How Can China Achieve Its Non-fossil Energy Target? An Effective Allocation of China's Renewable Electricity Consumption Obligation

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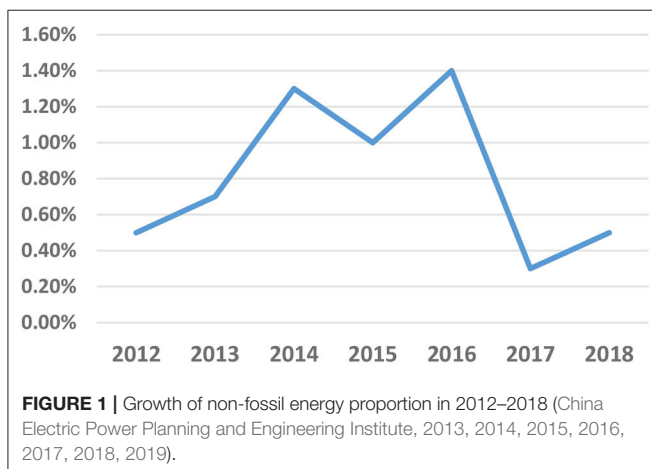
Promoting the consumption of renewable energy is an important way to optimize power structure, control greenhouse gas emissions and fulfill Intended Nationally Determined Contributions (INDCs) in the Paris Agreement. China's INDCs is to reduce carbon intensity by 60–65% in 2030 (compared to 2005) and promote non-fossil energy consumption proportion in primary energy consumption to 20%. On one hand, China has accomplished its 2020 carbon intensity target in 2017; on the other hand, China also faces certain difficulties achieving the target of 15% non-fossil energy consumption proportion in 2020 and 20% in 2030. Setting appropriate annual overall renewable electricity consumption (REC) and allocating it at sub-national scales can help China reach both carbon intensity and non-fossil energy consumption proportion targets. To this end, we couple the "top-down" and "zero sum gains-data envelopment analysis (ZSG-DEA)" models to form a comprehensive model for the appropriate allocation of REC. First, the "top-down" model was used to calculate the annual overall REC based on the non-fossil energy proportion target. Second, we applied the multi-principle "ZSG-DEA" model to allocate the overall REC effectively among provinces. Based on our analysis, the total REC which can be reached by Chinese government's policy of renewable electricity consumption guarantee mechanism (REC guarantee mechanism) still needs to increase by 15.36 to 20.25% compared with the overall REC calculated by our effectiveness model. In order to achieve non-fossil energy target, 26 provinces need to increase the consumption of renewable electricity compared to their initial shares required by the REC mechanism, most of which are developed coastal areas. Our empirical results provide a scientific basis for the Chinese government to achieve its non-fossil energy targets through the REC guarantee mechanism. We also provide policy makers with ideas for determining the total amount of REC and adjusting the province's consumption responsibility.

Keywords: Intended Nationally Determined Contributions (INDCs), Zero sum gains-data envelopment analysis (ZSG-DEA), renewable electricity consumption, allocation, top-down model

INTRODUCTION

The development and utilization of non-fossil energy has become an important way for countries around the world to ensure energy security, protect the environment, and respond to climate change (National Development and Reform Commission, 2017). China, as the world's largest greenhouse gas emitter (Zhou et al., 2012), announced its INDCs in 2015, which proposed that its carbon dioxide emissions peak around 2030, striving to reach the peak as soon as possible; the intensity of CO_2 emission reduces by 60% to 65% in 2030 compared to the level of 2005; the proportion of non-fossil energy in primary energy consumption increases to about 20%; the 2030's volume of forest reserves increases by 4.5 billion m^3 compared with 2005 (Ye et al., 2017; Mo et al., 2018). In 2017, China's carbon intensity decreased by about 46% compared with 2005. It had exceeded the target of 40–45% reduction in carbon intensity in 2020 three years in advance. However, achieving the target of 15% non-fossil energy in 2020 and 20% in 2030 is still a challenge (Shan et al., 2012; Ye et al., 2017). "The China Energy Development Report 2018" shows that in 2018, non-fossil energy accounts for 14.3% of total primary energy consumption, which means that China needs to increase its non-fossil energy share by at least 0.7% to achieve the 2020 non-fossil energy target. However, as shown in **Figure 1**, the growth of China's non-fossil energy share has significantly slowed down in recent years. Compared with 2016, the non-fossil energy share increased by only 0.3 percentage points in 2017. "China Electric Power Development Report 2017" pointed out that the construction period of nuclear power is extended, and the scale of installed capacity is not expected to meet the planning expectations, which will affect the proportion of non-fossil energy consumption by about 0.2 percentage points.

Non-fossil energy power generation is the main means to increase the proportion of non-fossil energy (Cheng et al., 2010; Shan et al., 2012; Zhou et al., 2012). Studies have shown that the contribution rate of the non-fossil energy power industry to the realization of China's non-fossil energy target is about 80% (Cheng et al., 2010; Ouyang, 2010). Under the influence of the Japanese nuclear leak accident, the development of nuclear power in China has slowed down, which means

the realization of non-fossil energy target will mainly depend on the development of renewable energy in the near future (Cheng et al., 2011). Promoting renewable energy generation and consumption requires a balance between top-level design and the underlying foundation. In terms of top-level design, it is necessary to strengthen national legislation, formulate, and improve a series of policy systems related to renewable energy development, such as green power systems, green energy labeling systems, quota systems, renewable energy generation price mechanisms, and preferential investment, and financing mechanism (Yu, 2013; Liu, 2019), etc. In terms of the underlying foundation, it is necessary to coordinate the construction of renewable energy power generation facilities and renewable energy power transmission channels among provinces and regions (Xu et al., 2015; Wang, 2017), and develop renewable energy power generation technologies and large-scale energy storage technologies (Zhao, 2019), etc.

Since the Renewable Energy Law was officially implemented in 2006, China's renewable energy power industry has developed rapidly. In 2018, the installed capacity of renewable energy was 729 million kilowatts, accounting for 38.4% of the total installed power capacity, and renewable energy power generation reached 1.87 trillion kWh, the share of renewable electricity in total electricity increased from 20% in 2012 to 26.7% in 2018 (Zhao, 2019). However, curtailment of renewable electricity generation -i.e., the abandonment of electricity generation of effective power capacity-is becoming part of the "New Normal"[1] as wind and solar installation expand across the country (Qi et al., 2018). For example, from 2010 to 2018, 219.9 terawatt hours (TWh), or as much as 13 percent of overall wind generation, was abandoned. In order to further promote the consumption of renewable energy, China's National Development and Reform Commission and the National Energy Administration issued the "Notice on Establishing and Perfecting a renewable electricity consumption Guarantee Mechanism"[2] (referred to as the "REC guarantee mechanism") in May 2019, marking China's renewable portfolio standard policy was formally introduced (Li, 2019). The "REC guarantee mechanism" is one of the most important supporting policies in the renewable energy development process following the Renewable Energy Law (Wang, 2019). According to the experience of renewable portfolio standard in other countries, the "REC guarantee mechanism" can effectively achieve China's non-fossil energy target and establish a long-term mechanism to promote the development and consumption of renewable energy (Jin, 2019). As China's main and most restrictive renewable energy policy in the short term, its design plays a decisive role in achieving China's non-fossil energy goals.

The renewable portfolio standard has been widely used in the energy policy design of many countries and regions in the world. Up to now, more than 100 countries or

FIGURE 1 | Growth of non-fossil energy proportion in 2012–2018 (China Electric Power Planning and Engineering Institute, 2013, 2014, 2015, 2016, 2017, 2018, 2019).

[1]China Daily, "The 'new normal' means the Chinese economy has entered a new phase that is different from the high-speed growth pattern exhibited in the past. It is a new trend that features more sustainable, mid- to high-speed growth with higher efficiency and lower costs." http://www.chinadaily.com.cn/opinion/2014-10/10/content_18716671.htm.

