Research on the allocation strategy of global carbon emission rights based on FAHP-EWM-TOPSIS

Shihao Gong[1], *Xiuwei* Shang[2,*], and *Bingqian* Zhou[3]

[1] College of Transportation Engineering, Dalian Maritime University, Dalian 116000, China
[2] College of Information Science and Technology, Dalian Maritime University, Dalian 116000, China
[3] College of Maritime Economics and Management, Dalian Maritime University, Dalian 116000, China

Abstract. As a scarce public resource, carbon emission rights are essentially a new type of development rights. The rational allocation of limited carbon emission rights is crucial to international climate governance. On the basis of the multi-index method allocation model, this paper proposes a global carbon emission rights allocation model based on FAHP-EWM-TOPSIS, which uses fuzzy analytic hierarchy process and entropy weight method respectively. Determine the subjective weight and objective weight of the evaluation indicators, and use the idea of minimizing the difference to find the optimal proportion of the subjective and objective weights, and then obtain the optimal combination weight, and finally combine the TOPSIS method to score and calculate the reasonable distribution of rights and interests of countries around the world. The results show that the fair share of most countries in the world is between 1% and 2%. Compared with other carbon emission rights allocation strategies, this model takes into account the more comprehensive distribution principles, and the differences between different countries are small, which can better reflect the principle of fairness. The research results provide a new scheme for the allocation of global carbon emission rights, which has certain reference value for future global climate governance.

Keywords: FAHP, EWM, TOPSIS, Allocation of carbon emission rights.

1 Introduction

Excessive emission of greenhouse gases is the main cause of global warming. Climate problems caused by global warming have brought a huge impact on human production and life. Therefore, emission reduction has become an international consensus. Atmospheric resources are shared resources in the world, and climate issues need to be dealt with by all countries in the world, which leads to the issue of responsibility for carbon emissions. The carbon emission problem is a historical global problem, and carbon emission is temporal,

* Corresponding author: sxwdlmu@dlmu.edu.cn

that is, the current carbon content in the atmosphere is the accumulation of more than 100 years. Over the past 100 years, developed countries have developed rapidly their industrial economies and carbon emissions have dominated the world, while developing countries, due to their backward economy and technology, are more vulnerable to the impact of today's world climate problems, but have to suffer more serious consequences. In this situation of unequal resource utilization and responsibilities, developing countries have proposed the concept of carbon emission rights.

Carbon emission right refers to the right granted by nature or law to emit greenhouse gases into the atmosphere for its own survival and development, and it also reflects the division of emission reduction responsibilities[1].

At present, there are big differences between developed and developing countries on the issue of carbon emission rights allocation, and there are two representative schemes for this issue. The first is the per capita annual emission convergence method mainly advocated by developed countries. The main idea is that the per capita carbon emissions of developed and developing countries will converge at a certain point in the future. But the plan tacitly acknowledges the unfairness of the "convergence" of history, reality and the future. On the premise of the unfairness of the per capita annual emission convergence law, developing countries such as Brazil put forward the historical responsibility method in the Brazilian proposal, adhering to the principle of "whoever pollutes should take care of it"[2], taking historical cumulative emissions as the evaluation standard. This scheme is more in line with the interests of developing countries, but whether it will have an impact on global economic benefits is still open to question.

The above two schemes are relatively representative research results in this field, but at present, countries around the world have not yet reached a consensus on the allocation of carbon emission rights. The reason is that there are still disputes among countries on which distribution principle and distribution method to adopt to better reflect fairness. In fact, as explained in the next section, the allocation of carbon emission rights has attracted extensive attention in the academic world, but so far, most of the research on the allocation of carbon emission rights still focuses on national groups or national provinces, regions, Industry sector. Therefore, there is an urgent need for a carbon emission rights allocation scheme based on a global perspective, which not only ensures global fairness, but also takes into account the productivity of human society. Based on this, this paper will construct a fair and reasonable indicator system of carbon emission allocation rights from the perspective of fairness and efficiency, and on this basis, explore the carbon emission rights that countries in the world should enjoy. It is hoped to take into account global benefits on the basis of global equity, so as to achieve sustainable development of global ecology and economy.

