Original Article

Policy implication of nuclear energy's potential for energy optimization and CO_2 mitigation: A case study of Fujian, China

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A B S T R A C T

China is undertaking an energy reform from fossil fuels to clean energy to accomplish CO_2 intensity (CI) reduction commitments. After hydropower, nuclear energy is potential based on breadthwise comparison with the world and analysis of government energy consumption (EC) plan. This paper establishes a CI energy policy response forecasting model based on national and provincial EC plans. This model is then applied in Fujian Province to predict its CI from 2016 to 2020. The result shows that CI declines at a range of 43%—53% compared to that in 2005 considering five conditions of economic growth in 2020. Furthermore, Fujian will achieve the national goals in advance because EC is controlled and nuclear energy ratio increased to 16.4% (the proportion of non-fossil in primary energy is 26.7%). Finally, the development of nuclear energy in China and the world are analyzed, and several policies for energy optimization and CI reduction are proposed.
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1. Introduction

China is the largest energy-consuming country worldwide, accounting for 23% of global energy consumption (EC) in 2015 [1] and the largest CO_2 emissions (CE) since 2012 [2]. These findings have increased international pressure on China to control its emissions. Therefore, China has pledged to reduce its CE per unit GDP, i.e., CO_2 intensity (CI) by 40%—45% in 2020 compared to the 2005 level and seek to meet the emission peak before 2030 [3]. However, studies have predicted that China's emissions peak would emerge in 2035 and 2047 [4,5]. Simultaneously, China is at a crucial economic development period marked with massive energy consumption. The use of coal as the main energy source in China accounts for the large gaps among the average energy optimization level of China, the United States (US) and the world. These gaps necessitate rigorous emission reduction. Therefore, energy structure reform is inevitable. The government has set specific goals that non-fossil energy in primary energy consumption accounts for 15% and 20%

by years 2020 and 2030, respectively. China's energy reform can be seen from the three Five-Year Plans (Fig. 1). The usage priority of different energy categories reveals the energy structure tilting from fossil fuels to clean energy, and particularly promotes the ranking of nuclear energy. Coastal area has become an essential part of nuclear power development with a high energy optimization level [6]. Simultaneously, as China's most well-developed, major energy consumption and emissions regions, to study whether its energy structure optimization can achieve the national emission reduction target or not is particularly important.

A number of studies have focused on the decomposition of CE drivers, which investigated the factors affecting emission at the national [7—11], sector [12—14] and regional levels [15,16]. Considering different research methods, scopes, and time periods selected, the contributions of various factors are slightly different. Simultaneously, these studies collectively prove that adjusting the energy structure positively reduces emission; however, it fails to specify the energy plans in different regions considering various energy optimization levels, especially in the nuclear energy development plan, although several studies in South Korea, EU, and China [17—20] have indicated that the usage of nuclear power can reduce emissions. Provinces are practical implementers of CI reduction goals in China. Given China's massive potential for future nuclear energy development, providing a specific and feasible

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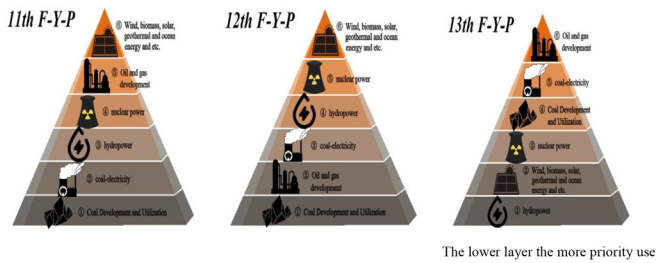
Fig. 1. Energy use priorities pyramid map of the three five-year plans.

nuclear energy adjustment plan for provinces is necessary. To fill these gaps, Fujian Province, which was designated as the first provincial ecocivilization construction demonstration area and the first national ecological civilization experimental area in China, was chosen as the specific study area in this paper. Thus, its EC structure will be forecasted and then its CE and CI will be calculated during 13th Five-Year Plan (2016–2020) to analyze whether it can achieve the national goals in energy optimization and emission reduction, for providing a learning reference for other provinces in China or even areas of other developing countries.

This paper is arranged as follows. In Section 2, the EC structure in the world, as well as in China and Fujian Province will be compared. The statuses of the nuclear energy development and the nuclear power plant in China will be analyzed. A CI energy policy response forecasting model based on national and provincial EC plans is established. This model includes a hybrid GA-BP neural network model for EC prediction and the calculation methods of CE and CI. The results of the predicted energy structure in Fujian, including CE and CI will be analyzed in Section 3. Meanwhile the necessary development of nuclear energy in China, the situation, and the problems that should be addressed by the world's nuclear energy will be discussed. Suggestions will be presented to forward policy in order to achieve low carbon emissions in China and other developing countries at the end of the paper.

