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Is the Renewable Portfolio Standard in China Effective? Research on RPS Allocation Efficiency in Chinese Provinces Based on the Zero-Sum DEA Model

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Abstract: As one of the countries with the most rapid development of new energy, China has been committed to exploring countermeasures to the challenges of new energy consumption. After more than ten years of consideration and consultation, the "renewable portfolio standard"(RPS) for "renewable energy power consumption responsibility weighting" has landed in China. However, in the official affirmation issued by the National Energy Administration, theoretical support for the basis of the initial quota allocation is still lacking. In this study, we examine the efficiency of the weight allocation scheme for renewable energy power consumption responsibilities, which was announced by the National Energy Administration in 2018 and which is based on the BCC-DEA efficiency model. The results indicate that most provinces have low allocation efficiency under this allocation scheme. Therefore, we propose an optimal allocation scheme for a renewable energy consumption quota, based on the ZSG-DEA model. With the achievement of its target, this study's allocation scheme would ensure 100% efficiency in all provinces, improve provincial economic efficiency, and simultaneously bring economic growth. After analyzing the fairness before and after adjustment of the RPS, our findings suggest that the adjusted RPS allocation scheme can promote equity in per capita renewable electricity consumption.

Keywords: renewable portfolio standards; China's renewable energy consumption; zero-sum DEA model; ZSG-DEA model

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1. Introduction

Energy and environmental issues are becoming subjects of the world's focus; reducing greenhouse gas emissions is critical to mitigating the effects of climate change [1]. For many countries today, increasing the share of renewable energy in power production is the leading solution. For example, the European Commission plans to increase the share of renewable energy in power production to 27% by 2030 [2,3]. Several studies have shown that reducing energy intensity can effectively stimulate economic progress in emerging economies [4]. Therefore, further reductions in energy intensity and emissions are significantly important for developing countries' economies and sustainable development.

As the world's largest developing country, China is experiencing rapid growth in energy consumption and significant greenhouse gas emissions [5]. In 2019, China's primary energy consumption was 2650.2394 Mt (4.8% higher than in 2018), accounting for 24.3% of total global primary energy consumption; CO_2 emissions were 10.17 billion tons, accounting for 28% of world CO_2 emissions [6,7]. Environmental pollution has attracted the attention of the Chinese government, which is actively promoting the development of renewable energy and the reduction of greenhouse gases [8]. In the United Nations General Assembly in September 2020, President Xi Jinping proposed achieving carbon peaking by 2030 and carbon neutrality by 2060. As a major coal power producer, the power sector plays an important role in China's renewable energy development and carbon reduction process. Therefore, increasing the share of renewable energy in the power sector is an essential pathway for China in achieving energy transition [9,10].

In recent years, China has developed many incentives to promote the development of renewable energy [11,12]. Since the introduction of the Feed-in Tariff (FIT) in 2005, applicable law has ensured the entry of renewable electricity to the grid, resulting in very rapid development and continued optimization of China's power supply structure.

As shown in Figures 1 and 2, in addition to technically mature hydroelectric power generation, non-hydraulic renewable energy sources (NHRES), such as wind power and photovoltaics, have grown substantially; the power production share of renewable energy sources (RES) reached an installed capacity exceeding 35% by 2019 [13]. However, China's original institutional model of power planning, operations, and mechanisms have become increasingly incompatible with its development, and many deep-seated contradictions have emerged [14]. On the technical level, the systemic and guiding role of power planning is weak. The development scale of wind power and photovoltaic power generation proposed in the original institutional model is lower than the actual development scale and potential. This scale deviation exacerbates the difficulties and contradictions that arise due to consumption [15]. On the mechanism and system levels, due to the lack of a previous renewable energy consumption guarantee mechanism and unclear local consumption responsibilities, it is difficult to effectively implement the renewable energy power consumption target, so the phenomenon of abandoned wind, light, and water sources occurs in many places [16,17]. The average wind abandonment rate in China has gradually increased, reaching as high as 21% in the first half of 2016. Since 2015, China's average wind abandonment rate has remained high, at around 12% [18]. Moreover, the growing capital subsidy gap under the feed-in tariff (FIT) subsidy mechanism has made the financial burden increasingly heavy, with the renewable electricity subsidy gap reaching 120 billion yuan in the first half of 2018 [19].

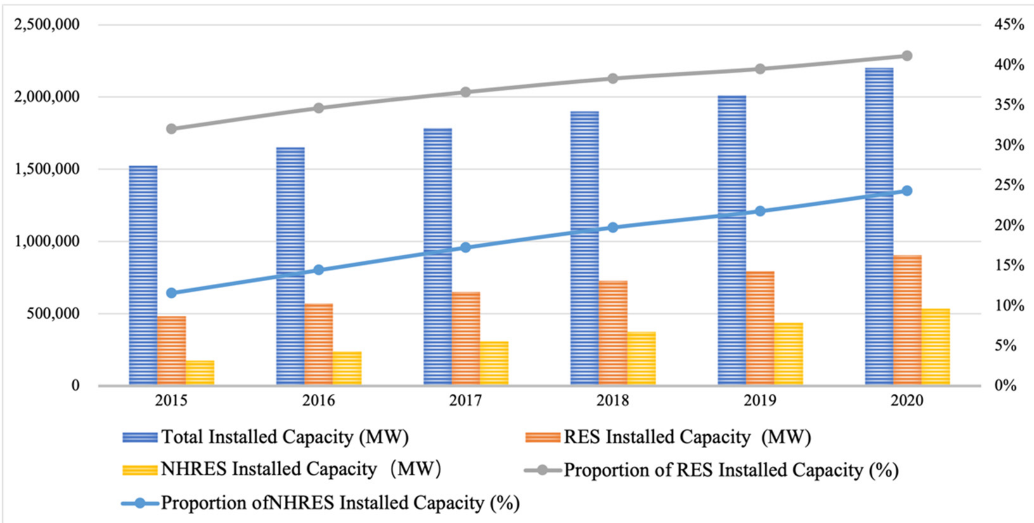

Figure 1. Total installed capacity and renewable energy capacity in China, and their respective shares.

How can we solve the above problems in renewable energy consumption in China, economically and effectively? According to the experience of some countries, a renewable energy quota system is an effective way [20]. However, different countries' power systems, grid structures, and economic systems differ significantly, so it is not easy to transfer the existing international quota system directly to China. After more than a decade of consideration and three solicitations, on 10 May 2019, China's National Energy Administration officially released its Notice on Establishing a Sound Renewable Energy Consumption

Mechanism (thereafter referred to as the "Notice") [21,22]. The quota system was implemented in the form of "renewable power responsibility weighting." After one year of simulation, complete monitoring and evaluation were carried out from 2020 onwards. Representative documents and differences in the development process of the policy are shown in Table 1.

