Optimization of Initial Carbon Emission Allowance Allocation in Industrial Industries: A Case Study of Zhejiang Province, China

Kaiheng Hu, Qifen Li, Yongwen Yang, Junkai Deng
Shanghai University of Electric Power, Energy and Environment Engineering Institute, Shanghai, China

Abstract—The construction of carbon market is one of the important means for China to reach the goal of carbon peaking and carbon neutrality, and the allocation of initial carbon emission right quota is the key link in carbon market transaction. At present, the historical method is the commonly used allocation method of initial carbon emission rights in China, and the use of this method is unfair and inefficient. Therefore, this paper proposes an allocation optimization model, selects a number of indicators, and optimizes the allocation of initial carbon emission rights based on the hierarchical analysis method and entropy weight method. Example analysis shows that the allocation optimization model helps to share the carbon emission responsibility and improve the allocation efficiency, realizes the optimal allocation of initial carbon emission rights among industrial sectors, and provides support for the emission reduction of industrial sectors.

1. Introduction

With the double growth of the world's economy and population, human activities have led to the emission of large amounts of greenhouse gases, and global warming is increasing [1]. In order to cope with the global climate change problem, so far some countries have co-signed conventions [2,3] to provide legally binding for emission reduction, and carbon trading mechanisms have been proposed, and each country has begun to develop its own carbon emission right trading market. For the free allocation of initial carbon emission rights, each industry or region has different economic development status, it is not possible to do equal treatment, but should bear "common but differentiated responsibilities [4]", which is also the basic guiding principle of carbon emission rights allocation. How to rationally and effectively allocate carbon emission allowances has become a hot issue in carbon trading.

Currently scholars' studies on carbon emission allowance allocation fall into two categories. The first category is allocation principles, and domestic scholars [5,6] mainly start from the principle of energy fairness to analyze the future distribution of carbon emission quotas and trends after China enters a new stage of economic development. The second category is allocation methods. Scholars [7,8] mainly based on the historical method and benchmarking method to equitably allocate carbon emissions at the provincial level in China.

Based on the above literature, this paper proposes an optimization model of initial carbon emission right allocation that takes efficiency and fairness into account. It constructs an inter-industry carbon emission right allocation index system and comprehensively evaluates the weights of the indexes based on the hierarchical analysis method and entropy weight method to realize the optimized allocation of the initial carbon emission right of each industrial industry in Zhejiang Province, and puts forward emission reduction suggestions for the direction of emission reduction of industrial industries in Zhejiang Province.

2. Distribution optimization model

2.1 Analytic hierarchy process

Analytic Hierarchy Process, referred to as AHP, refers to the decision method that decomposes the elements always related to decision into levels such as goals, criteria and schemes, and carries out qualitative and quantitative analysis on this basis.

The process of subjective evaluation using analytic hierarchy process is as follows:

Construct a judgment matrix for each indicator, and score and rank its importance by means of expert scores or questionnaire scores. The judgment matrix is shown in Table 1.

<table>
<thead>
<tr>
<th>B</th>
<th>A1</th>
<th>A2</th>
<th>...</th>
<th>Am</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>A11</td>
<td>A12</td>
<td>...</td>
<td>A1m</td>
</tr>
<tr>
<td>A2</td>
<td>A12</td>
<td>A22</td>
<td>...</td>
<td>A2m</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Am</td>
<td>Am1</td>
<td>Am2</td>
<td>...</td>
<td>Amm</td>
</tr>
</tbody>
</table>
In the judgment matrix constructed in Table 1, the relation in Eq.(1) must be satisfied.

\[
\begin{align*}
A_{ij} &> 0 \\
A_{ij} &= 1/A_{ji} \\
A_{ii} & = 1 \\
i &\neq j \\
i, j & = 1, 2, \cdots, m
\end{align*}
\]  

(1)

The scale of the judgment matrix is shown in Table 2. In the comparison process, 1-9 is used to assign importance.

