China Council for International Cooperation on Environment and Development

SPECIAL POLICY REPORT

Sustainable Oceans Management under the Vision of Carbon Neutrality

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China Council for International Cooperation on Environment and Development (CCICED)

Sustainable oceans management under the vision of carbon neutrality

(SPS Ocean Governance)

CCICED Special Policy Study Report

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** The co-leaders and members of this special policy study (SPS) serve in their personal capacities. The views and opinions expressed in this SPS report are those of the individual experts participating in the SPS Team and do not represent those of their organizations and CCICED.*

1. Executive Summary and Recommendations

1.1. The issue

Economic activities related to oceans, seas, and coasts – the so-called ocean economy - covers a wide range of interlinked established and emerging sectors. The value of the global ocean economy is an estimated US$2.5trn annually, equivalent to the size of the world's seventh-largest economy and China's gross ocean product has been estimated to RMB 3.41 trillion in 2021, accounting for 8 % of China's overall Gross Domestic Product (GDP). The long-term potential for innovation, employment creation and economic growth offered by the ocean economies in the future is impressive. It must be pointed out that the ocean economy is highly dependent on the marine spatial environment and resource endowment. Essentially, its economic value is determined by the value of the products and services provided by the marine space and its ecosystem.

The ocean also offers a wide array of potential ocean-based mitigation options that can contribute to carbon neutrality goals, including, but not limited to, the grooming of carbon efficient ecosystems ("blue forests"), the use of the ocean's inherent energy potential, minimizing the carbon footprint of ocean-based activities such as shipping, the use of the ocean floors' ability to store carbon and reusing carbon in marine production, as well as restructuring of the fisheries and human consumption of aquatic products towards low carbon ocean-based protein and other sources of nutrition. These options should obviously be based on cautious considerations of the ocean's carrying capacity and the proper functions of the ocean ecosystems.

Ocean economy and ocean-based carbon mitigation are tightly intertwined and connected; however, challenges exist in green development of ocean economy, or in implementing Sustainable Blue Economy (SBE) principles while considering the potential role of the ocean in both adaptation and mitigation of climate changes for the carbon neutrality goals.

In recognizing that a healthy ocean is a prerequisite to draw on the benefits that the ocean provides, an integrated ocean management approach is thus required to strike the balance between the environment, economy, and society, and between short-term economic gains and long-term prosperity of the ecosystem services. Fundamentally speaking there is a need to turn around the approach to and understanding of the ocean as a living system, putting the processes that enables the ocean to generate goods and services at the centre of management, to conserve and restore to ensure sustainability. Therefore, the future ocean governance framework must take a comprehensive and sustainable approach; it also must be more adaptive to maximize the synergies between blue economy and carbon neutrality. In doing so it must also actively work toward equitable participation, opportunities, and costs for all segments of society, including women and other groups who are typically marginalized in this context.

The Special Policy Study on sustainable blue economy towards carbon neutrality (SPS Ocean Governance) aims in the current CCICED 5-year phase (phase VII) to study and recommend governance systems, blue finance systems and green technologies which can contribute to accelerate the SBE, in the context of carbon neutrality as an opportunity for transformation into sustainable blue economy. It also aims to examine the current blue economy framework and needs & tools for carbon neutrality goals in the context of the overarching goals of SPS Ocean Phase VII. And finally, it will investigate how co-existence and synergies across ocean industries can strengthen both the blue economy and the development towards carbon neutrality.

CCICED, at its annual meeting in 2023, agreed to put forward a policy recommendation that encourages the Chinese government to "accelerate the Blue Transition of the Marine Industry, and Promote the Sustainable Blue Economy as a Policy Pillar of the High-quality Development Strategy". To achieve this, it is recognized that it will be important to establish a sustainability-oriented ocean economic accounting and a blue finance framework and to investigate and adopt sustainable blue economy definitions and principles in China in the 15th Five-Year Plan and develop policy drivers around it. Furthermore, a blue transition of the marine industry will have to be achieved through technological innovation and the dual-carbon strategy.

To build further on this policy recommendation, the SPS on Ocean Governance, has during 2023-2024 focused on 4 specific topics: (1) Ocean Economy and Blue Finance, (2) Ocean Energy Industry Transition, (3) Deep Seabed Mining Industry Design and Transition, and (4) Offshore Aquaculture Industry Design and Transition. Throughout these topical research, special attention has been paid to marine biodiversity by, for instance, following the agreements reached at the Biodiversity COP15 to protect 30 % of land and sea by 2030 (3030 Agreement), as well as to conserve and sustainably use marine biological diversity of areas beyond national jurisdiction (BBNJ Treaty). Based on these studies, the SPS Ocean Governance this year put forward five policy recommendations under two headings, including for each recommendation relevant actions and mechanisms to pursue to move toward implementation of the recommendations.

1.2. Recommendations: Framing Sustainable Blue Economy

1. **Accelerate the blue transformation of marine industry through the active implementation of carbon neutrality and the acceleration and promotion of carbon positive activities, and promote the sustainable blue economy as a pillar of high-quality development strategy.**
    - Achieving the green transition of the marine industry through technological innovation and the dual-carbon strategy.
    - Strengthen the top-level design and build integrated governance strategies for the sustainable blue economy, and develop corresponding policy drivers.

2. **In order to achieve a more ambitious transformation, sustainable blue economy should be included in the top-level policy framing with clear definitions and principles, and well as incorporated into the next 5-year plan to drive the necessary changes.**
    - Investigate and adopt sustainable blue economy definitions and principles in China in the 15th Five-Year Plan, develop policy drivers around them, and establish a sustainable marine economy classification based on these principles.
    - Clear guidance must be given as to defining the blue finance taxonomy of available instruments and investment opportunities. This should be considered both for national purposes and for international cooperation programmes.
    - The expanding industries in the blue economy, such as coastal infrastructure, energy, shipping, sea foods, need to tie environmental sustainability considerations into their finance approval and monitoring strategies, establishing specific indicators to have a baseline and tracking mechanism.

1.3. Recommendations: Incentives for industry transition

3. **Strengthen the top-level design of the ocean renewable energy industry, including a national strategic plan, comprehensive/integrating resources mapping, industry promotion action plan and financial support policy, to construct the infrastructure of ocean energy industry design/transition.**
    - To enhance the leading effects of research & innovation & integrated ocean management in the process of making ocean energy the future major contributor to the Chinese/global carbon neutrality.
    - To enable the multiple-scenario utilization or demonstration of ocean energy, especially focus on the new industries like offshore photovoltaic, wave/tidal energy and offshore green hydrogen, to apparently make the contribution to sustainable blue economy easily calculated from the ocean energy industry.
4. **Develop an integrated governance strategy for deep-sea mining and formulate policies to support it.**
    - Strengthen scientific knowledge of the deep sea, fully assess the marine ecosystem impacts of deep-sea mining, and ensure that the development of deep-sea mineral resources is based on sound science, technology and management.
    - Investigate the potential environmental impacts of deep-sea mining, establish technologies for environmental monitoring, environmental impact assessment, and environmental restoration for deep-sea mining, consultation on the development of the environmental management system for deep-sea mining.
    - Strengthening global international cooperation towards international consensus of deep-sea mining governance framework.
5. **Formulate a comprehensive governance strategy for offshore aquaculture that inclusively considers the demands of coastal communities, the marine and coastal ecosystems, and stakeholders, including**

women and other marginalized groups, across the industry value chain, and implement robust and inclusive governance policies.

- Accurately evaluate the resource utilization efficiency of different mariculture forms. Identify mariculture forms suitable for offshore transition and those better suited for nearshore/land-based systems, and implement a governance approach that promotes orderly classification.
- Strengthen spatial planning for offshore aquaculture, paying particular attention to interactions with ecological hotspots such as peripheries of MPAs, critical biological habitats, and migration corridors. Explore synergies and mutual benefits with industries like eco-tourism and marine energy.
- Promote cutting-edge research in marine engineering equipment for offshore aquaculture, enhancing resilience against extreme weather events and the utilization of renewable clean energy sources.
- Strengthen research into the biology and ecophysiology of target species for offshore aquaculture, breeding suitable species/varieties and developing aquatic feed ingredients with low ecological footprints, noting also the importance of using climate-resilient strains of target species and developing farming technologies capable of adjusting to changes in environmental conditions.
- Enhance the supporting industry chain for offshore aquaculture, particularly considering the direct participation of marginalized groups like small-scale operators and women in aquaculture production, as well as in product transportation, processing and sales.
- Implement necessary government interventions aligned with market principles, such as establishing aquaculture insurance, implementing ecological subsidies, and incentives for industry transformation.

2. Introduction

The Special Policy Study on Sustainable Ocean Management under the vision of carbon neutrality (SPS Ocean Governance) aims in the current CCICED 5-year phase (phase VII) to study and recommend governance systems, blue finance systems and green technologies which can contribute to accelerating the blue economy, while utilizing the overarching aim of carbon neutrality as an opportunity to ensure a full and equitable transformation of the ocean economy into a sustainable blue economy (SBE). Furthermore, it is its aim to investigate how co-existence and synergies across ocean industries can strengthen both the SBE and the development of ocean-based solutions towards carbon neutrality.

SPS Ocean Governance over the 5-year period will conduct research on seven specific topics, three overarching topics and four industry specific topics. These are:

- Ocean economy and blue finance*
- Ocean-based solutions for carbon neutrality
- Science-based and societal-based ecosystem restoration
- Industry design and transition
    - Ocean energy*
    - Seabed mining*
    - Offshore aquaculture*
    - Marine tourism

Topics marked with an asterisk indicates studies that have been initiated and which form the basis for this report. Separate reports have been prepared for each of these policy topics, and while this present report contains a summary of challenges, opportunities and potential policy directions pertaining to these four topics, further supporting details and background information will be found in the stand-alone topical reports.

In considering these topics special attention has been placed on marine biodiversity by e.g., following the agreements reached at the Biodiversity COP15 to protect 30 % of land and sea by 2030 (30x30 Agreement), as well as to conserve and sustainably use marine biological diversity of areas beyond national jurisdiction (BBNJ Treaty), in order to promote the protection of the ocean and its biodiversity, and the fair-sharing of its resources and ecosystem services.

3. Framing the Issues

3.1. Global context

The ocean is constantly being explored for new uses of its space and resources, leading to a steady increase in the economic value it provide. Existing and potential new economic activities related to oceans, seas, and coasts—the so-called ocean economy, or blue economy— thus cover a wide range of interlinked established and emerging sectors. The value of the global ocean economy today is an estimated US$ 2.5 trillion annually [1], with a contribution of 3.3 % to the global GDP [2], equivalent to the size of the world's 7th largest economy. Nonetheless, this value is expected to be underestimated due to limitations in valuation methods and data sources, among other factors. The Organisation for Economic Co-operation and Development (OECD) estimates that the economic value of ocean-based industries would double between 2010 and 2030 [3]. According to projections from OECD, the blue economy could by 2030 outperform the growth of the global economy, both in terms of value added and employment. The long-term potential for innovation, employment, and economic growth offered by the ocean economy is promising. The proliferation of the blue economy in political discourse has gained traction in recent years; however, there remains no standardized definition [4].

