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# Regional Climate Change Adaptation Based on the PSR Model—Multi-Case Comparative Analysis on a Global Scale

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**Abstract:** Regional climate change is affected by global warming, large-scale inter-regional circulation, and land use/cover. As a result of different ecological, economic, and social conditions, climate adaptation actions vary from region to region, including community-based adaptation in small island developing states, enhancing flood resilience in Europe, weather index insurance promotion in Africa, climate change adaptation based on traditional knowledge in the Polar Regions, and global joint decision-making in terms of regional issues of the Ocean. This paper takes the above five typical cases as the research objects, and the multi-case comparative research method is adopted to discuss regional climate change adaptation based on the pressure–state–response framework. It found that: (1) regional climate change adaptation faces significant pressure from cross-regional flows of finance, population, and species under climate change; (2) climate change hotspot maps based on climate change projections show regional climate vulnerability; (3) responses for regional climate change adaptation require active promotion of multi-level governance with horizontal and vertical cooperation. In the future, regional climate change adaptation should focus on inter-regional climate justice and equality, regional climate change adaptation pathways optimization, and how to effectively learn from typical regional climate adaptation cases.

**Keywords:** climate change; regional adaptive development; the PSR model; multi-case comparative analysis

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## 1. Introduction

Reconstructions of historical mean temperature series indicate that the globe experienced a 1 °C temperature rise in the second half of the twentieth century [1] and that the intensity and frequency of extreme climate events are expected to increase in the future, enhanced by climate–human–carbon feedbacks [2–5]. Global warming, large-scale circulation, and land use/cover rapidly alter regional climates, with potentially irreversible economic, social, and ecological impacts. Regions can be defined geographically and ecologically, such as the Mekong River Basin or the Mediterranean region [6], but most regional climate change adaptation occurs at the global or national level in macro-regions and at the local level in sub-regions [7]. As the impact of climate change deepens, regional climate change adaptation will contribute to the construction of the overall landscape of the adaptation. The first global climate adaptation summit came to an end on 28 January 2021, and the Chinese government proposed the need to appropriately scale up climate adaptation actions, enhance the effectiveness and durability of adaptation actions, and form a strong synergy for climate change adaptation [8]. However, most existing research mainly focuses on regional climate change projections [9], regional agricultural climate adaptation [10–13], climate adaptation capacity evaluation [14], or the introduction of regional climate change adaptation policies [15] and less on climate change adaptation as a whole. Based on the pressure–state–response (PSR) model, this paper uses a combination of multi-case comparative analysis and content analysis to conduct a comparative analysis of five typical regional cases of climate change adaptation around the world.

## 2. Research Design

Taking five typical cases of global regional adaptation to climate change as research cases, this paper uses a multi-case comparative analysis to validate and enrich regional climate change adaptation under the PSR model. The research flowchart is shown in Figure 1.

