in the face of climate hazards and new sustainable development opportunities as well as potential financial interests for the marine fishery industry under future climate risks.

2.2.2. Step 2: Risk Identification

This step addresses objective (A). We adopt the top-down evaluation method in the risk identification step based on the extent and levels of the climate risk impact. An analysis of how human society (e.g., fishery operators or fishing communities) is affected by climate change is regarded as the main content for risk identification. Furthermore, we examine the driving factors of vulnerability and evaluate relevant fields in accordance with the goals.

In this evaluation method, stakeholder participation is of critical importance. The focus of the evaluation of the impact and vulnerability caused by climate change will differ with the roles of stakeholders. Therefore, to reduce subjective bias in the evaluation process, we adopt participatory collaboration of diverse stakeholders to understand the different sources of hazards and the different ways in which these hazards affect the marine fishery industry. Furthermore, we attempt to obtain a more complete picture of the risks through a wide range of systematic observations. To complete this evaluation, we employ the following methods:

- (1) Document analysis: Based on the 2030 SDGs and international trends, we examine the extent to which climate change affects the marine fishery industry and its resources. This analysis forms the basis of the field research.
- (2) Field research: Based on the results of the document analysis, we design the direction and key topics for the field research to accurately determine the impact of climate change faced by different marine fishery operators, the risk sources, and the degrees of and differences in operators' risk perceptions. We also attempt to ascertain specific actions taken by different marine fishery operators to mitigate and avoid the direct and indirect impacts of climate hazards on the marine fishery industry.
- (3) In-depth interviews with stakeholders: We focus on observing the climate adaptation actions and risk perceptions of marine fishery industry operators, fishery agencies, and research and experimental institutions. We aim to understand these stakeholders' adaptations when facing climate change and historical extreme weather hazards. We adopt the snowball sampling method for the survey.
- (4) Comparative analysis: We conduct a quantitative comparative analysis to analyse local marine fishery industries' adaptation measures in response to climate change, develop the causal relationship between the research issues, summarize existing adaptation actions, systematically compile a considerable amount of field data, and derive theoretically grounded implications.

2.2.3. Step 3: Choice and Exploration of Policy Responses

In this step, we address objective (B), the requirements of which have gradually become key considerations in the policy planning process. Given the above research goals, we adopt

the top-down approach to policy evaluation during the policy choice and exploration step. Furthermore, in accordance with the classification of climate-related risks and opportunities defined by TCFD [21,22], we propose recommendations for future climate policy planning and adjustments. The recommendations are divided into two parts: climate-related risks and opportunities.

- (1) Climate-related risks: These risks are divided into two types: (1) risks related to the transition to a lower-carbon economy and (2) overall risks related to climate change. Transition risks: These include broad changes in policies, laws, technologies, and the market that will enable the marine fishery industry in Taiwan to ease into and adapt to the requirements of climate change [22]. Physical risks: These include actual risks caused by long-term climate change and imminent extreme weather hazards as well as the indirect effects of direct impacts on industries and the disruption of supply chains to the marine fishery industry in Taiwan [22].
- (2) Climate-related opportunities: The actions for mitigating and adapting to climate change also generate opportunities for creation, such as an improved resource use rate; technology innovation; enhanced supply chain resilience; the development of new markets, products, and services; and more diversified business operations. The focus should be on developing the nation's ability to adapt to climate change so that it can manage climate-related risks and more systematically seize opportunities for the marine fishery industry [22].

2.3. Stakeholder Participatory Processes

Stakeholders play a critical transitional role in developing climate change adaptation policies and maintaining sustainable development. If stakeholder participatory processes are not in place, then it is likely that agreement on the policy will not be reached and stakeholder support for the policy will not be secured [23,24]. Therefore, in this study, we develop a stakeholder participatory process to systematically identify key issues, select stakeholders, and integrate and present their views.

2.3.1. Strategy and Composition for Identifying Stakeholders

We observe the climate adaptation actions and risk perceptions of industry operators, fishery agencies, and research and experimental institutions. We aim to obtain a full understanding of the following issues: interviewees' risk perception in the face of climate-related risks, adaptation actions in response to climate change and historical extreme weather hazards, and possible directions of future adaptation policies for coping with climate-related risks.

Because the issues related to climate change and extreme weather events have varying degrees of impact on—and receive different levels of attention from—stakeholders such as industries, governments, and academic and research institutions, and because these stakeholders play different roles in the climate change adaptation process, the questionnaires used for the in-depth interviews related to different interviewees, as explained below. For industries, the interviewees were mainly members of local fishery associations, fishery operators, suppliers, and residents of coastal fishing villages. For fishery agencies, based on the different jurisdictions of these agencies, the interviewees were divided into officials of central government agencies and local government agencies. Academic and research institutions were also divided into central and local research/experiment institutions based on their research planning and task classification (Table 1). However, in order to prevent the possibility of having problems with the data due to the subjective reasons of the respondents, a total of 45 stakeholders were interviewed in this study (i.e., 15 industry stakeholders, 15 fishery administration stakeholders, and 15 academic and research institution stakeholders). Simultaneously, this study used MAXQDA software to analyse the interview data and synthesize comments.

