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ORIGINAL ARTICLE

Research on the environmental impact of tidal power generation in China

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Abstract
In recent years, the rapid rise of carbon dioxide concentration makes global warming increasingly serious, which leads to sea-level rise, coastal lowland inundation, glacier melting, extreme weather, species extinction and other environmental problems. China, as the largest carbon dioxide emitter, is facing climate change. In 2020, the Chinese government promised at the UN General Assembly to achieve the peak of carbon by 2030, and also put forward the goal of achieving carbon neutrality by 2060. To achieve the carbon peak and carbon in target, China needs to reduce the use of fossil energy and replace the use of fossil energy with renewable energy with less carbon dioxide emissions. Tidal energy, as a low-carbon renewable energy, is an important alternative to fossil energy. But can the tide be developed at the expense of the environment? In this paper, the impact of the development of tidal energy on the environment is analyzed and elaborated. According to the environmental impact, the solutions of developing environment-friendly tidal energy, wave energy and temperature difference energy are given. Based on this, policy suggestions are put forward to the Chinese government. The research results of this paper will provide reference for developing countries to develop and utilize tidal energy for power generation.

Keywords Tidal energy · Tidal power generation · Exploitation · Environmental impact

Introduction

After the industrial revolution, the global carbon dioxide concentration began to rise from 240 ppm. In May 2019, the monaroya Observatory of the National Oceanic and Atmospheric Administration (NOAA) of the United States detected that the carbon dioxide concentration exceeded 415 ppm for the first time in human history. With the rapid rise of carbon dioxide concentration, global warming is becoming more and more serious, resulting in sea-level rise, coastal lowland inundation, glacier melting, extreme weather, species extinction and other environmental problems. Since 2006, China has become the world's largest carbon emitter (Xu et al. 2021). In 2017, China's carbon emissions accounted for 28% of the world's total (Xc et al. 2020).

To cope with climate change, the Chinese government promised at the UN General Assembly in 2020 to achieve the carbon peak by 2030, and also put forward the goal of achieving carbon neutrality by 2060. It is not only the requirement for China to achieve sustainable development, but also the requirement for China to fulfill its international responsibilities. At the same time, it is also an important measure for China to play an exemplary role in energy conservation and emission reduction and drive the global emission reduction.

If the Chinese government wants to achieve the carbon peak and carbon in target, Chinese enterprises need to reduce the use of fossil energy and replace the use of fossil energy with renewable energy with less carbon dioxide emissions. In recent years, countries are striving to pursue, exploit and utilize greener and more environmentally friendly renewable energy. By 2050, the proportion of coal, natural gas and oil in primary energy will decrease from 85% in 2018 to the range of 65–20% respectively, while renewable energy will increase to 20–60%, according to BP's Energy Outlook 2020.

Tidal energy, as a kind of renewable energy with low-carbon emission, has been widely concerned in recent years. Its productivity principle is that in the process of rising tide, the turbulent sea water has great kinetic energy, and with the rise of sea water level, the huge kinetic energy of sea water

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is converted into potential energy. And in the process of ebb tide, the sea water rushes away, the water level gradually decreases, and the potential energy is transformed into kinetic energy (Ghaedi and Gorginpour 2021). The larger tidal range in the world is about 13–15 m. Scientists believe that the average tidal range above 3 m has practical application value (Kim et al. 2021). Available marine energy in the world is as high as 800×10^8 kW (Rhta 2019), according to statistics published by UNESCO. With the development of science and technology, there are growing tidal power generation projects in all countries.

To achieve the goal of carbon peaking and carbon neutralization, China should focus on renewable energy with low-carbon emissions, while developing tidal energy is a very good development direction (Liu et al. 2018). However, the development of renewable energy cannot be at the expense of the environment. Therefore, this paper analyzes the impact of the development of tides on the environment. This study is expected to provide suggestions and references for the Chinese government and enterprises to protect the environment when developing tidal energy.

Literature review

The main manifestation of tidal energy is generating power by tidal, that is, building dams and forming reservoirs using favorable terrain such as bays and estuaries for accumulating enormous amount of seawater, building hydroelectric power workshops powered by hydroelectric generating sets in or by the dams (Javidsharifi et al. 2018). There are many exploiting forms of tidal energy, which can be divided into two types, single-storage type and double-storage type, according to the number of reservoirs. Double-storage type can be classified by the height, scale, etc. (Yakai et al. 1998). Traditional tidal power generation makes full use of the natural conditions of harbors and estuaries to construct tidal barrage; as a result, it exerts an influence on the hydrodynamic force, ecological environment and navigation inside and outside the dams. Therefore, in the 1990s, a tidal power generation technology that does not occupy precious natural ports or bays was proposed, that is, Lagoon Tidal Energy Exploitation and Utilization Technology. From an emissions point of view, tidal energy could not cause any air, water or heat pollution. From an economic point of view, although the primary investment of tidal power generation is relatively high, the long-term benefits it brings are considerable (Li 2015). Obviously, there are some drawbacks in exploiting and utilizing tidal power such as the lower density and more unstable output compared with traditional energy, impact on the offshore ecology, as well as the problem of pollution, corrosion and siltation (Ma and Hou 2019).

