Blue energy in China: exploring the prospects and development path for marine renewable energy industries

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Abstract. Marine renewable energy has the characteristics of green and clean, wide distribution, nearby consumption, accurate prediction, and customization on demand. It can provide green energy solutions according to the needs of islands, ocean economic development, and energy consumption of offshore equipment. China has an excellent marine renewable energy resource. Facing great pressure on climate change and energy crisis, the Chinese Government has been showing a strong commitment to marine renewable energy. In this paper, we describe the resources distribution and technology status of marine renewable energy, analyse marine renewable energy strategies in China, and assessment and advices are given for each energy categories. This paper provides an overview of marine renewable energy industries, technology, policy, development trend, structure of industrial chains, challenges, opportunities in China, and provides recommendations for the development of marine renewable energy.

1. Introduction

Marine renewable energy refers to the renewable natural energy contained in the ocean, mainly including tidal energy, wave energy, ocean current energy, tidal current energy, temperature difference energy, salt difference energy, etc. In a broader sense, Marine renewable energy also includes offshore wind energy and solar energy on the ocean surface.

Marine renewable energy has the characteristics of green and clean, wide distribution, nearby consumption, accurate prediction, and customization on demand. It can provide green energy solutions according to the needs of islands, ocean development, and energy consumption of offshore equipment. It is a typical "smart energy". Compared with wind energy, solar energy and other renewable energy, Marine energy has the characteristics of diversified utilization forms and many additional products. Seventy-one percent of the earth's surface is covered by seawater, and oceans contain 97 percent of the planet's water, according to the Ocean Energy Vision released by the International Energy Agency'S Ocean Energy Systems Technical Cooperation Program (OES). Currently, about 3 billion people live within the range of 200 km from the coast, the development of marine renewable energy resources, not only can provide clean electricity supply for coastal areas, also have heating and cooling, water and other green low carbon products market potential, to "promote transformational Marine science solutions, to promote sustainable development" plays an important role [1].

Marine renewable energy industry represents the development direction of the future marine industry. The economic development of coastal areas provides a broad and stable market for the development of emerging marine renewable energy industry. With the development of marine

renewable energy industry, will effectively promote the marine equipment manufacturing, special materials, transportation, aquaculture, marine corrosion, marine engineering, power distribution, comprehensive utilization of seawater, such as a large number of upstream and downstream industries and the development of technology, to develop marine renewable energy industry is to adjust the ocean important way of industrial structure, change the growth way, It will play a major role in driving and guiding China's economic and social development.

China has an abundant marine renewable energy resource. Developing marine renewable energy has a strategic significance for China's sustainable development. Facing great pressure of climate change and energy crisis, the Chinese government has been showing strong commitment to ocean energies: In 2021, the government released the "14th Five-Year Plan (2021-2025)" to protect the marine environment, to respond to global climate change, and to accelerate development of the blue energy.

2. Marine renewable energy technologies in China

Technology Readiness Levels (TRLs) assessment method is commonly used to express the technology development stage. According to the assessment results with TRLs, Figure 1 provides the development stages of each marine renewable energy technology's level of technological readiness in China. Tidal range energy technologies are the most mature marine renewable energy technologies, tidal current energy and wave energy technologies have the ability to carry out technological demonstration, OTEC and ocean salinity energy technologies are still in the process of development [2].

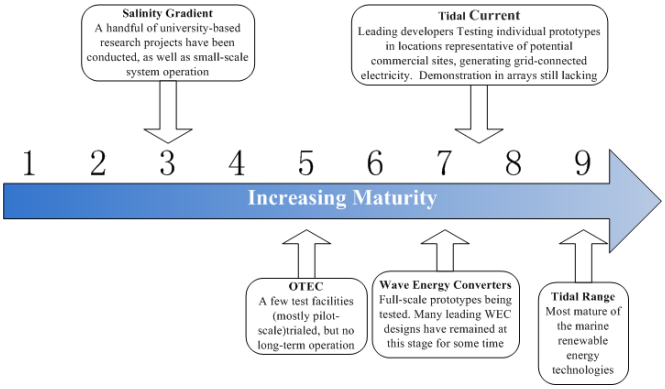

Figure 1. TRLs of marine renewable energy technologies in China.