2 Literature review

At present, many scholars at home and abroad have carried out research on carbon emission allocation, so there are a large number of review and empirical literatures in this field. For example, Acar et al.[3] conducted an empirical study on the convergence of per capita carbon emissions, and Zhou and Wang [4] summarized the carbon dioxide emissions allocation method. Since the 1990s, quite a number of scholars have focused on the distribution of carbon emissions in various countries. Most of these studies focus on a small number of countries. For example, Chakravarty et al.[5] studied large emitting countries with emissions of more than 1 billion,and thus "abandoned" many small countries, which is undoubtedly controversial in terms of fairness. Or to limit the study to a single country, studies on carbon emission allocation in China[6], Chinese regions[7], Chinese cities[8], and Chinese sectors and industries[9, 10] are particularly abundant.

Since its establishment in 2005, the European Union (EU) has limited total annual emissions of carbon dioxide by allocating a certain number of pollution permits through the implementation of the European Union Emissions Trading Scheme (EUETS). Studies have shown[11] that the program had a strong negative impact on carbon emissions, with little fluctuation in the impact on the economy. However, studies on the distribution of carbon emissions in Europe and the United States are rare, and those on the distribution of carbon emissions from a global perspective are even rarer. Therefore, this paper will take this as a starting point to explore the distribution of carbon emissions from a global perspective.

The main problem of carbon dioxide emission distribution is to find distribution principles that are recognized by all stakeholders. At present, it can be roughly divided into two categories, namely, the principle of fairness and the principle of efficiency. Although both fairness and efficiency have their own concerns, Zhou et al.[12] argue that efficiency can also be regarded as a type of fairness. On the basis of the principles of fairness and efficiency, a variety of carbon emission allocation methods have been proposed, such as game theory method, data envelopment analysis (DEA) and indicator method. The main principle of the game theory method is that each carbon emission subject plays a game to find the optimal allocation of carbon emission permits. For example, Filar and Gaertner[13] used the Shapley value method in cooperative game theory to study the distribution of greenhouse gas emission reductions in countries around the world. The advantage of this method is to consider the differences in the contributions and needs of each subject, but its operation is complex and its transparency and feasibility need to be verified. The essential idea of DEA method is linear programming, and it is also a typical method to study carbon emission allocation. For example, Chiu et al. [14] used the ZSG-DEA model to allocate carbon emission permits in sample countries. However, because the model pursues the overall optimality, its performance is weak in reflecting fairness. The multi-indicator method is widely used in the field of evaluating environmental performance[15], and it has also received more and more attention in the field of carbon emission allocation due to its great advantages in integrating different fairness standards.

Indicator weighting is the key to the multi-indicator method. Most of the current multi-indicator methods use a single subjective weighting or objective weighting[16], and the reliability of the results is still open to question. Even though some scholars use the subjective and objective weighting method comprehensively, they still have a certain degree of arbitrariness in determining the respective proportions of the subjective and objective weights. Therefore, this paper proposes a subjective and objective weighting model based on FAHP-EWM. At the same time, it innovatively uses the idea of minimizing the difference to optimize the proportion of subjective and objective weights, avoiding the subjectivity and randomness of artificial weighting. Finally, The TOPSIS model is then introduced to calculate the share of carbon emissions that each country should enjoy.

3 Basic theory

3.1 Fuzzy Analytic Hierarchy Process (FAHP)

Fuzzy Analytical Hierarchy Process(FAHP) is a comprehensive evaluation method that combines qualitative and quantitative. It combines the fuzziness of fuzzy decision-making and the consistency of AHP, and can transform the qualitative problem of evaluation indicators into quantitative problem. This increases the reliability of decision-making.

The specific analysis method of FAHP is as follows:

1) First, construct the index system $I_1, I_2, \cdots, I_n$, and construct the $n \times n$ fuzzy

judgment matrix $D=(d_{ij})_{n\times n}$ according to the subjective preference degree of experts for *n* indicators, combined with Tabel 1.

Table 1. Assignment of Relative Importance of Indicators by FAHP.