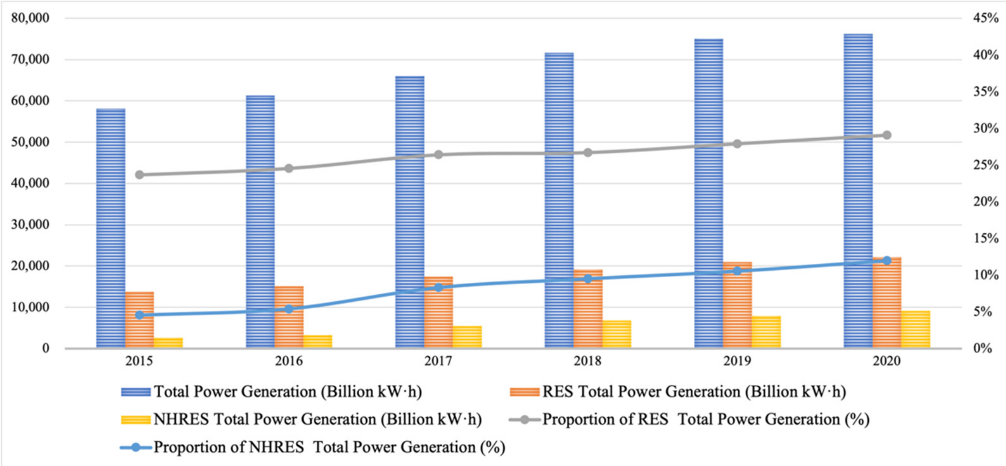

Figure 2. Total power generation, RES, and NHRES power generation and their respective shares.

Table 1. Typical documents and differences in the process of renewable energy policy formulation.

Date	Name	Sectors	Quota Subjects	Allocation Principles and Plans	Differences from the Last Policy
February 2012	Renewable Energy Power Quota Management Measures (Discussion Draft)	New Energy Department, National Energy Administration	1. Large power producer companies produce green power and generate quotas. 2. Grid companies at all levels acquire quotas. 3. Provincial governments consume quotas.	The more abundant the renewable energy power resources, the more quotas will be assumed as the principle, and there is no specific allocation scheme.	
February 2016	Guidance on the Establishment of a Target Guidance System for Renewable Energy Development and Utilization	National Energy Administration	1. All power supply entities (including power sales enterprises and direct power generation enterprises) to produce green electricity and generate quotas. 2. Collect quotas from grid companies at all levels for acquisition. 3. All social consumption quotas.	Allocate the task of renewable electricity quota by province and region.	1. The responsible body has changed. 2. The target of the proportion of non-water renewable energy power consumption is listed separately. It is suggested that a green certificate trading mechanism be established for renewable energy power.
February 2017	Notice on the Trial Implementation of Renewable Energy Green Power Certificate Issuance and Voluntary Subscription Trading System	National Development and Reform Commission, Ministry of Finance, National Energy Administration	No change compared to 2016.	No change compared to 2016.	1. Proposal to establish a voluntary subscription system for renewable energy green power certificates; suggestion of the trial issuance of renewable energy green power certificates. 2. Assign the task of completing renewable energy power quotas to provinces and regions.

Table 1. *Cont.*

Date	Name	Sectors	Quota Subjects	Allocation Principles and Plans	Differences from the Last Policy
March 2018	Renewable Energy Power Quota and Assessment Measures (Draft for Comments)	National Energy Administration Integrated Division	The provincial power companies, local power grid enterprises, other types of electricity distribution enterprises, industrial enterprises with self-provided power plants, direct purchase of electricity users involved in power market transactions and other market entities to change to bear the obligations of renewable energy power quota subject.	Allocation principles add consideration of factors such as cross-provincial and cross-regional transmission channel capacity and local power supply and demand. The allocation method uses the means of mandatory amortization.	1. There is no longer a quota production responsibility subject; the main body of responsibility for consumption has changed. 2. Market-based trading supporting the measures of consumption is proposed. 3. the subject of the assessment changed to green certificates. 4. Beijing, Tianjin, and Hebei quota tasks are no longer consistent.
September 2018	Renewable Energy Power Quota and Assessment Measures (Second Draft for Comments)	National Development and Reform Commission	Provincial power companies, local power grid enterprises; distribution and sales companies; independent power sales companies; power users involved in direct power trading; enterprises with self-provided power plants.	Allocation principles and provincial quota allocation method; nuclear tasks without major changes	The way to meet the assessment needs by selling "alternative certificates" to the grid companies. Once again, it is clear that the "green certificate" is the subject of the quota assessment.
November 2018	Notice on the Implementation of Renewable Energy Power Quota System	National Development and Reform Commission, National Energy Administration	Unchanged	On the basis of the previous "draft opinion", the development of the allocation indicators took into account the proposed indicators of renewable energy power quotas submitted by the provincial administrative regions themselves.	The allocation principle has been changed to take into account the proposed renewable energy power quota targets submitted by the provincial administrative regions themselves.
May 2019	Notice on Establishing a Sound Guarantee Mechanism for Renewable Energy Power Consumption (NDRC Energy [2019] No. 807)	National Development and Reform Commission, National Energy Administration	The first category is all types of grid companies that supply/sell electricity directly to power consumers, independent power sales companies, and power sales companies that have the right to operate distribution grids; the second category is power consumers that purchase electricity through the wholesale power market and companies that own self-provided power plants.	Allocation principles, allocation methods and allocation schemes remain unchanged.	1. Quota subject has changed. 2. Change the quota to renewable energy consumption responsibility weighting, according to the provincial administrative regions to allocate the proportion of renewable energy consumption.

Based on the above-mentioned policy development process, the focus for more than ten years was on who should be the main body in implementing the quota; however, the final formulation of China's renewable energy consumption policy provides the allocation principles and the allocation scheme. Nevertheless, the government has not provided a clear allocation method, a calculation model, or even a specific indicator system; ultimately, each provincial administrative region tends to achieve the result by referring to historical energy consumption data. Although this initial allocation scheme can accomplish the achievement of China's renewable electricity consumption target, its allocation efficiency is worthy of consideration.

In summary, few studies have questioned the allocation scheme in the current quota system in China. The purpose of this study is to analyze the rationality of this allocation scheme. On this basis, the study designed a quota system allocation method that is more suitable for the development of renewable energy in China. The remainder of this paper is structured as follows: In Section 2, a literature review is conducted to identify other research results and their shortcomings, and to provide the innovation points of this study. In Section 3, the efficiency of the existing quota allocation is analyzed using the DEA-BCC model. Then, a zero-sum DEA model is constructed to achieve quota reallocation. Section 4 develops an empirical analysis of 30 provinces and regions in China. Section 5 summarizes the research process and the conclusions of the article, and presents the study's limitations and directions for future research.

