Research on China's Renewable Energy Quota System Allocation Efficiency Based on DEA Model

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Abstract. With the deepening of China's energy transformation process, the promotion of renewable energy quota system has gradually received the attention of the government and scholars. National energy house has issued corresponding supporting policies for renewable energy quota system transactions for many times. Renewable energy quota is very important for the evaluation of economic benefits and energy conservation and emission reduction benefits. Based on Data Envelopment analysis, this paper establishes a model for evaluating the effectiveness of renewable energy quota system. The model takes the quota constraints of each province as input variables, the total installed capacity of each province and the CO2 emission of each province as input variables, and takes the total GDP of each province as output variable, calculates the technical efficiency values of each province under the conditions of taking into account and excluding the quota constraints respectively. Comparing the difference of technical efficiency between the two times, the optimal input-output benefit interval of the system is judged, and the inefficient DMU is pointed out, which direction and degree of improvement are put forward.

1. Introduction

As an important part of the global public energy system, renewable energy not only reduces greenhouse gas emissions, but also provides an important driving force for social, political and economic development, energy security, environmental protection and employment. In this context, the renewable energy quota system provides new ideas for key energy emission reduction and energy optimization transformation.

In recent years, since the introduction of renewable energy quota system, scholars in various countries have carried out extensive and in-depth research on renewable energy quota system. Literature [1] studies the current situation of the quota system in the United States, based on the current policy and development status of renewable energy coordination system in China, analyzes the development trend of the quota system in the future, and provides theoretical basis and guidance for the development of renewable energy quota system in China. Literature [2-3] analyzes the influence of China's renewable energy quota system on power sales, power grid construction and power dispatching of power grid enterprises, which has a strong practical significance for the development of China's renewable energy. Literature [4] studies the design of electricity market trading mechanism under the renewable energy quota system, puts forward a renewable energy trading mode based on...
curve, and solves the problem that the current renewable energy quota system in China only considers consumption and does not effectively evaluate the user friendliness to renewable energy generation from the perspective of policy and market. So as to enhance the market main body's enthusiasm of absorbing renewable energy. Literature [5-6] studies the impact of renewable resource quota system on economy and environment. At last, they all think that renewable energy quota system can achieve the effect of energy conservation and emission reduction, but there are different conclusions on the economic promotion. Literature [7] establishes a clear policy framework of renewable energy portfolio standards in China, and uses entropy weight method and multi regional power optimization model to distribute the regional responsibility of renewable energy development fairly and reasonably. In reference [8], a multi region power optimization model is used to quantitatively evaluate the sum carbon quota effect of China's power industry. This paper studies how to coordinate the policy objectives of resource protection and carbon emission cap, how to design power generation and transmission planning, and how to achieve the objectives of different policy combinations in the case of policy overlap, which has certain practical guiding significance.

In conclusion, scholars' research on renewable energy quota system focuses on the role of renewable energy quota on economy and environmental protection at the national level, the degree of synergy with other policies and other issues, while the research on local comparative analysis of renewable energy quota system is relatively rare. Based on this, this paper will establish the effectiveness evaluation model of renewable energy quota system based on data envelopment analysis. Taking the quota constraint indicators, the total installed capacity and the emissions of each province as input variables and the GDP of each province as output variables, this paper compares and analyzes the development of each province with and without the quota system constraints to obtain two technical efficiency values, and evaluates the distribution efficiency of the renewable energy quota system of each province.

2. The basic principle of DEA model

There are \(n\) departments or companies called \(n\) decision-making units. Each unit has \(m\) inputs and \(P\) outputs. Each unit or output is represented by different economic indicators. In the table, \(x_{ij}\) represents the input of the \(i\)-th input indicator of the \(j\)-th decision-making unit, \(x_{ij} > 0\); \(y_{rj}\) represents the output of the \(j\)-th output indicator of the \(r\)-th decision-making unit, \(y_{rj} > 0\). Suppose \(v_i\) is the weight coefficient of the \(i\)-th input index, \(v_i \geq 0\); \(u_r\) is the weight coefficient of the \(r\)-th input index, \(u_r \geq 0\). \(x_{ij}\) and \(y_{rj}\) are known data, which can be counted and predicted based on historical data; weights such as \(v_i\) and \(u_r\) need to be calculated through re-modeling.