2. Methods

2.1. Material overview

2.1.1. Comparison of the primary energy consumption structure between the world and China

China is the world's most energy-consuming country with a consumption of 3014.0 Mtoe (million tons of oil equivalents) in 2015, followed by the US at 2280.6 Mtoe; the difference is up to 32%. In China, coal decreased slightly from 65.6% to 63.7% during 2014–2015; however, this is still far higher than the world average (29.2%) and the US (17.4%). China's oil production ranks fourth in the world, following Saudi Arabia, US, and Russia, and it ranks second to the US in oil import. China's oil consumption is 18.6% lower than the world average (32.9%) and the US (37.3%), whose natural gas production consumption rank sixth and third worldwide, respectively. But its ratio at 5.9% in 2015 is far below the world average (23.8%) and the US (31.3%). Hydro-electricity accounted for 8.5% in China, which is higher than the world average and the US levels at 6.8% and 2.5%, respectively; however, it still has a huge gap compared to Norway (66%), Sweden (31.9%), Switzerland (30.4%), Brazil (27.9%), New Zealand (26.7%), and Canada (26.3%). Although the installed capacity and power generation of renewables in China rank first in the world, renewables only account for 2.1%, slightly less than the world average (2.8%) and the US (3.1%). Nuclear energy in China accounts for only 1.3%,

which is lower than that of the world average (4.4%) and far from that of the US (8.3%) [21].

Fig. 2 shows that the difference in the total proportion of fossil fuels and non-fossil fuels in China (88.2%, 11.8%), the World (85.9%, 14.1%) and the US (86%, 14%) is not significant. However, the use of coal as China's primary fossil energy source mainly accounts for the massive gaps among the average energy optimization level of China, the US and the world. This situation cannot be changed immediately. Among the renewable energy, China occupies a total proportion of 10.6% including hydro-electricity and renewables, exceeding that of the world average (9.6%) and the US (5.6%). This finding is accounted for by China occupying the leading position in hydroelectric development globally with the world's largest hydro-electricity station, the Three Gorges Dam, constructed in China.

In addition, the proportion of renewable energy in total energy consumption is shown in Fig. 3 [22], where the world average is approximately 10% and the US 4% from 1990 to 2014, whereas that in China greatly decreased. Hydro-electricity contributes most in renewable energy; however, its growth in China in 2015 (+5%) is less than half that of the historical average, which implies a lack of stamina. Although the nuclear energy ratio in China is lower than the world's average, especially compared to the US, the nuclear energy growth rate is up to 28.9%, which is more than twice the average of 12.4% over the past decade. China's nuclear power generation has surpassed that of South Korea, ranking fourth in the world [1]. Given that the Chinese government regards nuclear energy development with immense importance (Fig. 1), this energy can facilitate the energy reform greatly after the hydro-electricity.

2.1.2. Analysis of the primary energy consumption structure in Fujian Province

Given that the Statistical Yearbook of Fujian (2016) only includes data on hydro, nuclear, and wind powers in non-fossil energy, these three non-fossil energies are considered in this paper [23]. In this study, the optimization of energy structure refers to the proportion increased in non-fossil energy (hydro, nuclear and wind power) or share decreased in fossil energy (coal, oil and natural gas) in primary energy consumption. Fig. 4 shows that the percentage of non-fossil energy has reached over 15%, or even 20% (national energy optimization goals), in Fujian since 1990, except for individual years (2004, 2011). This finding indicates that the energy structure optimization level of Fujian has constantly surpassed that of the national level. However, the non-fossil energy share in different periods involved different situations, which can be divided into three sections. Stage I (1990–1997) the proportion increased in
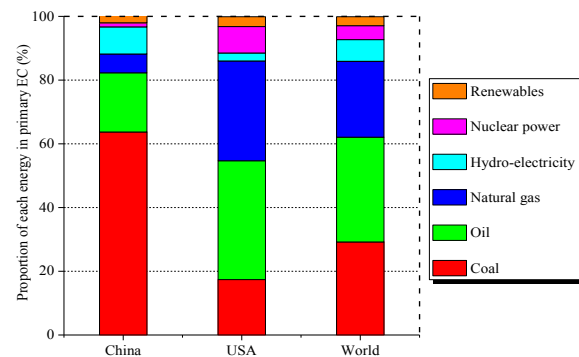
Data from the BP Statistical Review of World Energy (June, 2016)

Fig. 2. Comparison of the primary energy consumption between the world and China in 2015.
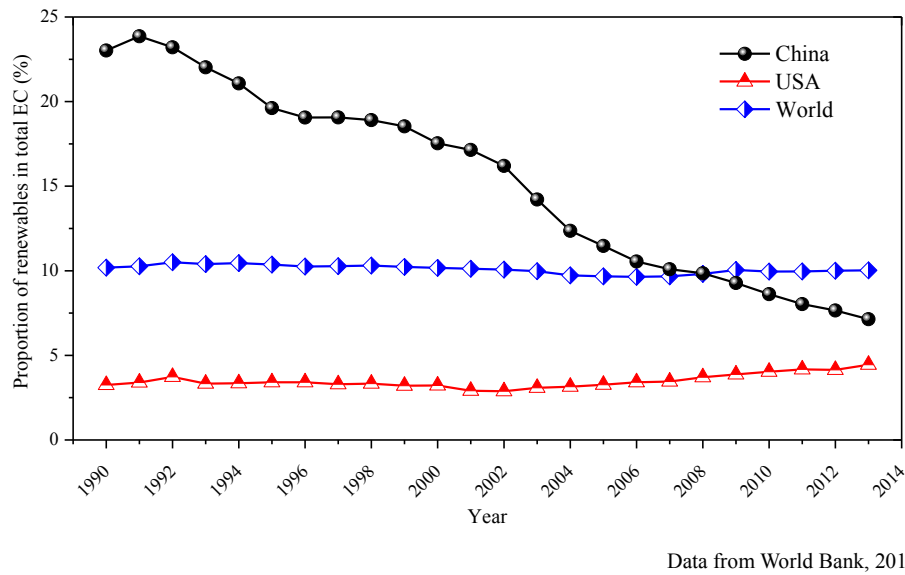
Data from World Bank, 2014

Fig. 3. Share of renewables in total energy consumption from 1990 to 2014.

