



Planning the R&D of Marine Renewable Energy Resources: Avoiding Bottlenecks and Ensuring Sustainable Development in Developing Marine Economies

Xueyin Ou^{1*}, Penghao Ye², Pierre Failler³ and Antaya March³

¹ Faculty of Economics, Hunan University of Finance and Economics, Changsha, China, ² School of Public Administration, Zhongnan University of Economics and Law, Wuhan, China, ³ Centre for Blue Governance, Faculty of Economics and Law, University of Portsmouth, Portsmouth, United Kingdom

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*Correspondence:

Xueyin Ou
1277279006@qq.com

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Planning for the research and development (R&D) of renewable energy resources (RERs) has not received enough attention. This paper aims to study the planning for the R&D of RERs in order to avoid bottlenecks and ensure sustainable development in developing marine economies. We have established a triple difference model (DDD) model and a wise pig game model between the theoretical government and enterprise. The data on RERs come from the World Bank and International Energy Agency databases. We have three contributions on the basis of distinguishing between mature and immature marine RERs technologies. First, it emphasizes the importance of developing R&D planning for marine RERs immature technology in the future. Second, the DDD model is used to empirically establish whether RERs planning has a significant positive impact on RERs' output, which explains the importance of existing RERs planning. Third, the wise pig game model is used to analyze the welfare benefits to the government brought by the R&D planning of marine RERs which proves the importance of future RERs R&D planning.

Keywords: marine renewable energy resources, avoiding bottlenecks, developing marine economies, planning R&D, difference in difference in difference

INTRODUCTION

As long as the world can develop 0.1% of total marine wave energy, it will be able to achieve 5 times the current world energy demand (Kumar et al., 2015). Marine renewable energy resources (RERs) are the largest undeveloped RERs in the world (Kumar et al., 2015). Most of marine developing countries are facing the problem of insufficient energy, thus they need to plan for the research and development (R&D) of marine RERs. Otherwise, if they encounter major natural disasters and epidemic disasters, such as earthquakes or COVID-19, they may be blocked intentionally or unintentionally at the key technology or sale point by developed countries and encounter a crisis of energy cut-off. Consequently, the theory of RERs becomes an important part of the theory of marine developing economies (Aktas and Kircicek, 2020; Coughlan et al., 2020; Isaksson et al., 2020; Raoux et al., 2020; Taveira-Pinto et al., 2020). Marine RERs include waves, tides, ocean

currents, salinity, thermal gradients, marine biomass, offshore wind energy, and offshore solar energy (Taveira-Pinto et al., 2020). Much progress has been made in literature and research toward understanding the relation of RERs with developing marine economies. It has always been known that marine RERs has great potential, but developing countries need to distinguish their theoretical potential from technological potential in order to plan marine energy research and development (Liao and Drakeford, 2019; He and Walheer, 2020). Furthermore, it is necessary to distinguish between mature RERs and immature RERs, as well as technologies required for the development of related supply chains (Gorelick and Walmsley, 2020; Taveira-Pinto et al., 2020). Most previous studies have assumed that apart from wind power, which is a relatively mature technology, the basic theory of renewable energy technology is difficult to develop. Recent research, however, has found that only when marine developing economies plan how to conduct R&D of RERs (Davies et al., 2014; O'Hagan, 2016; Li Y. B. et al., 2020), are they able to reach a breakthrough in basic theory of the RERs and ensure not to be blocked at the key technology or sale. The objectives of this research include: (1) distinguishing between mature and immature technologies for marine RERs; (2) analyzing the impact of triple difference variables on output of RERs and analyze the internal economic mechanism of the rapid development of RERs by DDD model; (3) establishing a smart pig game model to analyze governments' benefits in the process of the game between government and enterprises based on the R&D planning of RERs. Based on this, it is first necessary to establish what research has been covered in this field.

Experts in the field of marine RERs applied technology prefer to obtain technology application methods from research. In the study of wave and storm surges, a method of generating electricity using artificial lagoons was discovered. In their research of RERs in Lake Ontario and Lake Michigan, Sogut et al. (2018) found that wave power is more than 10 KW/m at its peak during the winter and about 1 KW/m during the spring and the summer, while the power generation potential contained in storm surges is very high, such as, the highest is 2.088×10^{11} KW/m (58 GWh). Based on their results, using man-made lagoons to generate synthesize storm surges can contribute to power generation (Sogut et al., 2019). Another useful mechanism for research of RERs is sensor buoy systems which can be used for monitoring marine RERs, such as energy coming from wind, waves, and marine currents (Garcia et al., 2018). Further research has been carried out through the use of a non-hydrostatic hydrodynamic model used to assess suitable areas for the extraction of marine currents' energy (Quesada et al., 2014). Following this, Deep et al. (2020) used the three-parameter Weibull model to measure the actual wind power of wind turbines, which is an improvement in the quality of wind speed measurement method of wind turbines, where the previous method by Quesada et al. (2014) overestimates wind speed by 25%.

In many cases, basic theory researchers tend to focus their plan on the basic theoretical research of renewable energy. However, in the marine RERs plan, it is necessary to build a variety of energy infrastructure paths that meet legal energy goals, in order to measure the impact of its land use and evaluate

its performance relative to electricity demand (Thomas and Racherla, 2020). Furthermore, the scheduling problem of the energy hub system should also be planned (Dolatabadi et al., 2019), which is rationalized by scholars through the use of models such as the optimal expansion planning model for an energy hub with multiple energy systems (Zhang et al., 2015), optimization models for residential energy hubs (Bozchalui et al., 2012), and an uncertain model of optimal energy hub operation (Pazouki et al., 2014). It is also necessary to carefully calculate the costs of technology, equipment, power transmission and maintenance in the process of planning the use of marine RERs (Liu et al., 2015). Furthermore, a virtual power plant, which uses coordinated control technology, smart metering technology and information communication technology, can integrate a large number of distributed energy sources in the smart grid, and can effectively solve the instability problem of wind power and solar power (Han et al., 2019).

This article differs from research in basic technology and applied technology of marine RERs. Our first contribution is to study the marine RERs R&D plan of developing marine countries from the perspective of economics (Matei, 2020). We distinguish between mature technologies and immature technologies of marine RERs, and attempt to provide research in basic technology and applied technology with a marine RERs a global economics perspective of mature and immature technology, and provide a collection of entrepreneurial opportunities' ideas for the development of the marine RERs industry chain.

Furthermore, extensive work has been done by economists, focusing on the economy policies of RERs. The marine RERs of some developing marine countries are showing a positive development trend (Varlas et al., 2017). The residents of few developing countries are often unwilling to use RERs and prefer to use wood as fuel (Okwanya et al., 2020). Often there is protest against the use of RERs, as the general population of developing countries cannot afford the price of RERs, especially where government policies do not consider the high installation and maintenance. Based on this, the governments of developing marine countries need to formulate policies on RERs investment and promote their use (Wang Q. et al., 2020), especially under the circumstance that the cost of traditional renewable energy such as wind and solar energy continues to fall. Energy system integration is also a difficult problem, which lacks effective policy and legal support in the EU (Cambini et al., 2020), let alone in developing countries. Thus, Odam and de Vries (2020) suggest that governments should carefully implement RERs policies guided by learning curve estimation. The more common RERs policies include low-carbon policies (Wendling et al., 2020), RERs production subsidies (Ravetti et al., 2020), RERs portfolio standards (Wendling et al., 2020), clean energy-related economic policies (Chen and Kim, 2020), and so on. At present, the application of RERs is recognized by the vast majority of residents in most of developing countries, and they have a willingness to consume RERs. With the continuous decline of RERs costs, most residents will soon have access to RERs. In order to quickly promote the application of renewable energy, governments of developing countries should consider the public's future acceptance or market adaptability (Chen and Kim, 2020) and

corporate investment income according to their own economic development level (Bakhtavar et al., 2020; Sukharev, 2020).

However, most of the economics academic research in these policy fields have not studied the R&D planning of RERs in the developing marine economy and have not paid attention to the bottleneck problems that marine RERs may face in the sense that they may easily be cut off from energy exporting countries. Fewer economic studies use a difference in difference in difference (DDD) model to assess the impact of energy planning. Therefore, our second contribution is that we choose the DDD model to study the impact of RERs planning on the related indicator. Economic research has not yet widely studied the marine RERs R&D planning game between government and enterprises from the perspective of game theory. Our third contribution is that we establish a wise pig game model to analyze the benefits obtained by the governments of developing marine countries in the R&D planning of marine RERs.

We get our desired results of the paper. Firstly, governments, enterprises, and researchers should pay attention to the distinction between mature and immature technologies for marine RERs, especially the R&D planning in the field of immature technologies. Secondly, the triple difference variable only has a significant positive impact on output of RERs which shows that RERs planning plays a great role in promoting its development. Thirdly, the growth of per capita GDP, R&D expenditure, R&D personnel and carbon dioxide emissions have a positive effect on the output of RERs. Lastly, under certain probability conditions, the government can maximize the welfare of the society by R&D planning of RERs. The results of the research can provide reference for governments, technical and economic theory researchers, and energy companies in various marine developing economies, stressing the importance of R&D planning of RERs and the need for further R&D planning.

This paper is structured into four sections. The following section provides theories which include RERs distribution theory, mature technology theory, immature technology theory and RERs planning theory. The section thereafter covers the data and DDD model, which shows the importance of RERs planning. Following that, the next section uses a wise pig game model to analyze the government's planning of RERs in marine developing countries, and the payment or benefits brought by it. The field of RERs R&D planning is also discussed. The last section concludes this work.

MATURE AND IMMATURE RERS TECHNOLOGY

The mature area of marine RERs includes mainly offshore wind energy (Held et al., 2019; Deep et al., 2020) and offshore solar energy (Hurst, 1990), within which the technologies are well developed and widely implemented. In this section, we distinguish between mature technologies and immature technologies of marine RERs based on high-quality literature, commencing with the distribution of marine RERs in two major developing marine countries, China and India.