2.1. Tidal range energy technologies

Tidal range energy generation technology is a technology that uses the difference of water level formed by the ebb and flow of the tide to make the tide with a certain head flow through the turbine installed in the dam and drive the generator to generate electricity. The principle is similar to that of hydroelectric power generation. The development and utilization of tidal range energy mainly includes the following development modes: single library two-way, single library one-way, double library one-way and double library two-way. As the most mature Marine power generation technology, traditional dammed tidal range energy technologies have been commercially available for decades.

In China, Tidal range energy technology is based on conventional hydropower mechanisms, and the Technology Readiness Levels is high TRL 9. China has built more than 100 small tidal range power stations since 1960s. But due to the technology level, local planning, operation and management and other factors, only Jiangxia Tidal Range Power Station and Haishan Tidal Range Power Station (under the implementation of transformation) in Zhejiang are still operating at present.

Shown in Figure 2, the Jiangxia Tidal Range Power Station adopts a new type of bidirectional horizontal shaft bulb tubular unit. In 2016, Jiangxia Tidal Test Power Station completed the efficiency improvement and capacity expansion transformation of unit 1, with the installed capacity reaching 4100 kW. Since 2010, China has completed the preliminary feasibility study of several tidal power

stations, including Jiantiaogang, Rushankou and Bazimen, and carried out research on new environment-friendly tidal power generation technologies, which has provided the technological foundation and resource conditions for large-scale development of tidal range power [3].

Figure 2. Jiangxia tidal power station and the turbine was being installed.

2.2. Tidal current energy technologies

In contrast to tidal range energy, tidal current energy is a different way of harvesting energy from tides (or other ocean currents). Tidal energy devices are placed directly in the water and generate energy through the horizontal flow of water. The tidal current energy is mainly concentrated in the strait, waterway and narrow inlet of the bay in the archipelago area. Due to the influence of the coastal morphology and seabed topography, the current velocity is large, and the accompanying energy is huge.

Tidal current energy power works like wind power by converting the kinetic energy of water into mechanical energy, which in turn can be converted into electricity. The power flow generation technology mainly includes vertical axis power flow generation technology and horizontal axis power flow generation technology.

The technical studies on the development and utilization of tidal current energy began during the 1980s in China. In recent years, the technologies of tidal current energy are developing very fast in China. The Technology Readiness Levels is high and the certain demonstration projects have been evaluated at levels 7-8. Since 2010, some tidal current technologies have been developed and deployed to demonstrate.

As shown in Figure 3, the LHD tidal current energy power generator set by Hangzhou LHD Co., Ltd. independent innovation research and development. In July 2016, the first 1000 kW unit of LHD project was successfully launched into the sea in Zhoushan, and was successfully integrated into the State Grid in August. Since May 2017, the unit has been connected to the grid around the clock, and by the end of December 2021, the unit has been continuously connected to the grid for more than 55 months [4].

In 2019, LHD Tidal Current Energy Power Generation Project officially signed the electricity purchase and sale contract with Daishan Power Supply Company of State Grid, and carried out the first settlement of the connected electricity generation, with the price of 2.58 yuan/kWh. This project lays a solid foundation for large-scale and commercial utilization of Marine tidal current energy resources in China.

Figure 3. LHD tidal current energy demonstration project [4].

Shown in Figure 4, the 60-650 kW serialized tidal current energy power generating units developed by Zhejiang University, the 300 kW tidal current energy units developed by Guodian Joint Power, the 600 kW tidal current energy units developed by Harbin Electric Machinery Factory, and the 300 kW tidal current energy units developed by Hangzhou Jianghe Hydropower have carried out sea trial operation successively near Island Zhairuoshan, Zhejiang province.

Figure 4. Tidal current energy units in sea trial.

In 2015, the "Zhoushan Tidal Current Demonstration Project" undertaken by China Three Gorges Corporation started to be implemented, as shown in Figure 5. Supported by this project, China's first national tidal current energy test site is expected to be put into operation in Island Hulu sea area of Zhoushan in 2022.