Table 1. Stakeholders in the marine fishery industry corresponding to climate risk types.

Stakeholder Type of Risk	Fishery Management Unit		Fishery Research Institute	Academic Research Unit	Industry			
	Central Government	Local Government			Fishers' Association	Fishery Operator	Supplier	Residents of Fishing Community
Long-term and short-term changes in the environment and fishery resources	V	-	V	V	-	V	-	-
Uncertainty in fishery production	V	V	V	V	-	V	V	V
Changes in operational stability	V	-	-	V	V	V	-	-
Adequacy of fishing equipment	-	V	V	-	V	V	-	-
Suitability of fishery adjustment policies	V	-	-	V	V	V	V	-
Stability of supply and demand in the fishery product market	V	-	-	-	V	-	V	V

"V" = direct impact; "-" = indirect impact.

2.3.2. In-Depth Interview Questionnaire and the UN SDGs

In this study, we tailored the questionnaires for the in-depth interviews to the different interviewees. The principles for designing questionnaires for different groups of stakeholders are explained in detail as follows (Table 2).

Table 2. Content of in-depth interviews linked to the United Nations sustainable development goals (SDGs).

Goals of SDGs	Climate Hazards	Key Issues	Stakeholders	Content of In-Depth Interviews
S13: Climate action <ul style="list-style-type: none"> Implement climate adaptation strategies Improve resilience in response to natural disasters 	Environmental change	<ul style="list-style-type: none"> Long-term environmental changes Extreme weather/climate disasters 	<ul style="list-style-type: none"> Central government Fishery research institute Academic research unit Fishery operator 	<ul style="list-style-type: none"> Have you noticed long-term and short-term changes in the environment in the past production process? What are the environmental changes that currently need attention in the fishery production process? What is the need for accuracy of long- and short-term environmental data? Have you started using new environmental monitoring technologies?

Table 2. Cont.

Goals of SDGs	Climate Hazards	Key Issues	Stakeholders	Content of In-Depth Interviews
S13: Climate action <ul style="list-style-type: none"> Implement climate adaptation strategies Improve resilience in response to natural disasters S14: Life underwater Strengthen the ability to prevent disasters Strengthen the ability of sustainable management 	Fishery production	<ul style="list-style-type: none"> Target species for fishing operations Area of fishing operations Uncertainty in operations Fishery production risk 	<ul style="list-style-type: none"> Central government Local government Fishery research institute Academic research unit Fishery operator Supplier Residents of fishing communities 	<ul style="list-style-type: none"> Did past weather disaster events have an impact on the production process? Has the target for catch species changed due to environmental changes in the past 20 years? Have you increased relevant facilities or adjusted methods of production in response to changes in weather? Are new opportunities or new technologies beginning to appear?
S13: Climate action <ul style="list-style-type: none"> Implement climate adaptation strategies Improve resilience in response to natural disasters S14: Life underwater Strengthen the ability to prevent disasters Strengthen the ability of sustainable management 	Adaptation management	<ul style="list-style-type: none"> Trend of national climate change policy Trend of overall agricultural policy Plan for long-term, medium-term and short-term fishery policy management Management or adjustment strategies of local fishery policy 	<ul style="list-style-type: none"> Central government Local government Fishery research institute Fishers' association 	<ul style="list-style-type: none"> What are the specific goals of the National Climate Change Program? What are the main actions of the current national fisheries policy in response to climate change? What are the long-term, medium-term, and short-term fishery policy and administrative unit plans for climate issues? Has the local government formulated relevant adjustment policies? Are existing adjustment policies adequate for coping with climate variability trends or disasters in the future?
S8: Department of Economic and Social Affairs <ul style="list-style-type: none"> Implement the resilience of the supply chain in response to climate risks Foster local suppliers S13: Climate action <ul style="list-style-type: none"> Implement climate adaptation strategies S14: Life underwater <ul style="list-style-type: none"> Improve small-scale fishers' access to fishery resources and opportunities in the market 	Supply, demand with the trade in seafood	<ul style="list-style-type: none"> Stability of the supply of seafood Changes in supply and marketing costs Changes in production costs Stability of seafood quality Competitiveness of seafood Diversification of seafood sales channels 	<ul style="list-style-type: none"> Central government Fishery research institute Fishers' association Fishery operator Supplier Residents of fishing communities 	<ul style="list-style-type: none"> Has environmental change caused a decrease in the supply stability of seafood or an increase in uncertainty? Have new or emerging markets been developed or added to adjust to possible losses caused by climate disasters?

- (1) Regarding interviews with industry stakeholders, the risks faced by this group are related mainly to long- and short-term changes in environmental and fishery resources, marine fishery production, and market supply and demand [1,18]. Therefore, the questionnaire focused on obtaining information on the following matters associated

with historical climate hazards: fishers' adaptation actions, climate awareness, the extent and scope of the impact of fluctuations and uncertainty in production as well as in supply and demand, the adequacy of existing facilities and equipment, and fluctuations in the operational risk.