2. Literature Review

The renewable portfolio standard (RPS) was first applied in the United States [23] and has since been implemented in many countries, including the United Kingdom, Belgium, Japan, China, and South Korea [24,25]. Many scholars have carried out comparative studies of the two surge policies, the RPS and the FIT, at their initial stages, with different conclusions due to policy differences among the countries and different perspectives in areas of research [26,27]. In terms of installed capacity, Sun and Nie argues that the FIT policy is more advantageous than the RPS policy, while the RPS has more cost advantages [28]. In fact, the RPS and the FIT are not completely independent of each other and can be implemented as complementary policies [29]. Dong and Shi studied China's RPS policy and argued that the current RPS policy is essentially a combination of RPS and FIT implementation. The effectiveness of the RPS policy is limited by the contribution of the FIT to renewable energy development [30]. That study also confirmed the rationality of the idea of a policy mix, as proposed by some scholars [31,32]. Sun and Kim analyzed the profit maximization of power producers under the RPS, and the carbon emissions trading policy in light of the current situation of renewable energy development in Korea. Their study concluded that setting different RPS ratios for different regions or different generators would be more conducive to achieving RPS goals than a uniform RPS ratio [33].

Regarding the evaluation of the effects of policy implementation, countries such as the United States, Japan, and Korea, as well as the European Union, have evaluated the benefits of the RPS at the national level, building various optimization, gaming, and combination models to confirm the applicability of policy implementation from multiple perspectives, such as cost-benefit, technological innovation, and market risk [34,35]. However, these studies focused on the effects of implementing different RPS policies in different countries, and they did not find the best way to achieve RPS goals [36].

Unlike other countries, China has set provincial RPS targets and established a minimum percentage of renewable energy generation as part of its total annual energy consumption. Subject to a final political assessment, provincial allocation targets are set to provide a guarantee to achieve the overall target [37]. In addition, all provincial governments, grid companies, electricity marketing companies, and electricity consumers have respective obligations to meet the RPS targets [38]. Nonetheless, Abbas, Wang, Bashir, Iqbal, and Ullah [39] pointed out some barriers and obstacles in the implementation of RPS policies in China, especially in the initial construction phase of the RPS. Since the distribution of renewable energy in China is uneven and economic development varies greatly from one place to another, an unreasonable quota allocation will lead to an intensification of the conflict between economic development and environmental considerations in each province [40]. Therefore, establishing reasonable quota obligations for each province is a complex task [41]. Furthermore, China differs from many countries, such as Australia, South Korea, and India, in that it has only an overall nationally based RPS target without a sub-level allocation policy [42]. While China is the only country that has set clear provincial RPS targets, there is limited research on the achievement of provincial RPS targets. The theoretical basis for the allocation of quotas has not been clearly explained, either in academic studies or in official documents issued by the National Energy Administration, and responsible provincial authorities are skeptical about the fairness and effectiveness of the currently prescribed quotas [43].

Navarro-Chávez [44] and others concluded that DEA can be an effective assessment tool for the analysis of energy efficiency issues in the future, through a comprehensive analysis. Not only can DEA evaluate the overall energy efficiency of a country and a region, but it can also evaluate the energy efficiency of individual units and provide guidance for improving energy efficiency [45]. Previously, many scholars in China and abroad have used DEA models to measure the efficiency of carbon emission rights allocation, and further studied the efficiency of carbon emission rights allocation using zero-sum DEA models, thereby proposing a fair and effective way to allocate carbon emission rights and promoting the development of low-carbon economies [46,47]. In view of the research results of DEA models in other fields, a DEA model approach is innovatively used in this paper to optimize the allocation efficiency of the RPS. Compared with other DEA models, this model can provide the optimal DEA allocation scheme in multiple iterations. Some major DEA models and their advantages and disadvantages are shown in Table 2.

Table 2. Major DEA models and their advantages and disadvantages.

Models	Advantages	Disadvantages
CCR-DEA	The model can calculate the efficiency of resource allocation with constant return of scale.	Cannot be applied in case of change in return of scale.
BCC-DEA	The model can calculate the efficiency of resource allocation in the case of a change in the return of scale.	The model can only give the relative efficiency of the initial state and cannot perform the integration of inputs or outputs to help it achieve DEA effective.
ZSG-DEA	The model can adjust the allocation scheme for non-desired outputs based on the DEA efficiency values of the decision units and gives DEA efficient allocation schemes by iteration.	The model requires multiple iterations and is computationally complex.

Currently, the global economy has been affected by the impact of the novel coronavirus outbreak, which has caused significant economic losses and a high degree of uncertainty about the short-term growth of the global economy [48]. According to data released by the National Bureau of Statistics of China, China's GDP growth fell by 6.8% in the first quarter of 2020 [49]. Under this unpromising economic environment, although the development of renewable energy is strategically important to reduce carbon emissions and to cope with the finiteness of fossil energy, studying the economics and effectiveness of quota allocation is of more practical importance at present in achieving China's consumption target. This paper addresses these issues and makes the following contributions.

1. In terms of the research content, we study the efficiency of renewable energy responsibility weight allocation in China, which is a new issue in the development process of renewable energy in China [50]. This is a problem that has not yet been focused on by scholars from the perspectives of theory or practice. Therefore, the research perspective and the methodology provided in this paper can fill some gaps.
2. In terms of research methodology, we adopt a zero-sum DEA model, which is suitable for the study of allocation strategies in keeping the total amount of allocations constant, and through which the allocation efficiency of the current allocation scheme in China can be improved. From the perspective of efficiency, the DEA-BCC model is applied to analyze the validity of the minimum consumption responsibility weights issued by the National Energy Administration; according to the output, the original scheme is reallocated using the ZSG-DEA model to achieve the Pareto optimum.
3. In terms of impact and sensitivity analysis, we compare the optimized scheme with the original scheme, analyze the impact of the change in allocation efficiency on GDP, and the impact on equity. We propose corresponding policy recommendations based on the analysis results.