Figure 5. Offshore step-up station and turbine.

2.3. Wave energy

The wave energy conversion device is the device that converts the kinetic energy of sea surface waves into another form of energy, such as electricity. Wave energy is a kind of energy converted from wind energy. The wind blows over the ocean and transfers energy to the sea through the sea-air interaction, forming waves and storing energy as potential energy (the potential of water mass away from the sea level) and kinetic energy (in the form of water movement). The total reserves of wave energy are huge and the wave energy density is low. The resources are widely distributed, but the distribution is obviously uneven. Energy has the characteristics of multi-directivity, and changes with time and region.

Under the support of the relevant programs and special funds from the Ministry of Natural Resources(MNR)，National Natural Science Foundation of China(NSFC), Ministry of Science and Technology(MOST) and Chinese Academy of Sciences(CAS), there have been more than 30 institutes and universities to carry out the study on wave energy converters including oscillating body type, pendulum type and raft type etc. The major institutes and universities include Guangzhou Institute of Energy Conversion (GIEC), NOTC, Shandong University, South China University of Technology, Ocean University of China, and others. Among them, some have completed the laboratory model tests,

and some have developed the engineering prototypes and conducted at sea tests, basically realizing the technical process of independent innovation. The TRL of wave energy converter was evaluated at levels 7-8 [5].

GIEC developed with independent intellectual property rights by the hawk wave energy technology, successively built 10 kw “Sharp Eagle 1”, 100 kw "Wangshan", and 260 kw "Pilot 1" device such as a multiple wave energy and realize the real sea state validation of hawk wave energy technology, offshore island grid power and offshore reef grid power supply.

In 2017, China started construction of its first megawatt wave energy power project. At present, two 500kW wave power generation units have been built and tested at sea, and expected to be put into demonstration operation in 2022, as shown in Figure 6.

Figure 6. Sharp-Eagle WEC.

Penghu, the world's first semi-submersible wave energy aquaculture integrated platform, has been conducting aquaculture demonstration in the fishing base for more than 24 months. As a successful case of "green development" combining Marine energy and mariculture, the platform has won orders from enterprises in many places.

As shown in Figure 7, Penghu, the semi-submersible tourism communication platform for wave energy cultivation, is 66 meters long, 28 meters wide, 16 meters high, with a working draft of 12 meters. It can provide 15,000 m³ aquaculture water body, with 20 people's living space, 300 cubic meters of storage space, and 120kW marine power supply capacity. Equipped with automatic bait casting, fish monitoring, water quality monitoring and live fish transmission and other modern fishery production equipment.

Figure 7. Penghu semi-submersible wave energy aquaculture platform [5].

2.4. OTEC

As shown in Figure 8, OTEC energy refers to the ocean heat energy stored in the form of temperature difference between surface and deep sea water, and the main source of its energy is solar radiation

energy hidden in the ocean. OTEC power generation technology basic principle is to use some of the warm ocean surface heating and evaporation, low boiling point working medium or via step-down make the water vaporizing to drive the turbine to generate electricity, at the same time using the cold sea water extracted from deep to the steam exhaust condensate after work, to make it back into a liquid, forming system.

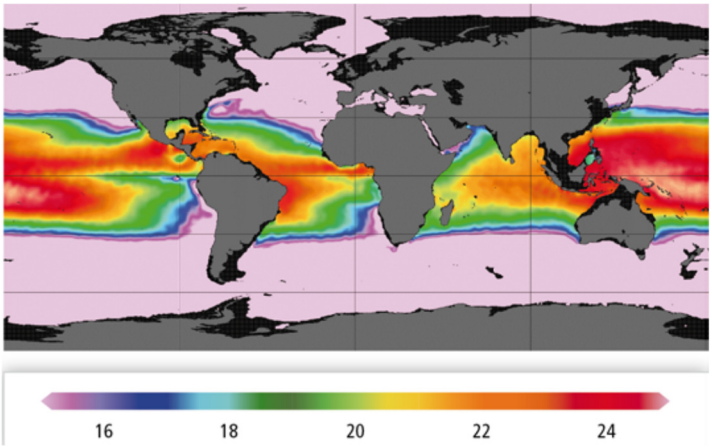

Figure 8. OTEC resource distribution [6].