[2]https://www.ndrc.gov.cn/xxgk/zcfb/tz/201905/t20190515_962446.html
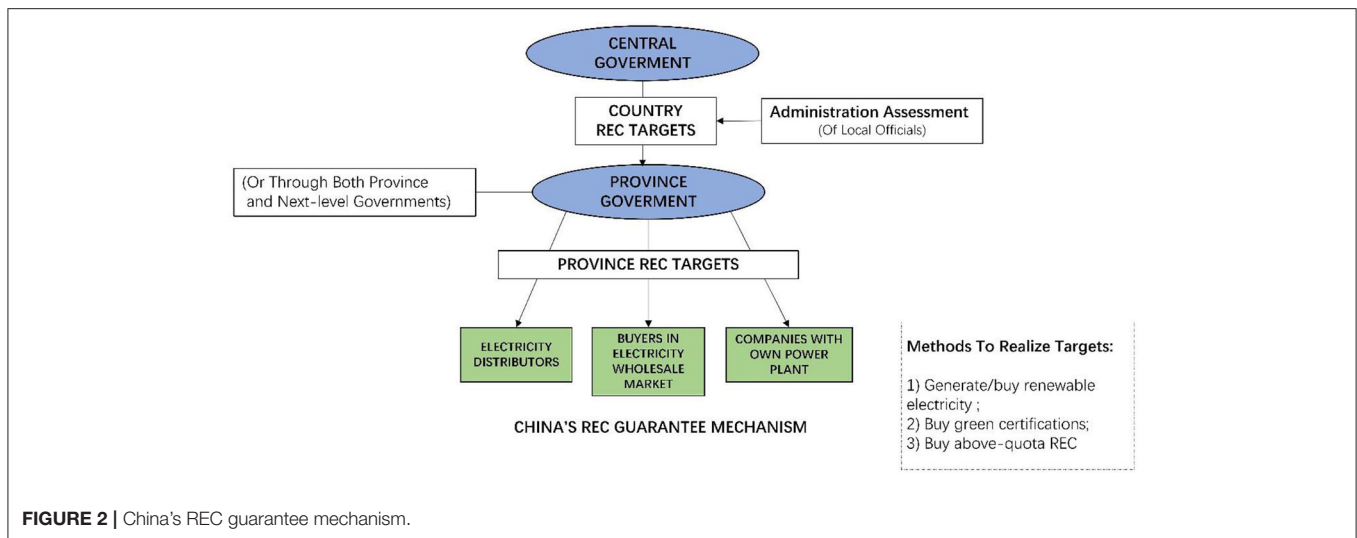
FIGURE 2 | China's REC guarantee mechanism.

federal states (provinces) have implemented different forms of renewable portfolio standard (RPS) (Heeter et al., 2019). The design of the RPS mechanism differs in terms of target, compliance entities, eligible resources, operating mechanisms, and penalties (Ringel, 2006; Li and Chen, 2008; Huang et al., 2013; Linnerud and Simonsen, 2017), etc. The renewable portfolio standard related research is also numerous. The research topics include implementation obstacles, implementation effects, and comparison with clean energy subsidy policies (e.g., Feed-in-Tariff) (Yin and Powers, 2010; Zhao et al., 2014; Chang and Li, 2015; Kwon, 2015; Siddiqui et al., 2016; Wiser et al., 2017; Anguelov and Dooley, 2019). However, it needs to be clear that China's REC guarantee mechanism (**Figure 2**) is different from the RPS in other countries and regions. China's REC guarantee mechanism is that the national-level government places an obligation on provinces to consume a specified fraction of their electricity from renewable electricity, and the provincial government organizes compliance entities to consume renewable electricity in various ways, while other countries' RPS do not set binding goals for the next-level administrative regions (Heeter et al., 2019). The obligatory proportion of renewable electricity (referred to as OP) for each province is the core design of China's REC guarantee mechanism. The OP is set according to renewable power installed capacity, power generation, society's electricity consumption in each province and electricity transmission among provinces, which fully takes the implementation capabilities of provinces into account. However, there are two problems of OP setting: on the one hand, the OP setting is independent of the INDCs, and it remains to be discussed whether the REC guarantee mechanism can achieve the guidance and motivation it should have. On the other hand, only the feasibility of OP is considered, and the principles of equity and efficiency are not taken into account. In view of the above two issues, this paper intends to optimize the allocation of REC in two levels. First, the total amount of REC can effectively achieve the INDCs; second,

the inter-provincial allocation takes the principles of equity, efficiency, and achievability into account.

The related research on the allocation of the constant total amount is more common in the allocation of carbon emission allowance, energy consumption, and so on among regions (Vaillancourt and Waaub, 2004; Miketa and Schrattenholzer, 2006; Wei et al., 2012; Wang H. et al., 2016; Wu H. et al., 2016; Wu J. et al., 2016; Wang Y. et al., 2017) and industries (Mu et al., 2016; Yang et al., 2017; Chastas et al., 2018). Common allocation methods include weighting method (Zhao R. et al., 2017; Chastas et al., 2018; Fang et al., 2018), scenario analysis method (Chen and He, 2016; Zhao Q. et al., 2017), and zero sum gains-data envelopment analysis (ZSG-DEA) (Gomes and Lins, 2008; Lin and Ning, 2011; Sun et al., 2012; Pan et al., 2015; Qian et al., 2015; Xiong et al., 2017). Among them, the ZSG-DEA model does not need to set weights manually, which largely avoids subjectivity and arbitrariness (Fang et al., 2019). It also can improve the technical efficiency of the entire system (Charnes et al., 1978; Banker et al., 1984), and overcome the unreasonable assumptions that the input or output variables of the decision making units (DMU) in the traditional DEA method are not restricted and unrelated to each other (Lins et al., 2003). More and more studies use ZSG-DEA as a reasonable and powerful means to ensure the allocation of resources and emissions. The principles that allocation should follow are also the focus of academic debate. Although the allocation methods used in the previous studies are different, most studies consider the principle of equity to be the primary principle of allocation (Fang et al., 2019). The literature quantifies the principle of equity from different perspectives such as egalitarianism (e.g., carbon emissions per capita; Pan and Zheng, 2009; Raupach et al., 2014), ability to pay (e.g., GDP per capita; Pan et al., 2014), and grandfather rights (e.g., historical carbon emissions; Wang L. et al., 2017). The allocation principles of efficiency (Miao et al., 2016; Zhao R. et al., 2017) and feasibility (Wang et al., 2011) are also increasingly taken into consideration. Including multiple distribution principles can

consider the differences between provinces comprehensively, and ultimately promote the effective implementation of allocation plans (Fang et al., 2019).

Existing literatures on the overall REC allocation mostly use renewable energy potential and consumption as allocation indicators, and the choice of indicators is relatively similar. Wu Rui and He Yongxiu used a top-down decomposition method to construct a target forecasting model for the total amount of renewable electricity and a quota index decomposition model based on renewable energy potential and consumption (Wu and He, 2014). Liu Zhen et al. introduced the EU renewable energy planning model and target decomposition process in detail, and proposed that when the overall target is decomposed into provinces, the renewable energy development potential, economic development level, and the status of renewable energy development should be considered. According to the actual situation in China (Liu et al., 2009), Liu Zhen proposed a target decomposition model based on renewable energy potential and energy consumption (Liu et al., 2011). Since China's REC guarantee mechanism has just been implemented, related research is still at the level of theoretical conception. Actually, there is not much research on the internal logical relationship between China's INDCs and REC allocation. In order to improve the scientific and political relevance of inter-provincial allocation of REC, this paper designs a comprehensive model for the effective allocation of renewable energy consumption based on the INDCs. The model includes two parts: the "Top-down" overall renewable electricity consumption model and a multi-principle allocation model based on "ZSG-DEA." In general, the contributions of this paper are: (1) we consider the differences between provinces comprehensively, and incorporate multiple principles and corresponding indicators into the allocation model of REC; (2) The comprehensive model for the effective allocation of REC clarifies the internal logical relationship among China's INDCs, the overall REC and allocation method, and provides a new perspective for the future related research; (3) The model can actually calculate the effective overall REC and inter-provincial allocation value, to compare the gap between policies and targets, which can be a reference for determining the renewable electricity consumption allocation in each region in the future.

The rest of the paper is structured as follows. In Section model, the renewable electricity consumption allocation model is designed. Section data and parameter settings describes the model data and parameter settings. Section results shows the results. Conclusions and recommendations are provided in Section conclusions and discussion.

MODEL

In addition to solving the problems of curtailment of wind power, solar power and hydro, the REC guarantee mechanism is also a main method for the Chinese government to increase the proportion of non-fossil energy in the short term. In order to ensure the realization of China's non-fossil energy targets, the allocation of REC needs to be considered from two aspects.

The first one is to calculate an effective overall consumption. The primary task is to clarify the quantitative relationship between the overall REC and non-fossil energy targets. This article uses the renewable electricity market 's contribution rate (Formula 9) to the national non-fossil energy target to reflect this quantitative relationship. The higher contribution rate is, the more effective the renewable electricity market is. The second one is to allocate the overall REC effectively among provinces. We define effective distribution under the principles of "efficiency, equity, and feasibility" and apply a multi-principal ZSG-DEA model to adjust the allocation to reach an optimal state. The model design framework is shown in **Figure 3**.