- (2) Due to the different jurisdictions of fishery agencies, the major risks that these agencies need to respond to are related to long- and short-term changes in the environment and fishery resources, marine fishery production, the appropriateness of management and adaptation, and fluctuations in the stability of the market [8,12]. Accordingly, the themes of the interviews were the directions of national climate adaptation policies, the division of adaptation authority between agencies and gaps in the division, future adaptation policy directions, and the need for these policies.
- (3) The major risks that academic and research institutions face are related to long- and short-term changes in the environment and fishery resources, marine fishery production, the adequacy of equipment and facilities, and operational risks [8,13,21]. Therefore, the themes of the interviews with this group were the adequacy of information in regard to responding to climate change and extreme weather hazards, the current situation of the promotion and education of climate change adaptation measures, and information and technology gaps given the future trend of climate change.

3. Climate-Related Risks, Challenges, Adaptation Policies, and Policy Directions for the Marine Fishery Industry

3.1. Types of Climate-Related Risks, Issues, and Challenges

Based on the information obtained from field research and in-depth interviews, four issues caused by climate change and extreme weather events that the fishery industry faces can be summarized: production, supply and demand, policies, and regulations. The corresponding risks can be divided into physical risks and transition risks.

The stakeholders affected by physical risks are mainly operators, suppliers, residents living on the coast, and local fishery associations. The risks can be classified as long-term environmental changes and extreme weather events. The risks and challenges related to long-term environmental changes include rising SST, rising sea levels, changes in rainfall patterns, seawater acidification, the flow potential of the main ocean current and its tributaries, depth changes in the distribution of the thermocline, the intensity of upwelling, and the duration of upwelling. The risks and challenges related to extreme weather events include extremely heavy rainfall, sustained high or low temperatures, and typhoons (Table 3).

Table 3. Adaptation policies and regulations, issues, and challenges for policy directions and directions of the marine fishery industry in response to types of climate-related risks.

Types of Climate-Related Risks		Issues and Challenges	Adaptation Policies and Regulations in Taiwan	Policy Directions
Physical risks	Long-term environmental changes	<ul style="list-style-type: none"> • Sea surface temperature rise • Sea-level rise • Changes in rainfall patterns • Seawater acidification • Flow potential of main ocean current and its tributaries • Depth changes in the distribution of the thermocline • Intensity of upwelling • Duration of upwelling 	<ul style="list-style-type: none"> • Greenhouse Gas Emissions Reduction and Management Act • National Action Plan on Responding to Climate Change • Land Planning Act • Coast Management Act 	<ul style="list-style-type: none"> • Plans for promoting the reduction in greenhouse gas emissions • Actions for climate change adaptation • Sustainable development of marine fishery industry
	Extreme weather events			

Table 3. Cont.

Types of Climate-Related Risks	Issues and Challenges	Adaptation Policies and Regulations in Taiwan	Policy Directions
Extreme weather events	<ul style="list-style-type: none"> • Extreme heavy rainfall event • Typhoon • Flood • Intensity of upwelling • Duration of upwelling 	<ul style="list-style-type: none"> • National Action Plan on Responding to Climate Change • Water Law • Agriculture Insurance Act 	<ul style="list-style-type: none"> • Fishery insurance system • Sustainable fishery development • Use of smart adaptation technologies
Policy management regulations	<ul style="list-style-type: none"> • Plans for promoting the reduction in greenhouse gas emissions • Actions for climate change adaptation and sustainable development of marine fishery industry • Supervision and management of production • Obligation to strengthen the reduction in greenhouse gas emissions lies with the industry 	<ul style="list-style-type: none"> • National Action Plan on Responding to Climate Change • Greenhouse Gas Emissions Reduction and Management Act 	<ul style="list-style-type: none"> • Plans for promoting the reduction in greenhouse gas emissions • Sustainable development of marine fishery industry
Transition risk	<ul style="list-style-type: none"> • Changes in the distribution of fishery operations • Changes in depth of fishery locations • Fishing season chaos • Increased job uncertainty • Increased variability in catch quantity and composition • Increased risk and danger of fishers' operations • Sudden increase in catches of nontarget species • Operating costs increase • New technology investment failure rate • Cost of low-carbon technology transformation 	<ul style="list-style-type: none"> • Greenhouse Gas Emissions Reduction and Management Act • Fisheries Act • Enforcement Regulations of the Fisheries Act • Water Law • Coast Management Act • Land Planning Act 	<ul style="list-style-type: none"> • Concrete plans to promote carbon emissions reduction • Sustainable development of marine fishery industry • Enable environmentally friendly fishery operations • Adopt smart technologies • Develop liveable fishing villages that are suitable for business
Supply, demand with trade in the market	<ul style="list-style-type: none"> • Decreased stability in the supply of seafood • Increased supply and marketing costs • Uncertainty in fishing grounds • Rising raw material costs • Changes in input costs and output demand • Changes in customer behaviour 	<ul style="list-style-type: none"> • National Action Plan on Responding to Climate Change • Fisheries Act • Enforcement Regulations of the Fisheries Act • Goods Stabilization Plan 	<ul style="list-style-type: none"> • Sustainable development of marine fishery industry • High-quality fishery production and consumption • Enhancing competitiveness of the industry • Improving economic security of the marine fishery industry sector