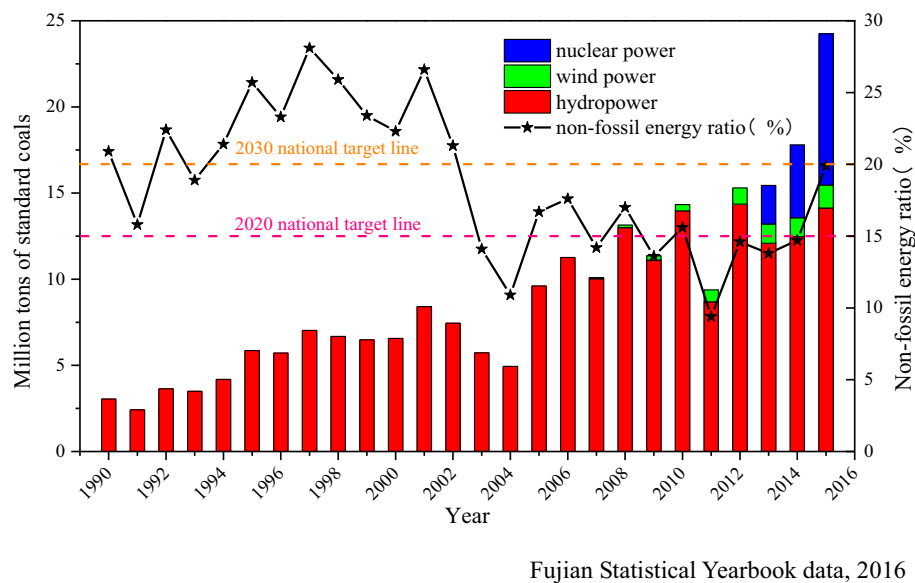Fujian Statistical Yearbook data, 2016

Fig. 4. Non-fossil energy amount and proportion in Fujian (1990–2015).

waves that fluctuant declined in Stage II (1997–2012). In the recent years of Stage III (2012–2015), the proportion rose again. The continuously increasing trend in the proportion of Stage I was accounted for by the hydropower addition and the low overall energy consumption. The decline in Stage II is attributed to the economic development that dramatically increased total energy consumption, especially fossil energy. Nuclear and wind power increased the ratio in Stage III again, which are 7.2% and 1.1% in 2015, respectively. Nuclear power is the main energy optimization after hydropower.

2.1.3. Nuclear energy development in China

China owns the world's most nuclear power plant (NPP) units under construction and the third largest total number of NPP units in operation. To date, China has 36 NPP units in operation with a total installed capacity of 32520 MW, and 21 NPP units under construction with a total installed capacity of 24040 MW. In 2015, nuclear power generation has accounted for 3.03% in national electricity production [24]. The goal of nuclear power in 2020 is to achieve 58 GW installed capacity and 16.5% average annual growth rate [6]. Evidently, the 13th Five-Year Plan on energy development indicates the focus on developing the "coastal nuclear power belt" (Fig. 5) China's coastal areas are far from the regions that produce coal and gas, whereas the rapid economic development in these areas increased energy shortage. Thus, there is a necessity and urgency to develop nuclear energy. Furthermore, these areas have rich suitable plant locations that render nuclear energy practicable. The NPP construction pace to build the "three pillars" of hydropower, nuclear power and thermal power is beneficial in maintaining economic growth while reducing emissions. Among the

coastal provinces, Fig. 5 shows Fujian with the most NPP units at 21 units including those in operation and under construction, as well as planned units [24].

2.2. General methods CO_2 intensity energy policy response forecasting model

This paper establishes a CI energy policy response forecasting model for EC policy adjustment (Fig. 6). Firstly, the province's historical EC data and the country's energy policy guidance are integrated into the GA-BP algorithm to predict the province's EC; secondly, EC is predicted to calculate its CE and CI using the emission coefficient method; thirdly, analyzing whether a province's CI decline can reach the national target or not and combining a province's EC structure adjusts the province's energy policy plan.

2.2.1. Energy consumption prediction
Backpropagation neural network (BP) is a kind of artificial neural network suitable for solving complex and nonlinear prediction problems. However, the BP neural network easily incorporates into the local minimum and lacks of generalization. Genetic algorithm (GA) has excellent global search ability. A combination of GA with BP, GA-BP algorithm can enhance the learning speed and strengthen the approximation and generalization abilities of networks [25–28]. For the prediction problem in this paper, empirical conditions are provided into the GA and then combined with the BP for an accurate prediction.

Using the Matlab2010a GUI toolbox based on the GA-BP algorithm, 1990–2015 energy data samples of Fujian are selected for training to forecast their EC from 2016 to 2020 (Table 2). The empirical conditions are summarized mainly from three aspects: the actual and expected average annual growth rates of the energy data in Fujian during the 12th Five-Year Plan (2010–2015) and the energy development instruction in China in the 13th Five-Year Plan (2016–2020) (Table 1).

