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Blue carbon governance for carbon neutrality in China: Policy evaluation and perspectives

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ABSTRACT

As a nature-based solution for climate change mitigation, blue carbon has been highlighted for realizing carbon neutrality in China. China's central and local governments have issued many policies to promote blue carbon protection and development. However, scaling up blue carbon restoration and protection is required for its substantial contribution to carbon neutrality. This study evaluates the characteristics of China's blue carbon policies using qualitative document analysis based on policy instrument theory. The distribution of different policy instruments among blue carbon policies and resources is analyzed. Suggestions for improving blue carbon policy supply are put forward combined with comparative experience from international organizations and other jurisdictions. The following policies should be strengthened to secure efficient blue carbon protection, restoration, and creation: blue carbon protection legislation, marine ecological compensation system, stable investment in blue carbon projects, integrated blue carbon verification system, and inclusion of blue carbon in regulated carbon markets.

1. Introduction

The catastrophic impacts of climate change have received widespread recognition through the advancement of scientific knowledge [1]. As global warming continues to escalate, the window of opportunity for effective climate mitigation strategies is closing, making sector-wide decarbonization an urgent necessity [2]. Nevertheless, achieving decarbonization across all sectors is a complex challenge, as it is heavily influenced by intricate economic and social factors. It represents a sociotechnological transition process that demands sustained technological advancements over a considerable period [3]. To combat climate change and adapt to its effect, society can consider capitalizing on nature-based solutions, which have remarkable carbon sequestration capacity [4]. Thus, a primary focus should be on enhancing the carbon sink capabilities of ecosystems to effectively address climate change and restore degraded environments [5]. Traditionally, terrestrial ("green") carbon sinks have received much of the attention [6], but as our scientific understanding advances, the significance of marine ("blue") carbon sinks is gradually coming to the forefront [7]. Recognizing the growing connection between ocean sustainability and climate change [8], many countries are now emphasizing the development of blue carbon sinks as integral contributors to emissions reduction.

In this study, we used the term "blue carbon sinks" to generally refer to carbon sequestered in marine and coastal environments. This includes the organic carbon captured and stored in mangrove forests, seagrass meadows and salt marshes [9] and marine fisheries

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[10]. The former is recognized globally [11,12] while the latter is gaining traction [13,14]. For instance, related measurement methodologies and management approaches are getting increased attention [15,16]. Studies have shown that by reducing the carbon footprint of fisheries and increasing biomass, the ocean's carbon sequestration capacity can be improved. For example, increased protection of priority areas is an effective means to protect biodiversity, improve fisheries efficiency and increase carbon storage [17]. Scholars have also discussed the role of Integrated Aquaculture-Agriculture (IAA) and Integrated Multi-Trophic Aquaculture (IMTA) in increasing carbon storage of fisheries [18]. Although many aspects of climate-based fisheries management remain to be explored, it appears clear that this would imply allowing stocks to recover to maintain a larger amount of biomass, increasing conservation measures for species particularly efficient in providing negative emissions, differentiation of fisheries within species as well as a new approach to ecosystem management [19]. Fishery management strategies that preferentially conserve large species may increase overall carbon stored in the fish community. Considering that many coastal provinces and cities in China regard fisheries carbon sinks as an important measure to achieve carbon neutrality and have introduced corresponding policies, this paper includes fisheries carbon sinks in the scope of policy analysis, so as to comprehensively reflect the government's efforts in enhancing blue carbon sinks [20].

Marine and coastal ecosystems contribute significantly to the sequestration of organic carbon. It is estimated that protecting the existing blue carbon ecosystems could prevent 304 Tg CO_2e/year, and large-scale restoration could remove an extra 841 Tg CO_2e/year by 2030, equivalent to 3 % of the annual global greenhouse gas emissions [11]. Similar to territorial carbon sinks, blue carbon sinks can also achieve co-benefits, including biodiversity, food security, coastal protection, and fishery enhancement [12]. For example, Sarwar (2022) and Waheed et al. (2023) indicated that blue economic factors, including fisheries, marine trade, and marine tourism, play key roles in sustainable economic growth [21,22]. Although the nexus between blue economy and carbon neutrality has been stressed, more studies are needed to explore policies and mechanisms to coordinate blue economy development and carbon emissions [23].