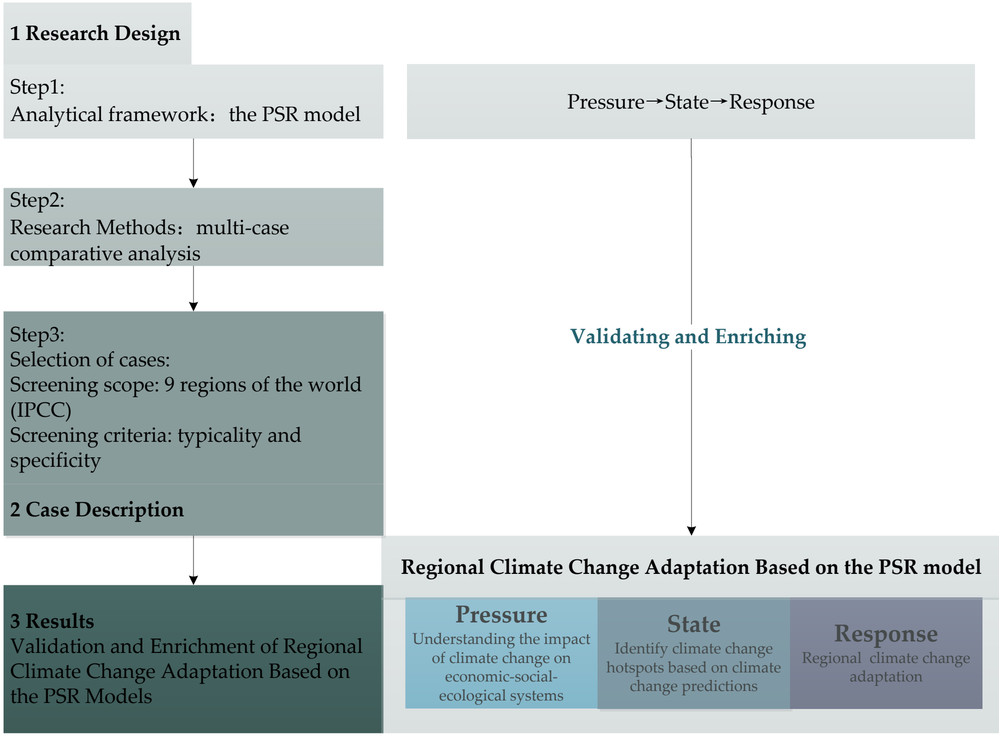


**Figure 1.** Research flowchart.

Firstly, the analytical framework used in this paper is the PSR model, which was proposed in the 1980s by the United Nations Organization for Economic Cooperation and Development (OECD) and the United Nations Environment Programme (UNEP). The PSR model starts from the mutual influence between humans and natural ecosystems and has a very clear causal relationship, i.e., a change in the state of the system due to stress is followed by a response through decision-making and the implementation of countermeasures [16]. In terms of regional climate change adaptation, "pressure" refers to the impact of climate change on economic–social–ecological systems, "state" refers to the current state of the system, and "response" refers to regional climate change adaptations that are oriented toward mitigation, prevention, restoration, and prevention.

Secondly, in order to validate and enrich the regional climate change adaptation under the PSR model, the multi-case comparative study method is chosen to carry out the analysis. There are two main categories of case studies: single-case and multi-case. The single case method is suitable for extreme or unique typical case analysis, and its advantage is that it can bring readers enlightenment through the detailed elaboration and fascinating storytelling of a case. Compared to the single-case method, the multi-case comparison sacrifices storytelling to be more comprehensive and multi-faceted to verify and explain the research findings, and the conclusions are more adequate and effective [17].

Again, following the principles of theoretical sampling, this paper uses typicality and specificity [18] as criteria for selecting cases. The steps used are as follows. (1) Dividing the world into nine regions. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) divides the globe into nine regions: Africa, Europe, Asia, Australia, North America, Central and South America, Polar Regions, Small Island Developing States (SIDS), and the Ocean [4]. (2) Identifying cases based on the specificity of the adaptation action, i.e., each case is required to have both common and differentiating factors compared to other cases. In order to respond to climate change, different regions use a combination of natural, economic, cultural, and social factors, in combination with an assessment of local vulnerabilities and their interactions with climate change. (3) Given the typicality and specificity of climate change issues and adaptation actions in SIDS, Europe, Africa, Polar Regions and the Ocean are typical (Figure 2); therefore, we have chosen these five regions as case studies.

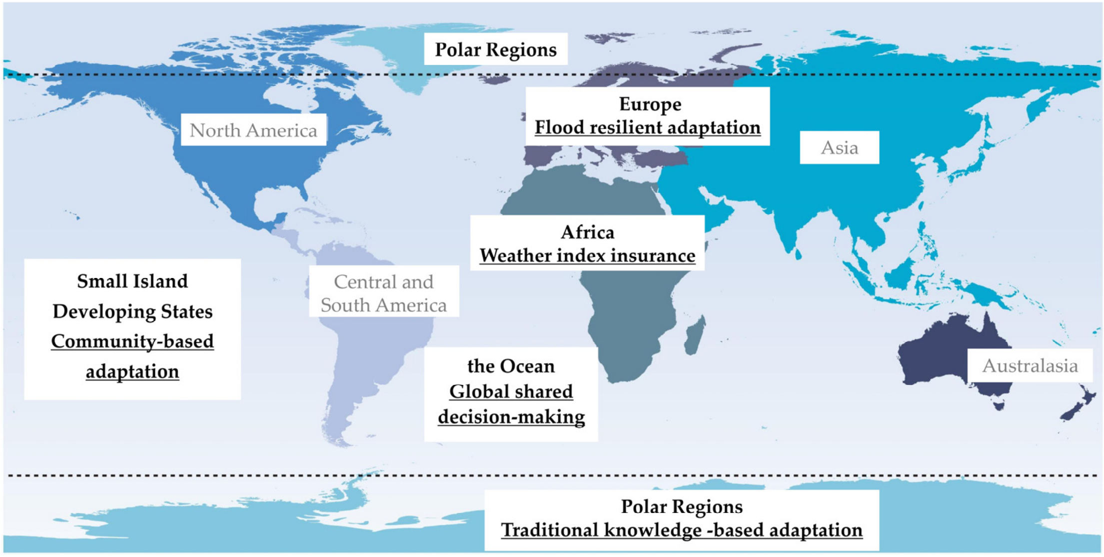


**Figure 2.** Typical cases of regional climate change adaptation around the world. World map source: "2014: Regional context. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change". Note: According to the Fifth Assessment Report of the IPCC, Figure 1 divides the world into 9 major regions. This article selects five typical cases for comparative analysis of regional climate adaptation, namely SIDS (community-based adaptation), Europe (enhancing flood resilience), Africa (weather index insurance), Polar Regions (traditional knowledge-based adaptation), and the Ocean (global shared decision-making).

(4) Finally, conduct a comparative case study based on historical information. To improve the reliability of the study, this paper uses information from multiple sources that constitute data triangulation. Data sources include the IPCC, reports published by major international organizations, research literature, news media press, other online information, etc. In addition, after collating case data through reading, interviewing, and data integration, this paper uses the PSR model as the support to carry out multi-case comparative analysis to promote the correlation and mutual verification of each case, closely link the process logic and research questions, and strive to improve the validity of the research.