2.2.2. Calculation of CO_2 emissions
The methods used to measure CE are the measured, material balance, and emission coefficient methods. The most used method in the academia is last one [14,29–31]. This paper uses three categories of fossil energy classification (coal, oil, and natural gas) to calculate emissions. Emissions originated from both combustion and production processes. The industrial production of CE comes from the production processes of cement, lime, calcium carbide,
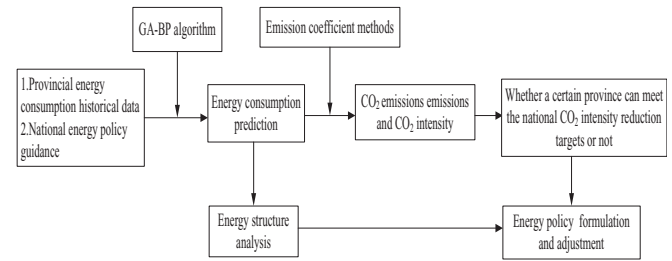

Data from IAEA, PRIS, China, 2017

Fig. 5. Distribution of NPPs in China.

Fig. 6. CI-energy policy response forecasting model.

and steel among others. Given that the statistical yearbook data is incomplete and the cement production process produces the largest proportion of emissions, this study only considers the emissions from the cement production process and selects the calculation method of the Oak Ridge National Laboratory, 1990.

$$CE = \left(EC_{coal} \times 0.720 + EC_{oil} \times 0.585 + EC_{natural\ gas} \times 0.404 \right. $$
$$\left. + EC_{cement} \times 0.136 \right) \times 44/12$$

The carbon emission coefficients for coal, oil, natural gas, and cement are 0.720, 0.585, 0.404, and 0.136 respectively; 44/12 is the convention coefficient from carbon to CO_2.

2.2.3. Calculation of CO_2 intensity
GDP is measured in RMB, and this paper uses the Fujian's GDP in the year 2005 as the base year constant price for calculating each year's actual annual GDP [32].

$$CI = CE/GDP_{base2005}$$

China's GDP growth slowed from 10.45% in 2010 to 6.9% in 2015. However, to meet the Chinese government's goals of doubling the GDP of year 2010 in year 2020, 6.5% of the GDP growth is settled as the bottom line [33]. Considering that the GDP of Fujian dropped from 13.9% to 9% during 2010–2015, five different GDP growth rates at 6%, 7%, 8%, 9%, and 10% are selected as prediction scenarios to forecast the CI in Fujian (6% and 10% GDP growth rates are the two limits that cannot be actually achieved to calculate the two extremes of CI).

2.3. Data sources

The forecast data sample used in this paper are all from the Statistical Yearbook of Fujian Province (2016); the specific energy data are shown in Table 2.

3. Results and discussion

3.1. Prediction of primary energy consumption in Fujian

3.1.1. Total energy consumption
Fig. 7 indicates a slowed growth trend of the total primary energy consumption in Fujian. From 2005 to 2014, the total energy consumption in Fujian increased from 57.6 to 121.1 million tons of standard coal, with an increase of 110%. During 2015–2020, the total energy consumption will rise from 121.8 to 162.5 million tons of standard coal, with an increase of 33%.

3.1.2. Energy structure
In spite of the continuous growth in fossil energy consumption (Fig. 7), Fig. 8 shows that the proportion of coal will drop from 54% in 2005 to 47% in 2020; this value is still high and the decline is

Table 1
Empirical conditions of the GA.

Types of energy	Expected average annual growth rate (12th FYP of Fujian)	Real annual average growth rate (12th FYP of Fujian)	Instruction (13th FYP of China)	Empirical Conditions (Given average annual growth rate)
Coal	7%	3.9%	controlling	≤3.9%
Oil	8%	5.6%	stabilizing	≤5.6%
Natural gas	24.6%	9.6%	increasing	≥9.6%
Hydropower	0.36%	0.2% (saturation)	increasing	≤0.2%
Wind power	48%	29.5%	increasing	≥29.5%
Nuclear power	–	31.4% (2013−2015)	increasing	≥31.4%

Table 2
Energy consumption data of Fujian (1990−2015).