Studies focused on analyzing blue carbon policies and their governance in specific countries or regions (such as Australia [24], Philippines [25], Indonesia [26], Malaysia [27]), blue carbon project implementation approaches [28,29], opportunities and challenges [30], and their effects and influencing factors [31,32]. The role of good governance in addressing environmental issues has been emphasized [33,34]. Indicators of good governance mainly include the rule of law, accountability, corruption control, political stability, and government effectiveness [35]. Scholars stressed the role of market-based approaches and the importance of local knowledge, acceptance, and participation in blue carbon development [36–38]. Contreras and Thomas (2019) assessed the performance of different global blue carbon governance approaches, such as market-based instruments, public investment, partnership initiatives, and community-centered management schemes [39]. Successful projects usually involved local stakeholders who considered alternative livelihoods [40]. The incorporation of ecosystem services into coastal conservation is a meaningful way to fund blue carbon projects. However, structural issues (time, finances, access to other resources, expertise and/or technical abilities, politics and political beliefs, personal motivation and identity, and localism) may be the main barriers [41]. Critical considerations for blue carbon development require inclusive project governance, sustaining livelihoods, and lower transaction costs through simplifying accounting and verification methodologies [42]. Pricillia et al. (2021) also suggested that livelihood, land tenure, local knowledge, and local capacity are essential considerations in blue carbon management [43]. In addition, Equitable benefit-sharing within local communities is also necessary [44].

China has set a carbon-neutral target by 2060, a clear target for decarbonizing the current social and economic development [45]. The value of blue carbon in biodiversity protection and climate change mitigation is widely acknowledged [46]. Regarding blue carbon governance, Lin (2019) believes that institutional difficulties in blue carbon protection lie in lack of climate financing mechanism, unclear property rights of blue carbon resources, and challenges in ecosystem service payment [47]. The development and protection of blue carbon must protect and restore salt marsh wetlands, mangroves, and seagrass meadows; improve the carbon storage function of microbiological carbon pumps; and build sustainable marine ranching and other critical coastal ecosystems [48]. In the process of blue carbon governance, scholars have put forward suggestions such as strengthening theoretical research and technological innovation, accelerating collaborative governance, and deepening market-oriented mechanisms [49].

Although blue carbon sinks have attracted increasing attention, in reality, specific blue carbon development actions are progressing gradually. This reflects the fact that obstacles exist in the science-policy interface, and policy implementation is less effective. Significant challenges exist in the social, financial, technical, and scientific dimensions, as they are both multidisciplinary and interacting [50].

Good governance is required to manage blue carbon effectively. Identifying policy gaps is the premise for establishing blue-carbon institutions. To describe the blue carbon policy landscape in China and analyze its policy deficiencies, this study uses a content analysis method combined with policy instruments theory to systematically review the characteristics of blue carbon policies. Suggestions for promoting the preservation and restoration of blue carbon resources have also been proposed. The current study contributes to the literature in two ways. First, a systemic exploration of China's blue carbon policies and governance is conducted from a macro perspective. Studies on blue carbon mainly focus on micro-policy analysis, which provides beneficial insights into blue carbon policy design. However, analyzing macro-policy instruments will reveal the landscape of the blue carbon policy supply and identify the weaknesses that must be strengthened to improve institutional design. Second, this study addresses feasible ways for China to improve blue carbon governance, including marine ecological conservation, incorporating blue carbon into the regulatory carbon market, and financing blue carbon projects. In China, blue carbon has attracted less attention than territorial carbon sinks. This study is helpful in extending the carbon market and carbon sink literature to marine carbon sequestration and storage, thereby formulating a complete and coordinated carbon neutrality approach.

2. Materials and methods

We used a qualitative document analysis (QDA). QDA is a research method for rigorously and systematically analyzing the content of written documents. The QDA process includes three key steps: (a) data collection, (b) analysis framework construction, and (3) content coding. The policy instrument theory is the theoretical basis for the construction of the analysis framework. Policy instruments are means to achieve one or more policy goals that are actually or potentially adopted by decision makers [51]. Classifying policy instruments helps to better understand and analyze the reasons for choosing different tools, provides greater insight into the factors driving the policy process, and compares different policy approaches [52]. Drawing on the widely used ideas of Zegveld and Rothwell (1985), this study divides policy instruments into three types: demand, supply, and environmental, and establishes an X–Y dimension framework [53,54].

2.1. Date collection

Based on the research progress on blue carbon sinks, keywords such as "blue carbon", "mangrove", "coastal wetland", "seagrass meadows", "marine fishery" and "marine ranch" were used. This study searched government portal websites and the Peking Law Database, and the selection principles were as follows: (1) the publishing agency should be authoritative, including legislation and government agencies; (2) the policy text involves specific measures, not just keywords; and (3) the policy document is within its validity period. After carefully reviewing the collected policy documents, we selected 60 documents that explicitly targeted blue carbon. After reading the sample policies, clauses that explicitly stipulated blue carbon related issues were extracted to prepare for subsequent text coding.