## 3. Case Description

### *3.1. Community-Based Adaptation in SIDS*

SIDS are mainly sovereign states and territories located in the southern and western Pacific Ocean, the central and western Indian Ocean, the Caribbean Sea, the eastern Atlantic Ocean off the coast of West Africa, and the Mediterranean Sea [4]. According to the United Nations Global Island Database, the planet's 175,000 islands are home to more than 650 million people and contain 70% of coral reef hotspots, 29% of biodiversity-rich areas, and 13% of UNESCO World Heritage sites [19].

While the economic, political, social, cultural, and geographical characteristics of SIDS are not homogeneous, climate change is making it a huge challenge for all of these regions to meet their economic and social needs with sustainable land use. On the one hand, many SIDS are particularly vulnerable to sea-level rise, ocean warming, ocean acidification, and extreme weather events due to small land areas, low elevation, and the situation that human communities and infrastructure are concentrated in coastal areas [4]. On the other hand, limited resources and geographical isolation make SIDS less able to adapt [20].

Globally, by 2050–2100, sea level increases are projected to exceed the global average by 30% in the Southern Ocean and North America, and by 10–20% in the equatorial region, with a significant increase in the frequency of the most intense tropical cyclones in the western North Pacific and North Atlantic [4]. Rapid sea-level rise and frequent extreme weather pose a huge challenge to climate change adaptation in SIDS. Community-based adaptation to climate change is rapidly gaining attention in SIDS because it is effective, widely applicable, participatory, consultative, and inexpensive. It specifically encompasses: ① Making use of local knowledge and traditional technologies to renovate communities [21]; ② Mutual support, risk sharing, and community networks are taken as core pillars of community-based adaptation [22]; ③ Community leaders promote culture and values-based cooperation [23]. In the Solomon Islands, people use concrete floors to keep their homes dry and build palm leaf roofs to avoid debris during tornadoes. Under the guidance of the Reciprocal Obligations of love, care for others, and maintaining community relationships, the community leaders (e.g., chiefs or church leaders) are in charge of organizing the redistribution of disaster resources [24].

### *3.2. Enhancing Flood Resilience in Europe*

Floods are one of the biggest natural hazards that Europe faces under climate change. More than 200 floods occurred in Europe from 2006 to 2013, which caused a total of EUR 52 billion in damage [25]. With global warming, more than 40% of Europe will experience 1-in-100-year floods more frequently [26], with France, the UK, Germany, Italy, and the Netherlands continuing to see an increase in relative risk [27].

The frequency of floods due to climate change has prompted European governments to take active adaptation actions, including ① Developing early warning systems and risk maps for floods. In 2000, the EU adopted the Water Framework Directive, which requires a comprehensive assessment of flood risk and continuous monitoring of risk drivers to enable early warning of floods; ② Conducting land use planning. Through watershed management to "keep water where it falls" and the designation of floodplains to "give rivers more space", the Netherlands has built 53 bunds to cope with floods, and the UK government has diversified its approach to flood prevention to minimize damage from flooding [28,29]; ③ Controlling floods using technical methods, including reducing peak flows by building reservoirs, improving dam safety, rationalizing flood releases, and sustainable urban drainage; ④ Relocating people and assets at risk of flooding [30]. While adjusting land use in risk areas and upgrading defenses can significantly reduce the adverse effects of flooding, they cannot eliminate the risk, and "planned retreat" may be essential [4].

### *3.3. Promotion of Weather Index Insurance in Africa*

Drought is a major risk to African agriculture, causing 40% of economic losses each year and accounting for 83% of agricultural disasters [31]. The intensity and duration of heat waves in Africa are expected to increase by the end of the 21st century, with a continued decline in soil moisture and an increased risk of agricultural drought [4].

Weather index insurance is considered well suited to the agricultural sector in Africa due to its low cost, free transferability, and low transaction costs that help overcome the moral hazards in traditional agricultural and disaster insurance markets [32]. To adapt to climate change, Index-based Weather Insurance (IWE) has been piloted in Malawi, Kenya, Ethiopia, Tanzania, Ghana, and Senegal with the help of international organizations such as the World Bank and the UN WFP. Weather index insurance is based on climate change as a basis for claims and quantifies the extent of agricultural losses caused by a climatic factor to determine the triggering conditions for which the policyholder will be paid when the climatic conditions reach a predetermined threshold [33]. In Kenya, weather index insurance was piloted in 2009 for maize and wheat, where insurance companies and farmers entered into insurance contracts for the early growth, flowering, and filling stages of the crop, with different trigger indices set for different growth stages. Farmers would receive a payout if rainfall exceeded or fell below the threshold (i.e., excessive rainfall or drought) during the contracted growth stage [34].

In terms of the operation of weather index insurance, accurate, authoritative, and high-quality climate data is central, and it is important to determine which weather conditions will cause losses. African countries have difficulties reaching international levels in collecting, analyzing, and processing weather data and agricultural data, which directly results in low payout standards and untimely payouts, which affects the diffusion of weather index insurance systems.