| EC (10 thousand tons of standard coal)	Total EC	Coal	Oil	Natural gas	Hydropower	Wind power	Nuclear power	Cement (10 thousand tons)
Time								
1990	1458.3	977.06	176.45	0	304.78	0	0	540.04
1991	1530.56	1085.17	203.56	0	241.83	0	0	646.87
1992	1624.05	1041.02	219.25	0	363.79	0	0	747.62
1993	1848	1143.91	354.82	0	349.27	0	0	902.39
1994	1953.54	1170.17	365.31	0	418.06	0	0	1104.2
1995	2279.91	1249.39	444.58	0	585.94	0	0	1511.17
1996	2452.18	1358.51	522.31	0	571.36	0	0	1504.52
1997	2499.11	1269.55	527.31	0	702.25	0	0	1522.42
1998	2578.62	1338.3	572.45	0	667.86	0	0	1594.46
1999	2771.64	1493.91	629.16	0	648.56	0	0	1825.81
2000	2942.6	1600.77	685.63	0	656.2	0	0	1513.64
2001	3163.09	1625.83	695.88	0	841.38	0	0	1525.53
2002	3492.11	2010.12	860.45	0	744.76	0	0	1698.69
2003	4062.55	2494.41	995.32	0	572.82	0	0	2116.27
2004	4527.8	2888.74	1136.48	9.06	493.53	0	0	2245.34
2005	5753.99	3417.87	1369.45	5.75	960.92	0	0	2713.62
2006	6396.85	3825.32	1439.29	6.4	1125.85	0	0	3343.93
2007	7109.26	4471.72	1620.91	7.11	1002.41	7.11	0	4449.69
2008	7734.2	4841.61	1554.57	23.2	1299.35	15.47	0	4593.36
2009	8353.67	5471.65	1628.97	116.95	1111.04	25.06	0	5446.5
2010	9189.42	5090.94	2278.98	385.96	1396.79	36.76	0	5793.2
2011	9980.23	6187.74	2395.26	459.09	868.28	69.86	0	6570.86
2012	10479.44	5983.76	2462.67	503.01	1435.68	94.31	0	7197.6
2013	11189.91	6367.06	2618.44	660.2	1208.51	111.99	223.8	7890.37
2014	12109.72	6418.15	3245.4	666.03	1247.3	108.99	423.84	7732.33
2015	12179.97	6150.88	2996.27	609	1412.88	133.98	876.96	7746.18
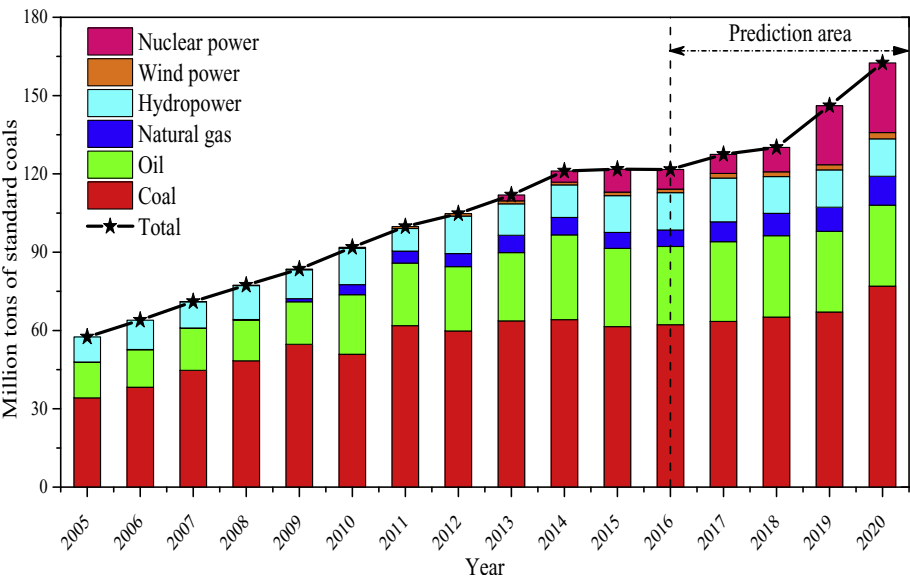
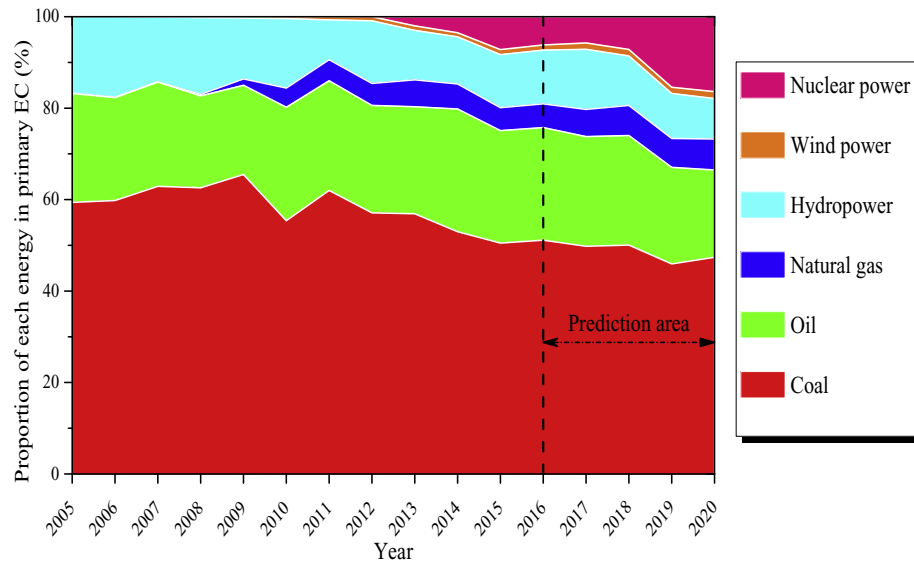Fig. 7. Primary energy consumption of Fujian (2005−2020).

Fig. 8. Energy structure in Fujian (2005–2020).

slow. This finding indicates that Fujian has already completed the national goal in comparison to the coal-drop target from 66% to 60% declared in the 13th Five-Year Plan. The proportion of oil, which fluctuates between 20% and 25% in 16 years, will be relatively stabilized. The share of natural gas will rise sharply from 0.1% in 2005 to 6.8% in 2020. Among the non-fossil energy, wind power will increase from 0.1% in 2007 to 1.5% in 2020. Given that Fujian is incapable of using nuclear energy until 2013, the province will experience a huge increase from 2% to 16.4% in 2020. Compared to the rapid growth of nuclear and wind power, the proportion of hydropower will drop from 16.7% in 2005 to 8.8% in 2020, which is the result from its saturation since 2006. Moreover, increasing wind and nuclear power reduces the hydropower proportion.