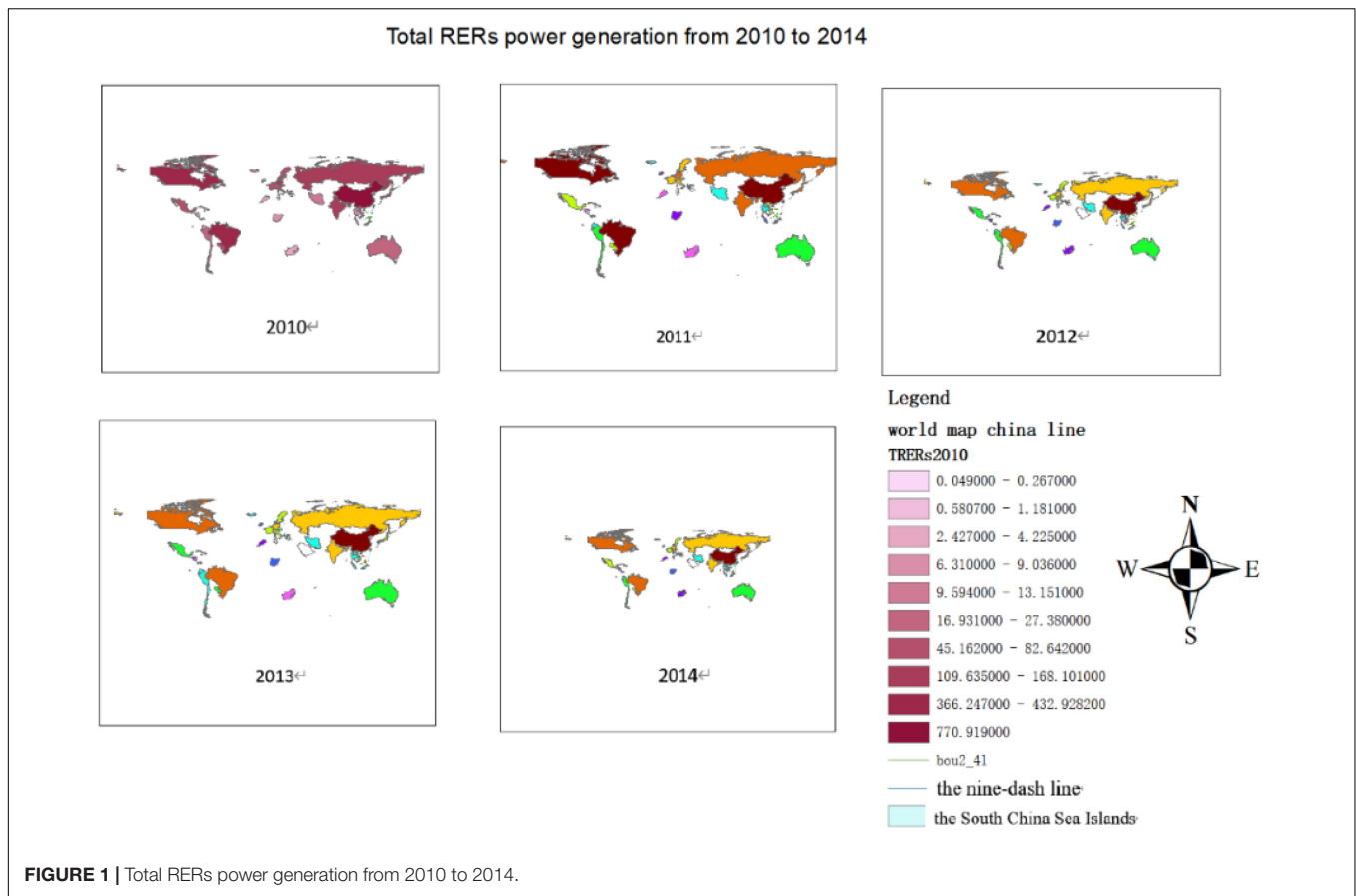
RERs Distribution

According to data from the 2014 to 2017 China Ocean Statistical Yearbook of total marine renewable energy power generation (billion kilowatt hours) of 48 coastal countries, we are able to establish RERs distribution in developing marine economies as shown **Figure 1**. Herein, showing the world's total RERs power generation data from 2010 to 2014. From the data of **Figure 1**, it is apparent that China has the largest renewable energy generation capacity in the world. The power generation from marine renewable energy in other developing countries is only about 0.003–5% of that of China in 2014. Such countries being Mexico, Argentina, Chile, Cuba, Ecuador, Haiti, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Peru, Albania, Belgium, Saudi Arabia, Mauritius, Morocco, Nigeria, Reunion, South Africa, Tunisia, Myanmar, Cambodia, North Korea, Laos, Malaysia, Thailand, and Vietnam. While the renewable energy generation capacity of China was 23%¹ of total generation capacity of China in 2014. The renewable energy generation capacity of several developed countries such as the United States, Brazil, Canada, India, Russia, Germany, Japan, Italy and France, are, respectively, 43, 33, 31, 15, 13, 13, 11, 9, and 7% of that of China in 2014. These data show that no matter whether it is a developing or developed country, their total amount of RERs is still relatively low. The maps of **Figure 1** can more intuitively show the gap in the total RERs power generation of countries from 2010 to 2014. Similarly, the data shows that total renewable electricity consumption (billion kilowatt hours) of 48 countries are equal to total RERs power generation (billion kilowatt per hour) of those countries from 2010 to 2012. These data show that marine renewable energy generation has been completely consumed and there is no surplus. Therefore, it is feasible to increase the generation of ocean renewable energy in market demand.

Next, we use the data of two major maritime developing countries, China and India, to illustrate the RERs situation. **Figure 2** was developed on the basis of the data from the 2018 China Ocean Statistical Yearbook, which shows the hydroelectric power generation of China's coastal provinces from 2013 to 2017. Hydropower has the highest utilization rate of marine RERs in China. Between 2013 and 2017, the province with the largest hydropower generation in China's coastal provinces is Guangxi, the second Fujian, the third Guangdong and the fourth Zhejiang from 2013 to 2017. It is notable, in the 2018 China Energy Statistical Yearbook, only hydro power and wind power data for 2017 are available. Hydro power made up 35837.39×10^4 tce (ton coal equivalent) and wind power 8885.95×10^4 tce in 2017. The official statistical data for China's biochemical energy, congen biomass power, waste to energy etc. is unavailable, which shows that this part of China's renewable energy has not produced scale. This indicates that China's renewable energy has room for planning in terms of regions and types.

The capacity of grid interactive renewable power (in megawatts) in India is shown in **Figure 3**. According to the 2018

¹According to 2016 China Statistical Yearbook, total RERs power generation of China is 5638.18 billion kilowatt per hour in 2014. 1284.326 divided 5638.18 equal about 23%.



India Statistical Yearbook, in 2017, the biggest small hydropower generating state of India was Karnataka, the second biggest Himachal Pradesh, and the third biggest Maharashtra. For the case of wind power in 2017, the largest source was in the Tamil Nadu state, the second Gujarat, the third Maharashtra, and the fourth Rajasthan. The amount of biochemical energy is very small in India. The largest biochemical energy producing state for 2017 was Maharashtra, the second Uttar Pradesh, and the third Tamil Nadu for congen biomass power. It is distributed in a wide area. The amount of Waste to Energy is less than the amount of bioenergy, which is compared with the total amount of renewable energy, it is not worth mentioning. The top states in terms of solar energy in 2017 were Andhra Pradesh, Rajasthan, Tamil Nadu, Telangana, Gujarat, and Karnataka. The top states in terms of total energy were Tamil Nadu, Karnataka, Gujarat, Rajasthan, Andhra Pradesh, Uttar Pradesh, and Telangana in 2017. The total RERs power in 2017 was 45,924 megawatts, while total installed generating capacity of electricity was about 350,367 megawatts. Therefore, the ratio of renewable energy power generation to total power generation was about 16% in 2017. India's data of RERs show that India have developed various RERs, but each type of RERs is not used on a large scale. Moreover, India's total RERs accounted for only 15.22% of China's total RERs in 2014.