2.2. Analysis framework construction based on policy instrument theory

According to policy instruments classification suggested by Zegveld and Rothwell, the functions of different policy instruments mainly include stimulating the supply and demand for targeted objects or providing advantageous infrastructural, financial, or regulatory environments. Policy instruments (e.g., supply, demand, and environmental) consist the X dimension of the analysis to reflect which policy instrument the government prefers. Meanwhile, the distribution of policy instruments among different blue carbon resources is reflected by adding the Y-dimension presenting blue carbon types.

2.2.1. X dimension: policy instruments to stimulate blue carbon

The X dimension of the policy analysis framework consists of three policy instrument types. Supply and demand policy instruments can promote carbon development directly, whereas environmental policy instruments play an indirect role.

(1) Supply type policy instruments are the primary driving force of policies related to blue carbon sinks. Supply type policy instruments include project construction, technology R&D, personnel training, information support, financial support, and other tools.
(2) The demand type policy instruments mainly reflect the pulling power of blue carbon development. Specifically, the government provides value realization methods for carbon sinks, biodiversity, landscapes, and other ecological values generated by blue

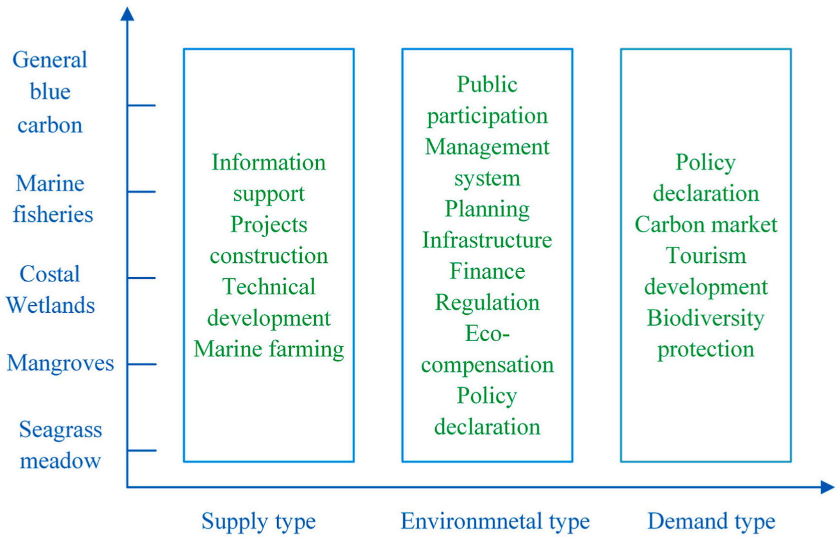

Fig. 1. The X–Y dimension analysis framework.

carbon sink projects. Demand type policy instruments mainly include carbon sink market construction, tourism project development, and biodiversity protection.

(3) Environmental policy instruments are used by the government to provide a robust institutional environment for promoting the development of blue carbon, including supervision, management, and financial and public participation. Environmental policy instruments can be subdivided into development restrictions, management systems, financial services, judicial protection, policy publicity, and public participation, aiming at providing legal, regulatory, financial, judicial, and social supports for blue carbon.

2.2.2. Y dimension: blue carbon types targeted by policies

Based on classification methods and research progress on blue carbon, this study selected blue carbon ecosystems (mangroves, coastal wetlands, seagrass beds, and marine fisheries) as the Y dimension of the analysis framework. Using this dimension will help determine the degree of attention received by different blue carbon resources in the policy field. As the distribution of blue carbon resources is geographically heterogeneous, the use of the Y dimension is also helpful in discovering spatial rules and socioeconomic background differences in different regions.

Through semantic interpretation of the policy text units, they were coded and classified according to the main content. Combining the X and Y dimensions, the analytical framework established in this study is shown in Fig. 1.

2.3. Content coding process

According to the two-dimensional policy analysis framework, 215 policy units from 60 policy documents were coded using NVivo 11 (released in 2015) [55], a qualitative analysis software that is widely used in academic research across various fields [56,57]. To ensure consistency and reliability of the coding, the process was conducted by two researchers who independently screened the policies, with a third person serving as an arbiter for any inconsistencies. Table 1 presents the coding list of the policy units.