Let the weight coefficient vectors of input index and output index be respectively:

\[
\begin{align*}
    v &= (v_1, v_2, \ldots, v_m)^T \\
    u &= (u_1, u_2, \ldots, u_p)^T
\end{align*}
\]

For each unit, an efficiency evaluation index can be defined as follow:

\[
    h_j = \frac{\sum_{r=1}^{P} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}}, \quad j = 1, 2, \ldots, n
\]

The efficiency evaluation index \(h_j\) represents the economic efficiency obtained by the \(j\)-th decision-making unit with multiple input index outputs.

The above model is a fractional programming with \(t = \frac{1}{v^T x_0} = tv, \mu = tu\) which can be transformed into the following linear programming model:

\[
\begin{align*}
    \text{max} h_{j0} &= \mu^T y_0 \\
    \text{s.t.} \quad w^T x_j - \mu^T y_j &\geq 0, \quad j = 1, 2, \ldots, n \\
    w^T x_0 &= 1 \\
    w &\geq 0, \quad \mu &\geq 0
\end{align*}
\]

For the convenience of discussion and calculation, the relaxation variable \(s^+\) and the residual
variable $s^-$ are further introduced, and the above inequality constraints are changed into equality constraints:\[
\begin{align*}
\min \theta \\
\text{s.t. } \sum_{j=1}^{n} \lambda_j x_j + s^+ &= \theta x_0 \\
\sum_{j=1}^{n} \lambda_j y_j - s^- &= \theta y_0 \\
\lambda_j &\geq 0, \ j = 1,2,\ldots, n \\
\theta &\text{ unconstrained, } s^+ \geq 0, \ s^- \leq 0
\end{align*}
\] (5)

This model is called CCR model. CCR model is used to evaluate the effectiveness of decision-making units. It is related to other decision-making units, so it is called DEA model to evaluate the relative effectiveness.

3. Effectiveness Evaluation of Renewable Energy Quota System

From the letter of soliciting opinions on the implementation of renewable energy power quota system, the latest distribution scheme of renewable energy power quota system in 30 provinces, autonomous regions and municipalities in China was found, and the effectiveness of the distribution scheme was evaluated.

3.1. Input variables

(1) Quota constraint indicators of each province

The effectiveness of quota constraint index will directly affect the efficiency of resource interests. Renewable energy quota should be the renewable energy proportion index realized according to the power consumption regulations of the provincial administrative region. The data comes from the total renewable energy power quota index 2018 issued by the national energy administration.

(2) Total installed capacity of each province

As a member of China's energy system, the installed capacity of renewable energy will directly affect its annual generating capacity, and to a large extent affect the reliability of calculation. The data source is China Statistical Yearbook.

(3) CO$_2$ emissions by provinces

The economic development is accompanied by the continuous increase of carbon dioxide emissions. It is of great practical significance to analyze the renewable energy quota constraints under different carbon dioxide emission levels for the optimization of economic development benefits of each province. The "method 1" in IPCC (2006) is used to estimate:

\[
\begin{align*}
\text{CO}_2 &= \sum_{i=1}^{14} \text{CO}_{2i} \quad i = \sum_{i=1}^{14} E_i * \text{NCV}_i * \text{CEF}_i \\
\text{CEF}_i &= \frac{\text{CC}_i \cdot \text{COF}_i \cdot (44/12)}{}
\end{align*}
\] (6)

Among them, CO$_2$ represents the carbon dioxide emission to be estimated; $i$ represents various energy fuels, including coal, coke, coke oven gas, blast furnace gas, converter gas, other gas, crude oil, gasoline, kerosene, diesel oil, fuel oil, liquefied petroleum gas, natural gas and liquefied natural gas; $E_i$ represents the combustion consumption of various energy; NCV is the average low calorific value of various energy sources, which is used to convert various energy consumption into energy units (TJ); CEF$_i$ is the carbon dioxide emission factor of various energy sources.