In China, the research and development of OTEC technology is still at the theoretical stage. Some institutions have carried out exploratory methods research on OTEC.

Aiming at the power supply problem of the ocean observation platform, the National Ocean Technology Center developed a 300w small-scale OTEC power generation test prototype. The system can complete thermal energy conversion under the environment of low temperature 12°C to high temperature 25°C. The lake test was carried out in Qiandao Lake in 2015, and the thermoelectric power generation test was carried out in the cold water mass of the North Yellow Sea in August 2016. The First Institute of Oceanology of the Ministry of Natural Resources has developed a thermoelectric power generation device with mixed working medium and mixed cycle. In 2012, it built a 15 kW thermoelectric power generation test system in Qingdao. In 2016, it also developed a 10 kW thermoelectric power generation test system with independent intellectual property rights.

In terms of theoretical research, Tianjin University has completed the theoretical research topic of hybrid ocean temperature difference energy utilization, and conducted research and experimental development on the miniaturized 200-watt ammonia saturated steam turbine. Ocean University of China proposed a dynamic cycle of ammonia water absorption based on the theory of "ejection-absorption", which improved the heat energy utilization efficiency of the cycle process, and developed a test platform to complete the test verification. The utilization of temperature difference energy in China is still in the research stage of device principle and experimental prototype.

3. Status of marine renewable energy industries

3.1. Marine renewable energy potential in China

China's marine renewable energy resources are characterized by wide and uneven distribution, large amount, variety and low quality. Marine renewable energy resources are distributed in all coastal areas, but the distribution is uneven among different regions. For example, tidal and tidal current energy resources are mainly distributed in the coastal areas of Zhejiang and Fujian, wave energy resources are mainly distributed in the coastal areas of Guangdong and Hainan, and thermal energy resources are mainly distributed in the South China Sea. The total amount of offshore Marine energy resources is rich and the types are complete, but the quality of some energy resources is low. For example, the power density of wave energy is generally not high, and there are few sea areas with large tidal range.

At the same time, because of different types of ocean energy resources characteristics and change rules of time and space, the development and utilization of technical characteristics and technical maturity of each are not identical, has now can't accurate estimate of various kinds of marine renewable energy resources study of marine renewable energy resources construction, more can't meet the urgent need of development and large-scale utilization of the oceanic engineering, In particular, there are still a series of key scientific and technological problems in assessing the technological and economic exploitable quantities of various marine renewable energy resources and predicting the impact of large-scale marine renewable energy development on the Marine environment.

3.2. Marine renewable energy industry chain

Marine renewable energy industry is a new industry with many specialties, long industrial chain and high technological content. The Marine renewable energy industry chain mainly includes the upstream, middle and downstream industries and their epitaxial industries [7].

Table 1. Marine renewable energy industry chain.

Stage		Industries
Upstream industry	Materials	ANISOLM, Composite material, Sealing material
	Spare parts	Blade, Electrical machinery, Gear case, Bearings, Cable, Transducer
	Survey and design service	Resource survey, Engineering design
	Technology	PTO, Comprehensive utilization, Control system, Mooring and platform
Middle industry	Equipment manufacturing	Turbine, Electrical equipment
	Engineering construction	Marine transport, Offshore construction
Downstream industry	Operation and maintenance	Power station operation and maintenance, Technical advisory service
	Service	Technical advisory service

Shown in Table 1, the upstream of marine renewable energy industries chain involves a wide range of technical fields and diversified technologies, which can drive a large number of related enterprises to participate in the industrialization of marine renewable energy.