In addition to supporting a host of economic opportunities, the ocean also offers a wide array of potential ocean-based climate mitigation options that can contribute to carbon neutrality goals. This includes, but is not limited to, the grooming of carbon-efficient ecosystems ("blue forests" or "blue carbon"), the use of the ocean's inherent energy potential, minimizing the carbon footprint of ocean-based activities such as shipping, protecting and potentially enhancing the ability of ocean sediments to store carbon (carbon capture and storage, or CCS), as well as reorienting food policy and fisheries management to value aquatic foods from fisheries and aquaculture as key sources of low-carbon ocean-based protein and micronutrients.

Society, the collective of individuals, communities, and groups that make up the social fabric of a region or nation, encompasses diverse stakeholders, including workers, employers, policymakers, marginalized and women and other vulnerable populations, civil society organizations, and future generations who all have different interests relating to the well-being of and opportunities associated with the ocean. The varied needs, rights, and contributions of all these groups is an essential aspect of ocean management and must be taken into consideration.

In recognizing that a healthy ocean environment is a prerequisite to draw on the benefits that the ocean provides, an integrated ocean management approach is required to strike the balance between the environment, economy, and society, and between short-term economic gains and long-term prosperity of the ecosystem services. Therefore, the future ocean governance framework must take a comprehensive and sustainable approach. The ocean can, if managed carefully, comprehensively, and strategically, play an important role in turning the tide of the current global triple crisis encompassing ongoing climate change, biodiversity loss and pollution.

3.2. The Chinese context

The ocean is a vital source of natural capital, goods and services that supports China's economic growth. It provides spatial resource including an 18,000 km continental coastline, a natural deep-water shoreline spanning over 400 km, more than 60 deep-water port sites, a 38,000 km^2 intertidal zone, and over 7,300 islands larger than 500 m^2. With a marine life count exceeding 20,000 species, including over 3,000 fish species, and a variety of marine ecosystems such as mangroves, salt marshes, seagrass meadows, coral reefs, kelp forests, and oyster beds, China's marine biodiversity plays a crucial role in ensuring food security, climate resilience, and a thriving tourism industry. This rich biodiversity supports the world largest seafood industry in terms of production scale, covering both wild-capture fisheries and aquaculture. The extensive coastal length and favourable conditions facilitate the development of a substantial marine renewable energy sector, which is the fastest-growing ocean economy sector in the country and the largest in the world, with almost 40 % of global offshore wind capacity currently in China. Moreover, emerging ocean economic sectors, such as alternative energy sources and bioprospecting, present opportunities for sustainable exploration and development.

Various marine economic sectors in China including coastal tourism, marine transportation, marine fishery, and marine biomedicine have been expanding and becoming important parts of the national economy. The annual production of China's ocean industry has been estimated to be around RMB 3.8 trillion (USD 0.54 trillion) in 2021 and RMB 3.9 trillion (USD 0.56 trillion) in 2022 [5], accounting for approximately 3 % of China's overall gross domestic product (GDP). Furthermore, according to the Reviving China's Ocean Economy: Empower Sustainable Development, the asset value of China's ocean is estimated to be around RMB 54 trillion (USD 7.7 trillion).

Over 50 % of China's large cities, more than 40 % of its population and 60 % of its GDP, are concentrated in the coastal provinces/metropolises. Coastal (mega) cities are, can and should be the engines in developing the synergies between blue economies and carbon neutrality goals. In response to the intense development of the marine industry around the world, marine industrial parks are increasingly being established in coastal areas. The marine industrial park can be an essential part of the Ocean economy (Ocean Province, Ocean City, and Ocean Capital) development plan in China, by integrating and synergizing ocean related industries, marine fisheries, ocean renewable energy, and maritime operation.

After decades of development and constant adjustment of the industries, China's ocean economy has generally stabilized. However, there is not a full awareness of the great pressure on marine ecosystems caused by the exploitation of the ocean. Climate change, biodiversity loss, pollution, etc. have all directly or indirectly become challenges to the development of the ocean economy.

As one of the world's leading maritime nations and the second-largest economy, China is actively growing its maritime power. The conservation of ocean health and sustainable development of ocean economy have been prioritized in China's recent development. China's ongoing promotion and implementation of the marine ecological civilization and its efforts to create an "ocean community with a shared future" demonstrate its global ocean governance aspiration and responsibility. The realization of these objectives requires not only government leadership, but also the involvement of businesses, academics, NGOs and the wider public.

3.3. Aiming for a Sustainable Blue Economy

Sustainable development is important to maintain long-term economic development and social well-being globally. The concepts of the blue economy and the green economy, introduced at different times, are both aimed at advancing sustainable development. Under the climate change scenario, which is also exacerbated by pollution and other development activities, both biodiversity and livelihoods are exposed to increasing risks. Ocean economic sectors need to be transformed towards a sustainable blue economy (SBE) because they are part of the threat to the ocean if their practices are not well regulated, while on the other hand they can be part of the solution to address climate change. **To achieve a more ambitious transformation, SBE should be included in the top-level policy framing with clear definitions and principles, and well as incorporated into the next 5-year plan to drive the necessary changes**.

The World Bank's definition of the blue economy is the "sustainable use of ocean resources for economic growth, improved livelihoods and jobs, and ocean ecosystem health." But such definitions do not offer principles or guidance for how to ensure and implement multiple bottom line goals including sustainability in economic development, gender and social equity, and environmental conservation. At its core the blue economy refers to socio-economic development through ocean-related sectors and activities with minimal environmental and ecosystem degradation [6]. The concept of the "blue economy" thus sets new requirements for the sustainable development of the ocean economy.

With the concept of SBE being widely disseminated globally, there is a growing international consensus on the development of an SBE. As blue economy being gradually incorporated into regional development strategy frameworks, some organizations have already proposed guidelines for SBE development, including guiding principles, focus and priority areas, initiatives, and recommendations. For example, WWF released the *Principles for a Sustainable Blue Economy* in 2015 and co-developed the Sustainable Blue Economy Finance Principles with the European Commission, European Investment Bank and the Prince of Wales' International Sustainability Unit in 2018, hosted by UNEP FI since 2019; and the G20 released the G20 *High-Level Principles on a Sustainable and Climate-Resilient Blue Economy* in 2023.

3.4. Equity

All human beings have equal rights and opportunities to participate in society regardless of gender, functional ability, sexual orientation, age, ethnicity, and religion. Gender equality is recognized as essential for the effective protection of oceans, the sustainable management of ocean and marine resources, and the accomplishment of the UN Sustainable Development Goals (SDGs). SDG 5, notes that gender equality includes the fair distribution of power, influence and resources between the genders. Policy making and implementation of framework through a gender responsive approach where all women and girls have equal opportunity and capacity to contribute at all levels of action in the decision-making process is much more likely to sustain welfare. Thus, there is recognition that ocean governance, including the ambition to move towards an SBE, requires gender sensitive and gender responsive planning, implementation, monitoring and evaluation at project, policy, and grassroots level.

Most countries, including China, have signed on to international commitments that obligate them to promote gender equality, eliminate discrimination, and mainstream gender throughout legislation, policies, and programs, including within environment and climate change programs. These commitments include the United Nations Framework Convention on Climate Change, the UN Convention on Biodiversity, the UN Convention on the Elimination of Discrimination Against Women, the Beijing Platform for Action, and the Sustainable Development Goals (SDGs).

Nevertheless, despite these obligations and while women and men have an equal stake in ocean governance, there remains a stark gap between men and women's participation in the blue economy, both in terms of numbers and the type of work. Cultural norms and practices have traditionally favored men in the ocean space, and women often have less access to resources, participation in decision-making, and access to their rights than men.

Women are more commonly found in lower-wage, informal, and subsistence activities such as small-scale fisheries, seafood processing, and coastal tourism, while men dominate the more formal, higher-wage sectors such as industrial fishing, maritime transport, offshore oil and gas, and marine engineering. These roles often come with greater job security and higher income potential. Men are more likely to hold leadership roles, influencing policy and decision-making processes that shape the blue economy. This disparity affects the prioritization of issues that impact women and their communities.

The economic benefits for women in the blue economy are consequently often lower due to their concentration in lower-paying jobs and sectors. This contributes to wider economic inequalities and limits their economic empowerment. Therefore, the future ocean governance framework must take into account these inequities and actively work toward equitable participation, opportunities, and costs for all segments of society, including women and other groups who are typically marginalized in this context.

Designing any effective action to achieve equality between men and women begins with ensuring the availability of sharp and reliable data to enable greater visibility of the gender challenge in decision-making processes. Furthermore, it involves ensuring that women and girls have equal access to education, training, decision-making processes, and financial resources with regards to SBE-related activities. In line with this, special attention was given to the issue of gender equality for ocean sustainability at the 2024 UN Ocean Decade Conference, which put forward recommendations and call for actions to reduce the gender gap, provide educational opportunities for young female scientists, and acknowledge the contributions of women in marine conservation efforts[1].

[1] https://www.unesco.org/en/articles/gender-equality-ocean-sustainability

4. Ocean Economy and Blue Finance

4.1. Introduction

The ocean is a treasure trove of resources and strategic space that supports future development, and the blue economy is an important engine for economic growth in coastal areas.

President Xi Jinping emphasized that "a well-developed marine economy is an important support for the construction of a strong marine country; It is necessary to accelerate the construction of world-class marine ports, a perfect modern marine industrial system, and a green and sustainable marine ecological environment, so as to contribute to the construction of a strong marine country."[2] Placing marine conservation in a very important position, Xi Jinping also emphasized that "We must care for the ocean as much as we care for life" in April 2019[3]. In July 2023, at the National Conference on Ecological Environmental Protection, it was emphasized to build a comprehensive pattern of protection and governance from mountaintops to the ocean, and to strengthen the spatial control of the ocean and coastal areas. After years of efforts, China's marine economy has achieved significant results in transitioning towards a quality- and efficiency-oriented approach: the construction of marine ecological civilization has been accelerated, and breakthrough results in marine scientific and technological innovation are achieved.

Meanwhile, the development of blue economy also faces many challenges: decline in coastal resource and environmental carrying capacity, poor nearshore environmental quality and degradation of marine and coastal ecosystems caused by high-intensity ocean development and utilization; problem of land-based pollution is still prominent, and the problem of marine garbage pollution is gradually emerging; marine ecological disasters such as red tide and green tide occur frequently; and loss of biodiversity. Marine industry lacks independent innovation capabilities, with a large gap comparing with international advanced competitors in areas such as green and digital development. Furthermore, implementation of the "dual carbon" target also poses phased challenges to the development of industries such as marine transportation and marine vessels. How to develop an SBE is an important issue facing the realization of United Nations Sustainable Development Goal 14, for meeting the goals of the Global Biodiversity Framework (GBF) and the Paris Agreement, and the construction of China's maritime power, which requires the joint efforts of stakeholders including the government, private sector, scientific research institutions, and civil society organizations.