Where CC$_i$ is the carbon content of all kinds of energy; COF$_i$ is the carbon oxidation factor of all kinds of energy, usually the value is 1, indicating that the energy is completely oxidized. In this paper, coal and coke are set as 0.99 and the rest as 1. (44 / 12) is the molecular weight ratio of carbon dioxide to carbon.

3.2. Output variables: Input variables

GDP is an important comprehensive statistical index in the accounting system. It can reflect the economic strength and market scale of each province, and judge whether the economy is in the stage of growth or recession. Therefore, this paper selects GDP as the only output variable, and the data
Source is China Statistical Yearbook. The variable data is shown in the following table:

Table 1 DEA model variables

| DMU (Province) | (I) Constraint Indicators of Each Province (%) | (I) Total Installed Capacity of Each Province (100 million kWh) | (I) Carbon Dioxide Emissions of Each Province (10^4 tons) | (o) Total GDP of Each Province (trillion yuan) |
|----------------|-----------------------------------------------|---------------------------------------------------------------|----------------------------------------------------------|-----------------------------------------------|
| Beijing        | 0.11                                          | 388.4                                                        | 9026.46089                                               | 2.8                                           |
| Tianjin        | 0.11                                          | 611                                                         | 16114.34627                                              | 1.8595                                        |
| Hebei          | 0.11                                          | 2817.1                                                      | 94897.21674                                              | 3.5537                                        |
| Shanxi         | 0.15                                          | 2823.94                                                    | 50842.07481                                              | 1.49735                                       |
| Inner Mongolia | 0.185                                         | 4435.94                                                    | 65057.42335                                              | 1.6103                                        |
| Liaoning       | 0.12                                          | 1829.27                                                   | 53920.41827                                              | 2.3942                                        |
| Jilin          | 0.2                                           | 800.33                                                     | 22855.6752                                               | 1.5289                                        |
| Heilongjiang   | 0.195                                         | 917.28                                                     | 30343.4192                                               | 1.62                                          |
| Shanghai       | 0.315                                         | 859.25                                                     | 20779.97926                                              | 3.0134                                        |
| Jiangsu        | 0.145                                         | 4914.74                                                   | 80264.1179                                               | 8.59                                          |
| Zhejiang       | 0.18                                          | 3312.33                                                   | 38399.45697                                              | 5.1768                                        |
| Anhui          | 0.13                                          | 2456.28                                                    | 38652.68336                                              | 2.7519                                        |
| Fujian         | 0.17                                          | 2200.67                                                   | 21477.0274                                               | 3.2298                                        |
| Jiangxi        | 0.23                                          | 1128.82                                                   | 22561.77925                                              | 2.08185                                       |
| Shandong       | 0.095                                         | 5162.74                                                     | 92855.4344                                               | 7.2678                                        |
| Henan          | 0.135                                         | 2739.63                                                    | 52677.07143                                              | 4.4988                                        |
| Hubei          | 0.39                                          | 2615.46                                                   | 33044.19491                                              | 3.6523                                        |
| Hunan          | 0.515                                         | 1434.67                                                   | 32195.29534                                              | 3.4591                                        |
| Guangdong      | 0.31                                          | 4503.36                                                   | 54358.37088                                               | 8.99                                          |
| Guangxi        | 0.51                                          | 1401.11                                                   | 20899.4975                                               | 2.0396                                        |
| Hainan         | 0.11                                          | 299.32                                                     | 3453.055372                                              | 0.4463                                        |
| Chongqing      | 0.475                                         | 728.1                                                      | 15694.68257                                              | 1.95                                          |
| Sichuan        | 0.8                                           | 3480.38                                                   | 29829.89811                                              | 3.698                                          |
| Guizhou        | 0.335                                         | 1899.1                                                     | 26841.21264                                              | 1.3541                                        |
| Yunnan         | 0.8                                           | 2955.06                                                   | 17777.45346                                              | 1.6376                                        |
| Shaanxi        | 0.175                                         | 1814.03                                                   | 26852.53516                                              | 2.1899                                        |
| Gansu          | 0.44                                          | 1349.15                                                   | 15619.38304                                              | 0.7677                                        |
| Qinghai        | 0.7                                           | 626.59                                                     | 5588.001513                                              | 0.2643                                        |
| Ningxia        | 0.2                                           | 1380.94                                                    | 14813.09885                                              | 0.3454                                        |
| Xinjiang       | 0.25                                          | 3010.78                                                   | 40922.81016                                              | 1.092                                         |