"Top-Down" Overall Renewable Electricity Consumption Model

The design of the "top-down" overall renewable electricity consumption model is as follows:

First, we assume that the three indicators of non-fossil energy consumption at the national level are: Q_n^0 represents the overall non-fossil energy consumption nationwide at the beginning of the planning period, and Q_n^t represents the overall non-fossil energy consumption after t years of implementation of the REC guarantee mechanism. Q_{nBAU}^t indicates the overall non-fossil energy consumption nationwide under the BAU (Business As Usual) scenario at the end of year t. The BAU scenario refers to the non-fossil energy consumption under the assumptions that no new policies will be introduced and non-fossil energy technologies remain at the old-previous, which means the non-fossil energy will maintain the original speed of development and the ratio of non-fossil energy in primary energy consumption will not change. n denotes non-fossil energy, 0 denotes the beginning of planning period and t denotes it is the t year of planning period. As a result, the three indicators of non-fossil energy consumption can be expressed as:

$$Q_n^0 = E^0 R^0 \tag{1}$$
$$Q_n^t = E^t R^t = E^0(1+\eta)R^0(1+\xi) \tag{2}$$
$$Q_{nBAU}^t = E^t R^0 = E^0(1+\eta)R^0 \tag{3}$$

E refers to the national overall primary energy consumption, R represents the ratio of non-fossil energy in primary energy consumption, η denotes the growth rate of national primary energy consumption during the planning period, ξ represents the growth rate of non-fossil energy ratio during the planning period. All these indicators are non-negative. The relationships among these three indicators are shown in **Figure 4**.

Therefore, the difference between non-fossil energy consumption with the application of the REC guarantee mechanism and non-fossil energy consumption under the BAU scenario in the planning period can be expressed as:

$$\begin{aligned} \Delta Q_n &= Q_n^t - Q_{nBAU}^t = E^t R^t - E^t R^0 \\ &= E^0(1+\eta)R^0(1+\xi) - E^0(1+\eta)R^0 \\ &= E^0 R^0(1+\eta)\xi = Q_n^0(1+\eta)\xi \end{aligned} \tag{4}$$

Similarly, we assume that the three indicators of renewable electricity consumption at the national level are: Q_m^0 denotes
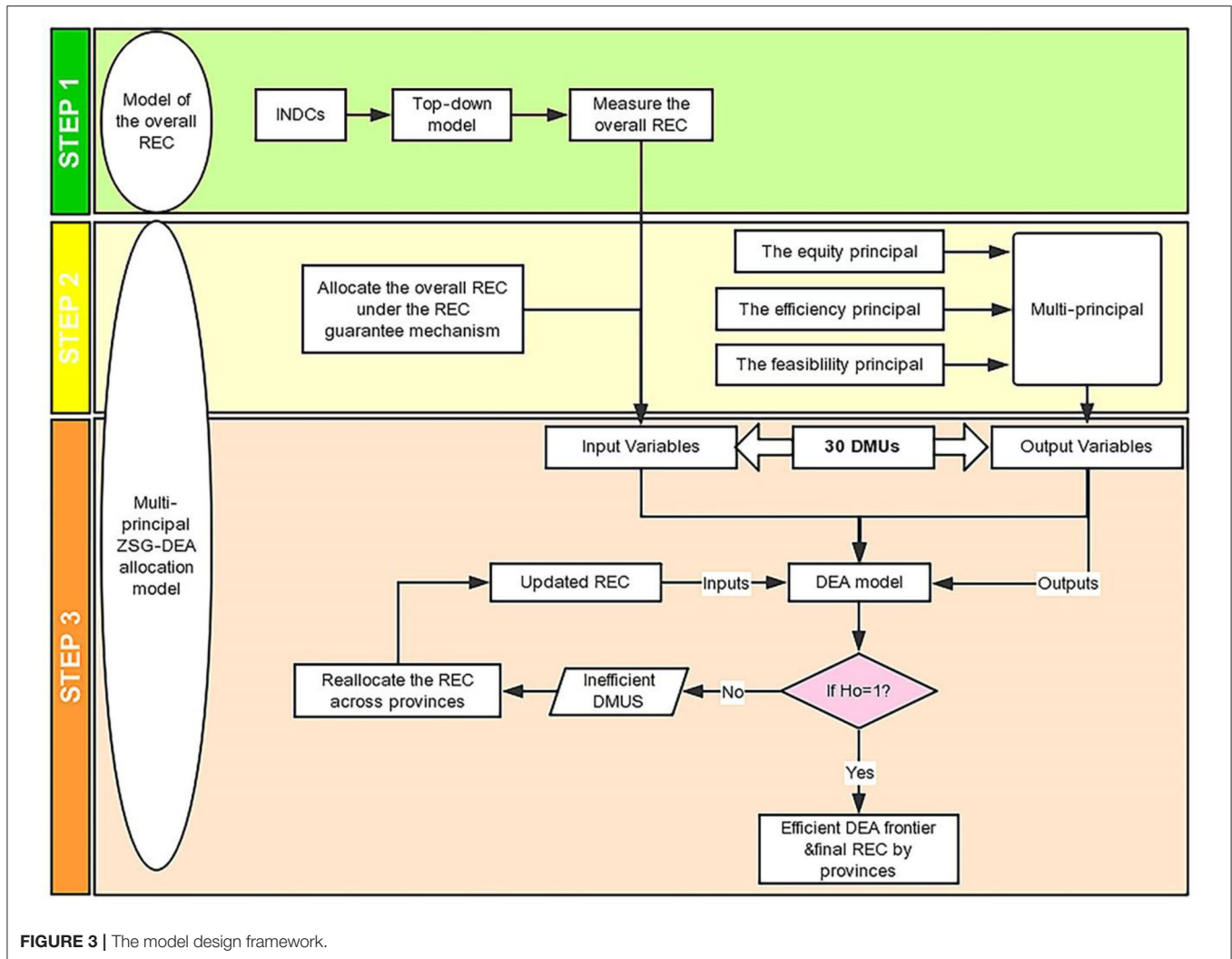
FIGURE 3 | The model design framework.

the overall REC when the planning period starts, Q_m^t denotes the overall REC after t years implementation of the REC guarantee mechanism (the implementation of this mechanism can encourage the innovation of power producers to develop cost-efficient renewable power generation technologies, which may lead to increase in ratio of REC to total electricity consumption) and Q_{mBAU}^t represents the overall REC under the BAU scenario at the end of year t.

Hence, these indicators of renewable electricity consumption can be written as:

$$Q_m^0 = C^0 \alpha^0 \tag{5}$$

$$Q_m^t = C^t \alpha^t = C^0(1+\beta)\alpha^0(1+\gamma) \tag{6}$$

$$Q_{mBAU}^t = C^t \alpha_{BAU}^t = C^0(1+\beta)\alpha^o(1+\gamma_{BAU}) \tag{7}$$

Where m refers to renewable electricity that differs from n, C denotes the national electricity consumption, α represents the proportion of renewable electricity in total electricity consumption, [[Inline Image]]refers to the growth rate of the country's electricity consumption, γ refers to the growth

rate of renewable electricity consumption ratio under the implementation of the REC guarantee mechanism and γ_{BAU} represents the growth rate of renewable electricity consumption ratio under the BAU scenario. The relationships among these three indicators can be expressed as in **Figure 5**:

Similarly, the difference between renewable electricity consumption with the application of the REC guarantee mechanism and renewable electricity consumption under the BAU scenario in the planning period can be expressed as:

$$\begin{aligned}
\Delta Q_m &= Q_m^t - Q_{mBAU}^t = C^t \alpha^t - C^t \alpha_{BAU}^t \\
&= C^0(1+\beta)\alpha^o(1+\gamma) - C^0(1+\beta)\alpha^0(1+\gamma_{BAU}) \\
&= Q_m^0(1+\beta)(\gamma - \gamma_{BAU}) \tag{8}
\end{aligned}$$