In China's marine renewable energy industry chain, except the core technology and industry of energy capture and conversion in the upstream industry, which is weak or not perfect, other industries have certain technology and industry foundation. With the rising strategic and economic status of marine renewable energy, it will play an increasingly leading and promoting role in the development and progress of other industries and related technologies. Shown in Table 2, its development will promote the development of a large number of upstream and downstream industries and technologies such as marine manufacturing, materials, transportation, aquaculture, Marine anticorrosion, Marine engineering, electric power distribution, comprehensive utilization of seawater, carbon-free hydrogen production, fuel cells and so on, which can directly contribute to the implementation of energy conservation and emission reduction strategy and the development of low-carbon economy.

After nearly 40 years of development, China has formed a professional team of marine renewable energy technology research and development, equipment manufacturing, offshore construction, operation and maintenance. According to incomplete statistics, at present, there are nearly 200 units engaged in Marine energy development and utilization, including scientific research institutes, universities and colleges, state-owned and private enterprises, etc. Enterprises account for 50% of the structure, and private enterprises show a rapid momentum. The participation of a large number of powerful enterprises has greatly improved self-innovation ability, equipment localization ability and

industrialization transformation ability, which is conducive to the extension of the industrial chain and the radiation of products and technologies [8].

Table 2. Marine renewable energy industry structure.

Industries	Structure	characteristics
Upstream industries	Special steel, sealing and anti-corrosion materials, blades, motors, gear boxes, bearings, hydraulic, tower, cable, frequency converter, survey and design	Technology and capital intensive
Middle industries	Power generation equipment assembly and debugging	Technology and labor intensive
Downstream industries	Power station operation, maintenance service and application	Labor intensive

3.3. Opportunities for marine renewable energy industry

Economic society will develop urgent needs for developing the marine renewable energy industry. The imperfect energy structure has become an important problem for the sustainable development of China's economy. The marine renewable energy has the characteristics of wide distribution, small environmental pollution, and sustainable use, which is conducive to the development of people and nature. There are so many coastal islands in our country that the economic development of the island urgently needs power support. The rapid development of the ocean economy raises huge demand for clean energy.

We have the resources to develop the marine renewable energy industry. The results show that the marine renewable energy resources in the China sea domain are relatively abundant, which provides the resource assurance for the development of the marine renewable energy industry in China.

China has technological reserves to develop a variety of ocean energy. China's wave and tidal energy technology has developed rapidly and has the capability of large- scale development.

3.4. Challenges for ocean energy industry

The long-term development goals are not clear enough. The lack of long-term planning goals and development paths in the national level of oceanic development will be less attractive to large and medium-sized enterprises, unable to effectively guide social capital into the ocean energy area, and it is difficult to maintain the stable development of the maritime energy industry and the talent team.

Fiscal support is limited. Our country's financial support force for advancing the development of the ocean can be low, lack of stability and long-term, and the support form is simpler, and the promotion of industrial development is not fully reflected.

There are no incentives for companies to participate. Europe and the United States and other developed marine energy countries promote the industrialization process by introducing incentive policies and relevant measures, including adjusting the on-grid price, providing electricity subsidies, introducing incentive tax policies, implementing power generation quota system, supporting infrastructure construction and financing support. Compared with foreign countries, China lacks relevant incentive measures or is not clear, and enterprises lack long-term stable expectations, which restricts the sustainable development of the industry to a certain extent.

The public services supporting industrial development, such as inspection and testing, are insufficient. Compared with the mature of renewable energy sources such as wind power, photovoltaic industry, ocean energy in test evaluation, technical support, advisory services, promote the achievement transformation ability of public services such as gap, especially the power generation device testing laboratory qualification and related technical standard is still not perfect, the test data credibility is low, can't meet the demand of industrial development with high quality.

3.5. Development for 2030

In addition to the closer from the mainland can directly by laying cable power supply of the island, the island at present mainly adopts diesel generating electricity, not only the high cost and serious environmental pollution problems, but due to various reasons such as geography, meteorology, transportation, often difficult to guarantee the stability of the power supply is unable to achieve economic and environmental protection. Abundant marine renewable energy resources and other renewable energy resources around remote islands lacking electricity provide an excellent choice for power supply. Local materials and nearby consumption can effectively meet the demand for power and energy in islands development. Coastal and island development provides a broad market demand for marine renewable energy.