Transition risks are related to three main aspects: policies and regulations, major marine fishery technologies, and trade and market supply and demand. The major stakeholders in policies and regulations are fishery agencies of the central and local governments. The main risk issues in this aspect are the total control of greenhouse gas emissions and the carbon trading system, the supervision of current work areas and needs in these areas, and emissions reduction and its significance. The major stakeholders of the marine fishery industry include local fishery agencies, fishery associations, and operators. The main issues include changes in the distribution of fishery operations, changes in the depths of fishery locations, fishing season chaos, increased job uncertainty, increased variability in catch quantity and composition, increased risk and danger of fishers' operations, a

sudden increase in catches of nontarget species, operating cost increases, the new technology investment failure rate, and the cost of low-carbon technology transformation. The major stakeholders in trade and market supply and demand include fishery agencies of the central government, fishery associations, marine fishery operators, and suppliers of seafood. The main risks and challenges include decreased stability in the supply of seafood, increased supply and marketing costs, uncertainty in the locations of fishing grounds, rising raw material costs, changes in input costs and output demand, and changes in customer behaviour (Table 3).

3.2. Policy Trends, Path Choices, and Specific Adaptation Actions of Operators

3.2.1. Climate Adaptation Policies and Regulations for the Taiwan Fishery Administration

Within the physical risk category, the proposed policies include integrated land management, water management, plans for promoting a reduction in greenhouse gas emissions, actions for climate change adaptation, and the sustainable development of marine fisheries. The issues related to imminent extreme weather include extremely heavy rainfall, sustained high or low temperatures, typhoons, and floods. The current policy measures adopted by fishery agencies in Taiwan include sustainable fishery development and the use of smart adaptation technologies (Table 3). For example, since 1988, the Ministry of Economic Affairs has implemented the “Allowable Energy Consumption Standards and Management Measures for Fishing Vessel Engines” and stipulated that the main and auxiliary engines of fishing vessels must be energy-efficient models. Since 2019, Taiwan’s fishery administration units have been promoting and encouraging energy-saving measures for fishing boats and promoting related policies. The main implementation projects include encouraging upgrades to energy-efficient engines, encouraging a switch to LED fishing lights, counselling for low-interest loan applications, cleaning the bottom and the propellers of boats before sailing, and regular maintenance of the main engine, freezers, and other fishing equipment.

Within the transition risk category, the proposed adaptation policies include concrete plans to promote carbon emissions reduction, facilitate water resource management, strengthen the recycling of marine fishery resources, enable environmentally friendly fishery operations, adopt smart technologies, and develop liveable fishing villages that are suitable for business. For example, to reduce the greenhouse gas emissions resulting from the production of the marine fishery industry, since 2000, Taiwan’s fishery administration units have begun to implement a plan to decrease the number of fishing vessels; and from 2016 to 2020, a total of eight fishing vessels and 166 fishing rafts have been bought out, resulting in a total carbon reduction of 21.33 thousand metric tons of CO₂. It is estimated that 200 fishing vessels will be bought out from 2023 to 2025, with an expected carbon reduction of 45.7 thousand metric tons of CO₂ by 2025. The risks related to the market and trade include decreased stability in the supply of seafood, rising costs in the supply and marketing of seafood, overall market uncertainty, rising costs of raw materials, changes in input costs and output demand, and changes in customer behaviour. The major adaptation policies include sustainable marine fishery development, improving the safety system in marine fishery production, high-quality fishery production and consumption, enhancing the competitiveness of the industry, and improving the economic security of the fishery and marine fishery sector (Table 3).

3.2.2. Specific Adaptation Actions of Operators

In response to the physical risks presented by long-term climate change and short-term environmental changes, operators currently adopt mainly proactive adaptation measures, including adjusting the design of fishing gear and the scale of fishing equipment; strengthening marine environment prediction and monitoring the technology, research, and development of fish migration path prediction; and enhancing weather warning systems (Table 4).

Table 4. Specific adaptation actions in the marine fishery industry corresponding to climate risks.