In summary, there is a gap in the present research on the efficiency of the current RPS quota allocation in China. In this study, a zero-sum DEA model is innovatively used to reallocate the original scheme to achieve optimal efficiency. This study also addresses the impact of allocation efficiency on GDP and fairness, and finally provides policy recommendations to promote fair quota allocation and renewable energy development

3. Methods and Models

Data envelopment analysis (DEA) is a nonparametric econometric method for evaluating the relative efficiency of multiple input-output decision-making units (DMUs) using linear programming techniques based on operations research theory [51]. It constructs the relative efficiency by converting multiple input and output variables into a ratio of a single virtual output to a single virtual input. Since Charnes and other scholars published their CCR models and BCC models, many scholars have continued to propose their DEA models. The traditional DEA model assumes that all DMUs are free to handle input and output variables in a free market, but in practice a zero-sum situation always occurs, which means that the sum of outputs remains constant. Therefore, the ZSG-DEA model was proposed by Lins et al. To achieve the optimal efficiency, some inefficient DMUs will reduce the inputs, while other DMUs will increase the inputs in the input-oriented model accordingly, making the total input eventually constant. Gomes and Lins derived the relationship between ZSG-DEA efficiency and classical DEA efficiency using the target evaluation theorem named by Gomes. Since then, the ZSG-DEA model has been widely used in the literature by Chiu et al. [46].

3.1. Efficiency Evaluation of the Initial Provincial and Regional Allocation of Renewable Energy Quotas in China—DEA-BCC Model

The DEA-BCC model has 30 decision units of the same type (denoted as DMU, i.e., 30 provinces). The renewable electricity consumption and the energy consumption of each province are used as input indicators, and the GDP and the population of each province are used as output variables. The specific model is shown below:

$$\begin{aligned} &\min\theta \\ &s.t\begin{cases} \sum_{i=1}^{n}\lambda_i y_{ij} \geq y_{oj} \\ \sum_{i=1}^{n}\lambda_i = 1 \\ \sum_{i=1}^{n}\lambda_i x_{ik} \leq \theta x_{ok} \\ \lambda_i > 0 \end{cases} \end{aligned} \tag{1}$$

where θ is the relative efficiency of the target provincial, λ_i is the proportion of the portfolio of other provinces in the reconstructed effective portfolio of a DMU relative to the target provincial district, y_{ij} is the magnitude of the different output variables in each province, i is the decision unit (province), j is the type of output variable, y_{oj} is the value of each output variable for each target province, k is the share of renewable energy allocation (i.e., the input variable, and the output variable is independent of the input variable), x_{0k} is the initial allocation for each province, and x_{ik} is the renewable energy allocation for the i-th province.

3.2. Optimization of Provincial and Regional Allocation of Renewable Energy Quotas—ZSG-DEA Model

The DEA-BCC model assumes that the input or output variables are completely independent of each other, i.e., that given any one province, its inputs or outputs do not affect the inputs or outputs of other provinces. However, if a certain input or output is required to be a fixed aggregate, this assumption no longer holds. In this case, it is necessary for the inputs or outputs to be correlated across provinces so that the aggregate is constant. In other words, if a province increases its input or output to achieve marginal efficiency, other provinces must reduce their inputs or outputs to keep the fixed total constant. This situation is very similar to the zero-sum game, where the parties involved in the game are in strict competition, and the gain of one party must mean the loss of the other party, and the sum of the gains and losses of the parties in the game is always "zero". There is no possibility of a win-win situation for both parties. In this case, the traditional DEA model can only provide the relative efficiency of the initial state, which cannot meet the requirement of fixed total input, so the ZSG-DEA model is needed, because it can be used to reconfigure inputs or outputs so that the allocation scheme of non-desired outputs can be adjusted according to the DEA efficiency values of the decision unit.

In the input-oriented zero-sum benefit DEA model, let the target province be a non-DEA efficient decision unit that must reduce the use of inputs (renewable energy allocations) in order to achieve DEA efficiency. Then, the amount of quota used by the target province to distribute to other provinces is as follows:

$$v = x_0 - \delta x_0 \tag{2}$$

where x_0 is the initial renewable energy allocation of DMU_0, v is the amount of renewable energy quota reduction, and δ is the zero-sum gain DEA allocation efficiency value. The allocation reduction v will be allocated to the other 29 provinces in certain proportions.

The quota v used for distribution to other provinces in the target province needs to follow a certain ratio, which is the percentage of the quota of the i-th province in the total quota. The renewable energy quota that the *i*-th province (DMU_i) will receive from the target province (DMU_0) is:

$$\frac{x_i}{\sum_{i \neq 0} x_i} \cdot x_0(1-\delta) \tag{3}$$

Since each province and region is making proportional reductions in inputs, the final input volume reallocation to the decision unit, DMU_i, is the difference between the sum of the new allocations that the *i*-th province receives from each of the other provinces and its own quota allocated to the other provinces. The redistribution of the final input (renewable energy quota) to the decision unit (province *i*) is:

$$x_i' = \sum_{i \neq 0} \left[\frac{x_i}{\sum_{i \neq 0} x_i} \cdot x_0(1-\delta) \right] - x_i(1-\delta_i) \tag{4}$$

In summary, by substituting $x\prime_i$ into Equation (1), the final ZSG-DEA model can be obtained as follows.

$$\min \delta$$
$$s.t \begin{cases} \sum_{i=1}^{n} \lambda_i y_{ij} \geq y_{oj} \\ \sum_{i=1}^{n} \lambda_i x_{ik} \leq x_{ok} \\ \sum_{i=1}^{n} \lambda_i = 1 \\ \sum_{i=1}^{n} \lambda_i x_i \left[1 + \frac{x_0(1-\delta)}{\sum_{i \neq 0} x_i} \right] \leq \delta x_0 \\ \lambda_i > 0 \end{cases} \tag{5}$$

In this study, the ZSG-DEA model is solved by an iterative method. Through multiple iterations, the input variables can be reallocated several times and, eventually, all DMUs will reach the effective boundary, i.e., 100% effectiveness. At this point, the input allocation result is the one that provides the best efficiency.

In summary, the symbols used in the model and their meanings are summarized in Table 3.

Table 3. Summary table.

Symbols	Implication
DMU	Decision making units
θ	Relative efficiency of the target provincial
i	The decision unit (province)
j	The type of output variable.
k	The share of renewable energy allocation
λ_i	The proportion of the portfolio of other provinces in the reconstructed effective portfolio of a DMU relative to the target provincial district
n	30 decision units (i.e., 30 provinces)
y_{ij}	The magnitude of the different output variables in each province
y_{oj}	The value of each output variable for each target province
x_{ik}	The renewable energy allocation for the *i*-th province

Table 3. *Cont.*

Symbols	Implication
x_{0k}	The initial allocation for each province
x_0	The initial renewable energy allocation of DMU_0
v	The amount of renewable energy quota reduction
δ	The zero-sum gain DEA allocation efficiency value
$x\prime_i$	The redistribution of the final input (renewable energy quota) to the decision unit (province *i*)

3.3. Indicator Selection and Data Description

The study of environmental efficiency can use the labor force (or population) and energy consumption as input variables, and the GDP and the renewable energy quota as output variables, where the GDP is the expected output and the renewable energy quota is the undesired output. We focus on the efficiency of renewable energy quota allocation in Chinese provinces, so we use the renewable energy quota as the non-expected output. In the efficiency evaluation model of DEA, there are various ways to deal with the non-expected output. However, in this paper, the non-expected output is considered as input; according to Lins, Gomes, Mello, and Mello [52], less input and more expected output will lead to higher efficiency. The electricity consumption and the energy consumption of renewable energy in each province, calculated in 2018, are used as input indicators, while the GDP and the population of each province are used as output variables. When the electricity consumption of renewable energy and the energy consumption are the same and the decision-making unit has a higher GDP and population, the allocation is more efficient.