4.2. Challenges and Opportunities

4.2.1. Identifying gaps in Chinese frameworks and policy directions

In recent years, the concept of the "blue economy" has been widely discussed both at home and abroad and has gained increasing consensus. At the global level, the value and strategic significance of the blue economy have gradually attracted great attention from various countries and have been put on the international policy agenda. China attaches great importance to the development of the blue economy, and to promote the development of the blue economy, it puts forward the "21st Century Maritime Silk Road" initiative and strengthens the "Blue Partnership". However, the development of the blue economy in China is still immature.

There are still various versions of the term of "sustainable blue economy". All official documents or reports have been using the notion of "ocean economy", while the term blue economy of SBE mostly appears in provincial events or occasions held by institutes attached to ministries. These terms usually refer to sustainable, modern and/or high-tech ocean economy. However, there is no consensus on the definition of the term "blue economy" in China, and many of the perceptions and views on the blue economy come mainly from the

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[2] The speech given by General Secretary Xi Jinping during the deliberations with the Shandong delegation at the first session of the 13th National People's Congress on March 8, 2018.

[3] The speech given by General Secretary Xi Jinping during his collective meeting with the heads of foreign delegations attending the multinational naval event marking the 70th anniversary of the founding of the PLA Navy in Qingdao on April 23, 2019. "推动构建海洋命运共同体（2019 年 4 月 23 日）"，载习近平著：《习近平谈治国理政》（第三卷），外文出版社，2020 年版，第 463-464 页

international level. Many international organizations offered the definition of SBE or blue economy, including UNEP, WWF, WRI, etc. Although there are different implications among these definitions, they all aim to narrow down the activities from an ocean-related economy to a sustainable paradigm. At the same time, there is still a lack of sufficient discussion on the boundary of the blue economy, which directly leads to the fact that the terms “blue economy”, “green economy” and “ocean economy” are often confused, mainly in two aspects: The first is to equate the “blue economy” with the “ocean economy”, ignoring the environmental sustainability, equity and inclusiveness, and climate resilience that the blue economy emphasizes; Secondly, most people think that the “blue economy” is the “green economy”, failing to recognize that the blue economy can achieve sustainable development through economic growth while achieving low-carbon, environmental protection and sustainable use of resources.

China has not yet formulated a national or provincial-wide systematic strategic plan for the development of the blue economy. At the international level, an SBE aims to promote low-carbon, environmentally friendly, and sustainable use of resources while also striving to protect and enhance the livelihoods of residents. However, China's major policies related to the blue economy emphasize more on the synergy between marine ecological protection and marine economic development, overlooking the protection and improvement of the population's livelihoods, including that of women and other marginalized groups, and lacking alignment with the global conversation on the blue economy.

There are yet not enough policy instruments or pragmatic methodologies for relevant entities to practice SBE. At least three aspects of methodologies should be developed. There should be a relatively clear definition of SBE - usually several principles, clear instruments, or screening tools (e.g. taxonomy) on what industries or practices are being considered as SBE should be provided. These tools can guide development departments to prepare policies to promote, central banks to design incentives, financial supervisory administrations to regulate the financial institutes, and statistic administration to calculate the volume of SBE. Investors interested in SBE should have appropriate methodologies to identify them. This can be sustainable projects ready to be funded, screening tools on specific sub-industries in detail, and/or training tools that can build their capacity. People should bear in mind that SBE is more dynamic than any other ecosystem-related investment, as the ocean is the least-known ecosystem. Therefore, it is crucial to develop toolkits to assess the economic activities of the ocean. Conservation organizations and research institutes, both international and domestic, will be the key users.

Another gap is a shared goal for the SBE. China is renowned globally for its carbon peak and carbon neutrality goal for its climate agenda. This common goal propels all related administrations to prepare policies accordingly and enables enterprises to “do the right things”. The indicator - carbon - is easy to break down and thus acts as a currency in the climate mitigation realm. Obviously, there is a gap between the ocean economy today and a common goal. Not only China but also other countries in the world face the same challenge. Fortunately, several attempts at ocean accounting, such as the ocean GEP or Reviving Ocean Economy, can somewhat serve as baselines. In the future, relatively simple and clear indicators and their measurements will be required, so that all stakeholders can be aware of their own progress.

The incentive level for local governments or entities to develop an SBE is still low. Currently, several provinces and cities are building their ocean pilot zones, each taking a specific sector to incubate their industrial expertise. In January 2024, Weihai City formulated and issued China's first catalogue of sustainable investment and financing support for blue industries, based on in-depth research on the innovative practices of green finance and the development path of blue finance at home and abroad, combined with the industrial characteristics and actual situation of Weihai City. The directory has seven major categories at the first level of classification, namely marine ecological protection and restoration and utilization, marine environmental protection, marine carbon reduction and efficiency industry, offshore clean energy industry, green upgrading of marine infrastructure, efficient utilization of blue resources, and marine green services. This initiative is an innovative sample of Weihai's development of the blue economy, which will promote the effective integration of industrial elements and financial capital and guide financial resources to focus on the blue economy. Such planning is smart, as the central government tries to maximize the efficiency of limited resources for the ocean and avoid duplicated investment. However, more resources should be mobilized to match these policies.

Promoting a sustainable economy related to the ocean is an important contribution to combatting climate change. Thanks to the combination of policy and incentive to reduce carbon emissions, China has smashed the price of renewable energy and enabled SMEs and even individuals to benefit from this movement. Similarly, policies to allow these groups to practice an SBE, subsidies for favourable activities to encourage innovation, organization of industrial clusters like industry parks, provision of appropriate capacity building will all help develop the SBE. Compared to climate, the SBE is equally, if not more, related to conservation in the field. Therefore, innovative solutions for mobilizing resources should also be further sought. These incentives should be built on the progress of the points mentioned above.

4.2.2. Governance system on ocean economic sectors and conservation matters

Currently, at the national level, China lacks a concrete and operational "blue economy" policy and a national strategy or development plan for the "blue economy" and has yet to distinguish between sustainable and unsustainable industries or products in its marine economic statistics. This status quo may not be conducive to integrating the allocation of resources to support the development of an SBE. In addition, China clearly delineates departmental responsibilities for internal management while emphasizing the development of the marine economy and the building of a marine ecological civilization. Therefore, the term "blue economy," which combines both meanings, is more suitable for external cooperation and more acceptable to the international community. However, the lack of a clear definition of "blue economy" or "sustainable blue economy" at the national policy level is not conducive to a systematic grasp by the relevant authorities of the balanced relationship between the development of the marine economy and ecological protection and is not favourable to the promotion of sustainable development.

SBE is cross-cutting, there are no dominating ministries or administrative sectors responsible for it, resulting in a lack of a leading governmental department. The lack of integrated governance at all levels would lead to conflicts in policy which may undermine the progress of SBE development.

China's legislation on the basic law of the oceans has never been completed. Existing marine legislation remains fragmented, showing a tendency towards fragmentation and sectionalization, with a relatively single scope of adjustment; there is little coordination and articulation between different marine legislation; and there is no effective integration of marine protection and development, integrated ocean management and so on, which poses an obstacle to the development of an SBE. In addition, there are still gaps in the legislation of many emerging areas of the oceans and seas that have a significant impact on the sustainable development of the blue economy, and there is a lack of overall planning and strategies for the sustainable development of specific marine industries.

The Party's third plenum resolution has announced that China is developing an environmental code[4] which will be the country's second legal code, following the civil code completed in 2020. The environment code is reported to comprise general provisions, pollution prevention, ecological protection, green and low-carbon development, and legal liability. The draft is projected to be presented to the NPC Standing Committee for its initial review in 2024, and the final code is expected to be ready by 2026. It is an opportunity that SBE principles and its related regulations be introduced in the code to support policy coherence.

4.2.3. Inclusiveness and livelihood of communities during the sustainable blue economy transition process

4.2.3.1. Inclusiveness from industry perspective

Even with the high growth in the 21st century of industrial activity in the ocean economy (dubbed “the blue acceleration”), small-scale (in some cases artisanal) fisheries are still the ocean’s largest employer. The most recent estimates show that these fisheries include significant numbers of people worldwide who participate in them for subsistence only, suggesting that the ocean and its small-scale fisheries can provide important safety nets to help prevent poverty and food insecurity. Hence any policy or collective action to shift ocean-use needs to include the voices of these users and their wider coastal communities, to ensure that their rights and traditional uses are protected as part of an equitable blue economy. Indeed, international policy goals (SDG14.b) and instruments have been agreed in order to secure a safe space in the increasingly crowded ocean for small-scale

[4] “Resolution of the Central Committee of the Communist Party of China on Further Deepening Reform Comprehensively to Advance Chinese Modernization". Adopted at the third plenary session of the 20th Central Committee of the Communist Party of China on July 18, 2024

fisheries, and some scholars have suggested that governments could zone coastal areas for small-scale fisheries, as one tool already being utilized in some countries. Regardless of the specific policy instruments, placing coastal communities at the centre of decisions for future ocean use will require a multi-pronged approach, but will also likely determine whether a future blue economy is by definition sustainable.

Throughout the entire fishing industry supply chain, women's contributions are significant in both pre-harvest tasks such as net repair and bait preparation as well as harvesting in coastal shallow waters. Their catches are essential for family nutrition and income support. Globally, women constitute more than 85% of the workforce, significant in both small-scale and industrial processing sectors. Despite their significant role in ocean economy sectors like fisheries, women often hold low-ranking, underpaid, or informal positions, instead of managerial roles and struggle to access resources like capital, credit, or training. Social norms and domestic responsibilities further limit their opportunities[5]. Thus, sustainable blue economy related policies should be inclusive to value women's contributions and recognize their distinct roles to assure their equitable livelihood opportunities.

4.2.3.2. Engagement for a broader public participation

The successful implementation and sustainability of an SBE greatly depend on public participation and acceptance. Failing to engage community in the process can undermine the recognition and effectiveness of the SBE development. The Department of Marine Ecology and Environment under the Ministry of Ecology and Environment (MEE) launched an online platform and an app to encourage public involvement in marine environmental protection and to gather coastal residents' views on coastal development and conservation. More efforts are needs to promote the importance of coastal and marine conservation among local communities, including women who often have more limited access to information and barriers to their participation in public forums. These platforms can serve as educational tools, as well as leveraging the collective community wisdom to inform policy making for developing sustainable blue economy in both national and local level.

4.2.4. Measurement and accounting of ocean's value

Currently, the valuation of the ocean economy worldwide focuses mainly on ocean industries, whereas the value assessment of marine ecosystem services remains at a relatively early stage and is still defining specific approaches and parameters. In addition, ocean-specific data is often aggregated with terrestrial data (for example combining marine and freshwater fisheries), making it more difficult to build understanding of ocean health and economic performance. While China has established a relatively sophisticated statistical investigation and accounting system for its ocean industries, gaps remain in marine ecosystem accounting and more can be done to improve it. It is important to note that especially for deep ocean ecosystems, the current knowledge gaps remain too significant and thus impedes the potential measuring or accounting of the values associated with these ecosystems. This further highlights the importance of the continuous deep-sea mapping and research efforts.