Combined with the policy instrument theory, the policy units were further coded using NVivo 11. This study primarily used NVivo11 software to encode and analyze the text. There are two common coding methods. The first method is deductive. It sets the coding nodes according to the research theme and then forms a research framework and more detailed coding through the deep mining of nodes. The second method is inductive, based on the steps of open encoding, spindle encoding, and selective encoding, namely, the text is first encoded meticulously and then grouped into several sub-nodes to form related categories. This study adopted the deductive coding method. The operation process is as follows: (1) we determined the dimensions of blue carbon policy analysis, and (2) based on the established analysis dimensions, we used NVivo 11 to establish nodes, code them, quantify the results of the coding analysis, and draw conclusions.

After determining the research dimensions and keywords, NVivo11 software was used to build the nodes and encode the text. First, “Environmental type”, “Supply type”, “Demand type” and “Source categories” were defined as tree nodes; second, sub-nodes were established under tree nodes; third, the words or sentences associated with the nodes were placed under the corresponding nodes; and fourth, the coding level of the “reference point-node-tree node” was formed (Table 2).

3. Results and discussions

3.1. X dimension: the distribution and characteristics of policy instruments

The detailed distribution of the blue carbon policy instruments is presented in Table 3. It indicates that blue carbon policy instruments include all three types, providing relatively comprehensive policy support for blue carbon protection, restoration, and

Table 1
Coding list of policy units for analysis.

	Policy Title	Policy Content	Code
14	Implementation plan for the National Pilot Zone for Ecological Civilization (Hainan)	Pilot projects for carbon sequestration in Marine ecosystems will be launched. Research the blue carbon standard system and trading mechanism, and explore establishing international carbon emission trading venues per the law.	5–2
21	Opinions on the complete, accurate, and comprehensive implementation of the new development concept and the work of carbon peaking and carbon neutrality	We will comprehensively promote the protection and restoration of Marine ecosystems and enhance the carbon sequestration capacity of mangroves, seagrass beds, and salt marshes.	11–2
99	Three-year Action Plan for Accelerating the Building of “Maritime Fujian” and Promoting High-quality Development of Marine Economy (2021–2023)	. Promote carbon-neutral pilot projects in the ocean. Pilot projects such as mariculture, coastal wetlands and mangroves, and Marine microorganisms will be carried out to enhance the capacity of Marine carbon sequestration and sink	28–3
204	Ecological and Environmental Protection Plan of Hainan Province during the 14th Five-Year Plan	To leverage the convenience of the free flow of cross-border capital through the Hainan Free Trade Port, attract international capital and foreign investors to participate in climate investment and financing activities, and make Hainan a window for cross-border climate investment and financing.	55–8

Table 2
Encoding process example table.

Tree Node	Node	Reference Point
Supply type	Information support	Carry out carbon sink storage monitoring and assessment and carbon sequestration potential analysis of typical ecosystems such as coastal wetlands, marine microorganisms, and mariculture, and explore the establishment of blue carbon databases.
	Projects construction	Increase ecosystem carbon sinks. Implement major projects for ecological protection and restoration. Promote the protection and restoration of marine ecosystems as a whole, and improve the carbon sequestration capacity of mangroves, seagrass beds, salt marshes.
Environmental type	Public participation	Citizens, legal persons and other organizations are encouraged to participate in the protection of mangrove resources through investment, donation, seed subscription, adoption and other means.
	Planning	Planning for the protection of mangrove resources shall be reasonably drawn up on the basis of the object and scope of protection, resource status and ecological functions.
Demand type	Market construction	Actively explore the regional carbon inclusion mechanism, support Weihai City in exploring the construction of a blue carbon trading platform, and promote the conversion of blue carbon sink from resources to assets.
	Tourism	Strengthen sailing tourism and cruise tourism and create a rich and diversified system of coastal tourism products
Source categories	Mangroves	Any unit or individual shall have the obligation to protect mangrove forest resources and shall have the right to stop and report the acts of damaging and occupying mangrove forest resources.
	Coastal wetlands	Strengthen the protection of protected natural areas and coastal wetlands, fulfill the responsibility of managing protected natural areas, and determine the list and area of important wetlands in batches.

Table 3
The distribution of policy instruments.

Type	Sub-item	Number	Type-based proportion (%)	Total-based proportion (%)
Supply type	Information support	4	8.51	1.86
	Project construction	27	57.45	12.56
	Technology R&D	12	25.53	5.58
	Marine ranch	4	8.51	1.86
	Sub-total	47	100	21.86
Environmental type	Public participation	21	14.09	9.77
	Management system	20	13.42	9.30
	Planning	43	28.86	20.00
	Infrastructure	12	8.05	5.58
	Financial tools	11	7.38	5.12
	Regulation	28	18.79	13.02
	Ecological compensation	8	5.37	3.72
	Policy publicity	6	4.03	2.79
	Sub-total	149	100	69.30
Demand type	Market construction	9	47.37	4.19
	Tourism development	10	52.63	4.65
	Sub-total	19	100	8.84

creation. The environmental, supply, and demand types accounted for 69.3 %, 21.86 %, and 8.84 % of the total, respectively. However, the three types of policy instruments presented significant differences. The government prefers environmental policy instruments when formulating blue carbon policies.