We define the contribution rate of the REC guarantee mechanism to national non-fossil energy target as (Unit is unified as standard coal):

$$\delta = \frac{\Delta Q_m}{\Delta Q_n} = \frac{Q_m^0(1+\beta)(\gamma - \gamma_{BAU})}{Q_n^0(1+\eta)\xi} = m^0 \frac{(1+\beta)(\gamma - \gamma_{BAU})}{(1+\eta)\xi} \tag{9}$$
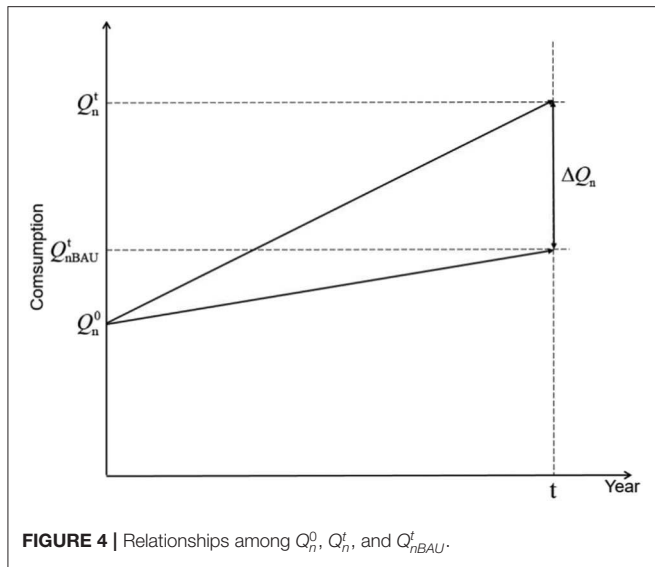
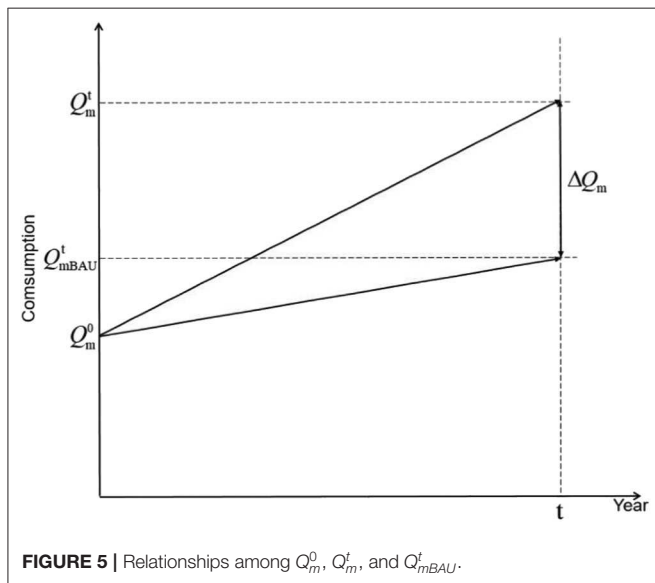**FIGURE 4 |** Relationships among Q_n^0, Q_n^t, and Q_{nBAU}^t.

FIGURE 5 | Relationships among Q_m^0, Q_m^t, and Q_{mBAU}^t.

m^0 denotes the proportion of national renewable electricity consumption in the national non-fossil energy consumption at the beginning of the REC guarantee mechanism's implementation.

After rearranging the formula (9), the growth rate of the renewable electricity consumption ratio after the implementation of REC guarantee mechanism can be expressed as:

$$\gamma = \frac{\delta(1+\eta)\xi}{m^0(1+\beta)} + \gamma_{BAU} \tag{10}$$

Then, the overall REC after t years implementation of the REC guarantee mechanism can be expressed as:

$$Q_m^t = Q_m^0(1+\beta)(1+\gamma_{BAU} + \frac{\delta(1+\eta)\xi}{m^0(1+\beta)}) \tag{11}$$

ZSG-DEA Model for REC Allocation

Data envelopment analysis (DEA), proposed by Charnes et al. (1978), can estimate production frontier and measure productive efficiency of decision making units (DMUs) through the ratio of multiple inputs to outputs (Banker et al., 1984). Assume that we allocate the overall renewable electricity consumption to N provinces (Each province is a DMU) and each DMU has an input factor × (Renewable electricity consumption) and P output factors y. Using the classic input-oriented BCC model (Banker et al., 1984), we can evaluate the efficiency of each province, as shown in formula (12):

$$\min h_o$$

$$s.t. \begin{cases} \sum_{i=1}^{N} \lambda_i y_{ip} \geq y_{op}, p = 1, 2, 3, \ldots, P \\ \sum_{i=1}^{N} \lambda_i x_i \leq h_o x_o \\ \sum_{i=1}^{N} \lambda_i = 1, i = 1, 2, 3, \ldots, N \\ \lambda_i \geq 0 \end{cases} \tag{12}$$

Where h_o represents the efficiency of province o, λ_i denotes the weight of DMU of i.

Although the classical DEA model can measure DMUs' efficiency, it is unable to bring each DMU together into the DEA frontier. What's more, the classical DEA model holds the hypothesis that all DMUs can freely produce input and output variables without influencing each other, which does not remain true when it comes to REC allocation, as the overall REC is a constant value. The reduced REC of one province must be distributed to other provinces, which means there is a zero-sum game. To deal with the constant constraint of total input or output, Lins et al. (2003) proposed the ZSG-DEA model. The ZSG-DEA model for renewable electricity consumption allocation is formulated as follows:

Provinces with an efficiency score of one are efficient units, while other provinces with a score of <1 are inefficient units. In order to improve the efficiency of inefficient units and make them reach the DEA frontier together, it is necessary to reduce the REC of provinces with an efficiency score of <1. The reduction volume of province o is:

$$d_o = x_o(1 - h_{Ro}) \tag{13}$$

Where x_o refers to the REC of province o, h_{Ro} is the efficiency value under the condition that the total amount of input is constant. Lins et al. (2003) proved that there is a linear correlation between h_o and h_{Ro}, which can be expressed as:

$$h_{Ro} = h_o \left[1 + \frac{\sum_{i \in W} x_i(1 - \rho_{io} h_{Ro})}{\sum_{i \notin W} x_i} \right] \tag{14}$$

W is a set of provinces with the DEA efficiency <1. $\rho_{io} = \frac{h_i}{h_o}$ denotes the DEA efficiency ratio between province i and province o.

To make sure the overall REC remains constant, the reduction volume d_o has to be divided proportionally to other provinces. As a result, the REC that province i will get from province o is:

$$r_{io} = \frac{x_i}{\sum_{i \neq o} x_i} d_o = \frac{x_i}{\sum_{i \neq o} x_i} x_o(1 - h_{Ro}) \tag{15}$$

As all provinces are adjusting REC simultaneously, the REC of province i will finally be adjusted to:

$$x'_i = \sum_{i \neq o} r_{io} - d_i = \sum_{i \neq o} \left[\frac{x_i}{\sum_{i \neq o} x_i} x_o(1 - h_{Ro}) \right] - x_i(1 - h_{Ri}),$$
$$i = 1, 2, 3, \ldots, N \tag{16}$$

Some provinces can't reach the DEA frontier after first reallocation, which means we need to reallocate REC again. After several round of reallocation, the efficiency of all provinces will finally reach one. The input oriented ZSG-DEA model is formulated as follows:

$$\min h_{Ro}$$

$$s.t. \begin{cases} \sum_{i=1}^{N} \lambda_i y_{ij} \geq y_{oj}, j = 1, 2, 3, \ldots, P \\ \sum_{i=1}^{N} \lambda_i x_i \left[1 + \frac{x_o(1 - h_{Ro})}{\sum_{i \neq o} x_i} \right] \leq h_{Ro} x_o \\ \sum_{i=1}^{N} \lambda_i = 1, i = 1, 2, 3, \ldots, N \\ \lambda_i \geq 0 \end{cases} \tag{17}$$

DATA AND PARAMETER SETTINGS

Parameters in the Overall REC Model

According to Formula (11), in order to calculate the overall REC, we need to know the following five parameters:

(1) ξ: the growth rate of non-fossil energy consumption proportion;
(2) m^0: the proportion of renewable electricity consumption in non-fossil energy consumption;
(3) η: the growth rate of national energy consumption;
(4) β: the growth rate of national electricity consumption;
(5) γ_{BAU}: the growth rate of renewable electricity consumption proportion under the BAU scenario;
(6) δ: the contribution rate of the REC guarantee mechanism to 2020 non-fossil energy target.

First, according to three official documents published by the Chinese government (the "13th 5-Years Plan" for Renewable Energy Development, the "13th 5-Years Plan" for Energy Development, and the "Strengthening Action on Climate Change-China's Intended Nationally Determined Contributions"), the non-fossil energy target can be expressed as "Non-fossil energy accounts for 15 and 20% of primary energy consumption in 2020 and 2030 respectively". We set the end of 2018 as the beginning of the planning period, and the end of 2020 as the end of the planning period. This is because the REC guarantee system designed the obligatory renewable electricity

proportion of the provinces by 2020, and has not yet specified each province's OP in 2030. The end of 2020 is selected as the end of the planning period of the model in this paper, which can better compare our results with the design of the REC guarantee mechanism. In 2018, China's non-fossil energy proportion in primary energy consumption was 14.3%, which means, in order to achieve the 2020 target, non-fossil energy proportion has to reach an annual growth rate of 2.42% at least. According to the calculation formula of $(1 + 2.42\%)^2 - 1$, resulting in a total growth rate of 4.90% (ξ) in non-fossil energy proportion within the planning period of 2018 to 2020.