Noticeably, for wind and nuclear power, the average annual growth rate given by the empirical conditions in Section 2.2.1 are all greater than or equal around 30%; however, the shares of wind and nuclear power will be 1.5% and 16.4%, respectively as indicated in the forecast results in 2020. The total non-fossil energy will account for 26.7% in primary energy, indicating that nuclear power will occupy the largest proportion and will be the main force of clean energy optimization. According to the state nuclear energy development plan, nuclear power will rapidly grow in Fujian, such that, by 2020, nuclear energy will account for 14%–20% of the provincial energy structure [34]; 16.4% of nuclear power is within the scope of national planning, making the prediction is reasonable.

3.2. CO₂ emissions and CO₂ intensity in Fujian

3.2.1. CO₂ emissions

A maximum CE of 0.32 billion tons will evidently emerge in 2020 during the 13th Five-Year Plan period. The CE increased from 0.13 to 0.29 billion tons from 2005 to 2014 with an increase of 116%. By contrast, an increase of 18% from 0.27 to 0.32 billion tons will emerge during 2015–2020. The CE of Fujian will depict an increasing trend, which slowed down after 2014 (Fig. 9).

3.2.2. CO₂ intensity

The CI in Fujian in 2015 is 35% lower than that in 2005 and only 5% less than the national target of the 40%–45% decline in 2020. Table 3 illustrates the CI decline of the predicted year based on 2005. Fujian will basically complete the national goal of CI cutting down target ahead of time by around 2016–2017 under the five

scenarios of GDP growth rate. CI will decrease from 43% to 53% in 2020, with a different velocity to fulfil the commitments at varying GDP growth rates. Furthermore, it is estimated that when the GDP growth rate is greater than or equal to 14%, Fujian can achieve the national goal of reducing CI to 60%–65% in 2030 by around 2019–2020. Although this GDP growth rate appeared merely in the last decade, when China slowed down the pace of economic development to pursue steady development, the GDP growth rate of Fujian in the next five years is hardly up to 10%, hence this consequence is impossible. Overall, Fujian can complete China's targets of CI reduction in 2020 in advance.

In the five economic development scenarios selected in this paper, the two extremes of GDP, 6% and 10%, are excluded. Based on the 2005 data, Fig. 9 shows that CI will decrease by 16%, 20%, and 23% in 2020 when the GDP growth rate is 7%, 8%, and 9% respectively. Generally, CI tends to decrease as the GDP growth rate increases. In 2015, the CI of Fujian was 35% lower than that of 2005. The decade will witness almost twice the CI drop in the latter five years (2016–2020) at a GDP growth rate of 7%. However, when the GDP growth rate is 8% and 9%, CI will decline more than the previous decade. Given the GDP growth rate of Fujian at 9% in 2015, the CI in the next five years will decrease to least equal to that of previous years or even more. By the end of 2020, it is predicted that the lowest CI of Fujian will occur in 2019 are 1.04, 1.0, and 0.96 tons/10^4RMB at three GDP growth rates of 7%, 8%, and 9%, respectively.

The CE growth will generally decelerate and the CI will decrease in Fujian from 2005 to 2020 (Fig. 9), simultaneously the CI reduction target will be achieved ahead of schedule (Table 3). According to the analysis in Section 3.1, this outcome is closely related to the provincial control of total EC and the development of nuclear energy. Moreover, results indicate that the higher non-fossil energy proportion is, the lower the CE and CI.

3.3. Necessity of nuclear energy development in China

The nuclear energy development (16.4%) in Fujian will help realize the CI reduction targets, which provides a reference for other provinces in China, especially along the coastal areas considering China's uneven energy distribution. Non-fossil energy such as water resources are mainly distributed in the southwest region; solar energy resources are mainly distributed in the northwest and the Qinghai-Tibet Plateau; and wind energy resources are mainly
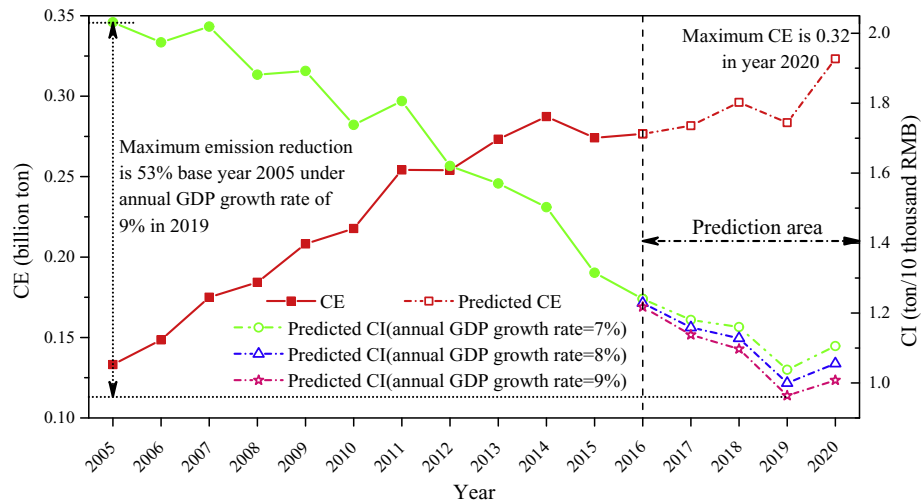
Fig. 9. CE and CI in Fujian (2005−2020).