Note: (I) represents the input variable of DEA model, and (o) represents the output variable.

3.3. evaluation results of DEA model

According to the data in Table 1, CCR model is used and DEA solver tool is used for calculation. The evaluation results are shown in the following table:
| DMU         | \( \theta' \) | Numerical change | DMU         | \( \theta' \) | Numerical change |
|-------------|--------------|------------------|-------------|--------------|------------------|
| Beijing     | 1            | 0                | Henan       | 0.275        | 0.756            |
| Tianjin     | 0.422        | 0.188            | Hubei       | 0.356        | 0.365            |
| Hebei       | 0.175        | 0.471            | Hunan       | 0.346        | 0.346            |
| Shanxi      | 0.095        | 0.14             | Guangdong   | 0.533        | 0.902            |
| Inner Mongolia | 0.08     | 0.115            | Guangxi     | 0.315        | 0.315            |
| Liaoning    | 0.182        | 0.337            | Hainan      | 0.417        | 0.417            |
| Jilin       | 0.265        | 0.029            | Chongqing   | 0.401        | 0.401            |
| Heilongjiang | 0.245       | 0.065            | Sichuan     | 0.4          | 0.4              |
| Shanghai    | 0.486        | 0              | Guizhou     | 0.163        | 0.163            |
| Jiangsu     | 0.345        | 0.655            | Yunnan      | 0.297        | 0.297            |
| Zhejiang    | 0.435        | 0.39             | Shaanxi     | 0.263        | 0.409            |
| Anhui       | 0.23         | 0.288            | Gansu       | 0.158        | 0.158            |
| Fujian      | 0.485        | 0.179            | Qinghai     | 0.152        | 0.152            |
| Jiangxi     | 0.297        | 0.043            | Ningxia     | 0.075        | 0.075            |
| Shandong    | 0.252        | 0.748            | Xinjiang    | 0.086        | 0.14             | 0.054 |

It can be seen from the table that before the quota system was implemented, only Beijing’s input-output was DEA effective. After the quota system was joined, Jiangsu and Shandong achieved DEA effective. Most provinces also tend to be more technology effective and scale effective. Therefore, the quota system played a certain role. After the quota restriction is increased, it can be seen from the evaluation results of DEA’s CCR model that after Jiangsu and Shandong provinces participate in the quota system, it is relatively easy to realize the efficiency is relatively effective, and the scale income is not changed. Other provinces, however, are still ineffective. This is closely related to various factors, such as economic development level, installed capacity, power generation cost, power generation capacity, grid efficiency, etc. Therefore, proper adjustment and improvement of these factors can make them effective and improve their economic development efficiency.

4. Summary

Based on the data envelopment analysis, this paper establishes an evaluation model for the effectiveness of renewable energy quota system, taking the quota constraint indicators of each province, the total installed capacity of each province, the CO\(_2\) emissions of each province as input variables, and the GDP of each province as output variables, respectively calculates the development of each province under the conditions of taking into account and excluding the quota system constraints and obtains two technical efficiency values. By comparing the difference between the two technical efficiency, the optimal input-output benefit interval is determined, and the non-effective DMU is pointed out and the improvement direction and degree are proposed. Through the linear programming model, this method can avoid the standardization of the index.

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