There are two main dimensions of the consumption responsibility weighting index.: The first dimension is the total consumption responsibility weighting and non-hydro power consumption responsibility weighting. The second dimension is the minimum consumption responsibility weight and the incentive consumption responsibility weight. The minimum consumption responsibility weight indicator is the minimum share of renewable energy electricity consumption that each province should achieve, while the incentive consumption responsibility weight does not specify how to incentivize, because the item policy promotion itself will cause the crowding out of traditional thermal power in most provinces and raise the economic cost caused by the rising energy cost; accordingly, this paper is only based on the dimension of minimum consumption responsibility weight for research. The Notice assigns the consumption responsibility weights for each year from 2018 to 2020. The 2018 dissipation responsibility weight is used as the reference value for self-verification of each provincial administrative region. Therefore, this paper multiplies the minimum consumption responsibility weight of 2018 by the total electricity consumption of the corresponding provinces to obtain the electricity consumption of renewable energy. The energy consumption of each province is calculated based on the product of energy consumption per unit GDP and the GDP of each province; the energy consumption per unit GDP, GDP, and population data are taken from the National Bureau of Statistics of the People's Republic of China.

4. Empirical Analysis

4.1. Allocation Efficiency of the Renewable Energy Quota

According to the above-proposed allocation scheme, the original DEA efficiency is solved by Matlab. The calculated initial efficiency values of the renewable energy quota for each province and region in China are shown in Table 4. In Table 4, we can see that the average value of initial efficiency is only 0.5718, which indicates that the overall efficiency of renewable energy distribution in China is not high and needs to be improved. In the initial allocation scheme, Guangdong Province, Yunnan Province, and Sichuan Province have a larger amount of renewable energy consumption. However, different provinces have different reasons, according to their characteristics. Guangdong Province has a developed economy, a large population base, and is dominated by light industry, so electricity consumption is high and more renewable energy consumption should be applied. Yunnan and Sichuan provinces, on the other hand, account for more than half of the hydroelectric power generation because of the abundance of their hydro resources.

Table 4. Efficiency of Quota Distribution by Provinces in China.

Province/ Municipality	Renewable Energy Consumption/ 100 Million kwh	Population/ Ten Thousand	GDP/ 100 Million Yuan	Energy Consumption/ton	DEA-BCC Comprehensive Efficiency Value
Beijing	133.62	2171	303,20	177,760,000	1
Tianjin	99.384	1557	188,09.64	103,453,020	0.8873
Hebei	414.655	7520	360,10.3	198,056,650	0.8089
Shanxi	271.347	3702	16,818.11	924,996,05	0.5717
Inner Mongolia	481.925	2529	17,300	951,500,00	0.2277
Liaoning	250.551	4369	25,315.4	139,234,700	0.7577
Jilin	146.96	2717	15,074.62	829,104,10	0.7762
Heilongjiang	198.237	3789	16,361.6	899,888,00	0.8019
Shanghai	490.38	2418	32,679.87	179,739,285	0.358
Jiangsu	807.932	8029	92,595.4	509,274,700	1
Zhejiang	735.87	5657	56,197	309,083,500	0.4598
Anhui	267.455	6255	30,006.8	165,037,400	1
Fujian	471.6	3911	35,804.04	196,922,220	0.4397
Jiangxi	314.678	4622	21,984.8	120,916,400	0.6216
Shandong	469.017	10,006	76,469.7	420,583,350	1
Henan	451.339	9559	48,055.86	264,307,780	0.9859
Hubei	705.2	5902	39,366.55	216,516,025	0.3793
Hunan	801.856	6860	36,425.78	200,341,790	0.3741
Guangdong	1654.95	11,169	97,149.56	534,322,580	1
Guangxi	680	4885	20,352.51	111,938,805	0.3047
Hainan	33.005	926	4832.05	265,762,75	1
Chongqing	416.25	3075	20,363.19	111,997,545	0.3229
Sichuan	1680.8	8302	40,678.13	223,729,715	0.2246
Guizhou	391.23	3580	14,806.45	814,354,75	0.3828
Yunnan	1128.8	4801	17,881.12	983,461,60	0.1803
Shaanxi	241.546	3835	24,438.32	134,410,760	0.6973
Gansu	509.07	2626	8246.1	453,535,50	0.2118
Qinghai	433.202	598	2865.23	157,587,65	0.0762
Ningxia	215.541	682	3705.18	203,784,90	0.1531
Xinjiang	664.692	2445	12,199.08	670,949,40	0.1506

Table 4 shows that the efficiency of each province and region varies greatly, with 16 provinces accounting for a larger share than the average efficiency level. Among the 30 provinces counted, only Beijing, Jiangsu, Anhui, Shandong, Guangdong, and Hainan reach 100% of the initial allocation efficiency. These provinces are followed by Henan Province, Tianjin City, and Heilongjiang Province, which all exceeded 80%. The lowest distribution efficiency is in Qinghai Province. In some provinces with significant economic volume and energy consumption, such as Shanghai and Zhejiang, the efficiency is not satisfactory, or even below average. This means that the renewable energy quotas in most provinces still need to be adjusted.

Under the original DEA model, the provinces that need to adjust the quota amount should target the provinces that reach the effective allocation. If we ask each province to adjust with the target province, according to the efficiency value and the slack variables of the original DEA model, although we will obtain the most economical renewable energy allocation scheme, this adjustment does not take into account the actual situation of each province comprehensively and may be hindered by some policies. For such phenomena and problems, the feasible solution is to implement total control; i.e., the overall renewable energy consumption of the country as a whole would remain unchanged as a hard constraint, while each province could choose different ways to fulfill the renewable energy consumption obligations according to its development. Obviously, this is a zero-sum allocation problem, so energy consumption can be redistributed with the help of the ZSG-DEA model, and then the optimization of the renewable energy quota could be carried out according to the efficiency value and the slack variables under the ZSG-DEA model.

4.2. Optimizing Allocation Efficiency of Renewable Energy Quotas

A fair allocation of renewable energy consumption should be such that the allocation is efficient in all provinces, either under the original DEA model or under the ZSG-DEA model. However, under the ZSG-DEA model, each province only adjusts its target value according to its wishes. When all provinces only adjust their targets, there may be an unbalanced result, i.e., some provinces may wish to reduce the renewable energy allocation, while others may wish to increase the renewable energy allocation. The result may be that it is difficult for each province to reach an agreement. Therefore, a multiple iteration approach is used in this paper.