4.2.4.1. Advance the valuation of marine ecosystem services

The ocean's value extends beyond providing essential resources; it also offers ecosystem services like climate regulation, water conservation, and cultural value. Recognizing these values is crucial for sustainable ocean development. While valuing marine ecosystem services is complex, efforts like the shared wealth fund by WWF provide a starting point. China should develop a national approach to valuing marine ecosystem services and integrate these values into policy and economic development decisions. Comprehensive marine data is vital for formulating sustainable blue economic development plans and improving the marine industry's efficiency. However, China lacks comprehensive laws and regulations on marine information sharing. Overcoming these challenges requires adjusted policies to enhance data collection and analysis, incentivizing public-private partnership, and leveraging technological innovation.

4.2.4.2. Improve comprehensive ocean accounting

The definition of the ocean economy in China, reflected by its statistics, has always been different from other countries. In historically powerful countries like the UK, France, and the US, the ocean economy usually takes a proportion from roughly 1 % to 2 % in their GDP, but China claims to be 6 % and Guangdong can reach 16 %, as the Statistical scales are different. It is a good opportunity to clarify the term, as there is no official definition at this moment, and the current implications mismatch with that of other countries. To align with global

[5] International Institute for Environment and Development (IIED), Steering Gender to the Centre of the Blue Economy. 2019.

standards, China needs to clarify its definition and refine its ocean industry statistics index. This includes incorporating a wide range of indicators like ocean capital, labour input, and scientific and technological innovation. Moreover, it is important to ensure that data concerning people, such as labour, is sex-disaggregated so that the differential impact of and contributions to the ocean industry on women and men is more fully understood. Regular revisions of the ocean industry statistics accounting system and the digitization of the industry are also necessary.

Improving the accounting of China's ocean economy, including ocean industry accounting and the valuation of marine ecosystem services, is crucial for informed decision-making in the SBE. Incorporating metrics related to ocean health, ecosystem services, and the link between natural capital and economic productivity into national accounts is a key strategy for implementing an SBE. For China, integrating more environmental and natural capital-related information into its existing accounts, and fully reflecting the health of the marine environment and the SBE's development and societal contributions, is a vital next step towards an SBE. China could benefit from engaging with the Global Ocean Accounts Partnership, which aims to incorporate marine sectoral and environmental data into national decision-making aligning with international standards.

4.2.5. Marine spatial planning and ecosystem-based management

National planning rounds that guide marine economic development have also spurred marine planning at provincial, municipal, and county levels, aiming to enhance China's marine spatial planning (MSP) system. Two key guidelines govern China's marine spaces usage: the national plan for functional zoning of major marine spaces and the regulation on coastal protection, utilization, and management. These guidelines establish a policy framework for allocating uses in different marine spaces based on three functions: industrial use and urbanization, agriculture and aquaculture, and ecosystem services provision. Coastal and marine spaces are then classified into four types, each with different natural capital values: optimized development zone, key development zone, restricted development zone, and prohibited development zone, the last of which is dedicated to natural capital conservation. This classification will be applied nationwide, to county-level administrative units and natural boundaries, and needs to be implemented promptly for effective coastal zone management in China.

Recognizing the true value of natural capital and ecosystem services across all coastal and marine spaces is essential for reflecting their worth and maximizing their role in all types of development, including urban and industrial areas. This can also promote sustainable development by facilitating the integration of multiple sectors in shared spaces. Furthermore, the realization of an SBE necessitates the integration of marine and coastal management through ecosystem-based approaches. As part of its ongoing reforms, China is working to merge its national plan for marine spaces and coastal protection regulation into a comprehensive territorial space planning system. This system aims to harmonize land and sea spaces, designate integrated conservation and utilization areas, and mitigate sectoral conflicts, particularly with the emergence of new industries like offshore renewables. To ensure alignment with sustainable blue economy principles, it is vital to set boundaries considering ecosystem limits to ensure sustainable use and conservation of crucial ecosystem services, underpinned by robust scientific evidence.

4.2.6. Guidance to developing a blue finance mechanism driving towards ocean sustainability

China's current industry policies lack a five-year plan and explicit favourable policy signals for the advancement of the blue economy.

At the financing policy level, first, there are no technical standards or taxonomy at the national level to define and identify blue industries and activities. This not only makes it difficult to comprehensively cover all areas of sustainable marine development but also brings a higher risk of assessment bias to project investment and financing activities, which restricts the large-scale development of blue finance in China. Second, the lack of blue information disclosure makes the capital market lack of basis for assessing and ranking the environmental benefits or green performance of enterprises, which in turn restricts the enthusiasm of financial institutions to invest in blue enterprises and blue projects. Third, the de-risking mechanisms for blue financing and investment needs to be designed to attract the private sector, as part of a wider supportive enabling environment. Fourth, China currently faces a lack of incentive policies and mechanisms for financial institutions to support SBE activities. Specifically, financial institutions have yet to integrate blue economy activities into their marine protected area (MPA) assessments. Moreover, local governments lack incentive mechanisms for enterprises and financial institutions that endorse SBE projects.

4.2.7. International collaboration of sustainable blue economy development

The global ocean covers over two thirds of the Earth's surface and by definition will require international collaboration to manage the effects of growing use and reduce conflict. China should champion global collaboration in managing ocean resources and encourage the worldwide adoption of the SBE. One aspect that has received attention is the role of international collaboration in helping to fund the transition to more sustainable ocean use, and particular public goods for this transition (e.g. development and implementation of conservation rules, cleanups, etc.). It is also important to join the agendas of SBE, climate actions and biodiversity conservation in partnership with the global community to meet the targets outlined in the Paris Agreement, the Convention on Biological Diversity (CBD), and Agenda 2030.

4.2.7.1. Promote greater international cooperation and collaboration in blue finance

Collaborating internationally on blue finance could stimulate SBE growth both domestically and worldwide. This includes the potential establishment of an international marine development bank in Shenzhen, aimed at promoting the sustainable expansion of the worldwide ocean economy. It's essential to further investigate cooperative financing methods for the SBE with global partners. This could encompass merging various forms of capital for conservation results, jointly tackling financing obstacles in the high seas, or collaborating with OECD DAC nations to provide concessional financing for SBE initiatives globally.

China can foster agreement among nations and regions through the Belt and Road Initiative's International Green Development Coalition to collectively advance sustainable development and achieve the Sustainable Development Goals (SDGs). In this scenario, identifying and assessing biodiversity risks in financing blue infrastructure development, mitigating the adverse effects of construction and operation on marine biodiversity, and optimizing ecological, economic, and social benefits are of significant practical importance. It is also recommended to utilize existing strategies for implementing the Belt and Road Initiative, such as strategic environmental assessments (SEAs) and natural capital accounting methods, especially in ecologically sensitive areas.

4.2.7.2. Advance international cooperation on maritime governance

China is an active participant in a multitude of international organizations and conventions related to the ocean. It has initiated Blue Partnerships with the EU, Portugal, Seychelles, and Mozambique, among others, to foster measures such as innovation in science and technology, integrated management of ocean zones, and capacity-building. During the 2022 UN Ocean Conference, China launched 16 Blue Partnership Principles, emphasizing cooperation in areas like marine ecological conservation, climate change mitigation, reduction of marine pollution, and sustainable utilization of marine resources. The Sustainable Blue Partnership Cooperation Network was also established to enhance cooperation among stakeholders. The adoption of WTO Agreement on Fisheries Subsidies in 2022 is also a solid demonstration of China's active role in international cooperation to prohibiting illegal, unreported and unregulated fishing as well as alleviating the global pressure of overfishing. In the ongoing international debate on deep seabed mining, it is also important for China in considering a precautionary approach to regulating seabed mining activities in order to protect the fragile marine ecosystems.

Climate change presents a significant risk to countries worldwide, especially those with coastal regions. This threatens the natural capital that an SBE depends on. China has already made progress in protecting and restoring ecosystems severely affected by climate change. However, there is potential for China to raise its ambitions for a climate-neutral SBE by building on existing progress and promoting similar solutions on an international scale. To further global ocean governance and the development of a SBE, China should maintain its proactive participation in international negotiations, advocate for the concept of ecological civilization, and support sustainable marine resource management and global climate change mitigation efforts.

4.3. Recommendations

- Investigate and adopt SBE definitions and principles in China in the 15th Five Year Plan and develop policy drivers around it, including integrated governance across all levels and SBE transition planning. The agenda of should be complementary to protecting, restoring and sustainably managing marine and coastal ecosystems as the bedrock of a sustainable blue economy, and therefore benefiting the long-term social, economic and environmental resilience.
- Clear guidance must be given as to defining the blue finance taxonomy of available instruments and investment opportunities, and creating the enabling policy environment with incentives and disincentives to attract new and sustainable forms of finance for sustainable blue economy initiatives. This should be considered both for national purposes and for international cooperation programmes.
- Some of the expanding industries in the blue economy, such as coastal infrastructure, energy, shipping, blue foods, need to tie environmental sustainability considerations into their finance approval and monitoring strategies, establishing specific indicators to have a baseline, and tracking mechanism.

5. Industry design and transition

5.1. Introduction

A key direction for China's future prosperity and the ongoing value of the ocean is the transition to sustainability of sectors of the blue economy, as well as the acceleration of low-carbon development of ocean industries. Many of these solutions are already well aligned with China's five-year plan for the ocean economy. It is important to understand the environmental impacts of different sectors across the SBE. It is essential in this context to promote an understanding of ecosystem services, to make industrial and commercial circles aware of the environmental impacts of their operations, and to build science-based targets for impact reduction and sustainable development across different sectors.

5.2. Ocean Renewable Energy

5.2.1. Introduction

Each Ocean Renewable Energy (ORE) technologies (wind, wave, current, tidal range, ocean thermal) are under consideration in different stage of development and will presents its own unique challenges. ORE, specifically offshore wind, sees a rapid growth in installed capacity and environmental, socio-economic and technical challenges needs to be considered. China, the world's biggest energy consumer, is stepping up its push into offshore renewable energy, proposing higher green power consumption targets. Achieving the needed renewable energy transition will not only mitigate climate change, but also stimulate the economy, improve human welfare and boost employment worldwide. ORE is a fast-growing ocean economy which is advancing the goals of low-carbon and circular economy. Although offshore wind reached only recently a policy turning point, whilst other ORE technologies are at an early stage of development, there are encouraging signs that the investment cost of technologies and the price of electricity generated will decline further towards commercially viable energy generation. Enhancing knowledge of the ORE technologies potential impacts is crucial to inform future growth plans and inform effectively licensing for ORE activities. Ongoing review of environmental impacts associated with the growing ORE sector and emerging ORE technologies will ensure that the best and most up-to-date information is available to decision makers, developers and stakeholders. Furthermore, the opportunity of integration emerging ORE technologies into military applications, electricity generation for remote communities, freshwater generation or aquaculture applications, could be further opportunities. ORE technologies offer opportunities for China to develop a new industry, create jobs and take advantage of opportunities within its competency to global markets.