3.1.1. Supply type policy instruments

Supply type policy instruments accounted for 21.86 % of all the policy instruments. Project construction included ecological restoration, marine ranches, coastal zone beautification, and biodiversity protection. For example, the Implementation Plan for Strengthening the Protection of Coastal Wetlands and Strictly Controlling Reclamation (2019) of Zhejiang Province proposed building marine ranches and artificial reefs, and carrying out ecological protection and restoration of coastal wetlands, beaches, bays, and islands. Information support accounted for only 1.86 %. Establishing a blue carbon assessment system faces technical difficulties. Scholars have studied carbon sequestration in ecosystems such as mangroves, seagrass meadows, and coastal marshes, but most are macroscopic mechanistic studies with prominent regional characteristics. From the perspective of accounting methodology, unified and standardized accounting technology and related monitoring systems have not yet been established. Consequently, researches on the evaluation standards, certification, and accreditation of blue carbon accounting require more policy support.

3.1.2. Environmental type policy instruments

Planning policies accounted for 28.86 % of the environmental policy instruments, including the functional zoning system, blue carbon conservation target planning, and mangrove resource conservation planning. For example, the 2015 National Plan for Marine Functional Zones delimited restricted development zones, including marine fishery protection zones, marine protected areas, islands, and their surrounding waters; prohibited development zones, including marine nature reserves at all levels. This plan focuses on protecting the ecological environments of these areas and limiting or prohibiting their development and utilization. The primary function of the zone system is to provide an important guarantee to prevent excessive development and destruction of blue carbon resources. This creates important ecological regions where blue carbon resources are located within a strict regulatory framework [58]. Blue carbon construction and resource protection planning promote the protection of blue carbon resources. However, the implementation of the plan was affected by complex socioeconomic and political factors. Different regions have different planning designs and implementation levels owing to their different development and resource status levels. In addition, planning often lacks coercive power and does not result in serious liability consequences if relevant targets cannot be achieved, leading to uncertainties in the protection, restoration, and creation of blue carbon resources [59].

Supervision and management are essential environmental policies, accounting for 18.79 % of the environmental policy instruments. China has gradually strengthened its protection of blue carbon resources by restricting development activities, implementing law enforcement inspections, preventing invasive species, and strengthening the management and control of nature reserves. However, the main purpose of these activities is to preserve biodiversity, and their implementation effects are still relatively weak. According to the recent monitoring results of the State Oceanic Administration in relevant ecological monitoring areas, China's offshore marine ecosystems are deteriorating further [60]. The deterioration of the marine ecological environment is mainly manifested in the following aspects: the severe decline of marine living resources, over-exploitation of marine resources, eutrophication and nutrient imbalance, serious degradation of estuarine spawning grounds, and gradual disappearance of some spawning grounds [61].

Public participation is also an important aspect in protecting blue carbon resources. Policy processes could be more inclusive of the local people and include them at different stages of development. Accepting inputs from multiple stakeholders at the developmental stage may help encourage policy reform and create more effective policies [62]. Accounting for 14.09 % of the environmental measures, public participation policies focused on voluntary protection actions, supervision of illegal behaviors, social capital investment, and access to relevant information.

Ecological compensation accounts for only 5.37 % of the environmental policy instruments. China has not established a national marine ecological compensation mechanism, and only a few local regulations are available [63]. Shandong, Hainan, Fujian, Guangxi, and Hebei have formulated relevant management regulations and technical standards for marine ecological compensation, such as the Measures for Marine Ecological Compensation in Shandong (2016), Guangxi Marine Ecological Compensation Management Measures (2019), and Hebei Marine Ecological Compensation Management Measures (2020). However, challenges exist within the scope, fund sources, and compensation approaches. The focus of marine ecological compensation in China is to compensate for the damage caused by marine and coastal engineering projects. The government should establish key marine nature reserves to repair affected ecosystems within a narrow scope [64]. As marine ecological compensation funds mainly rely on government financing, the funding channels are too narrow. In addition, a single compensation method for the marine ecology cannot effectively satisfy the actual needs of marine ecosystem restoration.