Governments of all countries have carried out research on the impact of tidal power exploiting on the marine environment. The Canadian government has carried out this research in the Bay of Fundy, Gulf of Maine and other areas that rich in tidal energy, aiming to solve the environmental problems caused by TPPs, such as obstruction of fish, sediment deposition and the changing of flowing state (Liu et al. 2017). Experts from the Scottish Executive have carried out a study on the strategic environmental impact of marine energy development in Scotland, describing the potential impact of tidal power generation on birds, marine mammals, benthos, fish, shellfish and seascapes (Wang 2008). The environmental impact of tidal energy equipment can be classified into general environmental impact, impact on landscape, hydraulic environment and biology, the influence generated by noise and chemical impact, according to a report on marine energy conversion equipment published by Wave and Tidal Energy Association in New Zealand (Huang 2010). Some scholars have studied the hydrodynamic conditions, sedimentary environment and ecosystem changes caused by the exploitation and utilization of tidal energy, respectively.

Current development of tidal power generation

In the early twentieth century, the United States, Germany, France and other countries began to study tidal power generation (Neill et al. 2021). Germany built its first TPP on the North Sea coast in 1913. While the world's first commercial TPP is the Rance Tidal Power Plant, which is located in Rance, France. It was built for 6 years from 1960 to 1966, and it installed 24 mechanisms with installed capacity of 240 million kW (Copping 2012). The Sihwa Lake Tidal Power Plant in South Korea is the world's largest, with an installed capacity of 254 MW, which was completed in 2011. With a hydro-generator unit, an installed capacity of 17,800 kW and an annual power generation capacity of 50 million kW h (Cui et al. 2015), the Annapolis Tidal Generating Plant is the North America's earliest, which is located in Annapolis Royal, Nova Scotia and was completed in 1984.

With an installed capacity of 398 MW, MeyGen tidal energy project is the world's largest tidal power generation project. It is now under construction in Pentland Firth, northern Scotland, and is expected to be completed in 2021 (Frith 2015). The planned Penzhin TPP Project on the Kamchatka Peninsula in Russia is under construction, with an installed capacity of 87,100 MW and an annual generating capacity of 200 TW h. Once the Penzhin TPP is completed, its installed capacity will be four times of that in Three Gorges Hydroelectric Power Station in China (Gerhild et al. 2012).

China is one of the countries with abundant tidal energy resources in the world, with theoretical reserve reaching 1.1×10^8 kW. However, the exploitable tidal energy is only around 0.2179×10^8 kW (Longpellier 2010). China's first TPP was built in Shandong in 1957. Later in the year of 1970, two TPPs were built, Jin'gang TPP and Baishakou TPP. The latter one was the largest plant in Asia at that time. Both of them are located in Rushan, Shandong province. At present, only eight plants with a total installed capacity of 6120 kW in China are still operating, of which the largest one is Jiangxia Experimental Tidal Power with 3900 kW in Zhejiang province (Huang et al. 2015). Compared with other countries, the development of tidal power generation in China relatively lags behind.

The impact of tidal power generation on marine environment

According to previous studies of experts and scholars as well as the analysis of the author, the impact of tidal power generation and its utilization on marine environment are shown in the following five aspects:

Impact on the living environment of offshore marine life

Tidal change will have an influence on the area of the bay, which will be harmful to the organisms in the bay, leading to a reduction of their living space and a decline in quantity. It will also have an impact on offshore seafood farming, resulting in a decline in seafood production. Some offshore birds might lose foraging grounds for the lack of food supply. Some marine creatures, such as sea turtles, are used to migrating offshore or inhabiting into bays to mate and lay eggs. When back to reservoirs, they will approach tidal power plants, which can be harmful as well.

The stability of water environment in reservoirs is destroyed

The water in the reservoir of TPPs cannot be exchanged smoothly with the water in the sea, so that the water in the reservoir needs to be replenished by land water. If the river water with large runoff or sediment concentration flows into the reservoir, the water temperature, salinity and sediment concentration in the reservoir will change and the stable environment will be destroyed. If there is no land water in the reservoir, the sediment concentration will be reduced and the stability of the water environment will be destroyed, which will further affect the survival of marine creatures.

Impact on the tides in the nearby water

The establishment of TPPs will change the law of tides' fluctuation. Dynamic tidal energy dam has a significant influence on the original characteristics of the tides. The tidal range on the side facing the tidal wave propagation of the dam body changes obviously, and the tidal range will be slightly delayed at high and low tides; the range of the other side is relatively small, but the phase position changes greatly, and will be slightly delayed at high and low tides. As a result, tidal power dams can alter the distribution of existing tidal currents. Nearby offshore tidal range will also change relatively, which will have a greater impact on the offshore ecological environment.