5.2.2. Challenges and Opportunities

5.2.2.1. Issues

To identify the issues for ocean energy industry design/transition and its contribution to SBE towards carbon neutrality, which could act very significant role in the future formulation of polices and developing routes, several crucial factors would be clarified and illustrated with extension to different scopes and industrial sectors that is not only limited to carbon or marine industry. The following points should be further investigated to support the conclusion of future challenges in ocean energy industry design/transition:

- the possibility of gradually expanding ocean energy to become the future alternative or even mainstream power source for our industrial civilization, in the process of stepping into the carbon neutrality stage within the whole society scope.
- new methodology to precisely estimate or calculate the concrete economic contribution to blue economy from ocean energy industry, which has considered the sustainable development and comprehensive economic-environmental-social benefits and impacts.
- the negative influence or impacts which the ocean energy industry could cause, including the potential or even unforeseen threats from its long-term and large-scale expansion.
- more widely social factors which could be the obstructs for the quick development of ocean energy industry.

Without the consideration of sudden burst in new generation power technologies like the controlled nuclear fusion, the sustained growth of ocean energy utilization is obvious and expectable. Therefore, it is very essential for the industrial sector to clear the obstacles in the routes of ocean energy towards its industry transition and new industry shaping. The issues have been concluded and merged into one major direction which need to be solved in the following industry promotion action.

5.2.2.2. Challenges

An electrified energy system is more obviously efficient than a fossil-fuelled energy system on today's energy industry. At global scope, the UK government has doubled its energy demand from the source of clean and sustainable energy supply. Hence, the predicted shift towards electricity will be the key future energy transition target and it will de-couple the energy needs with the fossil fuel supply, which can clearly claim the contribution to carbon neutrality. Ocean energy industry varies from offshore oil and gas, offshore wind, marine renewables to the green hydrogen generation and even deep marine energy extraction, has shown the feature of novel energy industry and highly consistency with the energy transition trends. But more challenges have appearing as the ocean energy industry are completely high-tech and high-risk industry sectors, which need to overcome not only its natural risks and difficulties caused by the strong and tough marine circumstance but also the new challenges which brought by the industry transition.

Fortunately, the major challenges have been already recognized and new study works is just ongoing conducted by the industrial community to try to track and find the best solutions. Some practical results have shown great possibility to prove this promising target and more detailed objectives have been set up to support the future overcoming for the new challenges. The challenges which the international industrial community has identified and listed as the following:

- The green transition of traditional offshore oil & gas industry: enhancing the electrification level for offshore oil & gas platform and large-scale connection with offshore green power
- the cost increase due to the green power alternation
- the complete change of technical infrastructure in offshore oil & gas sector
- the lack of engineering facilities in this new direction
- Global offshore wind industry stepped into the deep and remote era: quick development of offshore floating wind turbine technologies and fast growth of floating wind farms
- The increase of the water depth cause the rapid growth of installation cost for offshore wind turbines
- The long-distance transportation makes it very difficult during the O&M process in deep and remote areas
- Survival ability and reliability for offshore wind turbine in deep and remote areas

- Industrial cultivation and acceleration to the and promising ocean energy industry: apparently improving the TRL (Technical Readiness Level) of offshore solar, wave/tidal current energy and natural gas hydrates
- The limited demonstration scale of wave/tidal current energy
- High cost and relative low reliability
- The obstacles in technologies exploration for new industry due to the lack of confidence and commercial perspective
- Implement the industrial level production of offshore green hydrogen in generation scale and cost: significantly reducing the LCOE (Levelized Cost of Energy) for offshore renewable energy and creating the competitiveness of green hydrogen from offshore renewable energy
- Widespread understanding for the usage of green hydrogen and green fuels
- Safety and stability control in hydrogen generation
- Storage and transportation technologies

5.2.3. Recommendations

The ocean energy industry in China has just entered a very quick growth stage but still under the old version of the industry design. The industry transition and new design seems very necessary to improve the current industrial level and enhance the economic output and contribution to blue economy during the following five or ten years, so the policy will be very sensitive and significant to ensure the industry just keeping in the right pathway to the industrial transition and shaping the new industry.

Based on the latest research and conclusive summary, we proposed the following policy recommendations, which can act as research finding and guidance support to promote the SBE towards carbon neutrality:

- To strengthen the top-level design of ocean energy industry, including a national strategic plan, comprehensive/integrating resources mapping, industry promotion action plan and financial support policy, to construct the infrastructure of ocean energy industry design/transition.
- To enable the multiple-scenario utilization or demonstration of ocean energy, especially focus on the new promising industry like offshore photovoltaic, wave/tidal energy and offshore green hydrogen, to apparently make the contribution to SBE easily calculated from the ocean energy industry.
- To enhance the leading effects of research & innovation & integrated ocean management in the process of making ocean energy the future major contributor to the Chinese/global carbon neutrality.
- To enlarge the collaboration scope with the international academic or industrial partners to integrate the global knowledges and research outputs.

5.3. Deep-sea mining

5.3.1. Introduction

Deep-sea mining is a complex process, ranging from the exploration of mineral deposits, mining, transport of ore, pre-processing and deep refining. While deep-sea mining has the potential to generate direct economic benefits, it also has a wide range of environmental and social impacts.

Environmentally, deep-sea mining can cause irreversible damage to seabed ecosystems, generate sediment plumes and chemical contamination with metals, and affect marine biodiversity and ecosystem function. Based on current research, it is understood that once deep-sea ecosystems are destroyed due to human activities, restoration efforts would be difficult and very expensive, if at all possible. Studies of sediment impacts are still very limited, and there remain significant uncertainties about the long-term consequences of sediment plumes. Economically, deep-sea mining is characterised by large investments with high risks and uncertainties, although proponents are attracted by the potential for high returns.

Socially, deep-sea mining activities can raise numerous social and ethical issues, such as impacts on indigenous communities, inequitable access to benefits for women and other marginalised groups, and environmental justice. In particular, women and marginalised communities often bear a disproportionate share of the environmental degradation and social disruption caused by deep sea mining. For example, women in coastal communities may face increased food security burdens due to impacts on fisheries, on which they often depend for both food and income. In addition, these groups often have limited access to the economic benefits generated by such activities, exacerbating existing social and economic inequalities. In the future, it is the aspiration that the financial and other economic benefits from deep-sea mining will be carried out for the benefit of all humanity, according to the UN Convention on the Law of the Sea. Additionally, deep-sea mining projects have supported oceanographic research and initiatives aimed at increasing the participation of women and marginalized groups in marine scientific endeavours.

To promote gender equity and inclusion, it is essential that deep sea mining projects actively involve women and marginalised groups in all stages of decision-making. This means not only ensuring that they have access to relevant information and resources, but also creating platforms where their voices can be heard and their concerns addressed. For example, holding community consultations.

It is important to note that especially for deep ocean ecosystems, the current knowledge gaps remain too significant and thus impedes the potential measuring or accounting of the values associated with these ecosystems. This further highlights the importance of the continuous deep-sea mapping and research efforts.

Deep-sea mining, as a new form of resource development, also requires a comprehensive assessment of its carbon emissions and environmental impacts. Carbon emissions from deep-sea mining come mainly from equipment operation, ore transportation and smelting, while the degradation of organic carbon on the seafloor also generates potential carbon emissions as well as potentially impairing the capacity of the deep ocean in climate regulation. There are still technical, regulatory and policy challenges to attain responsible extraction practices, and effective policies and measures based on sufficient scientific research are needed to facilitate informed decision-making on whether or not deep-sea mining should be pursued.

5.3.2. Challenges and opportunities

5.3.2.1. Calculation of carbon emissions from deep-sea mining

Carbon accounting for deep-sea mining faces a variety of challenges, including data acquisition and accuracy issues, complexity of accounting methods and technical and policy barriers. In terms of data acquisition, the difficulty, cost and lack of data precision directly affect the accuracy of the accounting results. The accounting boundaries are not unified, and there is a lack of unified standards and norms, making it difficult to compare and synthesize the results of different studies.

Currently, there is very limited discussion of the potential carbon footprint and emissions from deep-sea mining processes, focusing on sediment plumes, i.e., the process of organic carbon decomposition resulting from sediment resuspension. Here, it is important to note there are two types of sediment plumes; one from the seafloor resulting from the resuspension of particles, and one from the discharge or midwater plume. Some studies suggest that sediment resuspension from seabed mining operations, which covers the first type of sediment plumes but not the second type (and which is expected to spread further), may be limited to a relatively small temporal and spatial scale. However, this is still a matter of contention, and other studies suggest the consequences of plume dispersals could be a lot more significant and lasting. For example, Spearman et. al. (2020) combined in situ observations with numerical modelling and found that most sediments stirred up during seafloor mining will settle within 1 km of the centre of disturbance [7]. Preliminary results from a deep-sea mining exploration contractor, Global Sea Mineral Resources' (GSR), tracking of the behaviour of sediment plumes in the Clarion Clipperton Sea between Hawaii and Mexico indicate that sediments are mainly dispersed near the mine site, and resuspension is confined to 5 m above the seafloor, which is much lower than the resuspension heights of sediments in some natural marine environments. At the same time, the rapid settling of sediment plumes can also be effective in reducing carbon emissions due to organic carbon oxidation; for example, model calculations suggest that concentrations of mining-unknown plumes will rapidly dilute to natural background levels within a day of mining cessation [8]. In addition, a study by Haffert et. al. (2020) in the DISCOL test area in the Peru Basin found that one year after a seafloor mining impact, biogeochemical processes in the sediments had returned to pre-impact conditions [9]. The above suggests that the potential carbon emissions from the mining process might have a small impact range and are in the controllable range.

However, these predictions are premised on very small-scale component tests of in situ prototype mining equipment carried out over a very short duration at a small location. Moreover, most studies have focused on only one resource type, namely, polymetallic nodules found on abyssal plains, and do not consider the two other deep-sea mineral resources, the crusts and the sulphides, which are found at seamounts and hydrothermal vents. While helpful for modelling purposes, the predictions drawn from such experimental exercises might not be accurate. In fact, there are compelling studies that suggest otherwise. On the other hand, the mechanisms of decomposition and fixation of marine organic carbon are very complex. In some cases, sediment resuspension does not necessarily result in significant organic carbon oxidation and CO2 emissions. Sediment deposition following operational disturbance is faster and more conducive to protecting and burying organic carbon than background deposition rates in the marine environment. Disturbance of the original depositional environment may also trigger other carbon storage mechanisms that result in carbon burial. For example, during sediment resuspension, dissolved carbon in seawater may adsorb onto sediment particles and be preserved as the particles settle rapidly [10]. Then again, while mining of mineral deposits causes unavoidable and potentially irreversible damage to seafloor ecosystems, the rapid settling and preservation of small biological detritus can also store some of the biogenic carbon. Thus, in addition to the obvious carbon burial utility arising from fuel-powered processes, the potential carbon emissions from deep-sea mining need further careful assessment and study.