Financial and subsidy policies, including ecological restoration, taxation, land rights, and financial support, accounted for 7.38 %. In 2022, Zhanjiang City proposed that financial institutions shall support mangrove protection and restoration and mangrove ecotourism development. Financial innovation is encouraged around the construction of the Mangrove City and financial institutions are required to vigorously innovate green credit products, promote the development and trading of blue carbon, and accelerate supply of insurance products and services. In 2021, the State Council issued Opinions on Encouraging and Supporting Social Capital to Participate in Ecological Protection and Restoration, exploring the approaches for social capital to carry out ecological protection through public-private partnerships (PPP) and other models. According to the regulations, those who meet specific conditions can enjoy corresponding preferential tax policies. For ecological protection and restoration projects that have achieved a certain scale and expected goals, the developers can obtain a certain share of the right to use natural resources assets. They can engage in developing tourism, healthcare, sports, facility agriculture, and other industries. For forest and grassland restoration projects, no more than 3 % of the restoration area can be used for ecological industry development.

3.1.3. Demand type policy instruments

Demand type blue carbon policies account for the lowest proportion (8.84 %) and only include tourism development and market construction. Blue carbon resources are an important resource base for tourism development in coastal areas [65]. Tourism development promotes local protection or restoration of important blue carbon ecosystems to realize the synergistic economic and environmental benefits [66]. Tourism development has focused on conserving marine fisheries and mangrove resources, and local governments have formulated detailed plans and policy measures for marine carbon sink tourism.

Regarding carbon emissions trading system, the inclusion of blue carbon sinks has attracted increasing attention [67]. Expanding the scale and enhancing the social impact of carbon trading are important [68]. Some regions have begun to pilot the blue carbon market to expand trading from terrestrial to blue carbon sinks. However, related policies and measures are vague and lack operational guidance. Therefore, the blue carbon sink trading system is far from perfect [69]. The Carbon Emissions Trading Management Measures (Trial) issued by the Ministry of Ecology and Environment in 2020 provides a fundamental basis for establishing and improving the national carbon emissions market. To standardize the registration, trading, and settlement of carbon emission rights nationwide, the Ministry of Ecology and Environment formulated the Rules for the Registration and Management of Carbon Emission Rights (Trial), Management of Carbon Emission Rights Trading (Trial), and Management of Carbon Emission Rights Settlement (Trial) in 2021. However, ecosystem carbon sink trading at the national level is limited to forestry carbon sinks. Blue carbon sinks are not included in the voluntary certification of emission reduction mechanisms. Only some blue carbon sink trading has been piloted at the local level [70]. For example, 380 ha of newly planted mangroves in the Zhanjiang Mangrove National Nature Reserve were developed from 2015 to 2020 according to the Certified Carbon Standard (VCS) and Climate Community Biodiversity Standard (CCB), and the blue carbon sink trading was completed in 2021. It became the first mangrove carbon sink project in compliance with the VCS and CCB in China [71]. In 2022, the Xiamen Property Rights Trading Center, the first marine carbon sink trading platform in China, completed a blue carbon sink trading project of 15,000 tons for mariculture and fisheries, with a transaction value of 120,000 yuan. The implementation of the above projects provides experience for blue carbon sink trading; however, the policy system still needs to be improved to reduce trading costs and improve trading efficiency. In China, there are some adverse factors in the development of carbon sink projects, such as small project scales, uncertainty in proving project additionality, and restrictions on the independent disposal of carbon sink income by blue carbon resource management institutions such as carbon emission reduction owners and trading subjects [72].

3.2. Y dimension: the distribution of policy instruments among different blue carbon types

The policy instrument and blue carbon type dimensions were combined for the cross-analysis. The classification of policy-text units is shown in Fig. 2. Policies related to blue carbon sinks mainly include general provisions covering all blue carbon resources and policies targeting at certain types of carbon sinks. In recent years, China's general carbon sink policies have expanded with specialized policies mainly targeting at fisheries and mangroves. Moreover, policies on coastal wetlands have gradually increased, whereas regulations on seagrass meadows decreased [73]. This reflects China's increasing emphasis on nature-based solutions regarding carbon neutrality.

In terms of fishery policy, the main policy objectives focus on improving fishery output through marine ranching construction and reducing the damage caused by fishery development to the marine environment. However, relevant policies have focused on project construction, planning, supervision, management, and other fields. The development of fishery carbon sinks lacks sufficient policy and financial guarantees, and numerous enterprises lack funds to explore new models, develop new technologies, and upgrade aquaculture facilities. Therefore, they cannot adapt to the development of modern carbon sink fisheries. Although project construction directly increases the fishery carbon sink, the number and scale of projects are still limited, and most are in the preliminary planning stage.