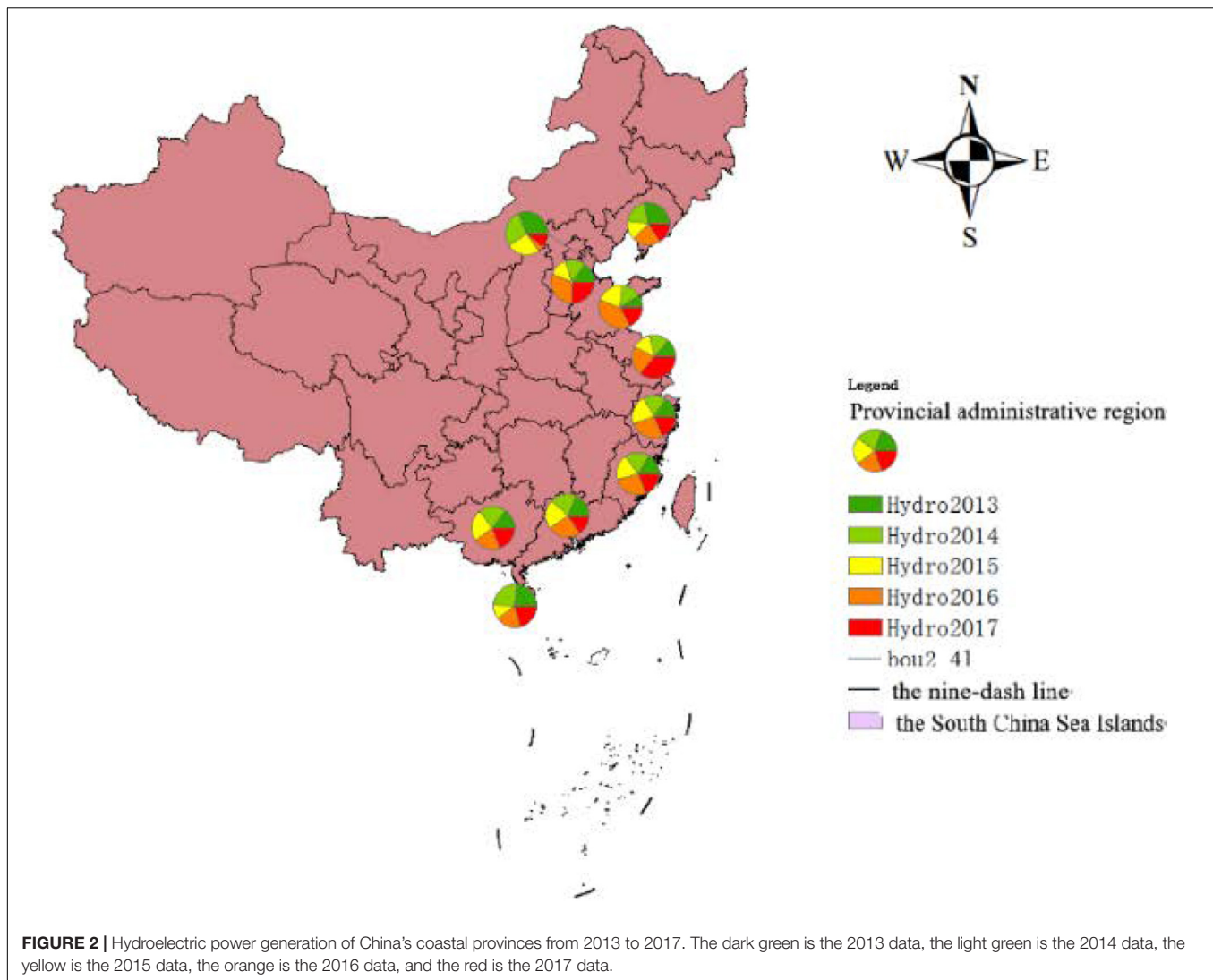
The above analysis of **Figures 1–3** show that RERs are an important part of the national plan of developing coastal countries, but great potential for marine RERs still exists.

Because big energy producing and consuming countries such as China, the chairman's important speech at the Climate Ambition Summit in December 2020 specifically emphasized increasing the total installed capacity of wind and solar power generation, and did not mention the plan for marine RERs. Small energy countries and energy weak countries are more worried about energy shortages than developed countries. Many small developing marine economies rely on imports for energy. When they encounter earthquakes, natural disasters or major epidemics such as COVID-19, they may be cut off from the energy giants. If the small marine developing economies plan the R&D of RERs, they can alleviate the problem of energy shortages in the long term.

Hypothesis 1: In developing marine countries, there is more room to plan for marine renewable energy in both the types and geographical areas, which include waves, tides, ocean currents, salinity, thermal gradients, marine biomass, offshore wind energy and offshore solar energy.

Mature Technology Offshore Wind Energy

Wind energy technology is the most mature technology and the fastest growing of all RERs in the world (Deep et al., 2020) but does have life cycles. The turning point of wind energy growth was in 2011, where wind energy in the world reached



saturation and the distribution of the wind energy network was not planned in practice (Zhang and Guan, 2019). This led to fierce competition in the wind power product market. Its mature technology includes nacelle (Madvar et al., 2019), the analysis of gust characteristics (Fan et al., 2020), the novel hybrid wind-solar-compressed air energy storage system which can solve the intermittent problems of wind and solar energy (Ji et al., 2017), the technology development of scavenging wind energy by using the electromagnetic effect (Chen et al., 2018), and the manufacturing of various parts of wind power generators, to name a few. The top three countries in the world for offshore wind power installations are Britain, Germany and China. The Chinese government will no longer subsidize the installation of wind turbines from 2021.

Tidal Energy

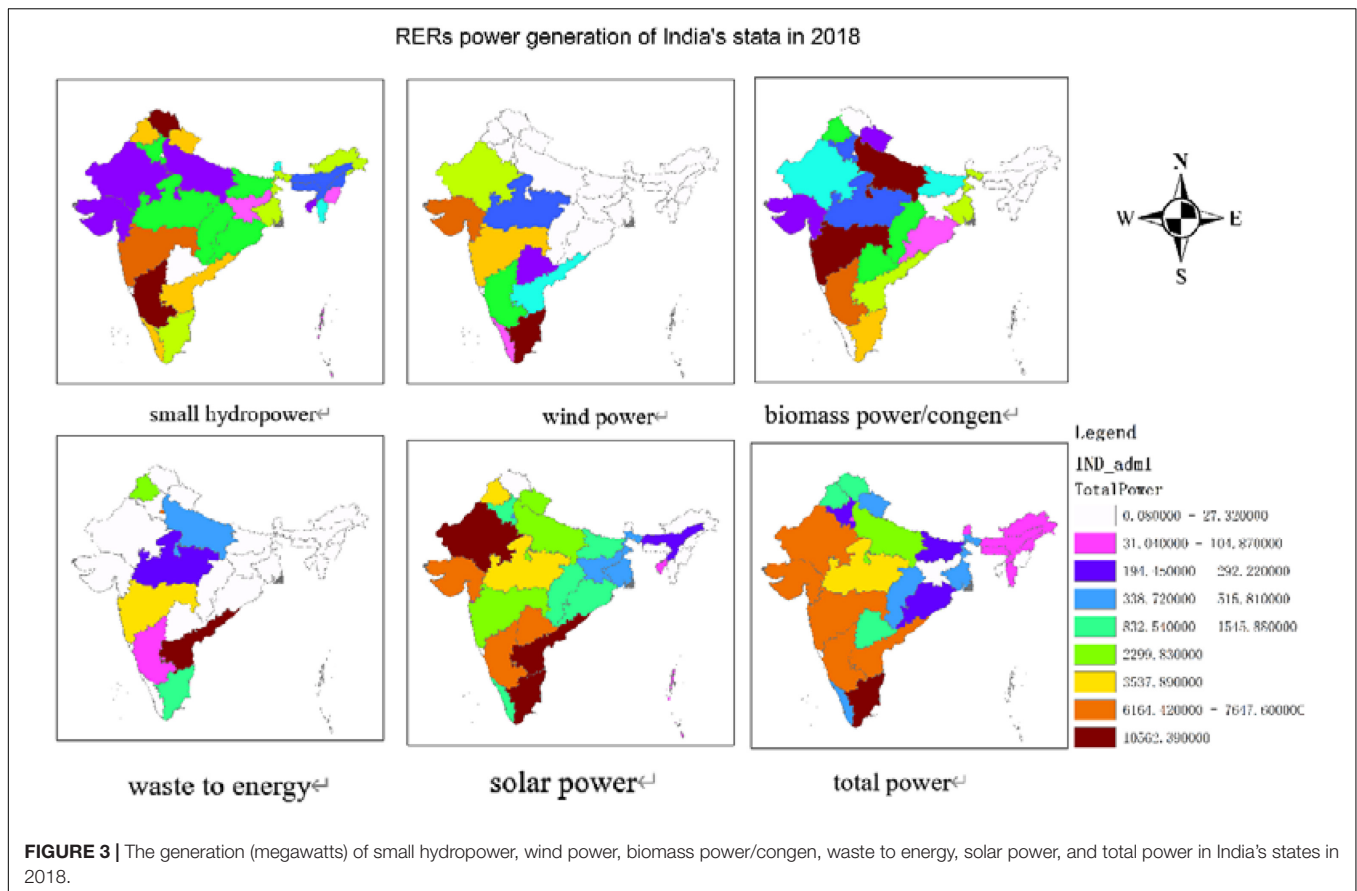
There are three evolving forms of tidal power plants. Single-storage one-way power stations, that generate power when the tide rises or falls; single-storage two-way power station,

capable of generating power during both rising and falling tides; double-storage two-way power stations, which through the establishment of upper and lower reservoirs can generate electricity 24 h a day. However, none of these reservoirs can generate electricity at low tide.

Offshore Solar Energy

The technology of solar power generation is notably mature, and the photovoltaic industry in China is already saturated. Solar power generation directly converts light energy into electric energy, or converts thermal energy into electric energy. Solar cells are the intermediary for this conversion of electrical energy. However, the application of offshore solar power is still not extensive. It is necessary to create new materials to convert ocean solar energy into electricity, so that ocean renewable solar energy can be widely used.

Hypothesis 2: Mature technology provides a technological platform for the R&D planning of marine renewable energy resources in developing marine countries.



Immature Technology

Variability, uncertainty, low power density, harsh environmental conditions and distribution are always RERs's challenges, which coupled with regulatory barriers, environmental barriers and technology costs barriers (Osorio et al., 2020), therefore, the widespread use of offshore RESs is greatly restricted.

Offshore Wind Energy

Due to the non-linear and random characteristics of wind energy, wind energy prediction is still a challenging task (Zendehboudi et al., 2018; Yang et al., 2019). Wind energy conversion is also a complex technology that has not been fully controlled. Near-inertial wind energy has always been overestimated, and it is necessary to use surface floating objects for accurate estimation (Liu F. et al., 2019). Determining how to accurately estimate ocean wind speed by the cyclone celestial navigation system requires the development of professional knowledge. Since it is difficult to forecast wind energy, only a breakthrough in the forecasting method can solve the problem. The prediction method that scientists prefer is that of artificial neural networks, but there is still a certain technical gap between this method and accurate prediction of wind energy (Marugan et al., 2018). Offshore wind power construction, maintenance, equipment life, impact on navigation safety and fishery, fatigue load of wind turbine blades, resistance to strong earthquakes, and resistance to strong typhoons are all issues that need to be resolved. The

development of offshore energy is limited by the geotechnical structure, as it is difficult to establish a complete geological and geotechnical classification map suitable for all offshore RESs, because the map will vary greatly depending on the geotechnical structure type of RERs (Coughlan et al., 2020; Taveira-Pinto et al., 2020).