With the development of China's pelagic fishery and deep-sea aquaculture industries, the comprehensive utilization of marine renewable energy can not only provide power generation and seawater desalination, but also provide sufficient nutrient supply for deep-sea fisheries by using nutrient-rich cold seawater. The development of ocean energy can also provide sustainable energy, fresh water and food supplies for future undersea cities.

The core index of China's marine renewable energy development goal is the total installed capacity of marine energy power stations. On the basis of accelerating the research and development of key marine renewable energy technologies, improving the demonstration effect and scale of power generation devices, and improving the supporting capacity of the industrial chain, efforts are made to achieve the increase of the total installed capacity of marine renewable energy.

In order to achieve the set development goals of China's marine renewable energy technology and industry, this paper studies and sets up 4 complementary technology development paths that need to be promoted simultaneously.

- Pathway 1: Enhancing Theoretical Foundation (2021-2030)

Improving the methods of environmental assessment for marine renewable energy stations.
Breaking through key technology for high efficient conversion mechanism.
Exporting the innovative marine renewable energy products and services.

- Pathway 2: Advancing Demonstration Projects (2021-2030)

Realizing the target of marine renewable energy installed capacity before 2030 in China.
Marine renewable energy will be main power supply of remote islands.
Marine renewable energy demonstration clusters will be built.

- Pathway 3: Facilitating Shared Infrastructure (2021-2030)

Building the marine renewable energy resources database.
Accelerating the construction of national Marine renewable energy test sites.
Establishing the standard systems of marine renewable energy.

- Pathway 4: Extending International Cooperation (2021-2030)

Encouraging the introduction of advanced Marine renewable energy technology and experience.
To be active in marine renewable energy global cooperation and realize position in global market.

3.6. Suggestions for marine renewable energy

Focusing on the responsibilities and requirements of promoting the development of marine renewable energy and other emerging marine industries, strengthen the research and promotion of "carbon peak and carbon neutral" strategic deployment, offshore energy supply system and marine green and low-carbon energy industry, formulate the industrial development roadmap and specify key areas and development goals. We will accelerate the introduction and implementation of medium - and long-term development plans for Marine green and low-carbon energy industries, including marine renewable energy. We will accelerate the development of a national marine renewable energy center and improve the business support system that can promote the integrated development of Marine energy. We will promote the establishment of a state-level support system for the development of the marine renewable energy industry, accelerate the construction of innovation centers, test sites and

testing and certification platforms, and do a good job in supporting industrial development and management [9].

Establishing a standard and standard system for the marine renewable energy industries. In accordance with the different development stages of the industry, standards for evaluation, installation and operation and maintenance of marine renewable energy resources shall be formulated step by step according to the overall planning of marine renewable energy standards and specifications, and a standard and specification system for the marine renewable energy industry shall be established.

Strengthen the support for the training of marine renewable energy professionals, improve the mechanism of personnel training and selection, and cultivate a group of senior compound talents and senior technology R&D talents urgently needed for the development of marine renewable energy industry; Through the implementation of the marine renewable energy project, it accelerates the integration of Marine energy administration, industry, university and research, and brings into being a number of strong joint marine renewable energy innovation teams. Encourage universities, research institutions and enterprises to jointly train high-level personnel in oceanography, and support enterprises to establish oceanography teaching and practice bases; In the program for visiting scholars and overseas students sent by the State, the exchange and study of ocean energy talents is an important part, and universities, research institutes and enterprises are encouraged to attract high-end talents from overseas.

4. Conclusions

With abundant marine renewable energy resources and numerous islands, China has good conditions for large-scale exploitation and utilization of marine renewable energy industry. Marine renewable energy industry as a strategic emerging industry, has the will guide strong whole construction machinery industry chain length, etc., at the national renewable energy industry policy support, the good and the enthusiasm of the enterprise development of marine renewable energy abate, smart grid, independent power supply technology such as long-term development laid a solid foundation for development of marine renewable energy industry. We must seize the precious development opportunity, take the initiative to break through the bottleneck of commercial application and realize the leapfrog development of marine renewable energy.

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