Second, China consumed 1815.90 TWh (Equivalent to 223.17 million tons of standard coal)[3] renewable electricity in 2018, while non-fossil energy consumption was 663.52 million tons of standard coal (Mtce) (China Electric Power Planning and Engineering Institute, 2019). Thus, m^0 is 33.63% at the early stage of the planning period.

In this article, we use the elastic coefficient method (Xue and Zhang, 2013) to predict the national energy consumption (Wu and Huang, 2016) and national electricity consumption (Yang and Wang, 2018) in 2020 under three scenarios, and then derive their corresponding growth rates. Under the planned GDP growth rate of the 13th 5-Years Plan, the growth rate of national energy consumption is 4.8% and that of national electricity consumption is 10.59%. The average GDP growth rate in 2015–2018 is 6.7%. Considering that the larger the national economic base, the more difficult it is to grow. During the planning period of 2018–2020, we set the GDP growth rate in the pessimistic scenario to 6.0%. The GDP growth rate under the optimistic scenario is 6.7%. Under the pessimistic scenario, the growth rate of national energy consumption is 4.16% and that of national electricity consumption is 5.06%. Under the optimistic scenario, the growth rate of national energy consumption is 9.10% and that of national electricity consumption is 11.19%. The parameters of η and β are shown in **Table 1**.

Since only 4 years of renewable electricity consumption proportion data are available (2015–2018) (NEA, 2016, 2017, 2018, 2019), a gray prediction model GM(1,1) (Deng, 1982; Hamzacebi and Es, 2014) suitable for small data volume is used to predict the 2020 renewable electricity consumption proportion. The calculation result is 27.71%. According to the National Renewable Energy Development Report, the proportion of renewable energy electricity consumption in 2018 is 26.50%, and the growth rate of renewable electricity consumption ratio in 2018–2020 under the BAU scenario is calculated as 4.57% (γ_{BAU}).

At last, we set three contribution rates δ based on what may happen in the future. First of all, it is assumed that no new policies to promote the consumption of non-fossil energy will be introduced in the future, and the old policies will not promote the consumption of non-fossil energy further more. The growth of non-fossil energy consumption is entirely stimulated by the REC guarantee mechanism, which means the contribution rate of the REC guarantee mechanism to

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[3] According to the Energy Conversion Standard Coal Reference Coefficient Table of the China Energy Statistics Yearbook, the conversion standard power coefficient of electricity is 0.1229 kg standard coal / kWh.

TABLE 1 | The growth rate of national energy consumption and electricity consumption under three scenarios.

	2017	2018	Elasticity coefficient (%)	Scenario hypothesis	The growth rate of GDP	2018E	2020E	Growth rate during the planning period
National energy consumption (Mtce)	4485.29	4640.00	0.42	Pessimistic hypothesis	6.0%	4598.31	4876.80	4.16% (η_1)
				13th 5-years plan	6.5%	4607.74	4862.76	4.80% (η_2)
				Optimistic scenario	6.7%	4611.51	4874.69	5.06% (η_3)
National electricity consumption (TWh)	6363.60	6900.20	0.96	Pessimistic hypothesis	6.0%	6730.01	7527.78	9.10% (β_1)
				13th 5-years plan	6.5%	6760.70	7630.75	10.59% (β_2)
				Optimistic scenario	6.7%	6772.90	7672.19	11.19% (β_3)

The data comes from the China Statistical Yearbook.

TABLE 2 | Parameters setting of the overall REC model.

Scenario hypothesis			ξ	m^0	η	β	γ_{BAU}
Scenario number	Economic growth hypothesis	Contribution rate hypothesis (δ)					
1	6.0%	80%	4.90%	33.63%	4.16%	9.10%	4.57%
2		90%	4.90%	33.63%	4.16%	9.10%	4.57%
3		100%	4.90%	33.63%	4.16%	9.10%	4.57%
4	6.5%	80%	4.90%	33.63%	4.80%	10.59%	4.57%
5		90%	4.90%	33.63%	4.80%	10.59%	4.57%
6		100%	4.90%	33.63%	4.80%	10.59%	4.57%
7	6.7%	80%	4.90%	33.63%	5.06%	11.19%	4.57%
8		90%	4.90%	33.63%	5.06%	11.19%	4.57%
9		100%	4.90%	33.63%	5.06%	11.19%	4.57%

the realization of the non-fossil energy goal is 100% in the planning period; Second, assuming that no new policies to promote the consumption of non-fossil energy will come out in the future, and because of the lag in the role of policies, the old policies continue to promote the increase of the non-fossil energy proportion, but the REC guarantee mechanism still plays a major role due to its strong binding force. We assume that contribution rate of the REC guarantee mechanism to the achievement of the non-fossil energy target is 90% under the second situation; Finally, assuming that the old policies still play a role and new policies will come out in the future, however, it is clear that there will be no policies that are more restrictive than the REC guarantee mechanism. We assume that the REC guarantee mechanism plays a major role and contributes 80% to the achievement of non-fossil energy goal under the third situation.

As analyzed above, here we set the parameters as **Table 2**.

Indicators and Data of the ZSG-DEA Model
Input Variable of the ZSG-DEA Model
In order to better compare the results of this article with the design of the REC guarantee mechanism, we use the ratio (φ) of the achievable consumption of each province under the REC guarantee mechanism requirements divided by the sum of provinces' achievable consumption as the basis for the initial allocation. We can get the province i's achievable consumption (x_i^0) through multiplying the OP of province i required by the REC guarantee mechanism and the predicted electricity consumption of province i in 2020. The initial allocation coefficient is $\varphi_i = \frac{x_i^0}{\sum_i^N x_i^0}$. Considering that the development of nuclear energy and biomass energy has a certain contribution to the non-fossil energy target, here we demonstrate the allocation under the scenario of economic growth of 6.5% and contribution rate of 90% without loss of generality. The initial allocation of province i is $x_i = Q_m^t \varphi_i$, which is the input variable of the ZSG-DEA model.

Output Variables of the ZSG-DEA Model
In this paper, we consider the principle of equity, efficiency and feasibility when we determine allocation indicators. Historical renewable electricity consumption, total electricity consumption, and energy consumption gap are selected as output variables for REC allocation. They are expected to reflect the principle of feasibility, equity and efficiency respectively. An analysis of the reasons for choosing output variables is as follows:

When decomposing the overall REC, comprehensive consideration should be given to the renewable energy resource endowment status, renewable energy development potential, economic development status, and grid development status of each province (Liu et al., 2009; Wu and He, 2014). The historical renewable electricity consumption in the province can reflect the renewable power resource endowment and grid development in the region to a certain extent (Lv et al., 2019). Based on data availability, we choose average historical renewable electricity consumption of each province as the embodiment of the regional renewable power resources endowment status. Historical renewable electricity consumption data comes from annual "National Renewable Energy Development Monitoring Evaluation Reports."

From the perspective of equity, the higher the total electricity consumption is in a province, the more renewable electricity should be consumed. And the total electricity consumption is linked to GDP to a certain extent, it can also reflect the economic development of the region (Yang and Wang, 2018). Therefore, we chose the total electricity consumption as an indicator of

TABLE 3 | Each province's energy consumption constraints and energy consumption gap (Mtce).

Province	Total energy consumption in 2015	Incremental energy consumption control target by the 13th 5-years plan	Total energy consumption constraint in 2020	Predicted total energy consumption in 2020	Energy consumption gap
Beijing	685.30	80.00	765.30	743.91	21.39
Tianjin	826.00	104.00	930.00	868.45	61.55
Hebei	2939.50	339.00	3278.50	3099.82	178.68
Shanxi	1938.40	301.00	2239.40	2013.90	225.50
Inner Mongolia	1892.70	357.00	2249.70	2162.03	87.67
Liaoning	2166.70	355.00	2521.70	2168.55	353.15
Jilin	814.20	136.00	950.20	739.31	210.89
Heilongjiang	1212.60	188.00	1400.60	1310.78	89.82
Shanghai	1138.70	97.00	1235.70	1227.64	8.06
Jiangsu	3023.50	348.00	3371.50	3391.34	−19.84
Zhejiang	1961.00	238.00	2199.00	2266.69	−67.69
Anhui	1233.20	187.00	1420.20	1449.22	−29.02
Fujian	1218.00	232.00	1450.00	1477.25	−27.25
Jiangxi	844.00	151.00	995.00	1050.33	−55.33
Shandong	3794.50	407.00	4201.50	3912.90	288.60
Henan	2316.10	354.00	2670.10	2511.74	158.36
Hubei	1640.40	250.00	1890.40	1805.55	84.85
Hunan	1546.90	238.00	1784.90	1704.96	79.94
Guangdong	3014.50	365.00	3379.50	3499.71	−120.21
Guangxi	976.10	184.00	1160.10	1181.02	−20.92
Hainan	193.80	66.00	259.80	246.68	13.12
Chongqing	893.40	166.00	1059.40	1183.11	−123.71
Sichuan	1988.80	302.00	2290.80	2187.27	103.53
Guizhou	994.80	185.00	1179.80	1151.64	28.16
Yunnan	1035.70	194.00	1229.70	1155.78	73.92
Shaanxi	1171.60	217.00	1388.60	1458.31	−69.71
Gansu	752.30	143.00	895.30	793.73	101.57
Qinghai	413.40	112.00	525.40	478.16	47.25
Ningxia	540.50	150.00	690.50	718.67	−28.17
Xinjiang	1565.10	354.00	1919.10	2011.21	−92.11

The data comes from the "13th 5-years plan for comprehensive energy conservation and emission reduction" (lack of data for Tibet).

economic development. The total electricity consumption in 2020 is predicted by the electricity elasticity coefficient method (Xue and Zhang, 2013) and the data comes from each province's statistical yearbooks.