Quantity Scale d_{ij}	Degree of Language Description
0.5	Both indicators are equally important
0.6	I_i is slightly more important than I_j
0.7	I_i is significantly more important than I_j
0.8	I_i is strongly more important than I_j
0.9	I_i is extremely more important than I_j
0.1, 0.2, 0.3, 0.4	Determined by $d_{ij}+d_{ji}=1$

2) Further, according to the order consistency and satisfactory consistency of the fuzzy judgment matrix, construct the fuzzy consistent judgment matrix $E=(e_{ij})_{m\times n}$ on the basis of matrix *D*, where

$$e_{ij}=\frac{\sum_{j=1}^{n}d_{ij}-d_{ij}}{2n}+0.5 \tag{3.1}$$

3) Finally, the subjective weight $w_s=\left(w_{s1},w_{s2},\cdots w_{sn}\right)$ corresponding to each indicator is calculated from the fuzzy consistent judgment matrix *E*, where

$$w_{sj}=\gamma_{sj}/\sum_{j=1}^{n}\gamma_{sj} \tag{3.2}$$

$$\gamma_{sj}=\frac{2\sum_{i=1}^{n}e_{ji}-1}{n(n-1)} \tag{3.3}$$

3.2 Entropy Weight Method(EWM)

Entropy Weight Method(EWM) can reflect the amount of information according to the degree of variation of the indicator, and then obtain the objective weight.

The specific calculation process of EWM is as follows:

1) Collect *n* indicators values of *m* factors to form an *m*n* input matrix, transform the interval attributes, and perform standard 0-1 transformation to ensure that all values of the matrix are in the [0,1] interval. Get the normalized matrix $Z=(z_{ij})_{m\times n}$.
2) Calculate the probability matrix *P* from the normalized matrix *Z*, the calculation equation of each element P_{ij} is as follows:

$$p_{ij}=z_{ij}/\sum_{i=1}^{n}z_{ij} \tag{3.4}$$

For the j^{th} indicator, its information entropy $e_j\,(j=1,2,\cdots,n)$ is

$$e_j=-\frac{1}{\ln m}\sum_{i=1}^{m}p_{ij}\ln(p_{ij}) \tag{3.5}$$

3) Calculate the objective weight $w_j\,(j=1,2,\cdots n)$ of each indicator, where

$$w_j = \delta_j / \sum_{j=1}^{n} \delta_j \tag{3.6}$$

$$\delta_j = \frac{1-e_j}{\sum_{j=1}^{n}(1-e_j)} \tag{3.7}$$

3.3 Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS)

TOPSIS can build an evaluation system based on the existing data and use the optimal and worst distances to sort the evaluation objects, which is suitable for the presence of quantitative indicators.

The specific process is as follows:

1) Establish an evaluation decision matrix, standardize it, then obtain a standardized decision matrix $Z=(z_{ij})_{m\times n}$ (m is the number of evaluation objects, n is the number of indicators).
2) According to the weight vector $w=[w_1,w_2,\ldots,w_n]^T$ of each indicator, construct a weighted standardized decision matrix $C=(c_{ij})_{m\times n}$, where

$$c_{ij} = z_{ij} \cdot w_j \tag{3.8}$$

3) Determine the positive ideal solution c_j^* and negative ideal solution c_j^0 (j=1,2,⋯,n) of each indicator, where

$$c_j^+ = \max\{c_{1j}, c_{2j,}, \cdots, c_{mj}\} \quad c_j^- = \min\{c_{1j}, c_{2j,}, \cdots, c_{mj}\} \tag{3.9}$$

4) Calculate the distance s_i^* , s_i^0 (i=1,2,⋯,m) from each evaluation object to the positive and negative ideal solutions, where

$$s_i^* = \sqrt{\sum_{j=1}^{m}(c_{ij}-c_j^*)^2}, s_i^0 = \sqrt{\sum_{j=1}^{m}(c_{ij}-c_j^0)^2} \tag{3.10}$$

5) Calculate the relative progress $f_i^*(i=1,2,\cdots,m)$ of each evaluation object, where

$$f_i^* = s_i^0 / (s_i^0 + s_i^*) \tag{3.11}$$

The larger f_i^* is, the closer it is to the positive ideal solution, and the farther it is to the negative ideal solution, which should be given priority in sorting.