Types of Climate-Related Risks	Issues, and Challenges	Specific Adaptation Actions
Physical risks	<ul style="list-style-type: none"> • Sea surface temperature rises • Sea-level rise • Changes in rainfall patterns • seawater acidification • Flow potential of the main ocean current and its tributaries • Depth changes in the distribution of the thermocline • Intensity of upwelling • Duration of upwelling 	<ul style="list-style-type: none"> • Adjust the design of fishing gear and the scale of fishing equipment • Strengthen marine environment prediction and monitoring technology • Research and development of fish migration path prediction technology • Enhanced weather warning system
	<ul style="list-style-type: none"> • Extreme heavy rainfall event • Typhoon • Flood • Intensity of upwelling • Duration of upwelling 	
Transition risk	<ul style="list-style-type: none"> • Plans for promoting the reduction in greenhouse gas emissions • Actions for climate change adaptation and sustainable development of marine fishery industry • Supervision and management of production • Obligation to strengthen the reduction of greenhouse gas emissions lies with the industry 	<ul style="list-style-type: none"> • Developing a notification mechanism for governments and related organizations • Building a post-disaster recovery mechanism • Introducing transition risk insurance for marine fishery industry
	<ul style="list-style-type: none"> • Changes in the distribution of fishery operations • Changes in depths of fishery locations • Fishing season chaos • Increased job uncertainty • Increased variability in catch quantity and composition • Increased risk and danger of fishers' operations • Sudden increase in catches of nontarget targets • Operating costs increase • New technology investment failure rate • Cost of low-carbon technology transformation 	<ul style="list-style-type: none"> • Improve the location of operating fisheries and fishing practices • Establish an insurance system • Strengthen fishery forecasting technology • Research and development of fish migration path prediction technology • Implement preventive risk management • Private insurance for capital equipment • Invest in vessel stability and safety improvement technology • Establish emergency rescue mechanism • Diversify capture fisheries livelihoods
	<ul style="list-style-type: none"> • Decreased stability in the supply of seafood • Increased supply and marketing costs • Uncertainty in fishing grounds • Rising raw material costs • Changes in input costs and output demand • Changes in customer behaviour 	<ul style="list-style-type: none"> • Improve the mode of operations • Develop the Internet of Things for seafood

The adaptation actions for fishery production technology include improving the location of operating fisheries and fishing practices; strengthening fishery forecasting technology as well as research and development of fish migration path prediction technology (For example, Taiwan's aquaculture experiment unit began to implement forecasts of marine fishing ground for *Mugil cephalus* in 2020); implementing preventive risk management; offering private insurance for capital equipment; investing in vessel stability and safety improvement technology; establishing emergency rescue mechanisms; and diversifying capture fisheries livelihoods. Adaptation actions for trade and supply and demand include

improving the mode of operations and developing the Internet of Things for seafood (Table 4).

3.3. Potential Gaps in Existing Adaptation Policies and Actions for Industry under Future Climate Change

In the face of long-term climate change and short-term extreme weather events as well as transition and physical risks, fishery agencies, research and experimental institutions, and marine fishery operators in Taiwan have begun to develop and implement specific adaptation actions. Given the high uncertainty of future climate change, however, the existing adaptation policies, actions, and measures for marine fisheries are still subject to many potential impacts.

In terms of physical risks, existing adaptation policies for long-term environmental changes and short-term extreme weather events mainly adopt engineering/structural methods that employ proactive measures to reduce possible risks. However, structural adaptation approaches still need to address a variety of issues, including decreased production capacity or interruptions in production (e.g., discontinued production, broken supply chains, and increased difficulty in transport from the fishing industries of *Anguilla japonica*, *Uroteuthis edulis*, *Sergia lucens*, *Auxis rochei rochei* in Taiwan), write-offs of existing assets and shorter asset life cycles (e.g., asset damage in high-risk regions), increased operating costs, and increased costs of infrastructure construction and maintenance (e.g., sudden damage to fishery facilities or the early end of facilities' life cycle due to damage) (Table 5).

In terms of transition risks, the potential risks related to existing policies and regulations include increased operating costs, asset write-offs or shorter life cycles due to policy changes, increased costs and decreased demand for products and services as a result of complying with policies and regulations, and difficulty insuring assets in high-risk regions. The issues related to production technologies include increased research and development (R&D) expenses for new or replacement plans, capital investments in technology development, the costs of developing new practices or processes, and labour force management and planning (e.g., issues related to safety, health, human rights, and absenteeism). Some potential issues related to trade and market supply and demand include changes in consumer preferences for seafood, decreased demand for products and services, and reduced production capacity or production interruptions (e.g., sales revenue decreases because facility costs for producing seafood or certification costs increase or because sales or production output of seafood decrease) (Table 5).

Table 5. Potential gaps and impacts of current adaptation actions in the marine fishery industry in response to climate risks.

Types of Climate-Related Risks		Specific Adaptation Actions	Potential Gaps in Existing Adaptation Policies and Actions for Taiwan's Marine Fishery Industry (Policy, Research, Economics, and Knowledge)
Physical risks	Long-term environmental changes	<ul style="list-style-type: none"> Adjust the design of fishing gear and the scale of fishing equipment Strengthen marine environment prediction and monitoring technology 	<ul style="list-style-type: none"> A decrease in production capacity or interruptions in production Write-off of existing assets and shorter asset life cycles
	Extreme weather events	<ul style="list-style-type: none"> Research and development of fish migration path prediction technology Enhanced weather warning system 	<ul style="list-style-type: none"> Increases in operating costs Increases in costs of infrastructure construction and maintenance

Table 5. Cont.