5.3.2.2. Environmental impacts of deep-sea mining

Although deep-sea mining is receiving renewed interests, it faces scientific, technological, regulatory and geopolitical challenges. For example, there are currently huge gaps in knowledge of deep-sea science, insufficient technical means for environmental monitoring and assessment related to deep-sea mining, the absence of international regimes such as exploitation regulations, the lack of a certain degree of data transparency and of rigorous science-based standards and guidelines, and geopolitical issues related to benefit-sharing from deep-sea mining and its impacts on land-based metal-mineral resource countries. Indeed, new research published in July 2024 suggests that some deep-sea resources (i.e. polymetallic nodules) may be capable of producing oxygen, which could prove to be a ground-breaking finding if verified by further research and capable of causing a paradigm shift in how we understand and appreciate the ecosystem functioning of the deep-sea [11]. Some groups have even argued that deep-sea mining activities if conducted in the near future and without sufficient safeguards would "represent the beginning of a large-scale uncontrolled experiment", while the legitimacy of deep-sea mining has been seriously called into question [12].

5.3.2.3. Deep-sea green mining technology

The development and application of responsible deep-sea mining technology faces multiple challenges, including (1) resource potential and demand growth. The global demand for metal resources continues to grow, especially in high-tech fields such as new energy batteries, electronic equipment and renewable energy equipment, where the demand for metal materials such as cobalt, nickel and copper is becoming increasingly urgent. At the same time, it is important to acknowledge that large scale technological change in many mineral rich fields, such as electric vehicle battery technology (including in China) with the development of lithium iron phosphate batteries, where the minerals needed in the batteries have significantly altered, thereby reducing and potentially even eliminating the need for metals (e.g. cobalt) that are also found on the deep-sea, although these resources remain critical in various industries [13]. Noting the case of lithium iron phosphate batteries, which have doubled their market share in the past two years and now represent 42% of the global battery market, future research and innovation could potentially reduce the need to turn to the deep-sea in the quest to obtain metals. As advances are made in finding substitutes or alternatives, and accompanied by growing investments to build a more circular economy, the profitability of deep-sea mining, which is already doubtful under current circumstances, will face further uncertainty.

After a long period of large-scale mining of mineral resources on land, known reserves are becoming smaller, exploration is becoming more difficult and mining costs are rising. However, an increased interest in mining across the world has also led to many more terrestrial mining reserves being discovered, and thus increasing the size of know reserves. Developments in terrestrial mining technologies are also making reserves that were previously not technically feasible to mine, available to mine. Deep-sea mineral resources could have potential in terms of reserves and quality, especially polymetallic nodules and polymetallic sulphides containing many key metals, which have broad development prospects. However, it is important to note that processing capacities and development are still under development and questions remain with respect to the efficiency with respect to the further processing and refinement of these minerals resources. Finally, the growing number of financial bodies, global industries and leading businesses that have committed to not support or source for the metals they require from deep-sea mining activities could also affect the demand and profitability of such activities.

(2) Environmental challenges and risks. The potential impact of deep-sea mining activities on the marine environment is a difficult issue for current technology and scientific assessment. For example, seabed mining may disturb a large amount of sediments and form suspended sediment plumes, causing irreversible damage to the surrounding ecosystems; the noise and vibration generated by seabed mining activities will put pressure on the survival and reproduction of deep-sea biological communities. In addition, due to the limitations of scientific and technological means and monitoring equipment, there is a relative lack of long-term, systematic research on these environmental impacts, resulting in a certain degree of uncontrollable environmental risks. Deep-sea mining technology needs to minimize these environmental risks through technological innovation and scientific assessment to achieve a balance between ecological protection and resource development.

(3) Technical bottlenecks and R&D needs. The deep-sea environment is extremely special, characterized by high pressure, low temperature, darkness, etc., which puts forward extremely high requirements for mining equipment and technology. For example, the seabed operation equipment needs to have the characteristics of anti-high pressure, anti-corrosion, high efficiency, etc., which poses new challenges to many fields such as material science, mechanical engineering, and control technology. At the same time, due to the environmental specificity and complexity of deep-sea mining, it is often necessary to combine a variety of advanced technologies, such as robotics, automation technology, remote control technology and intelligent systems, to cope with a variety of complex situations in the mining process.

(4) Jurisprudence and international norms. Deep-sea areas are usually defined as international public areas or "commons", and resource development needs to follow the provisions of the international law of the sea and relevant international treaties. The International Seabed Authority (ISA), an organization established under the United Nations Convention on the Law of the Sea, is responsible for managing and supervising mineral resource development activities in the international seabed area and to ensure the effective protection of the marine environment. Although there are some preliminary regulations and environmental protection guidelines, there are still loopholes and imperfections in the process of concrete implementation and enforcement. Indeed, with respect to future exploitation activities, negotiations at the International Seabed Authority remain ongoing amidst growing calls for a pause or moratorium. Many member states have remarked that there are many key outstanding areas that remain unresolved and thereby requiring a lot more attention and the need to increase significantly more safeguards into the regulatory framework, including the need for more science and other forms of knowledge. In addition, the interests, and claims of countries in the development of deep-sea minerals and their responsibilities for environmental protection need to be harmonized through more detailed and scientific regulations and international cooperation. Additionally, deep-sea mining would also have an impact on current metal mineral prices, and affect the social and economic development of terrestrial mining countries, including reducing the environmental damage, as well as the loss of human health to the miners themselves and the surrounding communities.

5.3.2.4. Deep-sea mining and "peak carbon, neutral" strategies

While deep-sea mining could provide key metals, such as cobalt and nickel, contribute to the energy transition, it still faces multiple challenges. Deep-sea mining areas are remote from land, the ore bodies are found thousands of metres under the sea surface, the host environments are complex, and the mining technologies are immature and potentially expensive, with no examples of commercialized mining to date. It is not given that metals from the deep seabed is even needed or necessary, bearing in mind recent technological innovations such as in electric vehicle batteries. The deep-sea hosts unique and fragile ecosystems, including important biological and genetic resources that are useful for pharmaceutical uses, whereby deep-sea mining is likely to cause significant and irreversible harm. Moreover, as cautioned by the United Nations Human Rights Commissioner, deep-sea mining also could potentially cause significant human rights violations, including the right to a healthy and productive ocean, while deep-sea mining raises concerns over human rights impacts, it also has the potential to reduce land-based mining impacts, such as displacement and pollution, and supports female participation and benefit-sharing with developing nations. In addition, deep-sea mineral resources are often polymetallic ores, with long processing and metallurgical processes that consume large amounts of energy, resulting in high processing and metallurgical costs as well as large footprint for deep-sea minerals. According to the technical and economic evaluation of polymetallic nodule mining, the cost of beneficiation and metallurgy accounts for more than half of the total cost [14].

The production process requires the supply of energy, which inevitably leads to carbon emissions. Deep-sea ecosystems are critically important to the ocean carbon cycle, and mining activities may lead to imbalances in the ocean carbon cycle, affecting carbon sequestration and storage and thus indirectly increasing carbon emissions [15]. Consequently, the United Nations Environmental Program Finance Initiative concluded that deep-sea mining as currently understood should not form part of the sustainable blue economy.

5.3.3. Recommendations

1. Development of a comprehensive carbon emissions assessment framework for deep-sea mining

(1) Establishment of a comprehensive methodology for assessing carbon emissions from deep-sea mining: Conduct basic surveys and small-scale field experiments on potential carbon emissions prior to the selection of sites and operations for deep-sea mining. For example, understanding the carbon storage capacity and ecosystem carbon health limits of the mining site will provide the basis for the development of an effective carbon emissions assessment methodology.

(2) Establishment of a comparative inventory of potential carbon emissions from marine protected areas and deep-sea mining areas: to formulate deep-sea mining plans in a graded and phased manner according to the environmental vulnerability, ecological value and carbon storage capacity of different ecosystems, so as to ensure that the carbon emission impacts of deep-sea mining are assessed in a scientific and comprehensive manner.

2. Promoting responsible technologies for deep-sea mining

(1) Developing responsible mining technologies and methods: building systems for seabed collection and sediment plume discharge with low environmental impact; and establishing in situ tailings treatment systems to reduce carbon emissions by disposing of mine wastes and tailings in situ in the deep sea.

(2) Innovating low-carbon deep-sea processing and metallurgical technologies and equipment: researching and developing environmentally sound, high-efficiency and low-carbon deep-sea mineral processing and metallurgical technologies to improve the recovery rate of valuable metal processing.

3. Enhanced monitoring and management systems

(1) Establishment of a system for monitoring and continuous observation of environmental impacts, including carbon emissions from deep-sea mining: in-depth study of the impact of mining operations on the carbon storage capacity of the marine environment, comprehensive observation, and effective tracking, calculation and assessment of the carbon footprint of seabed mining.

(2) Strengthening scientific research and environmental management systems: gathering of robust environmental baseline data, studying the potential environmental impacts of deep-sea mining, breaking through key technologies for environmental monitoring, assessment and remediation (which, based on current knowledge, is not scientifically feasible), consulting on the formulation of an environmental management system for deep-sea mining, and ensuring that technological and management tools are complete and sufficient scientific information is available for responsible and effective decision making.

4. Strengthening international cooperation and regulatory systems

(1) Strengthening global international cooperation: enhancing the international status of the development of deep-sea mineral resources, formulating international cooperative scientific programmes, rallying international scientific research efforts, and promoting the exchange of scientific knowledge; strengthening cooperation with the International Organization for Standardization and the International Seabed Authority, and using standardization to promote high-quality development.

(2) Constructing a comprehensive system of international laws and regulations: under the mechanism of the United Nations Convention on the Law of the Sea, ensure universal participation in the formulation of regulations on the exploitation of mineral resources in the international seabed area based on science and precaution;, ensure that the governance of mineral resources in international waters is more equitable and rational, and urge operators to carry out robust impact assessments and technological innovation.

(3) Ensuring coherence between future deep-sea mining activities with the recently adopted BBNJ agreement and the Kumning-Montreal Global Biodiversity Framework, among other internationally binding instruments that apply to the marine environment, and assessing how any potential deep-sea mining activities could affect the obligations, ambitions, goals and targets set by these other international agreements and processes.

5. Promoting clean energy applications

Developing non-fossil renewable and clean energy: Reducing the intensity of carbon emissions from deep-sea mining, actively adopting renewable and clean energy and other renewable energy sources, constructing a platform for the comprehensive supply of energy from the sea, realizing the large-scale storage and transportation of clean energy supplies and their efficient utilization, while ensuring the effective protection of the marine environment.

6. Increased public awareness and industry transparency

Raise public and industry awareness: Raise social awareness of the environmental impacts of deep-sea mining by popularising science, encouraging open debate and promoting inclusive and informed decision-making. It is particularly important to ensure that women and marginalised groups, who are often excluded from public forums but are among those most affected, have access to these discussions.

Implement gender mainstreaming policies: Create platforms specifically for the participation and feedback of women and marginalised groups. This could include organising community consultations and public forums that are accessible to these groups, providing information in local languages and formats that are easy to understand, and ensuring that their unique perspectives are included in decision-making processes.

Develop inclusive strategies and mechanisms: Establish benefit-sharing mechanisms that address the needs of women and marginalised groups and ensure that they receive a fair share of the economic benefits from deep-sea mining. For example, allocate a portion of mining revenues to community development projects that directly benefit these groups.