According to the results of the ZSG-DEA model, under renewable energy quota allocation, the adjusted renewable energy quota allocation result of each province can be obtained. According to the results of ZSG-DEA model, under renewable energy quota allocation, the adjusted renewable energy quota allocation results of each province can be obtained. Compared with the initial allocation announced by the National Energy Administration, 15 provinces, including Inner Mongolia, Shanghai, Zhejiang, and Fujian, need to reduce electricity consumption from renewable energy sources, with a total reduction of 451,226.3 million kWh. The remaining 15 provinces, including Beijing, Tianjin, Hebei, and Shanxi, need to obtain electricity consumption from these renewable sources, with a total increase of 451,226.3 million kWh. The total amount of this increase is equal to the total amount of its decrease because the total amount of renewable energy consumption is guaranteed to be constant.

In the process of increase and decrease, the degree of acceptance is different in each region; however, after one adjustment, the efficiency value remains low in most provinces, indicating that the allocation is still inefficient. Therefore, a second iteration is needed to calculate the efficiency values under the ZSG-DEA model. After the second adjustment, the average allocation efficiency improved to 0.9838, and most of the provinces were already close to full efficiency. The adjustment continued, and as shown in Table 5; after four rounds of iterations, the efficiency values of the zero-sum benefit DEA model for each province all reached 100%, achieving DEA validity. the initial allocation for each province and the final allocation after adjustment are provided in Table 5. Since the DEA model is relative, there is always room for quota adjustment, unless all regions have 100% efficiency.

Table 5. RPS Allocation Efficiency and Adjustment Results for the RPS.

Province/ Municipality	Initial Value		First Iteration		Second Iteration		Third Iteration		Adjustment
	Renewable Energy Consumption	DEA Efficiency Value	Renewable Energy Consumption	DEA Efficiency Value	Renewable Energy Consumption	DEA Efficiency Value	Renewable Energy Consumption	DEA Efficiency Value	
Beijing	133.62	1	259.321	1.00	262.850	1.00	262.974	1.00	129.354
Tianjin	99.384	0.89	171.262	0.89	173.469	1.00	173.549	1.00	74.165
Heibei	414.655	0.81	654.386	0.81	659.992	1.00	660.159	1.00	245.504
Shanxi	271.347	0.57	303.365	0.58	305.220	0.99	305.319	1.00	33.972
Inner Mongolia	481.925	0.23	218.256	0.23	215.972	0.98	216.000	1.00	−265.925
Liaoning	250.551	0.76	369.894	0.76	373.483	1.00	373.624	1.00	123.073
Jilin	146.96	0.78	221.842	0.78	224.390	1.00	224.489	1.00	77.529
Heilongjiang	198.237	0.80	309.294	0.80	312.720	1.00	312.851	1.00	114.614
Shanghai	490.38	0.36	299.199	0.31	296.716	0.98	296.730	1.00	−193.650
Jiangsu	807.932	1.00	1567.981	1.00	1589.320	1.00	1590.070	1.00	782.138
Zhejiang	735.87	0.46	641.744	0.45	633.538	0.97	633.128	1.00	−102.742
Anhui	267.455	1.00	519.059	1.00	526.123	1.00	526.371	1.00	258.916
Fujian	471.6	0.44	386.718	0.42	385.118	0.98	385.128	1.00	−86.472
Jiangxi	314.678	0.62	382.594	0.63	384.871	0.99	384.979	1.00	70.301
Shandong	469.017	1.00	910.237	1.00	922.625	1.00	923.060	1.00	454.043
Henan	451.339	0.99	863.984	0.99	875.396	1.00	875.789	1.00	424.450
Hubei	705.2	0.38	531.384	0.39	523.678	0.97	523.412	1.00	−181.788

Table 5. *Cont.*

Province/ Municipality	Initial Value		First Iteration		Second Iteration		Third Iteration		Adjustment
	Renewable Energy Consumption	DEA Efficiency Value	Renewable Energy Consumption	DEA Efficiency Value	Renewable Energy Consumption	DEA Efficiency Value	Renewable Energy Consumption	DEA Efficiency Value	
Hunan	801.856	0.37	601.949	0.39	590.856	0.97	590.384	1.00	−211.472
Guangdong	1654.95	1.00	3211.818	1.00	3255.529	1.00	3257.064	1.00	1602.114
Guangxi	680	0.30	414.860	0.31	407.900	0.97	407.758	1.00	−272.242
Hainan	33.005	1.00	64.054	1.00	64.926	1.00	64.956	1.00	31.951
Chongqing	416.25	0.32	265.666	0.33	264.445	0.98	264.487	1.00	−151.763
Sichuan	1680.8	0.22	801.318	0.25	745.963	0.92	743.026	1.00	−937.774
Guizhou	391.23	0.38	295.287	0.39	294.705	0.98	294.756	1.00	−96.474
Yunnan	1128.8	0.18	420.232	0.19	400.956	0.94	400.493	1.00	−728.307
Shaanxi	241.546	0.70	328.458	0.70	331.381	1.00	331.504	1.00	89.958
Gansu	509.07	0.21	214.782	0.22	212.129	0.97	212.153	1.00	−296.917
Qinghai	433.202	0.08	65.748	0.08	64.933	0.97	64.959	1.00	−368.243
Ningxia	215.541	0.15	64.816	0.15	64.929	0.99	64.959	1.00	−150.582
Xinjiang	664.692	0.15	201.584	0.16	196.960	0.96	196.959	1.00	−467.733
Mean		0.57		0.57		0.98		1.00	
Total	15,561.092		15,561.092		15,561.092		15,561.092		

The empirical results show that there is a significant difference between the initial allocation scheme published by the NEA and the Pareto optimal allocation scheme under the ZSG-DEA model, as shown in Figure 3.