Impact on the offshore environment through building TPPs

While building TPPs, it will have an impact on the marine and offshore land environment of the plant area, and influence the conversion of water flow between the bay and the sea, which will eventually affect the development of ecosystem in the sea area. Furthermore, it will produce construction waste, causing pollution of seawater, air and sand beach, destroying offshore environment. All of these changes will be harmful to the survival of creatures in the bay.

Increased sediment deposition

The gulf water exchange in TPPs is less smooth, the flow is smaller than before, and the sediment dynamics in the reservoir will change accordingly, resulting in increased sediment deposition along the gulf coast, affecting the survival of the marine benthos. If getting much worse, it will restrict the sustainability of the entire offshore ecosystem, and will take a long time making it back to normal.

Solution of tidal energy generation to marine environment

Developing environment-friendly tidal energy technology

Chinese enterprises and scientific research institutions should increase investment in research and development of environment-friendly tidal energy technology. The application of environment-friendly tidal energy technology can reduce the impact of tidal power station construction on local marine ecology. Environmental friendly tidal energy utilization technologies such as dynamic tidal energy and tidal lagoon power generation can be considered. Enterprises and scientific research institutions can also further

study the use of tidal phase difference inside and outside the natural harbor for power generation, and the use of tidal level difference formed by the hysteresis effect of natural coastal morphology such as Peninsula or strait for power generation, which has little impact on the marine ecological environment.

Developing wave energy technology

Chinese enterprises and scientific research institutions should speed up the research of high efficiency, high reliability and easy maintenance wave energy technology. The types of wave energy technology are scattered and in different stages of technological development, and the reasonable specifications of power generation devices have not been verified in practice. To realize the scale of wave power generation, the array generator is more effective than a single device. It has lower cost and less impact on the marine environment. At the same time, we should increase investment in the research and development of small wave energy equipment, which is more adaptable to the marine environment and more friendly to the marine environment.

Promote the development of ocean thermal energy technology

Chinese enterprises and scientific research institutions should promote the research and development of large-scale thermoelectric devices. The ocean temperature difference is about 20 ℃ due to the small temperature difference between cold and heat sources. The theoretical maximum thermal cycle efficiency is 6.77%, and the Rankine cycle efficiency is only 3%. The high efficiency thermal cycle with mixed working medium improves the current thermal cycle efficiency to about 5%. Comprehensive utilization has a large space for development. In addition to power generation, it has a wide range of comprehensive application prospects in seawater desalination, hydrogen production, air conditioning and refrigeration, deep-water aquaculture, etc. It has little impact on the marine environment. From the perspective of temperature difference energy resources and economic feasibility, ocean temperature difference energy technology is very suitable for the use of remote islands in tropical waters. The ocean thermal energy conversion power generation technology of these islands can be combined with the functions of seawater air conditioning, refrigeration and desalination.

Conclusion

TPPs will have an impact on the surrounding environment, but they also have many advantages in reducing carbon emissions. The experience of building and operating TPPs at home and abroad shows that the environmental problems that may be brought about by the exploiting and utilizing of tidal power can be reduced by changing means of design and management.

Promoting technological progress We should promote the cooperation with other countries and achieve technological progress. Although the exploiting technology of TPPs in China has been improved, its core technology still lags behind developed countries for tidal energy. The exploiting and utilizing of plants in the United States, the United Kingdom and Norway is mature and complete, and the double harvest of ecological benefit and economic benefit has been realized. Britain is the most advanced country of tidal power generation technology in the world. It can not only solve the problem of electricity consumption in Britain, but also develop sailing and other sports, tourism, leisure and entertainment projects, realizing a win–win situation of economic, ecological and social benefits. China needs to vigorously promote international cooperation with European countries, the United States and other countries in various aspects. Furthermore, China can fully learn and absorb advanced experience and technologies of other countries and apply them to the building and operating of tidal power generation.

Policy support The Chinese government should formulate special support policies to promote the development of tidal energy. China has been using tidal power generation for a long time, but its policy support is modest, especially when compared with developed countries for tidal energy, China still lags far behind. As a result, the cost of tidal power generation in China is high and the economic and social benefits are inefficient. As such, Chinese government should give corresponding support and preferential policies for the building and operating of China's TPPs before, during and after the project developing. For the introduction of hardware facilities as well as the foreign experience and technology, China should provide some subsidies or policy support like tax exemption. At the same time, China should introduce some protective policies to provide the necessary priority guarantee for the construction of tidal power stations in some suitable places. In terms of electricity management, the government should provide some preferential subsidies for customers who use tidal energy, so that the price of electricity generated by tidal energy is consistent with other forms of electricity.

Limitation

There are still very limited materials that the authors can read. It cannot cover all aspects of tidal power generation. With the development of science and technology, the

influence factors of tidal power generation on the environment may change at any time. The authors will continue to follow up the research on the environmental impact of tidal power generation.

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Declarations

Conflicts of interest The authors declare they have no conflicts of interest.

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