Promote education and capacity building initiatives: Provide training and education programmes aimed at increasing the participation of women and marginalised groups in the deep-sea mining sector. This may include technical training, leadership development and capacity building initiatives that enable these communities to actively participate in and benefit from mining activities.

5.4. Offshore aquaculture

5.4.1. Introduction

With the continuous rapid growth of the world's population and the improvement of people's living standards, people will put forward higher demands for high-quality animal protein in the foreseeable future. In the aquatic food production sector, capture fisheries are in the stage of reducing production capacity and optimizing production structure due to long-term overfishing, thus aquaculture is the main driving force of growth.

Excessively intensive nearshore aquaculture not only endangers the yield and safety of aquatic food through water pollution, disease transmission, etc., but also has profound negative impacts on coastal ecosystems and socioeconomic systems [16, 17, 18]. The excessive nutrients and drugs discharged by aquaculture activities have damaged the ecological environment quality, and aquaculture infrastructures have occupied important habitats for coastal organisms such as mangroves, seagrass beds, and salt marshes. In addition, with the increasingly diversified forms of utilization of the ocean, aquaculture will also compete for space with pillar marine industries such as shipping, ecological tourism, and marine clean energy.

Promoting the expansion of mariculture from nearshore to offshore has become an urgent need at this stage. According to the latest statistical yearbook data, China's "deep-sea cage" (water depth>20 meters) aquaculture production in 2022 was close to 400,000 tons. Although it accounts for less than 2 % of the total mariculture production, considering that the deep-sea cage aquaculture targets are almost all finfish, its production has accounted for one-fifth of the marine finfish aquaculture production [19]. With the promotion of public policies, deep-sea cage aquaculture production has quadrupled in the past 10 years, especially since 2017, and several world-first intelligent large-scale aquaculture infrastructures have been built [20]. A field monitoring study have shown that offshore aquaculture does have advantages in terms of environmental impact [21]. However, it should be noted that the offshore aquaculture industry is still in its early stages, and the global academic and industrial communities have not yet reached a sufficiently solid consensus on the definition, expansion potential, technical trends, and main risks of offshore aquaculture. Therefore, it is also necessary to collect more comprehensive scientific knowledge and organize more stakeholder-based decision-making processes to outline a clearer strategic path for the future development of offshore aquaculture.

5.4.2. Challenges and opportunities

5.4.2.1. Ecological risks

The impact of aquaculture on natural ecological environment has been a widely studied topic in recent decades. Compared to nearshore mariculture, offshore aquaculture areas are less disturbed by human activities, have better water exchange conditions, and stronger pollution assimilation capacity. However, offshore aquaculture also poses considerable ecological risks, some of which are due to the inherent characteristics of aquaculture activities and others due to the special characteristics of the offshore environment.

1. One of the most typical ecological risks of offshore aquaculture is the use of wild forage fish resources. The suitability of the environment and the high requirements for economic returns have led to the main target species of offshore aquaculture being high-value carnivorous finfish. The cultivation of these high trophic level species inevitably has a strong dependence on fishmeal and fish oil, both of which come from wild-caught forage fish resources [22]. The subsequent potential negative impacts include: Intensifying the overfishing of forage fish populations; Affecting the function of forage fish as a key intermediate element in the marine food web, reducing the quality of marine ecosystems; Reducing the proportion of forage fish catches directly consumed by humans, endangering food security in specific regions; Promoting the application of low-selectivity, high-environmental footprint fishing methods. With the rise in fishmeal and fish oil prices, there has been significant progress in the aquafeed formulations. The feed conversion ratio (FCR) of some well-studied species (such as salmon) has improved significantly, and alternatives to fishmeal and fish oil have been developed [23, 24]. However, whether these alternatives (such as soybean meal and insect meal) have lower ecological and carbon footprints remains to be verified. There is also insufficient feed nutrition research on some target species of offshore aquaculture, and it is necessary to continue to optimize FCR, micronutrient transmission, and protein absorption efficiency. If these challenges are not adequately addressed, the natural resource utilization efficiency of offshore aquaculture might be low, leading to adverse ecological risks.
2. In addition to the ecological risks caused using external biological resources, the ecological risks posed by aquaculture infrastructures themselves to the surrounding environment are also noteworthy. Since the main target species of offshore aquaculture are high trophic level finfish, if the residual feed and metabolites of the fish are too concentrated, it will produce an additional nutrient footprint, thereby changing the structure of the surrounding ecosystem. Although theoretically, the water exchange dynamics of the offshore sea areas are better and it is easier to mitigate the impact of additional nutrient input, there is still a lack of relevant empirical research on operating offshore aquaculture infrastructures, and further verification is needed. At the same time, the risk of escape of farmed organisms due to potential causes such as wind and wave damage, shark attacks, and equipment failures also needs to be guarded against. In addition, it is necessary to strengthen research on the interaction between offshore aquaculture and threatened wildlife. Compared to nearshore aquaculture, the areas where offshore aquaculture is located are less under human pressure, which means that the activities of threatened wildlife in the corresponding areas may be more frequent. Although aquaculture will not directly overlap with marine protected areas (MPAs), in the siting process of offshore aquaculture, it is still necessary to strengthen prior field biological surveys or use species distribution models (SDMs) and other simulation methods to ensure that potential aquaculture areas are not in the habitats and migration corridors of threatened wildlife. The design of aquaculture infrastructures should also pay attention to preventing entanglement of threatened wildlife, especially large flagship species such as whales, dolphins, and sea turtles that are easily attracted by farmed fish.

5.4.2.2. Economic risks

Overall, offshore aquaculture is a high-risk, high-reward type of aquatic food production. From China's current situation, offshore aquaculture has good economic benefits, and coupled with a series of incentive industrial policies implemented by the government, the enthusiasm of enterprises to invest in offshore aquaculture is still limited, and economic risks are the main reason [25]. The economic risks of offshore aquaculture mainly include the following aspects.

1. Compared with nearshore waters, the physical and biological environments of offshore waters are more complex, manifested in many aspects such as weather, currents, biofouling, and shark attacks, among which offshore wind and waves are the most prominent. Especially in the southeastern coast of China, where offshore aquaculture practices are relatively concentrated, typhoons are frequent in summer, and their impact on aquaculture infrastructures is devastating. Although nearshore aquaculture is also affected by typhoons and other extreme weather events, the topography of mud flats and bays can provide a certain buffer effect against wind and waves, let alone land-based recirculating aquaculture factories. In addition, offshore aquaculture infrastructures and target species are also more expensive and more vulnerable to external risks. The most critical issue is that the development of insurance systems specifically for offshore aquaculture is slow. Even if some products have emerged, the insurance clauses are extremely rigorous and far from enough to solve the worries of aquaculture enterprises [25].
2. Since offshore aquaculture infrastructures need to have the ability to resist wind and waves, the construction and operation costs are high, and it is necessary to ensure that their products have a certain competitive advantage in the market and that there are enough consumers willing to pay a higher price for them. This requires that the target organisms of offshore aquaculture be different from those of traditional aquaculture methods such as nearshore cage aquaculture, pond aquaculture, and land-based factory aquaculture to achieve staggered competition. On the one hand, the above requirements mean that the target species that offshore aquaculture can choose from fall into a narrow range. Whether these species can have excellent growth performance in the natural offshore environment and under intensive aquaculture conditions still lacks sufficient experience and technical support. On the other hand, the supporting industrial system for the high-value utilization of offshore aquaculture products is still incomplete, and it is difficult to guarantee sufficient market space, let alone more competitors will emerge when the scale of offshore aquaculture expands. At the current stage of development, these factors also constitute important economic risks faced by offshore aquaculture.
3. In recent years, with the rise of offshore aquaculture, marine engineering equipment enterprises have continuously increased their investment in the research and development of offshore aquaculture infrastructures. Significant progress has been made in terms of wind and wave resistance, automated operation, and clean energy application. However, this has also made the prices of aquaculture infrastructures higher and higher. Before the uncertainty of returns is effectively solved, the high initial investment further exacerbates the economic risks of offshore aquaculture. A Chinese study found that among the offshore aquaculture infrastructures currently in operation in China, those with an investment of less than 30 million yuan (~ US$ 4.14 million) are mostly invested by private enterprises, while large-scale infrastructures of 100 million yuan (~ US$ 13.8 million) or more are almost all invested by state-owned enterprises; the ownership of one large-scale infrastructure has even been transferred from a private enterprise to a state-owned enterprise [26]. The current economic entry threshold for offshore aquaculture is quite high, which also reflects that the market mechanism and its supporting system cannot fully stimulate the investment willingness of private capital and can only rely on government intervention to develop. This is undoubtedly an urgent need to change.

5.4.2.3. Social risks

While aquatic food production ensures the food and nutrition security of a large global population, it also provides essential livelihoods for many people. Globally, around 60 million people are directly engaged in capture fisheries and aquaculture [27], most of whom are small-scale operators, working on a personal or family basis to carry out basic production. However, the emerging offshore aquaculture industry is quite different from the above characteristics of the entire aquatic food industry. It has high capital investment requirements, high technical requirements, and high product prices, and can only be carried out and operated by enterprises of a certain scale and strength. In this context, whether the offshore aquaculture industry can transform the benefits it produces into fair social well-being is a question worth careful scrutiny.

1. The current orientation of offshore aquaculture is a relatively high-end form of aquatic food production. In terms of capital investment, its aquaculture infrastructures are large-scale and expensive, and the cost of cages with automation is in the order of tens of millions of yuan (~millions of US$), and a small number of them cost over 100 million yuan (~US$ 13.8 million). For small-scale operators, even if several families join forces, they are still far from the entry threshold. In terms of technical input, its aquaculture equipment is structurally complex, and the target species are generally high trophic level fish that need to be fed, so operators need to have rich professional knowledge in engineering technology or aquaculture. At the same time, due to the higher degree of automation of operations than nearshore aquaculture, the demand for primary labour has decreased. This makes it difficult for general livelihood fishers in coastal communities to directly engage in offshore aquaculture. When offshore aquaculture is an exploratory pilot, this social risk is not prominent. However, once the scale of offshore aquaculture expands rapidly and significantly replaces nearshore aquaculture and small-scale capture fisheries, it will block the original livelihood fishermen from the entry threshold and cause serious social problems. At the same time, the social risks of offshore aquaculture will not only affect practitioners but may also affect consumers. Considering profitability, offshore aquaculture products are all high-value seafood. If this industry expands rapidly and replaces some traditional aquatic food production, it will also change the market structure of aquatic food. The supply of low-cost aquatic food that low-income groups can afford (such as algae, shellfish, and small pelagic finfish, etc.) will decrease, which will have a negative impact on food and nutrition security in specific regions.
2. Gender equality is also a major focus when examining the social risks of an industry. Although there is currently no targeted research to reveal the gender equality situation in offshore aquaculture, from the perspective of the entire aquatic food production industry, the reality is not satisfactory. In the entire aquatic food value chain, from pre-harvest to post-harvest, women account for half of the workforce. Although women play a large and important role, aquatic food production is still a male-dominated industry. Due to gender-based barriers, women's access is often limited to non-formal, low-paid, unstable, and low-tech job categories [27]. A recent empirical study in the United States showed that the expansion of low-entry-threshold, low-return aquatic food production forms such as shellfish and algae aquaculture is more conducive to the direct participation of women in production; further, within this type of production form, industries with relatively low returns (algae aquaculture) have a higher female participation rate, while female workers still have limited access to industries with relatively high returns (oyster aquaculture) [28]. Offshore aquaculture is precisely a representative of high-entry-threshold, high-return aquatic food production forms, and the employment opportunities in it are highly scarce resources for the entire fishing community. Gender-based barriers further reduce employment opportunities for women within this industry. However, this does not mean that there is no opportunity for reform. The disadvantaged position of women in aquatic food production is often because under the traditional asset inheritance system, it is difficult for women to obtain ownership of production materials such as fishing boats and fish ponds [29]. The rise of offshore aquaculture is not the result of the natural evolution of traditional aquatic food production forms, especially small-scale production forms, but largely relies on the guiding role of policy governance. In the process of promoting industrial transformation, whether it is the transformation of capture fisheries or nearshore aquaculture to offshore aquaculture, the government can carry out targeted capacity building for women in fishing communities, such as technical training required for aquaculture work itself or upstream and downstream industries (fish fry farming, product processing, etc.). Especially for women who cannot access adequate harvest opportunities under traditional production forms, non-male-centered communication and learning spaces should be created that are responsive to women's unique needs and capacities. Considering that women often can make more environmentally friendly and more sustainable decisions than men [30], taking advantage of the opportunity of industrial transformation of offshore aquaculture to carry out gender-inclusive reforms and increase the participation of women in aquatic food production and management decisions is of great significance.