Tidal Energy

In order to utilize tidal energy, it is necessary to evaluate it. Determining how the high-resolution sounding method, tidal components, and high-order harmonic components affect the quantification of tidal flow energy is a research trend (Mejia-Olivares et al., 2020). The grid-connected tidal stream turbine (TST) flexible control method for grid failure is under study (Toumi et al., 2020). In Maine, United States, there is the world's first tidal power generating unit without a dam, but it has not yet contributed electricity to users. Establishing how to break through the limitations of tidal energy site selection, how to promote tidal power stations without dams and reduce the loss of tidal energy generation are difficult problems that need to be overcome.

Hydrogen Energy

At present, the four issues that need to be researched and developed for water-to-light complementary power generation include the ratio of water-to-light capacity, the issue of absorption

and access to the system, the issue of coordination with conventional power sources, and the issue of impact on grid operation (China Energy News, 2020).

Offshore Solar Energy and Thermal Gradients

The R&D of new materials to reduce the cost of solar energy, to alternate use of ocean thermal energy and offshore solar energy, to reduce the intermittent problem of combining wave energy and solar energy (Oliveira-Pinto et al., 2020), which requires scientists to spend more time on research (Straatman and Van Sark, 2008).

Marine Biomass

Marine bioenergy is the energy contained in marine algae. For example, macroalgae are chopped up and decomposed and fermented by bacteria to produce methane and hydrogen, which can be used as fuel to replace petrochemical energy. It is necessary to establish how to widely grow some invertebrate organisms in the ocean as raw materials for the production of biogas and biological fertilizers. Few scholars have conducted in-depth studies relating to this (Hackl et al., 2018).

Ocean Currents

Ocean current or ocean current velocity detection is on-site measurement by a staff member in a boat. It is important to note that it is inconvenient to adjust the position of the detector during the on-site measurement process, and new methods of the detection need to be created (Zhao et al., 2020). The generation mechanism, instability, variability, life cycle, destructive force, turbulence cascades, internal wave interaction and the choice of the best location of ocean currents are all areas where there are more questions than answers (McWilliams, 2016; Barnier et al., 2020). How to make ocean currents impact on the genetic structure of biota and provide solutions for marine biological biofouling is also a problem worth exploring (White et al., 2010).

Marine Biofouling

The marine pollution of offshore renewable energy equipment includes biofouling and non-biofouling. Biofouling mainly includes acorn barnacles, mussels, calcareous tuberculosis, bryozoans and kelp. Non-biofouling factors include physical and chemical characteristics of seawater such as temperature, PH, dissolved oxygen and organic content, hydrodynamic conditions such as current speed, wave exposure, distance from shore and depth to water, and underlying characteristics such as material composition, color, roughness, immersion time, and exercise time (Vinagre et al., 2020). Non-biofouling and biological pollution are intertwined, affect each other and aggravate each other. How to reduce biological and the factors which aggravate marine biological pollution, and how to accurately draw a map of biological pollution are problems that need to be solved.

Salinity and Thermal Gradients

The difference in ocean salinity can be used to generate electricity, but the technology for measuring salinity at high latitudes is not yet mature at the time of writing (Supply et al., 2020). The impact of the salinity difference between the two bodies of water on kinetic energy and how to use it for power generation requires

further research (Lee et al., 2016). Few scientists have studied the use of ocean thermal gradients to generate electricity.

Energy Storage Systems

The energy storage system is the most effective solution to the instability of marine renewable energy and can minimize power fluctuations in the hybrid power system. However, this effective energy storage system has not been used in practice (Aktas and Kircicek, 2020). The improvement of the energy storage system can increase the utilization rate of RERs (De Quevedo et al., 2019). Battery energy storage systems is a suitable technology to eliminate the uncertainty and instability of renewable energy (Hemmati, 2018). If marine developing countries are to establish a new paradigm that meets RERs power system, microgrid integration, synchrophasor-driven automation technology, flexibility and safety requirements, and robustness and reliability methods for generation and dispatch, etc., it will be also large-scale technology challenge (Aminifar et al., 2019; Failler et al., 2019).

Monitoring Marine RERs

In the monitoring of marine RERs, technical experts need to develop multi-sensor floating system energy parameters for monitoring the marine environment, and establish a dedicated floating sensor device that can easily sample wind, wave and ocean current energy (Garcia et al., 2018). In addition, they need to study how to use sound emission to monitor the health of marine renewable energy equipment (Walsh et al., 2017).

The Impact of RERs on the Marine Environment

There are many areas that have not been studied in depth on the impact of renewable energy on the marine environment, such as the influence of tidal underwater kites on the depth of fish distribution, the impact of offshore wind power plants on the living environment of marine birds and fish, and the influence of ocean salinity on the distribution pattern of anaerobic bacteria (Li Z. et al., 2020). Additionally, there has been a lack of research into the effect of thermal gradients on marine bacteria (Sollich et al., 2020) and the effect of natural thermal gradients on protein synthesis in marine organisms (Rastrick and Whiteley, 2020). How triple salinity shapes the water masses of the basin-scale oceans and affects the climate is also a problem that needs long-term tracking (Hu et al., 2020).

Hypothesis 3: Immature technologies provide technical and environmental challenges for the R&D planning of marine renewable energy resources in developing marine countries.

RERs Planning

The purpose of RERs planning is to reduce dependence on fossil energy consumption and reduce the pressure on the environment caused by carbon dioxide emissions (Su et al., 2020). Most countries in Africa have set targets to support RERs, among which the most successful country in attracting wind energy investment is Kenya (Kazimierczuk, 2019). The implementation of the European Union's renewable energy policy is very effective, because the European Union's has been committed to energy planning, and governments of various

countries have also provided appropriate policy support for RERs. Contrastingly, in some countries, such as Finland, RERs producers had little say in the formulation of energy policies (Ratinen, 2019). Therefore, if the developing marine economy countries want to develop renewable energy, they must provide certain support and planning for RERs (Gnatowska and Moryn-Kucharczyk, 2019), and further involve companies that produce RERs in the planning process.

Planning Basis

Wind resources in coastal areas are relatively rich, which can provide a theoretical basis for the planning of regions and seasons of wind power (Liu Y. Z. et al., 2019). The wind energy planning framework includes long-term wind speed sampling, wind speed prediction reliability, energy commercialization, wind farm profitability (Bernardes et al., 2018), electric vehicle charging networks (Mehrerjerdi and Hemmati, 2020), etc. Technology, environmental protection and energy prices are the most influential driving factors for the development of RERs (Chen et al., 2020). The improvement of the efficiency of renewable energy planning is also an issue that must be considered in the planning process.

Microgrid Planning

It is necessary for the government to properly plan the construction of microgrids in areas suitable for the development of RERs, because the flexible areas of microgrids can effectively improve the renewable energy utilization rate of microgrids, improve the reliability of microgrid operations, and reduce the load of large-scale grids (Su et al., 2020). Governments can integrate renewable energy into the microgrid energy supply system of the community to reduce carbon emissions (Bakhtavar et al., 2020), and create a multi-energy microgrid with optimal performance (Yang et al., 2020). In the planning of the microgrid balanced energy network, technical experts need to consider the characteristics of renewable energy and multi-energy loads, time series, auto-correlation and cross-correlation (Lei et al., 2020).

Excess Energy Planning

In the case of excess wind and solar energy, it is important to understand how to use them to produce hydrogen and promote sustainable energy development (Nadaleti et al., 2020). The energy storage system and the transmission network are combined to avoid the imbalance in the performance of RERs power generation, and the excess RERs can be transmitted to the power market for digestion (Zhang et al., 2020). But the uncertainties in the supply and demand of renewable energy resources pose intractable problems for planners.

The planning of RER requires the participation of the government, and the market for RERs requires appropriate laws, regulations and government documents. For the planning, design, operation and control of RERs systems, its technical optimization has become very important (Li et al., 2018; Aminifar et al., 2019). Scientists need to turn the problem list of RERs bottleneck technologies into a problem list of scientific research (Maciel et al., 2018), plan various RERs standards (Maciel et al., 2018), combine RERs to overcome their instability and

intermittent characteristics (Zhang et al., 2019), plan the optimal configuration of multi-energy systems, and consider demand response when planning RERs (Asensio et al., 2018).

Hypothesis 4: Different countries have certain plans for renewable energy resources, but there is no plan for the research and development of renewable energy resources. After a period of economic development in the previous plans, it is necessary to increase plans for new renewable energy technologies and remove some plans for mature and backward technologies.

METHODOLOGY

Samples and Data

For this research, 232 developing countries and developed countries were used as samples, in which there are 204 developing countries, 62 developing marine countries and 28 developed countries. The time span of the panel data is from 1990 to 2016. RERs output and consumption data come from the Sustainable Energy database of the World Bank. CO₂ emissions data comes from the International Energy Agency (IEA). Various GDP and R&D data come from the Sustainable Development Goals of the World Bank. Countries with coastlines belong to marine areas, and countries without coastlines belong to non-marine areas. Every country with a coastline is verified by Google Maps. The choice of planning time comes from Wikipedia². We use "country name + renewable energy + Wikipedia" or "country name + energy + Wikipedia" as search keywords on Google. For countries with renewable energy plans, the planning time is shown on Wikipedia. In some countries, there are several planning time nodes, then we just select the first planned time node as the planned time. For countries that do not have a renewable energy plan, we regard the establishment of their first renewable energy power plant as the planned time. Their first renewable energy power plant may be wind power, hydropower, etc., or any other form of RERs power plant. Data on CO₂ emissions comes from International Energy Agency (IEA).