### *3.4. Traditional Knowledge-Based Adaptation in Polar Regions*

The term Polar Regions refers to the region within the Arctic Circle (66 degrees north latitude). It is home to many indigenous peoples with diverse cultural, social, economic, and historical backgrounds, including the Inuit, Métis, Sami, and others in Russia, Alaska in the United States, Canada and Greenland, Aleutia, and elsewhere [35]. Most indigenous communities in the Polar Regions are located in highly vulnerable locations along marine and riverine coastlines, with problems including heavy dependence on natural resources for livelihoods, political and economic marginalization, and gaps in public health as well as poverty reduction. Land surface temperatures in the Polar Regions have become significantly warmer since the mid-20th century, with the Arctic Ocean projected to be nearly ice-free within this century. Permafrost has been melting continually, and the Arctic tree growth line has been shifting northward. Moreover, there has been a trend of marine species moving toward the poles [4]. Rapid climate change further affects the terrestrial ecology and the infrastructure of indigenous communities in the Polar Regions, putting them at great risk [36].

The indigenous peoples of the Polar Regions have a history of adaptation to changes in climate and natural resources. Indigenous worldviews are rooted in a holistic framework that connects land and water, earth and sky, plants and animals, and people and spirits, viewing Earth as a coupled social–biological–physical system where everything is interconnected. This framework under traditional perceptions contains historical knowledge accumulated by indigenous people over generations and has gradually become a knowledge base for adaptation to climate change [37]. Actions by indigenous communities to adapt to climate change include changing land use and settlement locations, changing hunting, grazing, and fishing times and locations, building permanent shelters on land to escape storms, etc. [38]. In addition, cultural values such as sharing, trust, perseverance, calmness, and respect for elders are important. However, the complex relationship between social, economic, and political factors and climate stress is an unprecedented challenge for indigenous communities in the Polar Regions, especially when the rate of climate change exceeds the rate of increase in the adaptive capacity of traditional social systems [39]. Strengthening the integration of traditional knowledge with technology and thereby empowering communities will facilitate rapid responses to climate change.

### *3.5. Global Shared Decision-Making in the Ocean*

According to the IPCC Fifth Assessment Report, the Ocean, other than the polar seas, contains seven sub-regions: High-Latitude Spring Bloom Systems (HLSBS), Equatorial Upwelling Systems (EUS), Semi-Enclosed Seas (SES), Coastal Boundary Systems (CBS), Eastern Boundary Upwelling Ecosystems (EBES), and the Eastern Boundary Upwelling Ecosystems (EBA). Semi-Enclosed Seas (SES), Coastal Boundary Systems (CBS), Eastern Boundary Upwelling Ecosystems (EBUE), Subtropical Gyres (STG) Gyres (STG) [4]. Since the 1950s, global mean sea surface temperatures have increased significantly, leading to a sustained increase in ocean heat content. Compared to the 1981–2010 average state, the global upper 2000 m ocean heat content was 19.67 × 1022 J higher in 2018, with the Southern Ocean, Pacific Ocean, Atlantic Ocean, and Indian Ocean being (6.91 ± 1.70) × 1022 J, (5.97 ± 1.07) × 1022 J higher, (4.95 ± 1.97) × 1022 Joules, and (1.84 ± 1.97) × 1022 Joules higher, respectively [40]. Furthermore, ocean acidification is occurring at an unprecedented rate because of the massive absorption of carbon dioxide lowering ocean acidity. Ocean warming and ocean acidification have led to melting ice caps, harmful algal blooms, coral bleaching, declining fish stocks and ecosystems, and increased the vulnerability of marine industries such as shipping, energy and mineral extraction, fisheries, and tourism [41].

The oceans are a global resource, with approximately 64% located outside the exclusive economic zones and continental shelves of the world's countries, and it is essential to develop coordinated solutions to ocean issues at the global level [4]. With rapidly increasing levels of exploitation, more and more people are calling for more effective decision-making frameworks to manage fisheries and other activities (such as bioprospecting) in these marine "public domains"; thus, international frameworks are becoming more and more valuable. There are many existing international conventions and agreements that explicitly recognize climate change and establish cooperative mechanisms for vertical and horizontal ocean adaptation with a common goal. On the one hand, breaking down national boundaries and planning ocean adaptation actions based on natural limits [42], such as the United Nations Convention on the Law of the Sea, which replaces the previous framework built around the concept of "freedom of the seas" by limiting territorial rights to three nautical miles off the coastline so as to provide a comprehensive framework for the legitimate use of the oceans and their resources, including maritime zones, navigational rights, protection of the marine environment, fisheries activities, marine scientific research, and the exploitation of mineral resources from the seabed beyond the limits of national jurisdiction. On the other hand, strengthening global–regional linkages. For example, the United Nations Environment Programme regularly holds regional seas meetings to compare adaptation options in different ocean regions and share experiences. The Food and Agriculture Organization of the United Nations brings together fisheries bodies and fisheries management organizations from different regions to discuss fisheries issues [43].