In addition, we also select energy consumption gap as an indicator. The energy consumption gap is the difference between the energy constraint that required by the "13th 5-Years Plan" and the predicted energy consumption in 2020. The smaller the province's energy consumption gap is, the more difficulty the province has in achieving the energy control target. The reason for choosing energy consumption gap is that currently more than 10 provinces across the country have proposed that the energy consumption target of the "13th 5-Years Plan" cannot be achieved[4]. According to China's "13th 5-Years Plan for Energy Conservation and Emission Reduction," renewable energy is

not included in the scope of energy consumption control[5]. Provinces that are not expected to meet their energy control goals can meet the energy needs of economic development by using more renewable energy. We hold the view that allocating more REC quota to areas with less energy consumption gap can loosen energy constraints on the economic development of provinces, which means each unit of renewable electricity produces more economic output. Based on the total energy consumption of each province from 2010 to 2017 (data from each province's statistical yearbooks), we use the GM(1,1) model (Deng, 1982; Hamzacebi and Es, 2014) to predict the total energy consumption of each province in 2020, and compare the predicted value with the energy consumption constraints of the "13th 5-Years Plan," the differences are energy consumption gap for provinces (**Table 3**). The DEA model requires inputs

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[4]http://www.qstheory.cn/dukan/qs/2019-12/15/c_1125346157.htm

[5]http://www.gov.cn/zhengce/content/2017-01/05/content_5156789.htm

TABLE 4 | Input and output indicators for each province in 2020.

Province	Initial allocation of each province (TWh)	Historical REC (TWh)	Total electricity consumption (TWh)	Energy consumption gap (Mtce)
Beijing	21.33	11.72	120.24	331.76
Tianjin	16.08	8.13	90.66	291.60
Hebei	73.09	36.11	412.05	174.47
Shanxi	42.46	25.13	217.61	127.65
Inner Mongolia	79.95	49.01	365.47	265.47
Liaoning	35.33	26.06	239.00	0.01
Jilin	21.62	14.64	83.12	142.26
Heilongjiang	30.60	15.92	99.53	263.33
Shanghai	65.67	47.88	168.29	345.09
Jiangsu	116.55	76.42	704.04	372.98
Zhejiang	104.94	76.65	479.71	420.84
Anhui	40.18	24.23	234.35	382.17
Fujian	59.52	53.97	258.14	380.39
Jiangxi	55.66	31.07	162.33	408.47
Shandong	74.77	39.49	632.28	64.54
Henan	69.12	40.28	365.33	194.79
Hubei	111.21	72.12	235.11	268.30
Hunan	113.86	73.70	196.52	273.21
Guangdong	238.93	191.79	684.95	473.35
Guangxi	98.92	74.38	167.31	374.07
Hainan	5.11	3.66	37.55	340.02
Chongqing	61.62	46.97	115.80	476.86
Sichuan	245.65	179.38	251.19	249.62
Guizhou	64.44	49.81	173.01	324.98
Yunnan	172.22	127.42	182.05	279.22
Shaanxi	46.61	21.55	183.32	422.85
Gansu	78.31	52.34	140.90	251.58
Qinghai	73.43	47.06	88.71	305.90
Ningxia	30.85	20.43	118.59	381.32
Xinjiang	101.53	46.66	381.61	445.26

and outputs indicators to be positive, but there are negative values in some provinces' energy consumption gap. Based on the consideration that allocating more REC quota to areas with less energy consumption gap, we use the maximum value of the energy consumption gap minus the value of each province's energy consumption gap.

Table 4 displays the input and output variables for each province.

RESULTS

The Overall REC

According to the "National Renewable Energy Power Development Monitoring and Evaluation Report 2018," the total amount of renewable electricity consumption in China (excluding Tibet) in 2018 (Q_m^0) was 1815.90 TWh. The achievable overall REC under the constraint of REC guarantee mechanism

is $Q_p^t = \sum_i^N x_i^0$ (1986.97 TWh). Using Q_m^0 and parameters in **Table 2**, we can calculate overall RECs (Q_m^t) that can achieve the non-fossil energy target under nine scenarios base on Formula (11). We can know whether the current REC mechanism can achieve the non-fossil energy target by simply comparing Q_m^t and Q_p^t.

China needs to consume 2292.16 TWh to 2389.34 TWh renewable electricity to accomplish the 2020 non-fossil energy target (**Figure 6**). The expected REC under the constraint of the REC guarantee mechanism still needs to increase by 15.36–20.25% to achieve the non-fossil energy target.

The Allocation of Overall REC

Figure 7 shows the evolution of the DEA efficiency value of the initial allocation and reallocation. It needs to be clear that in the allocation of REC, provinces with high efficiency values tend to have insufficient obligatory REC and need to increase their REC quota. Among the 30 provinces, Fujian, Shandong, and Hainan reach the DEA boundary in the beginning with their initial efficiency values equal to one. There are 14 provinces, whose initial DEA efficiency are higher than the average initial efficiency (0.794). Xinjiang 's DEA initial efficiency is the lowest, at 0.590. After the first reallocation, the average DEA efficiency increase to 0.960. The most effective provinces are still Fujian, Shandong, and Hainan. The DEA efficiency value in Xinjiang increase to 0.913 and the lowest value (Shaanxi) is 0.905. After the third reallocation, the overall DEA efficiency value reach one, and six provinces (Shanxi, Inner Mongolia, Heilongjiang, Guizhou, Shaanxi, and Gansu) are weakly effective with an efficiency value of 0.999, while other 24 provinces reach the DEA frontier. After the fifth reallocation, all provinces achieve the maximum DEA efficiency of one.

Figure 8 compares the REC adjusted by the ZSG-DEA model of each province (x_i') with the REC calculated based on the OP required by the REC guarantee mechanism (x_i^0).

It can be seen that in order to achieve the non-fossil energy target more efficiently, 26 provinces need to increase the consumption of renewable electricity, and four provinces can appropriately reduce the REC quota. Guangdong Province's REC increase the most, which is 63.09 TWh, and it also has the biggest amount of the REC after reallocation, at 265.15 TWh. Xinjiang province experiences the biggest reduction of 10.77 TWh. With the lowest reallocated REC (6.41 TWh), Hainan province has the highest increase rate of 48.33%. The five provinces with the highest increase rate are Hainan (48.33%), Fujian (48.33%), Shandong (48.33%), Liaoning (46.13%), and Guangdong (31.22%). The provinces that are reduced allocation are Xinjiang (−12.55%), Shaanxi (−10.84%), Heilongjiang (−8.92%), and Jiangxi (−6.70%).