DDD Model

The triple difference model is also called the difference in difference in differences (DDD) model. There are two reasons for the establishment of the DDD model. First, the sample does not meet the common time trend. Energy planning policies can be seen as a prerequisite for randomized trials, thus building a model is needed to evaluate the impact of renewable energy planning policies on renewable energy output. The difference in differences (DID) model and is usually used for the evaluation of policy shocks, but the prerequisite is that the sample must meet a common time trend. We had tried to use DID model but the samples do not conform to common trends in RERs

²Part of the data on the Wikipedia website come from the public, which will engender doubt about the scientific nature of the data in this article. However, in this case it is important to note the Wikipedia also has data from companies and governments which have been specifically used by this article, such as the establishment time of renewable energy companies and the government's release of renewable energy plans. These data are accurate.

planning because some countries plan earlier while others plan later, and the speed of RERs technology progress is also different. The DID model furthermore failed to pass the placebo test, which determines that the best alternative model to the DID model for policy impact assessment is the DDD model. Second, before using the triple difference model, it is necessary to check whether the time trend is significant. If the significance is not 0, the triple difference model can be used. From the regression analysis results in **Table 1**, it can be seen that the time trend variable is significantly not zero, which is a reason for utilizing the DDD model.

Based on the DDD method of Fu et al. (2015) and Kim et al. (2015), we build the DDD model in (1) to analyze the impact of planning for R&D on the output and consumption of RERs. There are two treatment groups and one control group in the DDD model.

$$\begin{aligned}
 OUTP_{RERs}^{ijt} = & \alpha_0 + \alpha_1 DevelopingMari + \alpha_2 RERsPlan \\
 & + \alpha_3 DevelopedMari + \alpha_4 DevelopingMari \\
 & \times RERsPlan + \alpha_5 DevelopingMari \\
 & \times DevelopedMari + \alpha_6 RERsPlan \\
 & \times DevelopedMari + \alpha_7 DevelopingMari \\
 & \times RERsPlan \times DevelopedMari + e_{ijt}
 \end{aligned} \tag{1}$$

Considering that the implementation of RERs planning will be affected by GDP, CO₂ emissions, research and development expenditure (RDEX) and researchers in R&D (RDRE), these variables need to be entered into the DDD model in order to avoid the endogenous problem. Thus, Eq. (1) changes into Eq. (2).

$$\begin{aligned}
 OUTP_{RERs}^{ijt} = & \alpha_0 + \alpha_1 DevelopingMari + \alpha_2 RERsPlan \\
 & + \alpha_3 DevelopedMari + \alpha_4 DevelopingMari \\
 & \times RERsPlan + \alpha_5 DevelopingMari \\
 & \times DevelopedMari + \alpha_6 RERsPlan \\
 & \times DevelopedMari + \alpha_7 DevelopingMari \\
 & \times RERsPlan \times DevelopedMari + \alpha_8 GDP + \alpha_9 CO_2 \\
 & + \alpha_{10} RDEX + \alpha_{11} RDRE + e_{ijt}
 \end{aligned} \tag{2}$$

Variable

The explained variable is $OUTP_{RERs}$. O'Hagan (2016), Maciel et al. (2018), and Salvador et al. (2019) establish that the final result of R&D planning is the output of RERs. Thus, we take $OUTP_{RERs}$ as the explained variable.

The dummy variables are *DevelopingMari*, *RERsPlan*, and *DevelopedMari*. Because we want to study the R&D planning of developing marine RERs, we regard developing marine countries as the first treatment group. Secondly, marine RERs planning in developed countries has an impact on developing countries, because developed countries will extend the idea of developing marine RERs planning to developing countries, and developing countries will also refer to relevant plans of developed countries. Thus, the developing countries are regarded as the second treatment group. The other countries are the control group. Therefore, we have three dummy

variables in Eqs. (3–5), which also act as the explanatory variables. Further, the DDD model derived several new explanatory variables, that is, *DevelopingMari* × *RERsPlan*, *DevelopingMari* × *DevelopedMari*, *RERsPlan* × *DevelopingMari*, and *DevelopingMari* × *RERsPlan* × *DevelopedMari*.

$$DevelopingMari = \begin{cases} 1 & \text{if } Mari \text{ ne Developing country} \\ 0 & \text{if non - } Mari \text{ ne Developing country} \end{cases} \tag{3}$$

$$RERsPlan = \begin{cases} 1 & \text{if have RERs Plan} \\ 0 & \text{if have no RERs Plan} \end{cases} \tag{4}$$

$$DevelopedMari = \begin{cases} 1 & \text{if } Marine \text{ developed country} \\ 0 & \text{if non - } Marine \text{ developed country} \end{cases} \tag{5}$$

Covariate GDP, PerGDP, and CO2E

There is a long positive correlation or the causal relationship between renewable energy and GDP, GDP per capita (*PerGDP*) and CO₂ emission (*CO2E*) (Apergis and Payne, 2014; Ohler and Fetters, 2014), thus *GDP*, *PerGDP*, and *CO2E* will have an impact on marine renewable energy and should be included as control variables in the DDD model.

Covariate RDEX and RDRE

R&D spending per GDP is an indicator of renewable energy R&D (Ragwitz and Miola, 2004), which can drive the output of RERs (Adedoyin et al., 2020). By their own strength and expansion of social networks, researchers can promote the output of renewable energy (Kumar et al., 2013). Thus, we take R&D expenses (RDEX) and R&D personnel (RDRE) as control variables in the DDD model. The variables of the DDD models and the descriptive statistics are shown in **Table 1**.

Result of DDD

We regress both model (1) and model (2) by two methods, Diff and OLS. The regression results are shown in **Table 2**.

For the regression results of the DDD model, the effectiveness of the policy can only be judged by the significance of the triple difference crossover variable. If the triple difference crossover variable is significant, the policy is effective. The OLS method and Diff command are used to estimate the model (1), and the triple difference variables are not significant, which indicates that the endogenous problem causes the model (1) to not obtain significant results. For the model (2) with covariate added, the regression results of both methods show that triple difference variables *DevelopingMari* × *RERsPlan* × *DevelopedMari* have a significantly positive impact on $OUTP_{RERs}$ at the significance level of 1%. The economic significance of this result is that the RERs plan of developing marine countries to increase the amount and the share of RERs power generation from 1990 to 2016. In other words, the RERs planning policies of developing

TABLE 1 | Variables of the DDD model and associated descriptive statistics.

No.	Variable	The meaning of variables	Obs	Mean	SD	Min	Max
1	Country		232				
2	Year		26			1990	2016
3	$OUTP_{RERs}$	Output of RERs	6,264	13924.41	59273.17	0	1398321.00
4	$DevelopingMari$	Developing marine countries	6,264	0.60	0.49	0	1
5	$RERsPlan$	Planning time	6,264	0.46	0.50	0	1
6	$DevelopedMari$	Developed marine countries	6,264	0.03	0.16	0	1
7	$DevelopingMari \times RERsPlan$	$DevelopingMari$ multiply by $RERsPlan$	6,264	0.23	0.43	0	1
8	$DevelopingMari \times DevelopedMari$	$DevelopingMari$ multiply by $DevelopedMari$	6,264	0.01	0.11	0	1
9	$RERsPlan \times DevelopedMari$	$RERsPlan$ multiply by $DevelopedMari$	6,264	0.02	0.16	0	1
10	$DevelopingMari \times RERsPlan \times DevelopedMari$	$DevelopingMari$ multiply by $RERsPlan$ and $DevelopedMari$	6,264	0.01	0.11	0	1
11	GDP	Gross domestic product (constant 2010 US\$)	6,264	2.49e+11	1.06e+12	0	1.70e+13
12	PerGDP	GDP per capita (constant 2010 US\$)	6,264	11361.02	19371.23	0	194368.40
13	CO2E	CO ₂ Emission	6,264	105.36	536.54	0	9188.38
14	RDEX	Research and development expenditure (% of GDP)	6,264	0.27	0.65	0	4.51
15	RDRE	Researchers in R&D (per million people)	6,264	426.43	1176.69	0	8006.67
16	i	$i = 0$, marine country; $i = 1$, non-marine country					
17	j	$j = 1, 2, \dots, 232$					
18	t	$t = 1996, 1991, \dots, 2016$					

TABLE 2 | Regression results of DDD model.

Model	(1)		(2)		(2)	
	Diff	Diff	OLS	OLS	Placebo test	
$OUTP_{RERs}$						
$DevelopingMari$			710.93*** (0.00)	340.06 (0.16)	-1448.08* (0.06)	
$RERsPlan$			27208.21*** (0.000)	8102.46*** (0.00)	7906.12*** (0.000)	
$DevelopedMari$			-251.02*** (0.00)	-9441.28*** (0.00)	-2465.11*** (0.00)	
$DevelopingMari \times RERsPlan$			4580.58 (0.16)	3929.66** (0.03)	4702.08 (0.01)	
$DevelopingMari \times DevelopedMari$			-623.26*** (0.00)	2311.26 (0.26)	-5267.29*** (0.00)	
$RERsPlan \times DevelopedMari$	-4.7e+03 (0.27)	-1.1e+04*** (0.00)	-12699.70*** (0.00)	6015.16*** (0.00)	-1814.17 (0.49)	
$DevelopingMari \times RERsPlan \times DevelopedMari$	-4.7e+03 (0.33)	-1.3e+04*** (0.00)	-4079.67 (0.33)	-13301.05*** (0.00)	-6186.33 (0.11)	
GDP				-6.46e-10 (0.88)	-7.32e-10 (0.86)	
PerGDP				0.12*** (0.00)	0.13 (4.95)	
CO2E				83.51*** (0.00)	83.72*** (0.00)	
RDEX				2019.79 (0.30)	1738.93 (0.36)	
RDRE				2.402** (0.05)	2.45** (0.04)	
cons			251.0213*** (0.000)	-2328.67*** (0.00)	-324.76 (0.70)	
R^2	0.06	0.63	0.062	0.63	0.63	

P-value in parenthesis. *** $P < 0.01$; ** $p < 0.05$; * $P < 0.1$.