## 4. Results

Different regions have different priorities when it comes to response to climate change due to unique ecological, economic, and social conditions. However, regional climate adaptation pathways share some commonalities based on the PSR model (Figure 3). Here, the pressure faced by regional climate change adaptation refers to the cross-regional movement of finance, population, species, and other elements due to climate change, state refers to the identification of climate change hotspots based on regional climate change projections, while the response is based on assessing regional climate vulnerability and leveraging decision-making and implementation by actively promoting horizontal and vertical cooperation at multiple levels of governance.

### *4.1. Pressure: Understanding the Impact of Climate Change on Economic–Social–Ecological Systems*

Factors such as finance, population, and species are sensitive to climate change and extreme weather events. As different regions face different climate change situations and have multiple levels of adaptive capacity, climate change will promote cross-regional flows of factors and further induce regional vulnerability. Climate change leads to the movement of factors across regions, and the resulting impacts may cross one or more borders. Understanding the causes and impacts of "cross-regional phenomena" at the global scale will facilitate regional climate adaptation actions to enhance human welfare and promote biodiversity conservation.

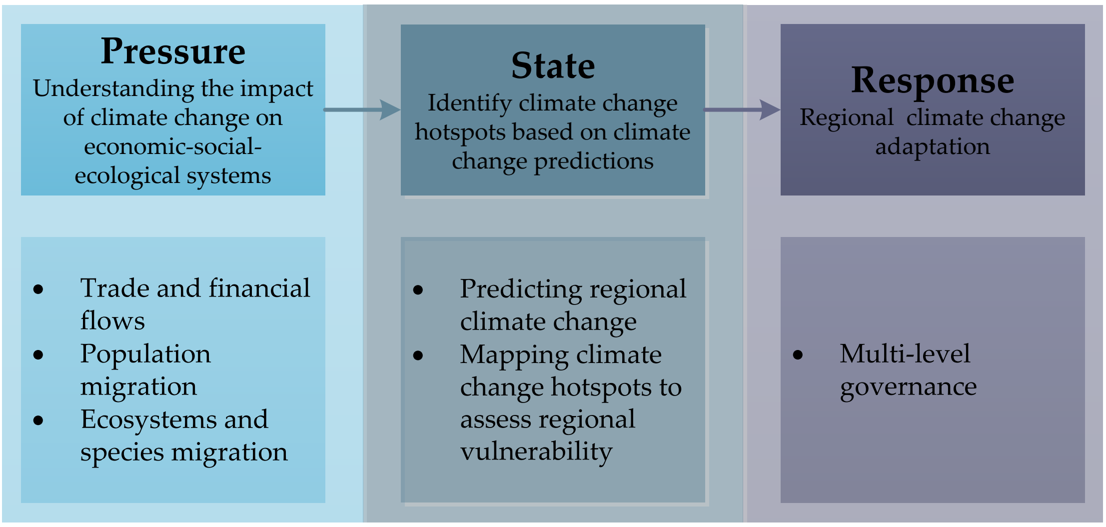


**Figure 3.** Regional climate change adaptation based on the PSR mode.

#### 4.1.1. Trade and Financial Flows

Regional climate change alters international trade patterns and financial flows by affecting the geography and investment environment. More specifically:

- Climate change alters trade routes. The IPCC Fifth Assessment Report, which analyzed the impact of climate change on the Arctic sea ice, found that medium icebreakers were able to reach only 36% of the Arctic ice sea area in 1980–1999 and are expected to reach 45% to 48% of the area in 2011–2030, and this increases to 58% to 69% in 2046–2065 [4]. Warming increases the navigable area, and three more routes will be added through the Arctic, which means shorter intercontinental transport distances and lower trade costs compared to the Panama and Suez Canal routes, which is beneficial to the development of international trade [44].
- Climate change changes the investment environment and increases the vulnerability of less developed regions. On the one hand, capital markets take adaptive measures based on risk expectations of adverse climate change, which in turn affects commodity and land lease market prices; less developed regions will face more unfavorable market competition and lack of financial support to cope with climate change as a result. On the other hand, global warming pressures prompt manufacturing industries to shift net emissions from developed to less developed regions, and this regional shift in emissions (i.e., carbon leakage) makes less developed regions more vulnerable [45].
- Extreme weather events expose regional resource development and international trade flows to frequent shocks of uncertainty. The year 2010 saw the worst flooding in 50 years in eastern Australia, which significantly reduced mining operations and damaged transport networks, resulting in a significant drop in coking coal exports [46]. Unfortunately, the intensity and frequency of extreme climate events are expected to increase in the future, enhanced by the use of fossil fuels [47,48].

#### 4.1.2. Population Migration

Historical evidence shows that regional climate change is a contributing factor to population migration. Specifically, ① extreme climate events, for example, the changing flood patterns in the Mekong River Delta region, are closely linked to migration, while drought and desertification in Niger have led to internal population movements [49]; ② sea level rise due to global warming, e.g., the islands of the Maldives have been "decimated" by massive submersion, and international migration is already being planned [50]; ③ competition for scarce resources as a result of climate change, such as in North Africa, where competition for natural resources has led to regional security issues and continued migration [51]. Population migration due to climate change is usually within countries, from affected areas to safer areas [52]. When faced with extreme climate events, migration could be international and usually occurs along established routes. For example, after Hurricane Mitch, Honduran migration tripled, and Nicaraguan migration increased by 40%, mainly to the southern United States, the traditional destination of migrants.