Types of Climate-Related Risks	Specific Adaptation Actions	Potential Gaps in Existing Adaptation Policies and Actions for Taiwan's Marine Fishery Industry (Policy, Research, Economics, and Knowledge)
Transition risk	Policy management regulations <ul style="list-style-type: none"> Developing a notification mechanism for governments and related organizations Building a post-disaster recovery mechanism 	<ul style="list-style-type: none"> Include increased operating costs (e.g., premium increase for marine fishery insurance) Write-off of assets or shorter asset life cycles due to policy changes Increased costs and decreased demand for products and services as a result of complying with policies and regulations Difficulty in insuring assets in high-risk regions
	Fishery production technology <ul style="list-style-type: none"> Improve the location of operating fisheries and fishing practices Establish an insurance system Strengthen fishery forecasting technology Research and development of fish migration path prediction technology Implement preventive risk management Private insurance for capital equipment Invest in vessel stability and safety improvement technology Establish emergency rescue mechanism Diversify capture fisheries livelihoods 	<ul style="list-style-type: none"> Increased expenses related to research and redevelopment of new or replacement plans Capital investments in technology development Costs of developing new practices or processes Labour force management and planning (e.g., issues related to safety, health, human rights, and absenteeism)
	Supply, demand with trade in the market <ul style="list-style-type: none"> Improve the mode of operations Develop the Internet of Things for seafood 	<ul style="list-style-type: none"> Changes in consumer preference for seafood Decreases in demand for products and services Lower production capacity or production interruptions

4. Future Adaptation Options and New Opportunities for the Marine Fishery Industry in the Face of Climate Change

Taiwan's marine fishery industry is susceptible to the direct and indirect impacts of long- and short-term environmental changes [3]. If marine fishery production constantly changes, this trend will bring about pressure on the economies and populations of fishing villages. It will also affect the socioeconomic situation, the stability of the supply of and demand for products, and food safety. Some examples of the above issues include the decreasing stability of fishers' income and increasing production costs [7]. Although many factors unrelated to climate change may also affect production and supply and demand in the marine fishery industry, climate change and extreme weather events bring about unique and highly uncertain challenges for the industry [8,16,25]. Although the extent of the impact of climate change on the marine fishery industry is still unclear, it is possible to forecast these impacts through choices and potential opportunities in the face of climate-related issues or to adapt based on the actual impact of climate change on the industry [25,26]. In the future, by learning, experimenting, and changing, local fishing villages and operators must employ both incremental adjustments and industry transformation to adapt to the impact and uncertainty of the natural environment.

In accordance with risk management principles and the results of this study, future climate change adaptation strategies for fishery agencies can be divided into two types: (1) proactive and (2) restorative post-disaster adaptation strategies. (1) The proactive

adaptation path helps the marine fishery industry adapt to uncertainty in the production process and increases local communities' resilience, while (2) adjustments to production and sales modes help to mitigate the possible risks presented by long-term climate change and short-term extreme weather events to the marine fishery industry and local coastal communities and reduce future uncertainty and fluctuations in the seafood supply.

The goal of a proactive climate adaptation strategy is to prevent risks through proactive management and prior planning [8,23]. Under this strategy, measures such as dispersion, reduction, and avoidance are adopted to mitigate the impact on fishing communities or industries when climate hazards occur [3]. Given climate change pressure and the vulnerability of the marine fishery sector, future adaptation strategies and plans should simultaneously consider and address comprehensive short- and long-term risks, whether they are related to climate or result from non-climate-related factors [23]. As such, based on the time frame of implementation, adaptation plans can be divided into short-term, medium-term, and long-term plans based on the degree of risk and urgency of the need [6,26]. However, the choice of adaptation plans for different periods and the adaptation actions adopted by operators will likely provide opportunities for potential short-term or medium- to long-term financial benefits (Table 6) [8,22].

Table 6. Future climate-related opportunities and potential financial impacts for the marine fishery industry under climate change.

Climate-Related Opportunities		Potential Financial Impacts
Type	Adapting Policy Plan	
Resource efficiency	<ul style="list-style-type: none"> Develop an integrated environmental monitoring system Strengthen the cooperative with coordination mechanism of cross-departmental management Provide environmental data to the producer Develop and innovate fishing operation technology Shift towards decentralized energy generation Use lower-emission sources of energy Participate in carbon market 	<ul style="list-style-type: none"> Reduced operating costs (e.g., through efficiency gains and cost reductions) Increased production capacity, resulting in increased revenues Increased value of fixed assets (e.g., highly rated energy-efficient equipment) Benefits to workforce management and planning resulting in lower costs Increased diversification of financial assets
Products and Services	<ul style="list-style-type: none"> Financial services and loan support Assess new assets and locations needing insurance coverage Develop new products or services through R&D and innovation Ability to diversify business activities and products 	<ul style="list-style-type: none"> Increased revenue through demand for lower emissions products and services Increased revenue through new solutions to meet adaptation needs (e.g., insurance risk transfer products and services) Reputational benefits resulting in increased demand for goods/services
Resilience	<ul style="list-style-type: none"> Develop a stakeholder participatory process Create incentive policies Improve the resilience of community and industry Adopt energy-efficiency measures Provide climate education for stakeholders and investment in and development of disaster response capacity 	<ul style="list-style-type: none"> Increased market valuation through resilience planning Increased reliability of supply chain and ability to operate under various conditions Increased revenue through new products and services related to ensuring resiliency
Markets	<ul style="list-style-type: none"> Adjust the sales method of seafood Access to new markets Ability to diversify business activities Shift in consumer preferences Use public-sector incentives 	<ul style="list-style-type: none"> Increased revenues through access to new and emerging markets Increased diversification of financial assets