Table 3
Decreased levels of CO_2 intensity compared to 2005 in the Fujian.

Time	2016	2017	2018	2019	2020
GDP growth rate					
6%	**−0.38**	−0.41	−0.41	−0.47	−0.43
7%	**−0.39**	−0.42	−0.43	−0.49	−0.46
8%	−0.40	−0.43	−0.44	−0.51	−0.48
9%	−0.40	−0.44	−0.46	−0.53	−0.50
10%	−0.41	−0.45	−0.47	−0.54	−0.53

distributed in the northwest inland (land wind) and the eastern coastal areas (sea wind). Energy resources are scarce for China's most economically developed eastern coastal areas. The transportation of clean energy from the south-western region to the east has immense financial costs and energy losses. Hydropower is the most technology mature and economically renewable energy in China. Thus, developing it in advance is indispensable (Fig. 1), and hydropower in China is already ahead worldwide. However, hydropower is unstable because water flow varies between the wet and dry seasons. Meanwhile, the construction of hydroelectric stations requires a large number of migrant works, and will affect ecological landscape and the daily lives of the residents of the area. In addition, coastal water resources for power generation are scarce; thus, they fail to meet energy needs even if at full development (such as Fujian Province). In contrast to other renewable energies such as solar and wind energy, reliability is a significant merit of nuclear power. Especially in China in 2008, a large range of snow and ice disasters occurred in the southeast areas, the region's power generation generally relies on the long-distance transport of "north coal to the south". Frozen snow seriously impacted the transport of coal, which affected a population of up to 100 million. Seven inland provinces such as Anhui, Jiangxi, and Hubei suffered the most, which drew people's attention to China's energy security system. NPPs require only a small amount of nuclear fuel to produce a large quantity of electricity. Developing nuclear power can reduce the risk for single-energy dependence and extreme weather. Therefore, increasing nuclear energy for the coastal and inland areas in China is conducive to reduce CE and energy security.

3.4. Analysis of nuclear energy in the world

3.4.1. Development status quo

The panic for nuclear power safety after the Fukushima nuclear crisis led to some countries in Europe abandoning nuclear power (Germany and Switzerland announced that will give up nuclear power in 2022 and 2034, respectively; Italy also abandoned nuclear after the referendum) or suspend or slow the development of nuclear power, turning to renewable energy [35]; however, most countries choose to continue nuclear development at a slow speed [36] (Fig. 10).

Fig. 11 shows that the ratio of the nuclear power to the total power supply in developed countries is generally over 30%. In contrast, the nuclear proportions in developing countries are generally less than 5%, which far below the world average 11.5% [37], indicating that nuclear energy in developing countries has great development space. In fact, this applies not only to China as India's nuclear power development goal is to increase this share from 3.5% in 2015 to 25% in 2050. Although South Africa is the only country in the continent with a nuclear power station, its ambitions to construct another six to eight stations were put on hold in March 2016.

3.4.2. Public awareness of nuclear power

3.4.2.1. Pertinent issues. The safety of nuclear power is relative. It is safe under strict supervision, reasonable location, and technical progress, but extremely dangerous under chaotic management and

Sourced from various resources and compiled by the Zeng Ming et al., 2015

Fig. 10. Summary of the world's nuclear policy changes after the Fukushima accident.
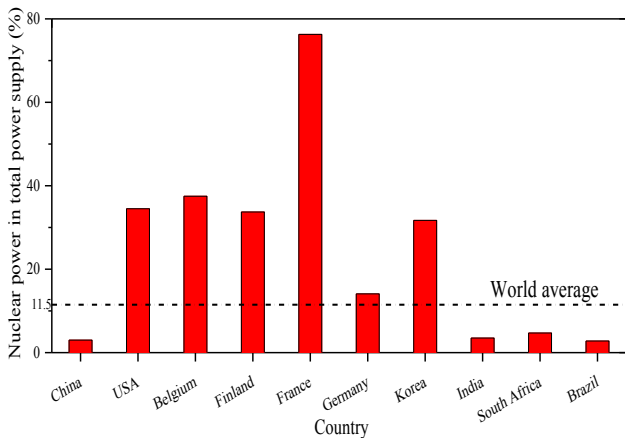
Data from IAEA, PRIS, Nuclear Share of power Generation in 2015

Fig. 11. Nuclear power share in the total power supply of each country.

radical technology [38]. The Fukushima nuclear crisis in Japan is an error stacking result of serious natural disasters and man-made responses. The local history of the tsunami is not considered in choosing the nuclear power plant site, and people failed to attach sufficient importance to small probability events such as an earthquake, which in return caused the tragedy. The reality about nuclear power is perceived as danger by the public after the incident. Furthermore, public opinion greatly influences government policy-making, especially in developed countries, which is the main reason why some European countries abandoned nuclear power. The public's concern about nuclear power is not how much electricity can be provided or how much environmental pressure is relieved or how much revenue is generated locally, but whether nuclear power is unsafe and has a negative influence on one's own life. Nuclear leakage causes public suspicion of nuclear safety, and such a feeling can hinder the development of nuclear power. The specific performances are the following three points:

a. Cognitive bias of nuclear safety: The probability of the occurrence of extreme accidents that may emit large amounts of radioactive substances in nuclear power plants can be controlled at 10^{-4}-10^{-6} per reactor per year. However, in the public mind, "very low probability event" and "impossible event" greatly differ.