TABLE 3 | Smart pig game of government and firm.

		Firms (piggy)			
		R&D (μ)		Not R&D ($1 - \mu$)	
		R&D success (η)	R&D unsuccessful ($1 - \eta$)		
Government (big pig)	Planning (v)	Planning success(ζ)	$GDP + SC - C_{R\&D-g1} + C_{swl}, Rev_1 + C_{R\&D-g1} - C_{R\&D-f1}$	$GDP - C_{R\&D-g1} - C_{swl}, C_{R\&D-g1} - C_{R\&D-f1}$	$GDP + SC - C_{R\&D-g1} + C_{swl}, Rev_2 + C_{R\&D-g1}$
		Planning unsuccessful ($1 - \zeta$)	$-C_{R\&D-g1} - SC - C_{swl}, Rev_3 + C_{R\&D-g1} - C_{R\&D-f1}$	$-C_{R\&D-g1} - C_{swl}, C_{R\&D-g1} - C_{R\&D-f1}$	$-C_{R\&D-g1} - C_{swl}, 0$
	Not Planning ($1 - v$)		$-SC - C_{swl}, Rev_4 - C_{R\&D-12}$	$-SC - C_{swl}, -C_{R\&D-12}$	0,0

TABLE 4 | The meaning of variables and strategies.

Variable	The meaning of the variable
Planning	The R&D planning of key technologies and basic technologies for RERs
Not Planning	No R&D planning of key technologies and basic technologies for RERs
R&D	Research and develop of key technologies and basic technologies for RERs
Not R&D	No research and develop of key technologies and basic technologies for RERs
GDP	Gross domestic product
ν	Probability of government planning
$1 - \nu$	Probability of government not planning
ζ	Probability of government of planning success
$1 - \zeta$	Probability of government of planning unsuccessful
μ	Probability of firm's R&D
$1 - \mu$	Probability of firm's not R&D
η	Probability of firm's R&D success
$1 - \eta$	Probability of firm's R&D unsuccessful
SC	Social welfare, such as green environment
$C_{R\&D-g1}$	R&D costs paid by the government if government planning leads to successful R&D of RERs, which is the external benefit of the enterprise
C_{swl}	The cost of social welfare loss, such as the treatment costs smog, air pollution, the consume of petrochemical energy, et al.
Rev_1	The firm's revenue obtained from firm's R&D of RERs when government planning success
$C_{R\&D-f1}$	Firm's application R&D costs of RERs when government planning success
Rev_2	The firm's revenue obtained from government's R&D of RERs when government planning success
Rev_3	The firm's revenue obtained from firm's R&D of RERs when government plans unsuccessful
Rev_4	The firm's revenue obtained from firm's R&D of RERs when government does not plan
$C_{R\&D-f2}$	Firm's application R&D costs of RERs when government planning unsuccessful

marine countries have a positive impact on the output of RERs. The rapid development of RERs has its inherent economic mechanism. At the same time, new problems will arise in the development process.

First, Government Economic Policy

The government of each developing marine country has different motivations to promote the use of RERs by economic policy. Their goal may be to discover new economic growth points, or to reduce CO₂ emissions in order to meet climate agendas and foster a better environment for the population. It may be that traditional energy deficiency or the awareness raised by environmental science and advocacy, that governments pay attention to aiming for low-carbon environments (Gallagher, 2013). Under the advocacy of the government RERs policy, the installation cost of RERs generator sets is declining, and the operating costs are falling (Nazir et al., 2019), alongside the increasing saturation of solar and wind energy. Under these circumstances, the government

has less and less support for RERs (Schaffer and Bernauer, 2014). For example, the Chinese government have canceled financial subsidies for the installation of wind turbines in 2021. This requires the governments of developing marine countries to make breakthroughs for RERs planning, and the opportunity for this breakthrough planning lies in the R&D plans for marine RERs.

Second, the Growth of GDP per Capita

According to the results of the OLS regression in **Table 2**, per capita GDP has a significant positive impact on RERs output, that is, for every one percentage point increase in per capita GDP, the output of RERs will increase by 0.126 percentage points, which is consistent with the conclusion of Simionescu et al. (2019). However, because Simionescu et al. (2019) uses EU data, the 0.126 percentage point in this article is higher than the 0.009 percentage point of their research, which is 0.117 percentage points.

Third, Carbon Dioxide (CO₂) Emissions

CO₂ emissions do not affect a single country, but affect the global environment and climate, thus reducing CO₂ emissions requires the joint efforts of all countries in the world (Mendonca et al., 2020). Generally speaking, the more CO₂ emissions there are, the output of RERs will increase rapidly (Mendonca et al., 2020). From **Table 2**, we establish that the relationship between RERs output and CO₂ emissions is positive, which is consistent with the conclusion of Ikram et al. (2020). For every unit increase in carbon dioxide emissions, the output of renewable energy resources will increase by 83.724 units. In **Table 2**, GDP does not have a significant impact on the output of RERs. The real GDP growth will increase the output of RERs through the indirect way of increasing carbon emissions (Dogan, 2017).

Fourth, the Support of RERs R&D

The development of basic technology of RERs is a long, uncertain and extensive process (Jacobsson and Johnson, 2000). Therefore, technological innovation of RERs in developing marine countries is mainly imitative innovation or direct introduction of RERs technologies from developed countries. China's RERs R&D expenditures are mainly government expenditures which bring about few breakthroughs in the basic technology of RERs, and private companies have no incentive to conduct RERs R&D. R&D personnel are mainly in universities and scientific research institutions, who promote the application technology of RERs (Huang et al., 2012). The empirical results of OLS confirmed this mechanism. The results in **Table 2** show that R&D expenditure has no significant positive impact on the output of RERs. R&D personnel have a significant positive impact on RERs output. For every percentage point increase in R&D personnel, the output of renewable energy can increase by 2.449 percentage points. If there are R&D funds and R&D personnel who specialize in marine RERs research, the R&D quality of marine RERs can be rapidly improved, and R&D bottlenecks can be quickly broken through. That is, R&D expenditure which brings knowledge accumulation and

knowledge spillover, all affect the RERs innovation in every developing marine country, but knowledge spillovers will reduce domestic RERs innovation and increase domestic knowledge reserves of RERs(Miremedi et al., 2019).

Following this, the use of a placebo test is needed to test the robustness of the model. We randomly selected 115 countries as developing marine economies and 116 countries as developed marine economies as the treatment group. The results of the placebo test are shown in **Table 2**. We judge whether the DDD model can pass the placebo test by the significance of the triple difference crossover variable. If the triple difference crossover variable is not significant, the DDD model passes the placebo test. The triple difference crossover variable *DevelopingMari* × *RERsPlan* × *DevelopedMari* is not significant at 1, 5, and 10 in **Table 2**, so the DDD model in **Table 2** can pass the placebo test.

DISCUSSION

Smart Pig Game Model

Based on hypotheses 1–4, the government’s R&D plan for RERs research and development is essentially a smart pig game between the government and enterprises. **Table 3** is the result of the game between the government and enterprises in renewable energy planning. The government acts as a “big pig” and the firms act as “piggy.” In the smart pig game, the government has two strategies, that is, planning and not planning. The probability of planning is v , and the probability of not planning is $1 - v$. In this case, the government’s planning refers to the R&D planning of key technologies, basic technologies and immature technology for RERs. The firm has two strategies too, and they can choose to carry out R&D or not. The probability of R&D is μ , and the probability of not undertaking R&D is $1 - \mu$. The meaning of variables and strategies is shown in **Table 4**.

If the government conducts R&D plans for key technologies, basic technologies and immature technology for the production of RERs, the government will designate some universities, research institutions or firms to conduct R&D on these technologies for RERs through a project tender. R&D costs are afforded by the government, not by enterprises. The government plans for R&D of RERs (instead of enterprises), because the R&D plan of RERs can bring about a green environment, eliminate haze, return fresh air to people’s lives, meet goals for low-carbon green growth, and save petrochemical energy consumption (Hong et al., 2009). Furthermore, R&D can dominate the consumption of RERs, whose effect on consumption is higher than the impact of policy and energy intensity (Wang R. et al., 2020). Additionally, the impact of R&D on RERs consumption is affected by the level of GDP, and the impact will be greater at a high level of GDP per capita (Kocsis and Kiss, 2014).The government may also subsidize firms that research and develop RERs, which can promote the development of RERs (Wu et al., 2020). However, if they are not used for R&D of basic RERs technologies, government subsidies will have a certain crowding-out effect on the R&D of RERs (Yu et al., 2016).