<table>
<thead>
<tr>
<th>Serial Number</th>
<th>Factor i versus factor j</th>
<th>Aij assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equally important</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Slightly important</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Relatively important</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>Strongly important</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>Extremely important</td>
<td>9</td>
</tr>
<tr>
<td>6</td>
<td>The median of two adjacent judgments</td>
<td>2, 4, 6, 8</td>
</tr>
</tbody>
</table>

By comparing each element index of the same level according to the importance degree, obtain a contrast degree contrast matrix.

Verify the consistency of judgment matrix B. The consistency verification of judgment matrix is the key and premise to improve the accuracy of index determination. Its fundamental purpose is to test whether the constructed judgment matrix is scientific and logical, so as to make the evaluation results obtained by the judgment matrix more reliable. Whether the matrix passes the consistency verification depends on the consistency ratio CR, as shown in Eq.(3).

\[
CR = \frac{CI}{RI}
\]  

(3)

In order to measure the size of CI, introduce a random consistency index RI. The size of RI is related to the order of the judgment matrix. In general, the larger the order of the judgment matrix, the more likely random deviation of consistency is to occur. RI can be found from Table 3.

<table>
<thead>
<tr>
<th>n</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI</td>
<td>0</td>
<td>0</td>
<td>0.58</td>
<td>0.90</td>
<td>1.12</td>
<td>1.24</td>
<td>1.32</td>
<td>1.41</td>
<td>1.45</td>
<td>1.49</td>
</tr>
</tbody>
</table>

Then calculate the relative weights of each layer. In this paper, the eigenvalue weighting method is used to calculate the corresponding weights. First, normalize all factors by column.

\[
H_i = \frac{a_{ij}}{\sum_{j=1}^{m} a_{ij}}
\]

(5)

Next, add the matrix by row.

\[
h_j = \sum_{i=1}^{n} h_{ij}
\]

(6)

Finally, calculate the weight vector.

\[
w_j^{(a)} = \frac{h_j}{\sum_{j=1}^{m} h_j}
\]

(7)

### 2.2 Entropy weight method

Entropy was originally a function of the state of matter in thermodynamics, created by the German physicist Clausius in 1865 while studying the heat cycle. In thermodynamics, the greater the entropy, the greater the disorder of the molecular system, and the more random the molecular motion, so we can understand that the entropy is a measure of the disorder in the system. So entropy can be extended to other research fields to represent the degree of uncertainty of a certain index.

The entropy weight method (EWM) is an objective evaluation method based on information entropy that can reduce the subjectivity of the weighting process. The higher the order of the system, the lower the entropy, and the greater the entropy. The entropy weight method shows the importance of the index according to the characteristics of different characteristics of the data itself, that is, the weight size.

The process of using entropy weight method for objective evaluation is as follows:

1. Select the index value to construct the decision matrix X.
2. After collecting the index data, it is necessary to process the data to some extent. This paper adopts the linear normalization method. After standardized processing, the original data is transformed into dimensionless index values, so that each index value is at the same dimensional level, and can avoid the problem that some values are too large and occupy too much weight. After data processing is completed, the evaluation and analysis of index weights can be carried out.

In the allocation index system, there are positive indicators and negative indicators, and the higher the value, the more CEA can be allocated. The standardized processing formula for positive indicators is shown in Eq.(9).

\[
x_{ij} = \frac{x_{ij} - \min(x_{1j}, x_{2j}, \cdots, x_{nj})}{\max(x_{1j}, x_{2j}, \cdots, x_{nj}) - \min(x_{1j}, x_{2j}, \cdots, x_{nj})}
\]  

(9)
A higher number of negative indicators means that fewer CEA are allocated. The standardized treatment formula for negative indicators is shown in Eq.(10).

\[ x'_y = \frac{\max(x_{ij}, x_{i2}, \ldots, x_{in}) - x_{ij}}{\max(x_{ij}, x_{i2}, \ldots, x_{in}) - \min(x_{ij}, x_{i2}, \ldots, x_{in})} \]  

(10)

Calculate the ratio of each indicator under each industry.

\[ p_{ij} = \frac{x'_{ij}}{\sum_{i=1}^{n} x'_{ij}} \]  

(12)

Calculate the entropy and difference coefficient in the matrix.

\[ e_j = -\frac{1}{\ln m} \sum_{i=1}^{n} p_{ij} \ln p_{ij} \]  

\[ d_j = 1 - e_j \]  