By looking deeper at the direction of electricity flow (**Figure 9**), one may notice that most provinces and autonomous regions that increase the REC significantly are in developed coastal areas and belong to the receiving end of power transmission. In contrast, most of the provinces and regions whose consumption is reduced or increased slightly belong to
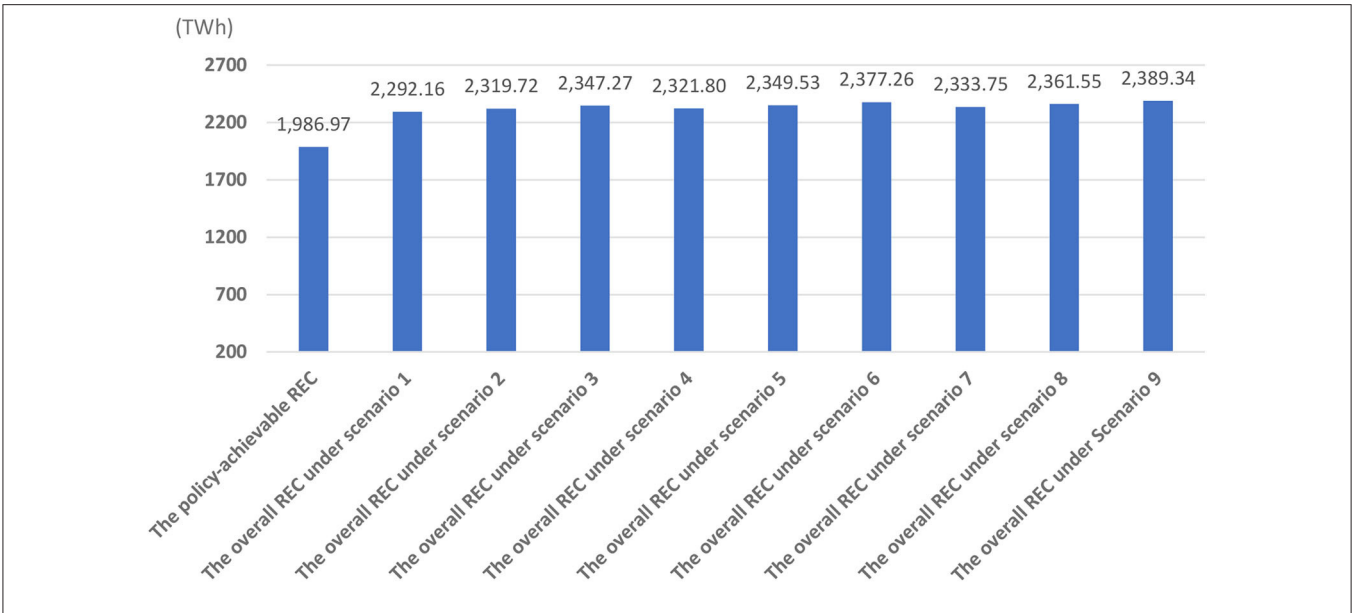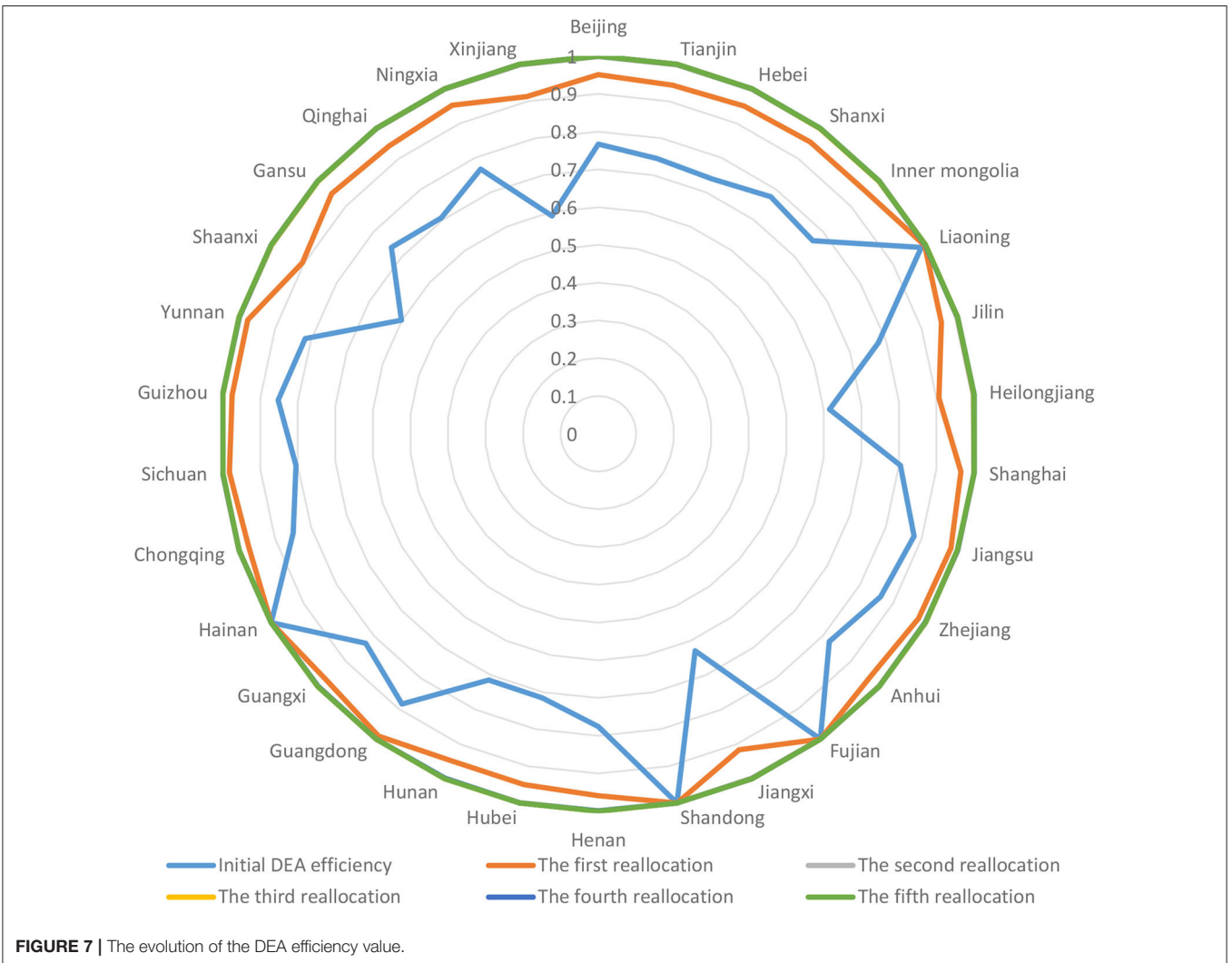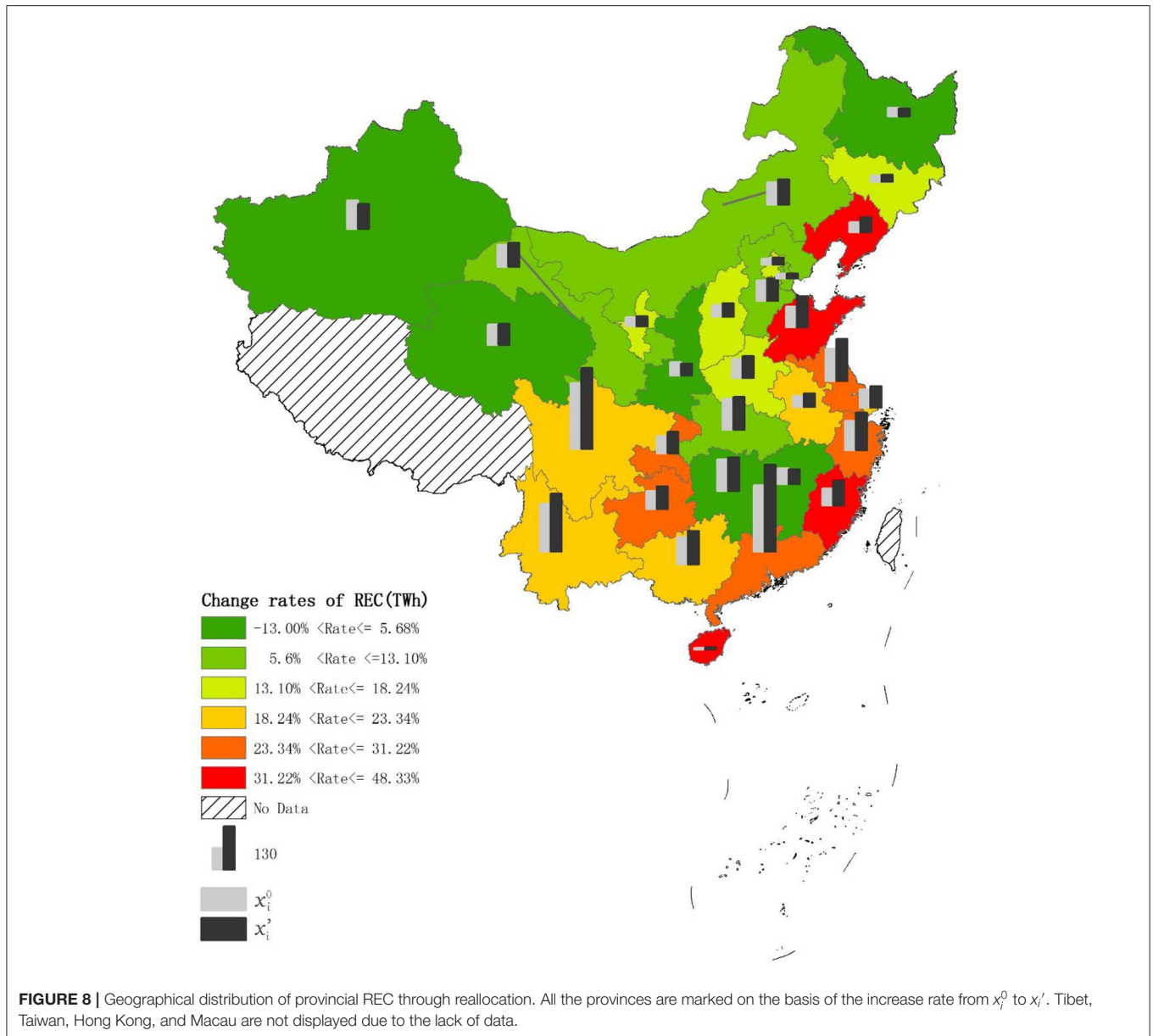
FIGURE 6 | Comparison of Q_m^t and Q_p^t.