From **Table 3**, we establish that if the government chooses planning, its expected benefits are as shown in Eq. (6).

$$E_{gov-planning} = \mu\eta v\zeta(GDP + SC - C_{R\&D1} + C_{swl}) + \mu(1-\eta)v\zeta(GDP - C_{R\&D-g1} - C_{swl} + (1-\mu)v\zeta(GDP + C_{R\&D1} - SC) + \mu\eta v(1-\zeta)(-C_{R\&D-g1} - SC - C_{swl} + \mu(1-\eta)v(1-\zeta)(-C_{R\&D-g1} - C_{swl}) + (1-\mu)v(1-\zeta)(-C_{R\&D-g1} - C_{swl})) \tag{6}$$

If the government chooses not to plan, its expected benefits are as in Eq. (7).

$$E_{gov-not\ planning} = \mu\eta(1-v)(-SC - C_{swl}) + \mu(1-\eta(1-v))(-SC - C_{swl}) + (1-\mu)1-v) \cdot 0 \tag{7}$$

From (6) and (7), we get (8).

$$\Delta E_{gov} = E_{gov-planning} - E_{gov-not\ planning} > 0 \tag{8}$$

From (8), we develop (9).

$$\Delta E_{gov} = 2\mu\eta v\zeta SC - \mu v\zeta SC + v\zeta GDP + 2v\zeta C_{R\&D-g1} - v\zeta SC - \mu\eta v SC - v C_{R\&D-g1} - v C_{swl} + v\zeta C_{swl} - \mu v\zeta C_{swl} + \mu SC - \mu v SC + \mu C_{swl} - \mu v C_{swl} \tag{9}$$

If we find the first derivative of (9) and assume that the first derivative is 0, we develop (10–13).

$$d(\Delta E_{gov})/d\mu = 2\eta v\zeta SC - v\zeta SC - \eta v SC - v\zeta C_{swl} - v SC - v C_{swl} + C_{swl} + SC = 0 \tag{10}$$

$$d(\Delta E_{gov})/d\eta = 2\mu v\zeta SC - \mu v SC = 0 \tag{11}$$

$$d(\Delta E_{gov})/dv = 2\mu\eta\zeta SC - \mu\zeta SC + \zeta GDP + 2\zeta C_{R\&D-g1} - \zeta SC - \mu\eta SC - C_{R\&D-g1} - C_{swl} + \zeta C_{swl} - v\zeta C_{swl} - \mu SC - \mu C_{swl} = 0 \tag{12}$$

$$d(\Delta E_{gov})/d\zeta = 2\mu\eta v SC - \mu v SC + v GDP + 2v C_{R\&D-g1} - v SC + v C_{swl} - \mu v C_{swl} = 0 \tag{13}$$

From (15), we develop (14).

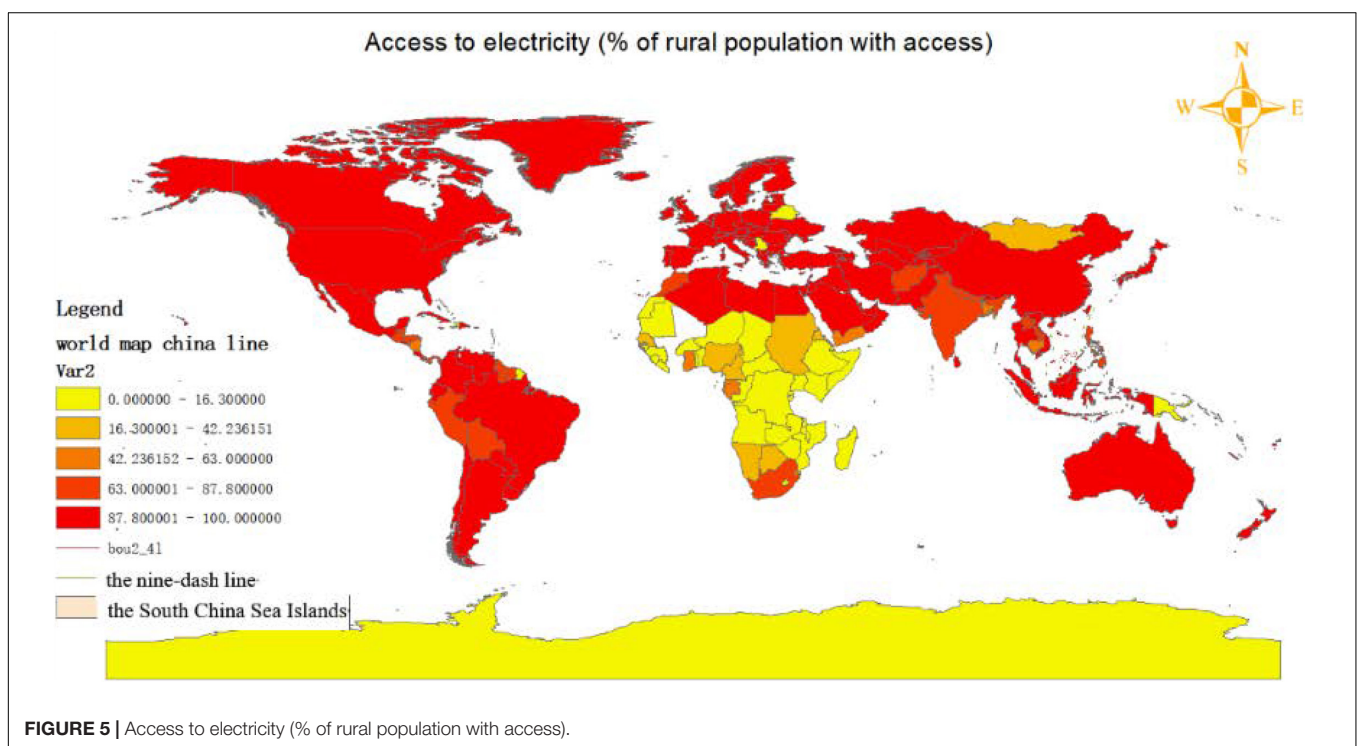
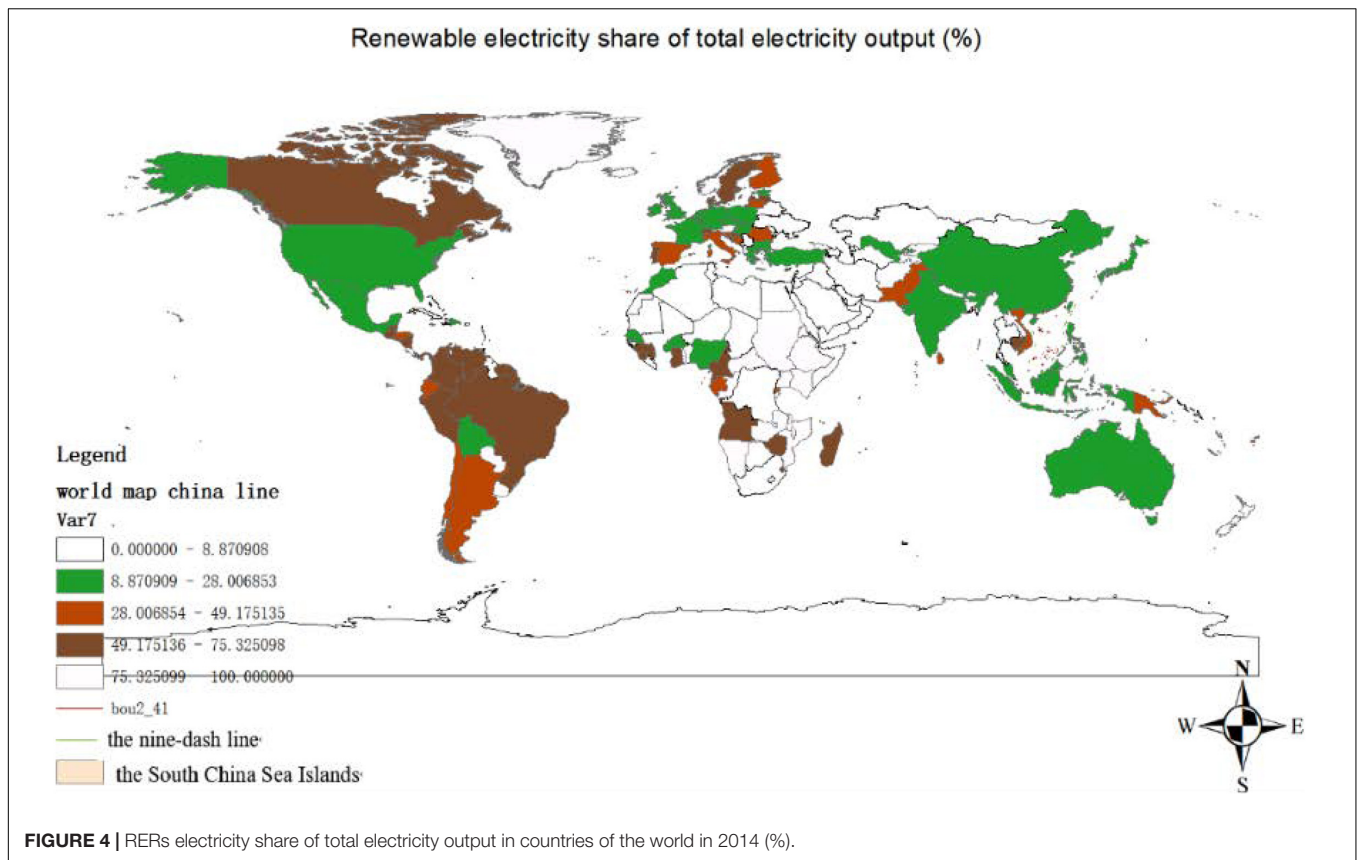
$$\zeta = \frac{1}{2} \tag{15}$$