(13)

(14)

Calculate the weight of the corresponding indicator.

\[ w_{ij}^{(e)} = \frac{d_j}{\sum_{j=1}^{n} d_j} \]  

(15)

The optimized allocation results of CEA are shown in Table 4. It can be seen that after the adjustment of analytic hierarchy process and entropy weight method, each industry has different degrees of adjustment. Industries with relatively high historical carbon emissions, such as A17, A18, A22, A23, A24, A35, etc., have obtained fewer CEA compared with the allocation results of the historical method, which indicates that industries with higher historical carbon emissions have more responsibility to reduce emissions. Among them, A37 industry has the largest reduction, reducing 2017.75 million tons of quotas. As the industry with the largest carbon emission and energy consumption in the industrial field of Zhejiang Province, A37 has a great direct consumption of fossil energy and a great task of emission reduction. However, industries with low carbon emission have obtained more carbon emission permits by their excellent emission reduction potential and capacity, among which the A33 industry has increased the most, with an increase of 4,417,600 tons of quotas. A33 has a huge consumption of electricity, and energy consumption is mainly concentrated in equipment operation, but the fierce market competition has promoted the continuous improvement of energy utilization efficiency and continuous progress of technology. It performs well in the two indicators of emission reduction potential and emission reduction capacity, which helps to obtain more CEA.

Table 4 Weight results obtained by analytic hierarchy process and entropy weight method

<table>
<thead>
<tr>
<th>Index</th>
<th>Emission reduction responsibility</th>
<th>Emission reduction potential</th>
<th>Emission reduction capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Historical carbon emissions</td>
<td>Carbon intensity</td>
<td>Energy intensity</td>
</tr>
<tr>
<td>The weight obtained by analytic hierarchy process</td>
<td>0.34</td>
<td>0.22</td>
<td>0.11</td>
</tr>
<tr>
<td>The weight obtained by entropy weight method</td>
<td>0.18</td>
<td>0.28</td>
<td>0.22</td>
</tr>
<tr>
<td>Comprehensive weight</td>
<td>0.26</td>
<td>0.25</td>
<td>0.17</td>
</tr>
</tbody>
</table>

The optimized allocation result reflects not only the whipping of high-carbon emission industries, but also the reward of low-carbon emission green industries, which contributes to the improvement of fairness.

2.3 Determining comprehensive weight

The comprehensive weight is expressed through the following equation:

\[ w_i = \alpha \cdot w_i^{(a)} + (1 - \alpha) \cdot w_i^{(e)} \]  

(16)

3. Case analysis

The weights of each index and the comprehensive weights obtained through the analytic hierarchy process and entropy weight method are shown in Table 4. Through comparison, it can be found that under the analytic hierarchy process, the weight is more focused on historical carbon emissions and carbon intensity, while under the entropy weight method, the weight is more focused on carbon intensity and energy intensity. However, the weight of emission reduction responsibility under the comprehensive weight is 0.68. The weight of emission reduction responsibility is higher than the emission reduction potential and profitability, and the emission reduction responsibility will play a larger role in the allocation of CEA, which indicates that if the industry emits too much carbon dioxide, resulting in too much carbon intensity or energy intensity, then the industry should bear more emission reduction responsibility. The proportion of emission reduction potential and emission reduction capacity is relatively small, which indicates that an industry with a good energy structure and rich economic income has less impact on the allocation of CEA, and will have less pressure to reduce emissions.
4. Conclusions

In this paper, the allocation optimization model is used to optimize the allocation of carbon emission rights among industries in the industrial field of Zhejiang Province. The results show that: first, the subjective and objective evaluation method combining the hierarchical analysis method and entropy weighting method can realize the reasonable allocation of index weights, and the optimal allocation under the subjective and objective evaluation method takes into account various factors, which reduces the role of the historical carbon emissions in the allocation to a certain extent; second, the allocation optimization model improves the fairness and efficiency compared with the commonly used historical method, and reduces the carbon emission right allocation gap among the industries. allocation gap between industries. The optimization method in this paper provides a realistic and feasible reference for the allocation of carbon emission rights among industries in Zhejiang Province.

References