b. Incomplete nuclear information: Given the special nature of nuclear power, public access to nuclear power information is limited. When people do not form a rational, correct, and fixed perspective because they lack clear background information, they may obtain false facts. The Internet has become one of the main ways for the public to obtain information, and negative or wrong information spread by the network can easily be strengthened and amplified, thereby forming a sense of fear and resistance from nuclear power in the public.

c. Distrust of authoritative institutions: After the Fukushima accident, surveys showed that public acceptance of nuclear energy decreased significantly, leading to a state of stagnation in Japan's nuclear plans. Another example is China's Jiangmen-Heshan industrial park for nuclear fuel. The government planned to build a large-scale nuclear fuel processing plant, but residents believed this project did not have sufficient environmental impact assessment and public consultation. Thus, a group protest was organized, and the project was cancelled. Except for

these factors above, the level of knowledge, life background, values, gender, economic status, occupation, and other factors can also affect the degree of public acceptance of nuclear power.

3.4.2.2. France as inspiration for public acceptance of nuclear power. France's nuclear power generation accounts for about 75% of the total power supply. The country ranks first in the world in terms of nuclear power supply, and this status results from the public's long-term support of nuclear power development. France has formed a complete legal system, and its experience of public communication in nuclear energy development can provide a good reference for other countries. Its main features are as follows.

a. The country has an advanced system of laws and regulations that can be observed by public communication work. Relevant laws and regulations are mainly "Environmental Code", "Nuclear Transparency and Security Law", "Civil Relations Act of Administrative Law", and "Administrative Relations and Public Relations Act."

b. Focusing on the right of citizens to knowledge, relevant departments were established to protect public access to nuclear power information. France established the "advanced committee on information transparency in nuclear energy" (consulting agency) and "local information committee" (regulatory authorities). The former is responsible for coordinating public communication throughout the country, finding issues, and providing measures. The latter is responsible for supervising the open information in nuclear power plants and encouraging information dissemination to the public based on the distribution of nuclear power plants.

c. The media provide accurate reports on plans and recommendations of nuclear power via a comprehensive online public communication strategy. Nuclear sites publish monthly environmental conditions, and a toll-free hotline was made available to answer calls from the public. Moreover, nuclear power plant organization visits (about 2000 times a year) are organized yearly, and thematic and periodic media information is published.

4. Conclusions and policy implications

The study establishes a CI energy policy response forecasting model to apply energy policy adjustment in Fujian province. Results show that controlling total energy consumption and increasing proportion of nuclear energy will allow Fujian to complete the national CI reduction target in 2020 ahead of schedule. For Fujian, the nuclear energy in primary EC at the ratio of 16.4% can become a reference value when formulating EC policy. For other regions, especially for coastal areas in China, Fujian provides a feasible means to reduce emission and to cultivate energy security. China's nuclear power units under construction rank first in the world but its nuclear power share in electricity supply have a big gap compared to developed countries, even much lower than that of the world average. Therefore, China should vigorously develop coastal nuclear power plants as demonstration projects for inland areas. Nuclear energy has huge development potentials not only in China, but also in other developing countries. Raising nuclear energy share is a feasible means to complete CI reduction target in developing countries. Finally, through the comparative study of nuclear power development in the world, guiding the public in cognition of nuclear energy correctly and actively by the government, whether in developing or developed countries, is crucial in nuclear development. The main factors affecting the acceptance of nuclear power are the particularity of nuclear energy, access to

nuclear information, trust towards the government, and familiarity to nuclear power. Therefore, this paper proposes the following suggestions to improve public acceptance of nuclear power.

(1) Improve nuclear legislation and establishment of departments related to public communications to protect and implement the public's right to know about nuclear power.
(2) Strengthen the dissemination of nuclear knowledge. The public should have the opportunity to learn about new developments in nuclear energy use and nuclear waste disposal technologies. Such opportunities can dispel public doubts and fears about nuclear power.
(3) Set a good image of nuclear power enterprises. Nuclear power plants work with residents to establish a good relationship during operation. The residents around nuclear energy facilities need to receive health education, health checks, and health advice. If radiation environmental monitoring data and health monitoring data are regularly published, the locals can obtain a rational and comprehensive understanding of nuclear power to eliminate their doubts.

The public's fear of nuclear power stems from nuclear radiation. Nuclear technology must be improved to enhance the safety of nuclear facilities. Developing environmentally friendly nuclear waste disposal methods and strengthening supervision of existing nuclear waste disposal sites can prevent the occurrence of nuclear accidents.

Notation

The following symbols are used in this paper:
$CE = CO_2$ emissions;
$CI = CO_2$ intensity;
EC_{cement} = energy consumption of cement;
EC_{coal} = energy consumption of coal;
$EC_{natural\ gas}$ = energy consumption of natural gas;
EC_{oil} = energy consumption of oil;
$GDP_{base2005}$ = Fujian's GDP in the year 2005 as the base year constant price;

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