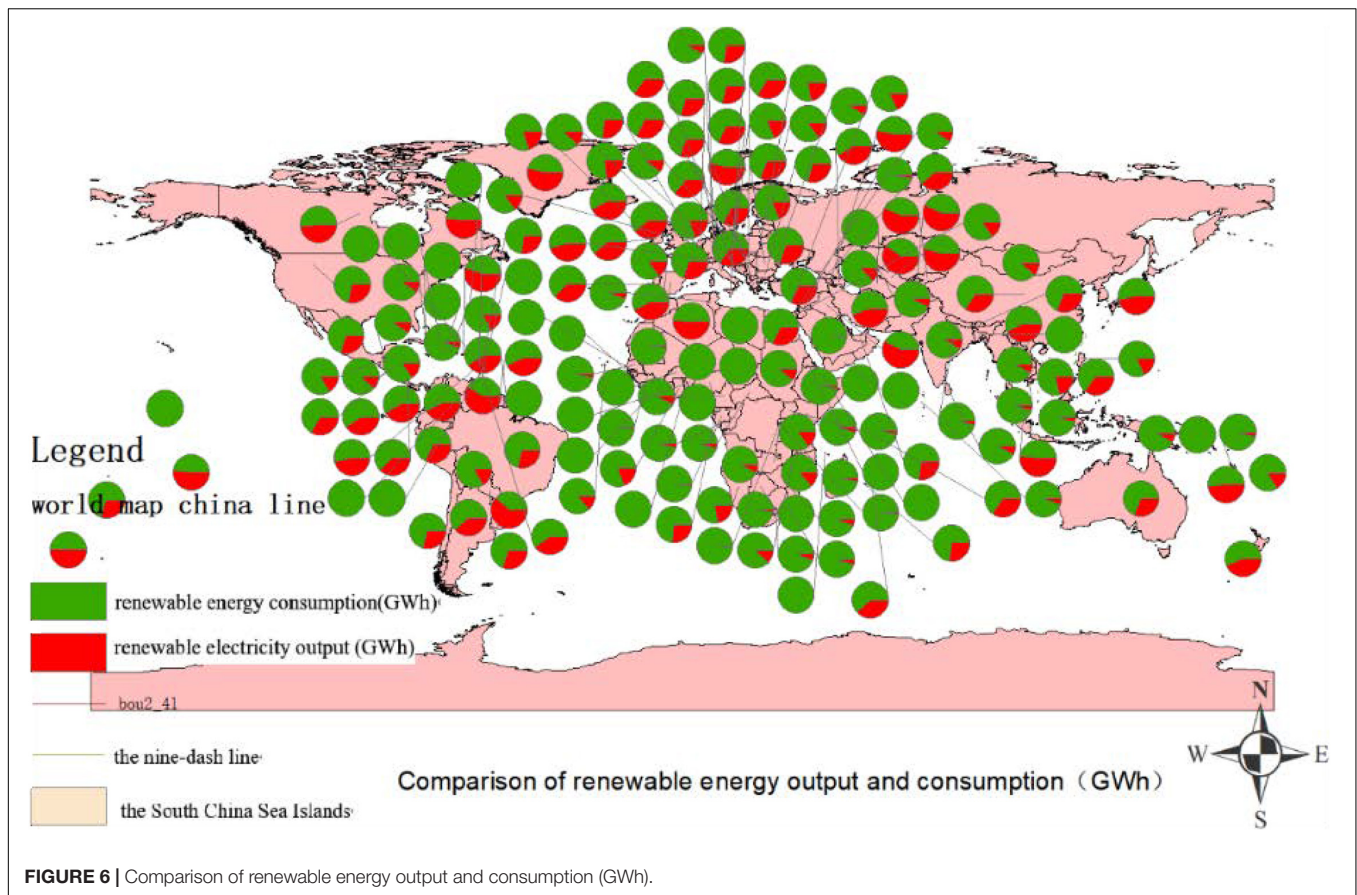
From (16) and (14), we obtain (15).

$$v = \frac{2}{3} \tag{16}$$

From (13–15), we develop (16).

$$\eta = any\ value \tag{17}$$





From (20), we suppose $\eta = 1$. According (17), (14), and (15), we establish (17).

$$\mu = 1 - \frac{GDP + 2C_{R\&D} - g_1}{SC - C_{swl}} \quad (18)$$

If (14–17) are established at the same time, ΔE_{gov} can reach a maximum, and the government chooses the planning of R&D.

Planned Area

From the share, output and consumption of RERs electricity, we can see where planning should take place to avoid bottlenecks in marine developing countries. According to the data of RERs in 203 countries around the world in 2014, sourced from the World Bank, the RERs electricity share of total electricity output can be established (Figure 4). In the World Bank database, some countries have no statistics. We treat missing data as 0. Countries where renewable energy power generation accounts for more than 90% of the national total power generation include Albania, Bhutan, Central African Republic, Congo Dem. Rep., Ethiopia, Iceland, Laos, Lesotho, Namibia, Nepal, Paraguay, and Tajikistan. However, RERs electricity share of total electricity output in countries of the world in 2014 is less than 20% in more than 90 countries around the world, and China's share is around 22%.

Countries with Access to electricity (% of total population) below 50% include Angola, Benin, Burkina Faso, Burundi, Central African Republic, Chad, Congo, Eritrea, Ethiopia, French

Guiana, Gambia The, Guadeloupe, Guinea, Guinea-Bissau, Haiti, Kenya, South Korea (Peoples Republic of), Lesotho, Liberia, Madagascar, Malawi, Martinique, Mauritania, Mozambique, Namibia, Niger, Papua New Guinea, Reunion, Rwanda, Sierra Leone, Solomon Islands, Somalia, Sudan, Tanzania, Togo, Uganda, Vanuatu, Western Sahara, Zambia, and Zimbabwe.

Countries where urban electricity supply accounts for less than 60% of the total population are mainly Angola, Benin, Burkina Faso, Burundi, Central African Republic, Chad, Congo, French Guiana, Guadeloupe, Guinea-Bissau, South Korea (Peoples Republic of), Liberia, Malawi, Martinique, Mozambique, Reunion, Sierra Leone, Somalia, Tanzania, Uganda, Western, and Sahara.

Countries where the percentage of rural population with electricity is below 50% are mainly Angola, Benin, Bermuda, Botswana, Burkina Faso, Burundi, Cambodia, Cameroon, Central African Republic, Chad, Congo, Djibouti, Eritrea, Ethiopia, French Guiana, Gabon, Gambia, The Guadeloupe, Guinea, Guinea-Bissau, Haiti, Kenya, South Korea (Peoples Republic of), Lesotho, Liberia, Madagascar, Malawi, Martinique, Mauritania, Monaco, Mongolia, Mozambique, Myanmar(Burma), Namibia, Niger, Nigeria, Papua New Guinea, Reunion, Rwanda, Senegal, Sierra Leone, Singapore, Solomon Islands, Somalia, Sudan, Tanzania, Togo, Turks and Caicos Islands, Uganda, Vanuatu, Western Sahara, Zambia, and Zimbabwe, as shown in Figure 5.

According to the conversion where 1TJ(terajoule) = 0.2778 GWh (gigawatt hours), we changed the number of units consumed, as stated by the World Bank in 2014, and compared the output and consumption of renewable energy with a pie chart, as shown in **Figure 6**. From this, we can intuitively see that the consumption of renewable energy in most countries is higher than the output.

The above data analysis shows that there is huge room for the development of RERs in all countries in the world. The utilization rate of marine RERs is lower, so all marine developing countries have room for the planning of R&D of marine RERs. The potential for the development of marine RERs is huge, because energy giants, like China, have been advocating residents to save electricity during the peak period of power consumption in winter, indicating that electricity supply is far from meeting demand. If there is an abundance of marine RERs power supply, the cost of electricity for enterprises can be reduced, and there would be no need for residents to save electricity. The government would then not have to worry about the exhaustion of fossil energy, and fossil energy conservation and CO₂ emission reduction targets can be achieved.

In short, there are its inherent economic mechanism for the increase in marine RERs output. Marine RERs planning and R&D are direct mechanisms that have a positive impact on RERs output. An indirect mechanism for increased output of marine RERs is as follows. Increasing GDP has led to an increase in CO₂ emissions, and an increase in per capita GDP has necessitated an environment of higher quality. This urges governments to implement the CO₂ emission reduction systems. The key to this implementation is to increase the output of RERs by planning marine RERs R&D.

However, in the process of marine RERs development, some problems will arise. For example, there are not enough and professional RERs R&D expenditures and R&D personnel. Neither the government nor enterprises pay attention to marine RERs R&D, particularly developing marine countries' governments lack marine RERs R&D planning. The existence of these problems will hinder the increase in marine RERs output.

CONCLUSION

This study focused on four theoretical hypotheses. Firstly, there is more room to plan R&D of RERs in developing marine countries. Secondly, mature technology provides a technological platform for planning the R&D of RERs. Thirdly, immature technologies provide technical and environmental challenges for planning of R&D of RERs. Fourthly, the previous plan of RERs needs to be continuously updated to increase the content of the marine R&D plan of RERs.

From this, four conclusions were established by using a DDD model and wise pig game model. First, the existing RERs planning of marine developing countries has a positive impact on the output of RERs, which shows that marine developing countries are correct in planning for RERs. Second, CO₂ emission, GDP per capita and R&D personnel also have

a positive impact on the output of marine RERs, which are variables that affect the output of RERs in addition to RERs planning policies. Third, the difference between the expected return of the government planning for R&D of RERs and the expected return of the government not planning for R&D of RERs is maximized, when the government has a probability of 2/3 for planning the R&D of RERs and the probability of a successful planning is 1/2, while the company conducts R&D of RERs with the probability of $1 - (\text{GDP} + 2C_{\text{R\&D-g}}) / (\text{SC} - C_{\text{swl}})$ and the probability of R&D successful is any value. The game payment that the government can obtain is the sum of GDP, social welfare (such as from having a green environment) and the cost of social welfare losses (such as the cost of haze, air pollution, the consumption of petrochemical energy, etc.), minus the cost paid for R&D of RERs by the government, which is $\text{GDP} + \text{SC} - C_{\text{R\&D-g}} + C_{\text{swl}}$. That is, if the government successfully plans for the R&D of RERs, and at the same time the enterprise joins the government's planned R&D of RERs' immature technology, the government can obtain the maximum benefits of the R&D plan of RERs' immature technology. Fourthly, all marine developing countries or their alliances need to plan for R&D of marine RERs. RERs' R&D planning needs to be carried out on the theoretical basis of this article, and RERs need to seriously consider R&D plans in immature technical fields.

Our most important contribution is to clarify the direct and indirect economic mechanisms for the increase in marine renewable energy output, and to emphasize the importance of marine RERs R&D planning in developing marine countries for which little work has been carried out by academia thus far. Furthermore, this work points out the main technical fields where RERs R&D planning can be carried out. Ultimately, it provides a basis on which further research and investigation can be pursued.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

XO contributed to the idea of the manuscript, gathered and analyzed the data, designed the models, and drafted the article. PF and PY discussed the model and the results. AM revised the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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