#### 4.1.3. Ecosystems and Species Migration

A clear impact of climate change is the natural migration of ecosystems and species. On the one hand, climate change displaces biogeographical regions, which in turn leads to ecosystem migration and functional changes [53]. In the future, boreal forests may be replaced by temperate forests and grasslands shifted to the tundra; deserts may expand in some areas and contract in others [4]. The ecological functions of tundra, boreal forests, mountains, Mediterranean ecosystems, and tropical rainforests are extremely vulnerable to climate change [54]. Changes in ecosystem migration and function will lead to dramatic changes in Earth's carbon balance, and whether biospheric feedback to the atmosphere (e.g., altered albedo, evapotranspiration, and carbon exchange) ameliorate or exacerbate the effects of climate change depends partly on the speed of their response [55]. On the other hand, widespread climate warming is causing species to migrate to higher latitudes, higher elevations, or deeper in the ocean [56]. It has been shown that species are shifting to the poles at an average rate of 6 km per decade [57]. However, future rates of climate change are likely to exceed the migration rates of most species, putting species at risk of extinction when they are unable to migrate fast enough to escape climate change.

### *4.2. State: Identify Climate Change Hotspots Based on Climate Change Predictions*

#### 4.2.1. Predicting Regional Climate Change

Regional climate is the result of the interaction of multi-scale perturbations (e.g., mesoscale, weather-scale, and planetary perturbations) and multicircle systems (e.g., atmosphere, biosphere, hydrosphere, cryosphere, and land surface) [58]. Regional climate change projections are an important basis for the development of regional vulnerability assessments and climate adaptation actions. Since the horizontal resolution of the General Circulation Model (GCM) is 100–300 km, there is some error in predicting regional climate change [59]. The Regional Climate Model (RCM) is generally used for regional climate prediction because of its higher horizontal resolution, more microscopic terrain, and land cover characterization. RCMs are increasingly used for regional climate prediction, especially for regions with high climate variability [60]. Through assumptions about future changes in greenhouse gases, aerosols, and land use, RCMs use the dynamical framework of numerical weather prediction models (e.g., RegCM2, RegCM_ICTP, RegCM_NCC, PRECIS, CWRF, etc.) to develop projections of regional temperature, precipitation, atmospheric circulation, extreme climate events, and El Niño phenomena [61]. Therefore, RCMs are also known as downscaling methods, including dynamical downscaling, statistical downscaling, and combined statistical and dynamical downscaling; the application process is shown in Figure 4 [62]. The IPCC Fifth Assessment Report embeds regional climate models into global climate models to make projections of climate change in nine regions of the world and to provide a basis for decision-making on regional climate adaptation.

However, regional climate projections continue to be limited by physical understanding, methods of observation and recording, and climate model selection. For example, what are the long-term observed trends, and what are their causes? How sensitive are regional climate change models to external forces (e.g., greenhouse gases vs. aerosols) under different spatial distribution types? How can robust changes in atmospheric circulation and precipitation changes be predicted? How do systematic errors in models affect climate change? How do internal variability and external forces in the climate system act mutually with each other?