4.1. Adaptation Plans for Short-Term Implementation

4.1.1. Developing an Integrated Environmental Monitoring System to Help Producers Obtain Scientific Data and Information

The marine fishery industry is highly sensitive to sudden extreme weather events and long-term climate change [8,26]. Nevertheless, in global or regional marine fisheries, there

are few cases of an integrated environmental monitoring system or environment-related information being provided to family-based marine fishery operators or individual fishers [9]. Meteorological information can be sent to local community members or marine fishery operators in advance through information dissemination and early-warning systems so that the recipients can interpret and evaluate the risks and impacts of imminent climate hazards [8,11]. The collection of long-term or integrated environmental information, however, is mainly viewed as a tool and an important reference for evaluating future adaptation policies or medium- to long-term plans, especially in terms of forecasting major impacts and potential risks that may be caused by climate change [13]. For example, meteorological information and telecommunication technologies can be combined through drones or satellites, and short-, medium-, and long-term forecast information, as well as risk evaluations, can be sent to marine fishery operators through the early warning system and communication equipment.

With regard to the development of an integrated environmental monitoring system, experimental institutions and fishery agencies in Taiwan have been continuously collecting and aggregating data from the environmental monitoring of specific fishing species and fishing grounds. The collected data are aggregated into geographic information systems or simple databases and periodically evaluated by technical staff. The information is then provided to users through the identification of warning signals for their consideration in decision-making or to help them assess their operational procedures.

In the future, marine fishery operators can be encouraged to incrementally incorporate the simple environmental data that they collect on their own, such as water temperature and salinity, into integrated environmental monitoring systems [13]. These data can serve as an important resource for helping to correct and improve the database generated by the monitoring system. Additionally, fishery agencies can provide information to operators through feedback mechanisms so that the two parties can build a trust-based relationship [18]. Marine fishery operators work on fishing grounds on a daily basis, and it is relatively easy for them to undertake on-the-spot observations and collect detailed data. Therefore, in the future, training in climate knowledge could be provided to operators to help them better understand the threats and impact they are facing and to improve their defence capabilities and adaptation to the potential impacts of climate change. Additionally, the operator and vessel-based environmental monitoring might include a mechanism for crowdsourcing the data by developing a way to easily send reports to a central database so that all participants will see the results and gain the benefits.

In addition, a lot of data still needs to be collected by professionals, or by offshore observation stations or remote sensing technology. The fishery policy planning should gradually establish a feedback and subsidy mechanism for fishery operators in order to cause these fishery operators more active in data collection. For example, the fishery administration has begun to guide the marine fishery industry to implement the responsible fisheries Index and fishery improvement project (FIP) in Taiwan and assist the industry to get the certification mark related to the production of seafood. The feedback of environment and production data are included in the scoring project in some marine fishery industries already.

4.1.2. Financial Services and Loan Support

The results of this study indicate that Taiwan's marine fisheries industry represents high-risk economic activities, and that the production process is susceptible to high uncertainty and increased variability caused by climate change. As a result of the high risk, financial institutions may refuse to provide financial services and loans to the marine fisheries industry, or they may provide these services only for certain catch species or charge higher interest rates. This is especially true for family-based and self-employed operators. Consequently, family-based marine fisheries operators do not have the adequate capacity or financial support to implement adaptation actions or plan for the future. Nevertheless, given the likely potential risks and uncertainty of future climate change, family-based and

self-employed marine fishery operators still need loans to prevent possible climate-related risks through prevention, mitigation, and avoidance measures [6].

Adaptation actions employ engineering methods such as the relocation of infrastructure facilities, hardware and software upgrades, and the maintenance, replacement, and renewal of facilities and equipment to prevent and mitigate the impact of extreme weather hazards. Implementing these adaptation measures, however, increases operators' production and operating costs. The results of the survey and interviews of this study indicate that many family-based marine fishery operators are unable to afford the costs of these extra inputs due to the limited profitability of their production and therefore choose to do nothing. Financial services and loan support are crucial for operators to build resilience to respond to climate hazards. Marine fishery operators who lose catch species need to promptly restore normal operations, but they rely on funding and support to smoothly control and adapt to the impact of climate hazards [8,12].