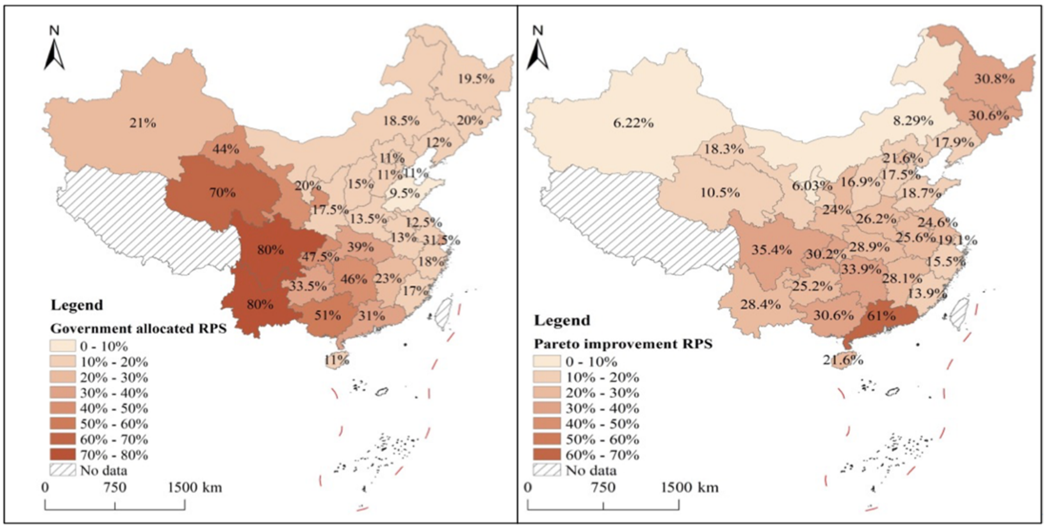

Figure 3. Comparison of the 2018 Pareto Efficiency RPS Allocation Scheme (**left**) with the RPS Allocation Scheme (**right**) published by the NEA.

The initial efficiency varies greatly, and the regions should have different quotas because of the variability in their economies, resources, and policies. From the perspective of national policymakers, the regions with high quota allocation efficiency should be allocated more quotas, while the regions with low efficiency should have fewer quotas. From a national perspective, redistribution of renewable energy quotas is necessary, because the redistribution leads to national efficiency gains and increases in total output by adjusting the quotas in the provinces.

4.3. The Economic Impact of Pareto Efficiency

From the perspective of efficiency change, the first change in efficiency is from no quota to allocated quota, while the second change in efficiency is from reallocation of the quota. The change of efficiency will directly promote the consumption of renewable energy and the improvement of resource allocation, and GDP is one of the output variables when calculating the efficiency value using the above model; the model principle shows that when the efficiency value is improved, it will have an impact on the output variable GDP.The specific results are shown in Table 6.

Table 6. Impact of RPS Allocation Efficiency Change on GDP.

Province/Municipality	Renewable Energy Consumption Changes/100 Million kWh	GDP Changes/100 Million Yuan
Beijing	129.359	248.5
Tianjin	74.168	196.3
Hebei	245.510	206.7
Shanxi	33.977	178.6
Inner Mongolia	−265.921	187.3
Liaoning	123.080	196.5
Jilin	77.533	154.3
Heilongjiang	114.620	134.2
Shanghai	−193.647	239.5
Jiangsu	782.168	432.1
Zhejiang	−102.760	267.9
Anhui	258.926	231.7
Fujian	−86.469	125.8
Jiangxi	70.306	78.6
Shandong	454.060	297.5
Henan	424.465	290.6
Hubei	−181.796	219.5
Hunan	−211.490	234.6
Guangdong	1602.175	432.1
Guangxi	−272.243	87.3
Hainan	31.953	−57.9
Chongqing	−151.759	100.6
Sichuan	−937.925	156.9
Guizhou	−96.470	−45.6
Yunnan	−728.316	−112.5
Shaanxi	89.964	113.6
Gansu	−296.914	−123.5
Qinghai	−368.241	−159
Ningxia	−150.580	−90.8
Xinjiang	−467.730	−154.6
Total	-	4066.8

Table 6 and Figure 4 show that the net output of China can be increased by 406.68 (billion yuan) by reallocating the quota while keeping the total amount of renewable energy consumption unchanged. There is significant scope for Pareto improvement. Beijing, Jiangsu, Shandong, and Tianjin benefited from the increased quota, while Shanghai, Zhejiang, Fujian, and Hunan benefited from the reduced quota. A small number of provinces, such as Qinghai, Ningxia, Gansu, and Xinjiang, showed a decreasing trend of GDP, which was also related to the local economic development. Of course, the results of this paper are rough, because other control variables of economic development were not considered; rather, only the perspective of resource allocation efficiency was considered in making an evaluation. However, even if there is a discrepancy between the estimated and accurate values, the general direction proves the necessity of reallocating renewable energy consumption quotas to achieve Pareto improvement.

4.4. Analysis of Fairness before and after the Adjustment of the RPS

The Lorenz curves before and after the adjustment of the quota target scheme are shown in Figure 5 by arranging, in order, the provinces' renewable energy consumption as a percentage of the country's, using the cumulative percentage of these indices as the vertical coordinate and the cumulative percentage of the population as the horizontal coordinate, respectively.

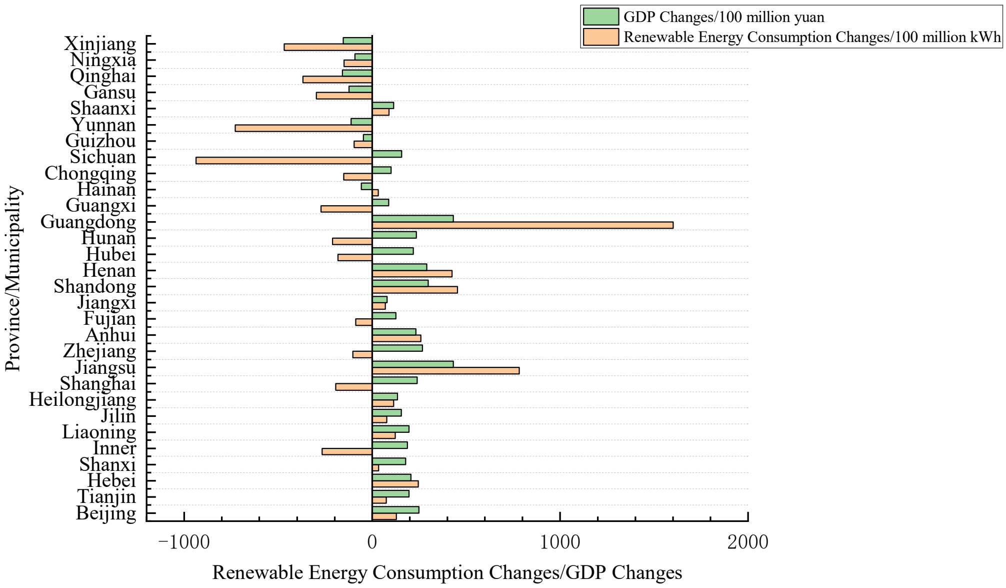

Figure 4. RPS Allocation Efficiency and Adjustment Results for the RPS.