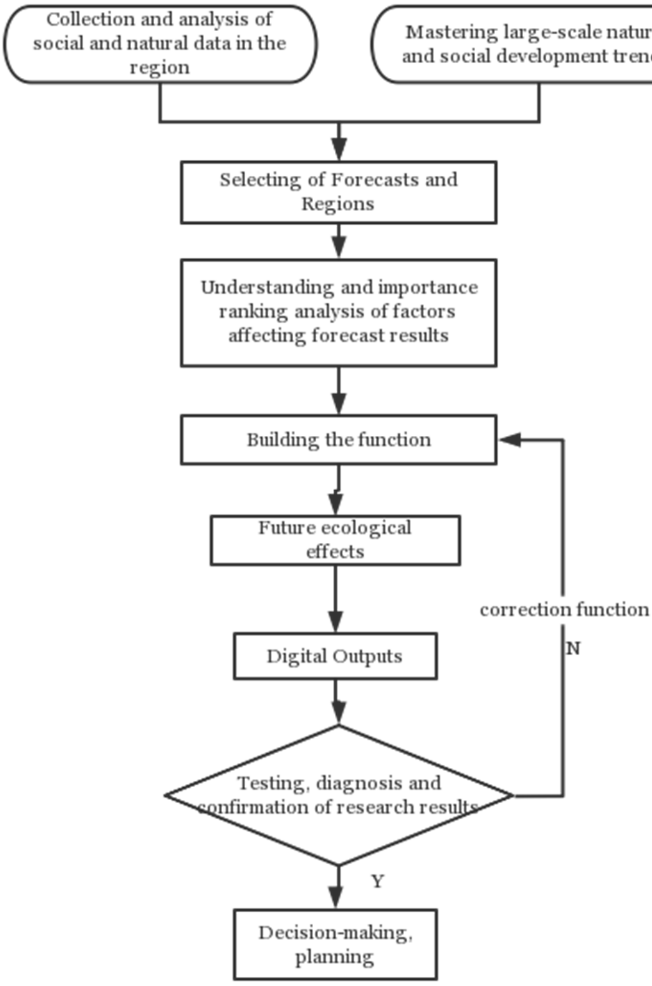


**Figure 4.** The application process of downscaling method in regional climate change. Note: taking the application of the downscaling method in ecological forecasting as an example, first, determine the forecast volume and area based on regional and large-scale natural and social information. Second, the historical data of the forecast variables are coupled to summarize the law of their development trend and the interaction between variables is considered to construct the statistical function relationship between the forecast factors and the variables. Third, accurate forecast results are obtained through the detection and function correction of the digital outputs, and finally, the decision-making and planning of regional climate change adaptation are carried out on the basis of the results, such as drawing climate change hotspot maps.

#### 4.2.2. Mapping Climate Change Hotspots to Assess Regional Vulnerability

Climate Change Hotspots (CCHS) are defined as areas of high climate variability, high exposure, high sensitivity, and low adaptation, which may be highly susceptible to conflict or disaster, leading to social regression [63]. Climate Change Hotspot Maps (CCHMs) based on regional climate change projections will draw the attention of decision-makers to areas that are particularly vulnerable to climate change by identifying possible climate change impacts and conveying them in the form of maps with strong visual elements. Examples include health risks caused by climate change [64], biodiversity hotspots [65], flood hazards [66], food security [67], and migration hotspots [68]. Most of the regions facing climate change would make use of mapping hotspots to identify priorities for policy action, priority areas for further research, or priority sites for funding [69]. The value of hotspot maps is that they are data-driven, making them a more "objective" basis for decision-making by quantifying vulnerability and resilience and downplaying culture, power relations, and local ecological knowledge [70,71].

Currently, the mapping and application of hotspots face three problems.

- The different types of climate change hotspot assessments require different climate parameters, which require specialized expertise in data collection and analysis. For example, for agricultural systems, water management, or natural disasters, the most important variables are the anticipated changes at the beginning of the rainy season, rainfall deficits during the growing season, changes in rainfall duration and intensity, changes in drought cycles, and temperature increases above crop-specific thresholds.
- The specificity of the policy audience is troubling. Some regions may use hotspot maps to prioritize plans, but many national policymakers do not trust global/regional mapping efforts because they question the veracity and objectivity of the data unless the data come from their own institutions.
- There are ethical risks associated with hotspot map applications. As more and more money is invested in climate adaptation development, financial incentives drive countries to portray themselves as climate-vulnerable [72], which will affect the objective neutrality of hotspot maps. If donors guide investments accordingly, poorly governed countries may be identified as the most vulnerable and thus receive funding support.

### *4.3. Response: Multi-Level Governance*

In practice, regional climate change adaptation increasingly exhibits a trend toward multi-level governance, encompassing interaction and dependence at both vertical and horizontal levels. Multi-level governance has been defined as the sharing of decision-making authority, responsibilities, and benefits among decision-makers in different geographic regions, in different domains, and at different administrative levels [73]. In the case of sovereign states, this implies horizontal and vertical cooperation of state authority upwards (i.e., inter-regional, globally), downwards (i.e., sub-state actors), and laterally (i.e., public and private sectors, different domains). The subjects of climate adaptation decision-making and the scope of their authority vary in several domains at different scales, encompassing international policymakers and institutions, national and local government departments, civil society organizations, the private sector at all levels, communities, and individual households. Figure 5 shows how organizations or sectors at different scales collaborate and participate in decision-making to promote climate change adaptation in various areas. From international policymakers and institutions, national and local government departments, civil society organizations, and the private sector at all levels, all the way down to households and producers, everyone collaborates with each other and makes decisions from different sectors and at different scales.

Specifically, there exist two types of horizontal cooperation, one happens between the same areas at different geographical/administrative levels, such as natural resource management in different countries, and the other occurs between different areas, such as the economic, energy, food, science and technology, and environmental sectors [74]. Inter-state cooperation to address climate change has long been underway, such as the 1993 North American Agreement on Environmental Cooperation, the 2014 US–China Joint Statement on Climate Change, the 2015 Paris Agreement, and the 2017 Letter of Intent between the China Meteorological Administration and the World Meteorological Organization on Promoting Regional Meteorological Cooperation and Building a Belt and Road Together. All of them have been promoting inter-country cooperation on climate adaptation. Inter-local cooperation is also being promoted, such as the normalization of meteorological cooperation in the Greater Bay Area of Guangdong, Hong Kong, and Macao in 2019. Vertical cooperation refers to the different scales of governance of participation in management from local to international, emphasizing "top-down" control by decision-makers in the process of policy formulation and implementation [75]. In this context, adaptation policies are developed at the national and regional levels, and further incentives are provided [76]. Local institutions and communities are important actors in the implementation of climate adaptation.