To help the marine fishery industry build adequate resilience, Taiwan's fishery agencies have undertaken a variety of policy adjustments, such as providing quick loans, reducing loan approval time, and increasing loan amounts, so that operators can improve their capacity to adapt to climate change. Not all funds invested in adaptation actions, however, will have a positive impact on operators. Therefore, the loan amount that operators can afford and operators' ability to efficiently adjust the impact caused by climate change or extreme weather events will be the key factors that determine the success of future adaptation actions [8]. In the future, developing appropriate management policies and poverty alleviation policies by offering small loans will be key to the implementation of these types of adaptation policies.

4.2. Adaptation Plans for Medium-Term and Long-Term Implementation

4.2.1. Technology Development and Innovation of Fishing Operations

The goal of adaptation strategies related to technology development and innovation is to reduce the sensitivity of the fishing operation system to long-term climate change or short-term extreme weather hazards and to mitigate the extent of risks and impacts by improving early-warning systems [12,18]. In recent years, technology innovation capacity in the international fishing community has rapidly improved. In particular, space technology has been adopted in fishing operations and management and plays an increasingly important role in coping with and adapting to the longer- and short-term impacts of climate change [17].

4.2.2. Development of a More Diversified Transport and Sales System by Entering New Markets

In the past, transactions at each stage of the seafood sales channel consisted mainly of spot trading in centralized markets, where the price was determined by market supply and demand and buyers and sellers were in roughly equal positions. In recent years, with the development of mobile communications, information technology, and new integrated technologies, consumers' livelihoods and consumption styles have gradually changed, leading to the development of increasingly diversified business models for transport and sales in Taiwan's marine fishery sector. This phenomenon is due to the strong growth of Taiwan's e-commerce and technological advancements, including audio and video streaming technology, home delivery services, and third-party payment systems. With continuous improvements in technologies and regulations, e-commerce has become more user-friendly and is increasing in popularity. Furthermore, with the increase in users, the transaction costs of e-commerce have gradually decreased. Under this model, however, it is still possible that merchants who control sale channels will have stronger price negotiation power after retail channels expand and become more centralized in the future, thereby harming the interests of family-based fisheries. Family-based fisheries have smaller-scale operations and comparatively weaker price negotiation power. Therefore, in future policy implementation, agriculture administration agencies should strengthen policy support for

this type of business and maintain diversified sales channels, thereby avoiding the issue of a single sales channel.

4.2.3. Climate Education for Stakeholders and Investment in and Development of Disaster Response Capacity

There is a need to undertake climate knowledge education for stakeholders at different levels of the decision-making system and to invest in building disaster response capacity so that communities can generate long-term capacity to respond to specific situations, thereby reducing risks and strengthening their resilience [7]. Some specific measures include the use of multiple knowledge systems and regional climate information in the decision-making process and the regular involvement of local communities, native residents, and stakeholders in governance adaptation arrangements and planning [16,17]. Through the promotion of climate knowledge and the use of local scientific knowledge systems, the effectiveness of adaptation measures can be improved by raising public awareness of local risks and the potential to respond to these risks and by increasing local understanding of, interaction with, and confidence in governance arrangements [27,28].

4.2.4. Development of and Opportunities for Restorative Post-disaster Adaptation Capacity

The goal of post-disaster climate adaptation management is to enhance the capacity of fishing villages or communities to adjust and return to normal conditions during and after disasters [18]. These types of adaptation actions or measures have the following characteristics: (1) rapid support and alternative means of support, (2) diverse and elastic adaptation methods that enable communities to increase their flexibility and resilience through a variety of adaptation combinations, and (3) different adaptation processes and steps after each disaster. With these adaptation actions, coastal communities and the fishery industry can reduce the losses caused by climate hazards and speed their return to normal conditions by improving their resilience and capacity to recover [8,18]. The main adaptation actions are adjustments in the sales distribution method for catches and reductions in economic losses caused by the sudden deaths of catch species.

To mitigate possible losses in the marine fishery industry and spread operating costs, existing marine fishery operators have begun to develop sales models that can promptly adjust to the supply of seafood. These models adjust the fish catch or market price decrease caused by a large number of sudden deaths, mainly through seafood freezing and processing. Additionally, processing increases the shelf time and sales life of seafood, thereby reducing the risks and impact of the deaths of catch species due to disasters. For example, the set net fishery of Taiwan has begun to promote the improvement of catch processing and technology of cold chain logistics and introduce the production and sales mechanism of local production and local consumption.

4.2.5. Establishment of a Cooperative Mechanism for Multi-Party in the Fishery

In recent years, the cooperative mechanism for multi-party has gradually become the main development trend of global fisheries' management and adaptation strategies for climate change. In particular, this includes the management regime of straddling and highly migratory fish stocks (for example, *Anguilla japonica*, *Thunnus orientalis*, swordfish, *Cololabis saira* of the marine fishery industry). Through the cooperative mechanism for multi-party, the fishery industry started the collection of survey data with an exchange of data for fishery production to adjust the impact of climate change on the marine fishery industry.

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