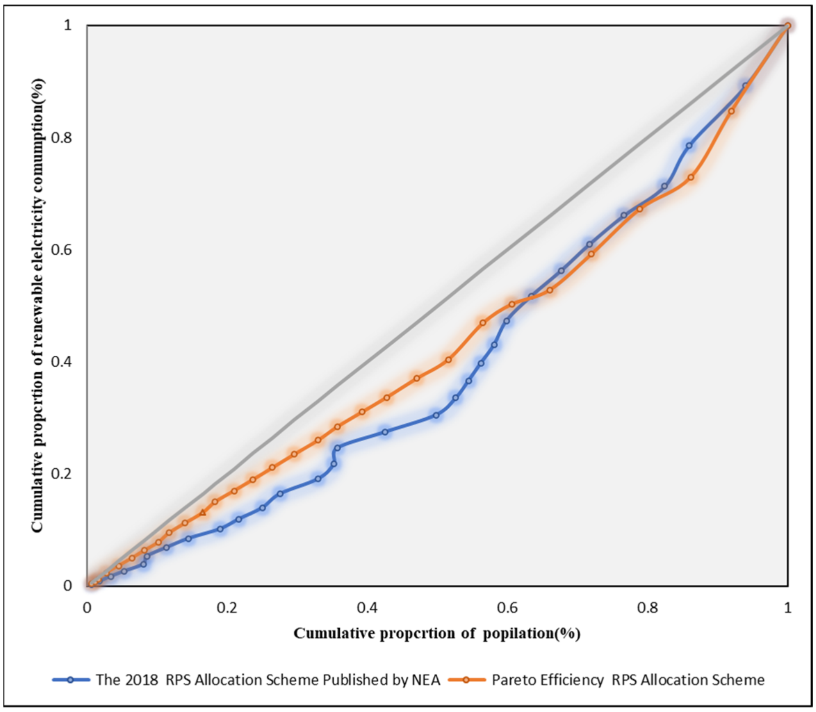

Figure 5. Loren Curve of Per Capita Renewable Energy Electricity Consumption in 2018.

The Gini coefficient of per capita renewable electricity consumption is 0.3796 when the allocation is made according to the RPS allocation scheme announced by the National Energy Administration in 2018, and 0.3428 when the allocation is made according to the adjusted Pareto optimal RPS allocation scheme. The Gini coefficient of per capita renewable electricity consumption decreases after the adjustment of the scheme, which shows that the curvature is smaller and the area enclosed by the diagonal is smaller when the Pareto optimal RPS allocation scheme is adjusted. This suggests that adjusting the RPS allocation scheme promotes equity in per capita renewable electricity consumption.

5. Conclusions and Policy Implications

5.1. Conclusions

Renewable energy consumption is not only an environmental concept, but also involves the fairness and efficiency of distribution among provinces. At present, the quota system plays a key role in controlling carbon emissions as a policy and as an instrument to promote the consumption of renewable energy. However, the allocation of quotas involves political, equitable, environmental, and historical factors. Therefore, the current allocation system is relatively inefficient. The efficiency can be improved through rational allocation to achieve Pareto optimality. The principle of this paper is the maximization of efficiency to ensure that all provinces achieve 100% efficiency after redistribution. This principle would not only greatly improve overall efficiency, but also provide economic gains through the improvement of Pareto optimality.

The ZSG-DEA model outperforms the traditional DEA model, due to the presence of a quota system. Therefore, this paper applies the output-driven ZSG-DEA model and its solution method to explore the efficiency changes that result from quota adjustment. In addition, the specific values of quota adjustment for different provinces are provided, where the number of provinces requiring a quota increase or a quota decrease are both 15. The adjusted allocation scheme is more efficient than the current one, and this paper is based on maximizing the efficiency of the whole country, while each province is focused on local economic and environmental objectives.

5.2. Policy Implications

Based on our conclusions, we believe that one-time measurements and adjustments do not allow the policy options that are needed to improve more quickly in the right direction; therefore, we build on the foundation with the following recommendations regarding the design of the renewable energy responsibility weighting scheme for each province.

1. The total renewable energy target needs to adapt to the national strategy and make a dynamic adjustment. The planning of the total renewable energy target should be subordinated to the national macro strategy and the laws of economic and social development. China has proposed the "30.60" peak carbon neutral target [53], which should be used to dynamically adjust the share of renewable electricity.
2. The total renewable energy target needs to guarantee China's power security. The development of the total renewable energy target needs to consider China's grid planning, especially the construction of the grid's long-distance transmission capacity. The short financing of the Shanxi spot market in 2021 under extreme weather and the waiver of wind power capacity in Texas, USA, are good examples of the need for renewable energy development to be paired with flexibility backup to guarantee regional electricity security.
3. The design of the renewable energy responsibility weight distribution scheme should consider the differences in various aspects, such as renewable energy resource conditions, the original energy structure, and the transmission capacity in each region. This not only ensures that the renewable energy in each province can be fully and effectively developed, but also ensures the fairness of the development in each region, so that people in the whole society can share the dividends that result from the development.
4. Timely post-evaluation of the effect of renewable energy responsibility weight allocation can help make adjustments. There is uncertainty in improving efficiency only by trading quotas among provinces, and mistakes in inter-provincial decision making is likely to result in lower efficiency. In addition, the implementation plan of each provincial government often deviates from the optimized plan, so timely post-evaluation of the allocation effect and the exploration of more adjustment tools and measures will be considered in future research. The process of adjustment should be long-term and continuous.

5. Focusing on the secondary distribution of renewable energy quotas has an important impact on the cost and efficiency of achieving the target. Although the actual situation varies from place to place and there are differences between programs, the fairness and reasonableness of the programs must be fully justified. Once the demonstration is approved, strict assessment and reward and punishment mechanisms are needed in the implementation.

5.3. Limitations and Future Work

Although this paper draws some interesting conclusions from the study of RPS quota allocation in China, the study has the following limitations.

1. While the study revolves around the quota allocation method of the RPS in China and proposes the allocation method with optimal allocation efficiency, it is based on some assumptions. Since China's RPS quotas are divided into hydropower quotas and non-hydro renewable energy quotas, the two are assessed separately in the total quota assessment process. In contrast, this study only analyzes the minimum consumption responsibility weights, and has not yet given separate consideration to the hydropower quotas and the non-hydro renewables quotas. Therefore, future research will study different kinds of quota assessment methods separately, to suggest more detailed optimal allocation schemes.
2. In this study, the quota allocation was carried out on a provincial and regional basis, which is tantamount to tacitly assuming that the responsible entity for the quota is the provincial grid company. However, China's RPS assessment includes both power sales companies and large power consumers. Most power sales companies are not only responsible for power sales in their own province, but their businesses span across multiple provinces and regions. Therefore, changing the target of the quota reallocation study to different power sales companies will be more relevant to the actual situation in China, and this is one of the directions of future research.

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