**Figure 5.** Climate adaptation decision-making in various fields under different scales. Note: Taking the environmental field as an example, under the vertical top-down scale, the decision-making scope, the scope of authority, and decision-making subjects are: Global—policy negotiations, development aid (Convention on Biological Diversity, CBD); Transnational—regional development, capacity building (Mekong River Commission, MRC; National—national adaptation plan, national communication, legal regulation (ministries/governments); Subnational—space planning, infrastructure support (states/provinces/cities); Local—local planning, behavioral participation (producers/consumers).

Regional multi-level governance at different scales will leverage decision-making and implementation advantages, such as shifting governance authority from the global level to the regional level, reducing the number of decision-makers. The presence of common interests makes negotiations less costly, and linking governance systems at different scales facilitates cross-border climate problem-solving [77]. At the same time, policymakers face the challenge of vertical multi-level governance and horizontal multi-sectoral policy coherence in achieving regional climate change adaptation. Specifically, on the one hand, how to maintain the consistency of regional climate adaptation policies in terms of vertical cooperation? On the other hand, how to coordinate compensation and equity among different sectors in different regions when it comes to horizontal cooperation? In most cases, the key to success lies in assigning specific governance tasks to appropriate regional scales and taking measures to ensure that cross-scale interactions serve as complement rather than competition [78].

## 5. Conclusions and Prospect

### *5.1. Conclusions and Limitations*

This paper uses a multi-case comparative analysis approach with five typical global regions to validate and enrich regional climate change adaptation under the PSR model. It found that:

- Climate change at different scales has profound and irreversible impacts on regional economies, politics, ecology, and societies. Regional climate change adaptation varies according to ecological, economic, and social conditions, with SIDS focusing on community-based adaptations, Europe on enhancing flood resilience, Africa promoting weather index insurance, indigenous communities in Polar Regions relying on traditional knowledge to cope with climate change, and the Ocean calling for global decision-making.

- Regional climate change adaptation analysis based on the PSR model framework finds that regional climate change adaptation faces significant pressure from cross-regional flows of finance, population, and species under climate change. Climate change hotspot maps assess the vulnerability of regional climate change adaptation based on climate change projections, and regional climate change adaptation response strategies take advantage of decision-making and implementation through horizontal and vertical cooperation at multiple levels of governance.

While this paper validates and enriches the regional climate change adaptation under the PSR model, the case study approach still has several limitations.

- The research process is susceptible to the ideas of the researcher and ignores some important information.
- It is hard to accurately measure the degree of interaction between the elements.
- In terms of the multi-case comparison, while emphasizing typicality and specificity, the cases lack in-depth exploration. In addition, although the cases were chosen to be as representative as possible, the findings are, after all, based on only five typical regions, and whether the conclusions are applicable to climate change adaptation in other regions needs to be further verified by more studies.

### *5.2. Prospect*

Regional climate change adaptation is a long-term social learning process that requires decision-makers to strengthen their knowledge of potential future changes and enhance their ability to cope with them. Future inter-regional compensation and equity, optimization of regional climate change adaptation pathways, and effective learning from typical regional climate change adaptation actions will become the key focus of regional climate change adaptation.

- Regional cooperation on climate change adaptation faces international and domestic challenges of climate justice and equal development. As the hardest hit by exposure to climate change risks, less developed regions lack adequate financing for climate change adaptation and are in urgent need of official assistance from developed regions. From the perspective of the international community, the principle of Common But Different Responsibility (CBDR), which requires developed countries to provide official assistance to developing countries for climate adaptation funding, has been widely recognized but not practiced. For example, the 2009 Copenhagen Climate Conference produced a draft agreement that called for developed countries to provide at least USD 100 billion in annual financial support to developing countries by 2020. However, according to the aid information provided by the UNFCCC secretariat, Japan provided JPY 1.3 trillion (about USD 10.5 billion), and France provided EUR 5 billion (about USD 5.4 billion) per year until 2020 [79]. The huge financial gap seriously affects developing countries' adaptation to climate change, so there is an urgent need to advocate for a basic consensus on climate justice to be formed and practiced globally in the future.
- In terms of optimizing regional climate change adaptation pathways, future regional climate projections need to further understand ocean–atmosphere–land interactions to enable the reduction of atmospheric circulation uncertainties [59]. Climate change hotspot maps emphasize objectivity and focus on their role in political discourse and guidance for policy-making; regional multi-level governance pays more attention to building trust and making political commitment among leaders, providing adequate financial resources, enhancing institutional implementation capacity, promoting the participation of the private sector and civil society organizations, and strengthening policy dialogue in key sectors [80].
- The method of starting from regional climate change adaptation pathways, combining their own characteristics, and taking typical regional adaptation actions as references has a strong significance for countries globally to adapt to climate change. For example, community-based adaptation in SIDS can be an inspiration for policy formulation in coastal areas to adapt to sea level rise and typhoons; Europe's resilience to floods can be

a reference for regions prone to flash floods; the promotion of weather index insurance in Africa is also an important way for agriculture to adapt to climate change; and the experience of Arctic indigenous communities in relying on traditional knowledge to adapt to climate change illustrates the important role of traditional knowledge and values in climate adaptation. The ocean region's call for global shared decision-making could provide a model for climate adaptation in other areas where international cooperation is urgently needed.

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