5.4.3. Recommendations

Offshore aquaculture, with its potential for large-scale, sustainable development, addresses the critical need for high-quality aquatic food sources. It also offers a powerful solution to the challenges of oversaturation in coastal marine activities and enables efficient collaboration among various blue economy sectors. As a leading offshore aquaculture country, China, alongside other major producers, should implement robust industry governance policies. These policies should inclusively consider the demands of coastal communities and stakeholders across the industry value chain. Additionally, active international scientific communication and management cooperation are essential. Key principles of offshore aquaculture governance include: 1) Scientifically assessing the environmental impacts of aquaculture activities, and ensuring that the transition to offshore aquaculture aligns with marine ecological conservation as far as possible; 2) Minimizing carbon emissions "from aquaculture activities and upstream and downstream industries, and exploring the feasibility of negative-emission mariculture practices in offshore waters; 3) Ensuring equitable access to the benefits derived from the production outcomes of offshore aquaculture for women and other marginalized groups; 4) Reducing operational risks and entry barriers in offshore aquaculture to foster a more diversified market pattern.

Specifically, it is recommended to:

- Accurately evaluate the resource utilization efficiency of different mariculture forms. Identify mariculture forms suitable for offshore transition and those better suited for nearshore/land-based systems. Implement a governance approach that promotes orderly classification.
- Strengthen spatial planning for offshore aquaculture, with particular attention to interactions with ecological hotspots such as peripheries of MPAs, critical biological habitats, and migration corridors. Explore synergies and mutual benefits with industries like eco-tourism and marine energy.
- Promote cutting-edge research in marine engineering equipment for offshore aquaculture. Focus on enhancing resilience against extreme weather events and the utilization of renewable clean energy sources.
- Strengthen research into the biological mechanisms of target species for offshore aquaculture. Optimize developing suitable species/varieties and accelerate the development of aquatic feed ingredients with lower ecological footprints.
- Enhance the supporting industry chain for offshore aquaculture, particularly considering the direct participation of marginalized groups like small-scale operators and women in aquaculture production, as well as in product transportation, processing, certification, and sales.
- Implement necessary government interventions aligned with market principles, such as establishing aquaculture insurance, implementing ecological subsidies, and incentives for industry transformation.

6. References

1. UNCTAD. Towards a Harmonized International Trade Classification for the Development of Sustainable Ocean-Based Economies, 2021. UNCTAD/DITC/TED/2020/4
2. Hoegh-Guldberg, O. et al. Reviving the Ocean Economy: the case for action - 2015.WWF International, Gland, Switzerland., Geneva, 2015: 60.
3. OECD. The Ocean Economy in 2030, OECD Publishing, Paris, 2016. DOI: 10.1787/9789264251724-en
4. Wuwung L, Croft F, Benzaken D, Azmi K, Goodman C, Rambourg C and Voyer MGlobal blue economy governance – A methodological approach to investigating blue economy implementation. Front. Mar. Sci., 2022, (9):1043881. doi: 10.3389/fmars.2022.1043881
5. Department of Marine Strategic Planning and Economics, Ministry of Natural Resources China Marine Economic Statistics Bulletin, 2021 and 2022.
6. World Bank and United Nations Department of Economic and Social Affairs. The Potential of the Blue Economy: Increasing Long-term Benefits of the Sustainable Use of Marine Resources for Small Island Developing States and Coastal Least Developed Countries, 2017. World Bank, Washington DC
7. Spearman, J., Taylor, J., Crossouard, N. et al. Measurement and modelling of deep sea sediment plumes and implications for deep sea mining. Sci Rep, 2020, (10): 5075. https://doi.org/10.1038/s41598-020-61837-y.
8. Gillard, B., Purkiani, k., Chatzievangelou, D., Vink, A., Iversen, M. H., Thomsen, L. Physical and hydrodynamic properties of deep sea mining- generated, abyssal sediment plumes in the Clarion Clipperton Fracture Zone (eastern-central Pacific). Elementa: Science of the Anthropocene, 2019, 7 (5). https://doi.org/10.1525/elementa.343.
9. Haffert, L., Haeckel, M., de Stigter, H., Janssen, F. Assessing the temporal scale of deep-sea mining impacts on sediment biogeochemistry. Biogeosciences, 2020, (17): 2767-2789. https://doi.org/10.5194/bg-17-2767-2020.
10. Hansell, D.A. Recalcitrant dissolved organic carbon fractions. Annual Review of Marine Sciences, 2013, (5): 421-445. https://doi.org/10.1146/annurev-marine-120710-100757.
11. Sweetman, A.K., Smith, A.J., de Jonge, D.S.W. et al. Evidence of dark oxygen production at the abyssal seafloor. Nat. Geosci., 2024, 17: 737–739. https://doi.org/10.1038/s41561-024-01480-8
12. Jaeckel, A., Harden-Davies, H., Amon, D.J. et al. Deep seabed mining lacks social legitimacy. npj Ocean Sustain, 2023, 2, 1. https://doi.org/10.1038/s44183-023-00009-7
13. International Energy Agency. Global Critical Minerals Outlook 2024, IEA, Paris https://www.iea.org/reports/global-critical-minerals-outlook-2024.
14. Zhuo, X. J., Wang, W. T., Xu, X. W., Zhang, T. et al. Scientific and Technological Development Report on the Exploitation and Utilization of Deep-sea Mineral Resources 2024,2024.
15. The United Nations Environment Programme (UNEP), 2024, Deep-Sea Mining, Accessed at https://wedocs.unep.org/bitstream/handle/20.500.11822/45494/deep_sea_mining.pdf?sequence=3&isAllowed=y.
16. Cao, L., Halpern, B.S., Troell, M. et al. Vulnerability of blue foods to human-induced environmental change. Nat Sustain, 2023, (6): 1186–1198 https://doi.org/10.1038/s41893-023-01156-y
17. Gephart, J. A., Henriksson, P. J., Parker, R. W., Shepon, A., Gorospe, K. D., Bergman, K.,... & Troell, M. Environmental performance of blue foods. Nature, 2021, 597(7876):360-365.
18. Cao, L., Wang, W., Yang, Y., Yang, C., Yuan, Z., Xiong, S., & Diana, J. Environmental impact of aquaculture and countermeasures to aquaculture pollution in China. Environmental Science and Pollution Research-International, 2007, (14): 452-462.
19. Bureau of Fisheries of MOA, National Fisheries Technology Extension Center, China Society of Fisheries. 2023 China Fishery Statistical Yearbook, 2023. Beijing: China Agriculture Press. (in Chinese)
20. Long, L., Liu, H., Cui, M., Zhang, C., & Liu, C. Offshore aquaculture in China. Reviews in Aquaculture, (2024),16(1): 254-270.
21. Welch, A. W., Knapp, A. N., El Tourky, S., Daughtery, Z., Hitchcock, G., & Benetti, D. The nutrient footprint of a submerged-cage offshore aquaculture facility located in the tropical Caribbean. Journal of the World Aquaculture Society, 2019, 50(2): 299-316.
22. Froehlich, H. E., Jacobsen, N. S., Essington, T. E., Clavelle, T., & Halpern, B. S. Avoiding the ecological limits of forage fish for fed aquaculture. Nature Sustainability, 2018, 1(6): 298-303.

23. Naylor, R. L., Hardy, R. W., Buschmann, A. H., Bush, S. R., Cao, L., Klinger, D. H.,... & Troell, M. A 20-year retrospective review of global aquaculture. Nature, 2021, 591(7851): 551-563.
24. Cottrell, R. S., Blanchard, J. L., Halpern, B. S., Metian, M., & Froehlich, H. E. Global adoption of novel aquaculture feeds could substantially reduce forage fish demand by 2030. Nature Food, 2020, 1(5): 301-308.
25. Lin, M. Developing large-scale deep sea aquaculture: problems, modes and realization ways. Journal of Management World, 2022, 38(12): 39-60. (in Chinese)
26. Li, D., Sun, W., Yu, H., Zhang, Y., & Han, L. The current characteristics and development suggestions of deep-sea aquaculture in China. Chinese Fisheries Economics, 2023, 41(05): 39-49. (in Chinese)
27. FAO. The State of World Fisheries and Aquaculture 2022. Rome: FAO, 2022.
28. McClenachan, L., & Moulton, A. Transitions from wild-caught fisheries to shellfish and seaweed aquaculture increase gender equity in Maine. Marine Policy, 2022, 146, 105312.
29. Elias, M., Zaremba, H., Tavenner, K., Ragasa, C., Valencia, A. M. P., Choudhury, A., & de Haan, N. Towards gender equality in forestry, livestock, fisheries and aquaculture. Global Food Security, 2024, 41, 100761.
30. UNFCCC. Dimensions and examples of the gender-differentiated impacts of climate change, the role of women as agents of change and opportunities for women, 2022. FCCC/SBI/2022/7 (01 Jun 2022), available from https://unfccc.int/documents/494455.

7. List of abbrevations

BBNJ: the Biodiversity Beyond National Jurisdiction

CBD: Convention on Biological Diversity

GDP: Gross Domestic Product

MSP: marine spatial planning

OECD: Organisation for Economic Co-operation and Development

CCS: carbon capture and storage

ORE: Ocean Renewable Energy

SBE: Sustainable Blue Economy

UNCTAD: United Nations Conference on Trade and Development

UNEP: United Nations Environment Programme

WWF: World Wildlife Fund