Mangrove protection is a policy area that attracted early attention and has formed a relatively systematic policy structure [74]. Related policies focus on the supervision and management, public participation, and tourism development of protected areas.

Recently, coastal wetlands have received increasing attention. Coastal wetland policies focus on the construction, planning, supervision, and management of projects. It lacks environmental policy instruments such as finance, technology R&D, policy publicity, and demand-based policy instruments such as market construction and tourism development. This reflects the prominent role of government supervision in coastal wetlands and a corresponding market mechanism is lacking [75]. In some areas, project construction has destroyed coastal wetlands. The supervision of government wetland management needs to be strengthened [76].

Among the blue carbon sink resources, seagrass meadows have received the least attention. Seagrass meadows are only used as blue carbon sinks in national and local climate and change response plans, and there is still a lack of specific policy supports. Seagrass meadows are biological communities with high primary productivity. Primary productivity refers to the ability of plants to fix carbon and convert it into organic carbon through photosynthesis. The annual primary productivity of seagrass is approximately 500–1000 g carbon per square meter, which is up to three times that of coral reef ecosystems [77]. However, compared with the historical

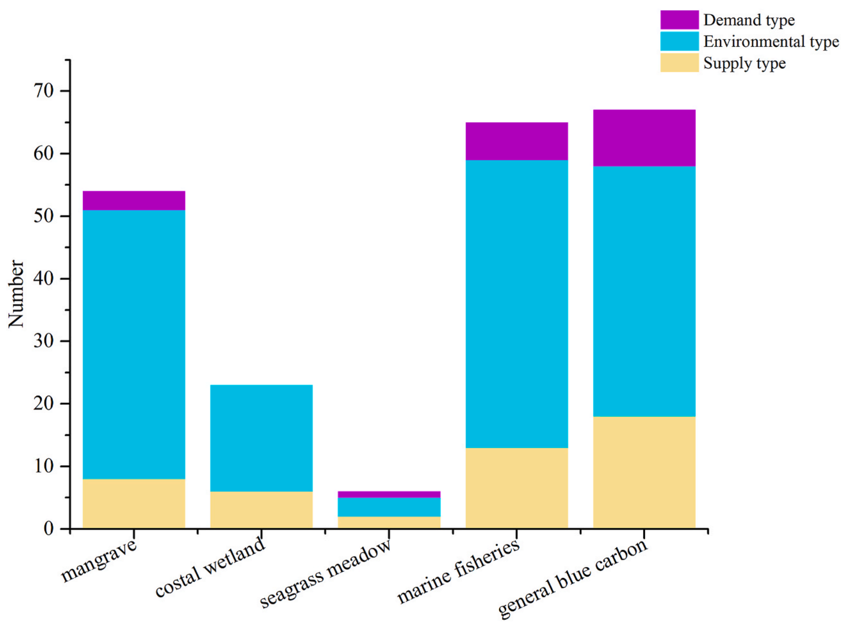

Fig. 2. Policy instruments distribution across different blue carbon resources.

distribution and species records, more than 80 % of seagrass meadows in China's coastal waters have disappeared. Strengthening the protection and restoration of seagrass meadows is crucial for promoting ecological environment in coastal waters and accelerating the recovery of marine living resources.

3.3. Policy implications

Insufficient policy supply has limited blue carbon protection. Content analysis of policies reflects the unbalanced distribution of policy instruments and weaknesses in supply and demand type policies. Although environmental policy instruments are the main instruments, they also need to be optimized to enhance implementation effects. Based on the aforementioned detailed policy instrument analysis, this study proposes the following policy recommendations that may optimize blue carbon policy instruments and provide a useful reference for policymakers.

3.3.1. Optimize environmental type instruments

Among environmental type instruments, the regulation system and ecological compensation need to be strengthened. First, environmental and climate-related laws could include specific provisions about blue carbon. For example, the Marine Environment Protection Law may acknowledge explicitly the carbon sequestration value of coastal ecosystems and provide detailed provisions for their protection. Considering less attention on seagrass meadows, specific regulations can be formulated for seagrass meadows.

Second, the improvement of marine ecological compensation system could provide more incentives for blue carbon protection and restoration. The environmental elements of the coastal ecosystem (including wetlands and mangroves) as well as marine biological resources should be compensated effectively. The compensation standards and methods could be considered from both economic and ecological perspectives [46]. China's marine ecological compensation system can learn from the Payment for Ecosystem Services (PES) system, a widely used instrument that generally includes three groups of environmental services: watershed protection, carbon sequestration, and biodiversity conservation [78]. Regarding compensation styles, the government's preferential policies for the ecological protection of the community, job supply, and technical training can also be used other than monetary compensation. Marine resource developers, who cause ecological damage to the marine ecosystem, can also fulfil eco-compensation by buying services from other market players [79].