FIGURE 7 | The evolution of the DEA efficiency value.

FIGURE 8 | Geographical distribution of provincial REC through reallocation. All the provinces are marked on the basis of the increase rate from x_i^0 to x_i'. Tibet, Taiwan, Hong Kong, and Macau are not displayed due to the lack of data.

the supply end of power transmission. This adjustment reflects the principle of equity, also known as "who uses electricity, who bears responsibility." Slight changes occur mostly in northern China, and the change rate of REC quotas in the central region is smaller than that of the national level (18.24%). Although Hubei, Hunan, and Jiangxi are power receiving areas, their OP settings in the REC guarantee mechanism are inherently high, so the rate of increase is relatively low.

Table 5 shows the comparison between the OP in the REC guarantee mechanism and the adjusted proportion values. It can be seen that, in order to meet the non-fossil energy target, under the principles of equity, efficiency, and achievability, 26 provinces need to increase the proportion of REC by an average of 5.46%. Ten provinces' increase rates are higher than the average increase rate. Sichuan needs to increase the

proportion value the most (18.68%)[6], while Xinjiang has the highest proportion to reduce (−6.32%)[7]. Although Guangdong needs to increase the biggest amount of the REC, the increase in

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[6]The predicted total electricity consumption in Yunnan province is relatively small in 2020. Based on equation *Proportion* = REC/total electricity consumption, the adjustment of consumption results in relatively big changes in proportion value.

[7]Part of the reason why Xinjiang province has big reduction in consumption is that its historical elastic coefficient is 2.07, resulting in higher volume of total electricity consumption and original allocation (93.35 TWh). Xinjiang's renewable electricity consumption in 2018 is just 5.73 TWh. The proportion value of Xinjiang is reduced by 30.41%, however, the consumption volume is increased by 20.4% to 6.90 TWh compared to 2018, which is rather more reasonable. According to historical data, the electricity consumption elasticity value in Xinjiang has been gradually reducing, with the last 3-years average of 1.34, so we believe the actual total electricity consumption of Xinjiang in 2020 could be much lower than predicted.

FIGURE 9 | National power transmission.

the proportion value is just 9.21% as it has the second highest total electricity consumption.

CONCLUSIONS AND DISCUSSION

This article takes the non-fossil energy targets of 2020 and 2030 in China's INDCs as the starting point to discusses the issue of the REC allocation. We formed an analysis framework for renewable electricity consumption allocation, which can provide some references for policy makers. In this framework, the "contribution rate" reflects the quantitative relationship between the renewable electricity consumption and the non-fossil energy target. The higher contribution rate is, the more effective the allocation is. We calculated the overall REC which can realize the non-fossil energy target under nine scenarios. China needs to consume 2292.16–2389.34 TWh renewable electricity to accomplish the 2020 non-fossil energy target, while the REC guarantee mechanism can only reach 1986.97 TWh. In other

words, current policy needs to increase the REC by 15.35–20.25% to achieve the non-fossil energy target. Allocation of the overall REC is another important problem. We adjusted the original allocation requested by current policy under the principles of equity, efficiency, and feasibility using a ZSG-DEA model to make sure all provinces reached the DEA frontier. Our empirical results show that to realize the non-fossil energy target under the scenario of economic growth of 6.5% and contribution rate of 90%, 26 provinces need to increase renewable electricity consumption. The general trend of adjusting is that coastal, developed provinces located in receiving end of power transmission should take more responsibility for renewable electricity consumption while policy makers could reduce the obligatory REC quota of some central provinces and provinces at supplying end of power transmission relatively.

The results of this paper not only assist policy makers to scientifically determine the total amount of REC and adjust the REC allocation plans among provinces, but also provide

TABLE 5 | The OP values in the REC guarantee mechanism and adjusted proportion values of each province.

Province	The OP values in the REC guarantee mechanism	Adjusted proportion value	Gap	Province	The OP values in the REC guarantee mechanism	Adjusted proportion value	Gap
Beijing	15.00%	17.06%	2.06%	Henan	16.00%	18.39%	2.39%
Tianjin	15.00%	16.56%	1.56%	Hubei	40.00%	42.39%	2.39%
Hebei	15.00%	16.43%	1.43%	Hunan	51.50%	51.79%	0.29%
Shanxi	16.50%	18.95%	2.45%	Guangdong	29.50%	38.71%	9.21%
Inner Mongolia	18.50%	20.92%	2.42%	Guangxi	50.00%	61.39%	11.39%
Liaoning	12.50%	18.27%	5.77%	Hainan	11.50%	17.06%	5.56%
Jilin	22.00%	25.41%	3.41%	Chongqing	45.00%	56.65%	11.65%
Heilongjiang	26.00%	23.68%	−2.32%	Sichuan	80.00%	98.68%	18.68%
Shanghai	33.00%	39.39%	6.39%	Guizhou	31.50%	39.80%	8.30%
Jiangsu	15.00%	18.22%	3.22%	Yunnan	80.00%	96.63%	16.63%
Zhejiang	19.00%	23.65%	4.65%	Shaanxi	21.50%	19.17%	−2.33%
Anhui	14.50%	17.68%	3.18%	Gansu	47.00%	51.32%	4.32%
Fujian	22.00%	28.92%	6.92%	Qinghai	70.00%	73.35%	3.35%
Jiangxi	29.00%	27.06%	−1.94%	Ningxia	25.00%	25.02%	0.02%
Shandong	10.50%	14.83%	4.33%	Xinjiang	26.00%	19.68%	−6.32%

certain insights for future power grid pattern planning. To meet the needs of renewable energy consumption and large-scale transmission of power across regions, it is urgent to scientifically plan the layout of the power grid, strengthen the construction of inter-regional and inter-provincial interconnected power grids. With adjustments of each province's obligatory REC in this paper, the key construction areas of the interconnected power grid can be determined.

To achieve the non-fossil energy targets, we hold the view that the primary problem that needs to be handled with is the consumption of renewable electricity. China has not yet established an national electricity market and there are serious inter-provincial barriers. Based on the interests of GDP and local employment, the province government prefers to use local thermal power rather than accept renewable electricity from other provinces. However, in the wet season, some regions' abundant renewable energy cannot be fully absorbed by the local market alone. There are still many surpluses that can and need to be consumed in a larger market. Many provinces with large scale installed capacity of renewable energy can consume a large proportion of renewable energy for a long time, indicating that technically renewable electricity can meet the daily electricity demand. For example, more than 80% of Yunnan's electricity comes from hydropower (NEA, 2016), Qinghai provinces whose area equivalents to two Japan has been able to use only renewable energy to supply electricity for 15 consecutive days (Xia, 2019). Therefore, if China can accelerate the construction and improvement of the unified national electricity market where provinces can freely allocate electricity, and with the development, and improvement of smart grids, and energy storage technologies, then consumption market of renewable electricity will be expanded. In conclusion, we reckon that China will eventually be able to achieve its non-fossil energy targets of 2020 and 2030.

We have to admit that there are certain limitations of this paper: (1) The assumption of constant growth rate we made while setting parameters for the model and predicting output variables is relatively strong. However, since this article discusses the short-term REC allocation planning, the growth rates of parameters and variables are more certain in the near future, so constant growth rate has little effect on the model's results. (2) The DEA method or ZSG-DEA model itself has some shortcomings. The DEA method emphasizes that the decision-making units are comparable, but the situation in different regions is often different, and this method may overemphasize the technical efficiency and ignore other principles. There are papers are discussing the question of DMU heterogeneity (Belotti and Ilardi, 2018), and we are also working toward this question, but we do not discuss it in this article. (3) This method is only suitable for short-term studies with relatively definite future conditions, not for long-term dynamic growth scenarios.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

AUTHOR CONTRIBUTIONS

JZ was responsible for the specific work of this paper optimized the structure and tone of this article. RG developed the model, carried out some of the calculation work, and wrote the manuscript. NX and CX contributed to the manuscript.

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