3.3.2. Enhance supply type instruments

Economic and information supplies are necessary to protect and restore blue carbon. Governments could consider various incentives to motivate businesses to promote green financing, low-carbon industrial technologies, and carbon-sink projects. Governments can strengthen the application of PPP and other cooperation models. The use of environmental policy instruments such as taxation, maritime rights, and land rights may also improve attractiveness of blue carbon projects. However, special funds for blue carbon restoration could be set up at the central or local level to ensure stable financial investment.

Furthermore, blue carbon verification system could provide an information basis for blue carbon protection, restoration, creation, evaluation and trading. It is necessary to develop a national uniform marine carbon sink measurement method and a blue carbon sink monitoring system in line with international standards to estimate the total capacity of blue carbon sink resources.

3.3.3. Promote demand type instruments

In terms of demand type policies, the carbon emission trading mechanism could be improved to effectively realize the value of blue carbon [80]. For example, the Mikoko Pamoja mangrove carbon project in Kenya generated an annual income estimated at US $12,000 through the sale of carbon sequestered by the mangroves. This is credited to the Voluntary Carbon Market through Plan Vivo Certificates, and approximately 3000 metric tons of CO_2e/year are sequestered per year [81]. Experience of blue carbon projects in Japan indicated that it is important to manage this natural capital to take advantage of co-benefits of blue carbon such as food provision, recreation, and biodiversity protection. These benefits should be considered in the design of blue carbon market, while risk exposure must be reduced by improving the cost-effectiveness of projects [28].

Currently, carbon sink transactions in China are voluntary. However, blue carbon has not been included in the CCER system or designated as an alternative method for emitters to fulfil legal obligations. According to Article 29 of the 2020 Measures for the Management of Carbon Emission Rights Trading (Trial), key emitters can use CCER to offset 5 % of the carbon emission quota each year. Blue carbon trading market should also be included in the national unified carbon emissions trading system. A sound blue carbon trading mechanism, a fair market environment, and an effective supervision framework will help to transform and upgrade the marine economy through blue carbon trading [82].

4. Conclusions

Nature-based solutions play a crucial role in the pursuit of carbon neutrality, and China has taken notable steps by implementing policies to reduce carbon emissions and enhance carbon sinks. However, the current capacity of blue carbon sinks to neutralize carbon emissions remains limited, making it imperative to expand and strengthen these sinks to achieve carbon neutrality effectively. This study offers a comprehensive analysis of China's blue carbon policies, expanding the scope of policy discussions from territorial ecosystems to marine ecosystems as nature-based solutions for climate change. Using the policy instruments theory, our study highlights the need to optimize institutional supply and take urgent action to promote blue carbon protection and restoration.

Despite extensive planning and public participation, there exists an imbalance in policy instruments, with a dominance of environmental tools and insufficient supply and demand tools. This lack of direct promotion for blue carbon sink development hinders progress in this area. To ensure sustainable protection and success, substantial capital investment and effective market demand are essential factors. Moreover, in the context of insufficient blue carbon sink policies, the protection policies for seagrass meadows are notably lacking compared to successful policies for mangroves and coastal wetlands. Drawing lessons from these successes, China should implement similar measures to promote the protection and restoration of seagrass meadows. Other key areas of focus include marine ecological compensation, integration of blue carbon into regulatory carbon markets, and sustainable investment.

In conclusion, although this study has some limitations, such as the availability of policy documents and the fragmented nature of blue carbon policies that restricted the number of samples for analysis, it provides valuable insights into China's blue carbon policies and calls for immediate actions to strengthen nature-based solutions for carbon neutrality. While this study identifies significant policy weaknesses and presents qualitative policy preferences, further research is necessary to propose detailed institutional constructions based on the absence of existing blue carbon policies. By addressing the identified policy gaps and fostering a comprehensive approach, China can take significant strides towards a more sustainable and carbon-neutral future.

Data availability statement

Data will be made available on request.

Ethics declarations

Review and/or approval by an ethics committee was not needed for this study because this study doesn't involve humans and/or animals.

Informed consent was not required for this study because this study doesn't involve interaction with or observation of people, and/or the use of peoples' data.

CRediT authorship contribution statement

Xuan Xu: Writing – original draft, Methodology, Formal analysis. **Guoao Wang:** Writing – review & editing, Writing – original draft, Formal analysis. **Ruiqi Fang:** Writing – original draft, Data curation. **Shengqing Xu:** Writing – original draft, Validation, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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