4 FAHP-EWM-TOPSIS allocation model

In order to reasonably evaluate the share of carbon emission rights in each country, we first selected 70 countries according to historical carbon emissions, economic volume and other indicators, then constructed a multi-indicator evaluation system on the basis of taking into account fairness and efficiency. Further use the FAHP-EWM-TOPSIS model to score the reasonable share of each country, and finally use the normalization operation to obtain the carbon emission share of each country.

Figure 1 shows the framework of FAHP-EWM-TOPSIS distribution model, which mainly consists of three steps: a) Preparation, b)Weight Calculation, c) Allocation Share Calculation. Then we will introduce the 3 steps in the following.

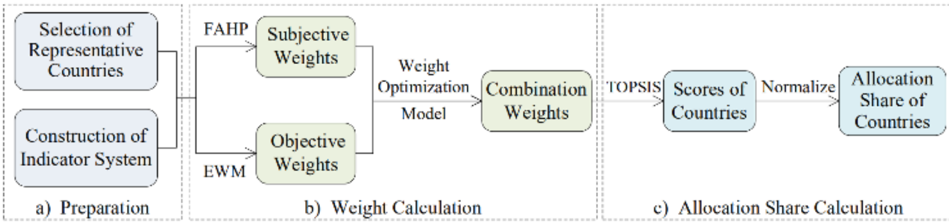

Fig. 1. Framework of Our Model.

4.1 Preparation

First, we select representative countries on a global scale for carbon emission share calculation. We have comprehensively considered the actual carbon emissions of countries around the world in the past 20 years, combined with the comparability and availability of indicator data, then selected 70 countries and regions as the research objects for the allocation of carbon emission rights. Their combined annual carbon emissions account for more than 90% of the global total, and their total GDP exceeds 85% of the global total. They come from seven continents, involving developed, developing and backward countries. Therefore, they are highly representative and comprehensive.

Considering that it is difficult to take into account the rights and interests of all countries in the world with a single indicator system, on the basis of the principle of fairness, we comprehensively consider the measurement of efficiency to build a multi-indicator evaluation system. At present, many specific allocation principles have been proposed at domestic and foreign[17], among which the representative principles are mainly the following four:

- **Per Capita Fairness:** Every citizen on the planet today has the same right to emissions, regardless of past and future[18]. But per capita fairness is only a superficial principle and needs to be revised by other fairness principles. We choose the country's total population (I_1) as a representative indicator of this principle.
- **Historical Contribution and Responsibility:** This principle holds that the more carbon emissions, the less space is left for future generations to emit, and the more emission reductions are shared, the more opportunities are left for future generations to enjoy atmospheric resources. Therefore, countries with historically excessive greenhouse gas emissions should bear the responsibility of compensation, while countries that have contributed to global fairness in carbon emissions can enjoy partial privileges. We use a country's technical cooperation contribution (I_2) and total carbon emissions (I_3) over the past two decades to measure its historical contribution and responsibility.
- **Economic Ability:** From the perspective of utility, if additional marginal emission units are allocated to poor countries with higher marginal income utility, the global welfare level can be better improved[19]. Therefore, carbon emission rights can be dynamically allocated according to the national economic strength. We choose GDP (I_4) and Gini coefficient (I_5) as indicators to measure comprehensive national strength and economic capacity.
- **Utilizing Potential:** From the perspective of resource utilization efficiency, countries with a higher level of scientific and technological development can generate higher benefits by emitting the same unit of greenhouse gas. In order to implement the principle of "making the best use of everything", there are some allocation preferences to countries with high resource utilization potential. We measure its resource utilization potential using the total number of R&D personnel (I_6), R&D expenditure (I_7), and education expenditure (I_8).

In order to realize the fair allocation of carbon emission rights based on the above four principles, we extract eight representative indicators, and finally construct the four principles basic indicator system. The structure of the indicator system is shown in figure 2.

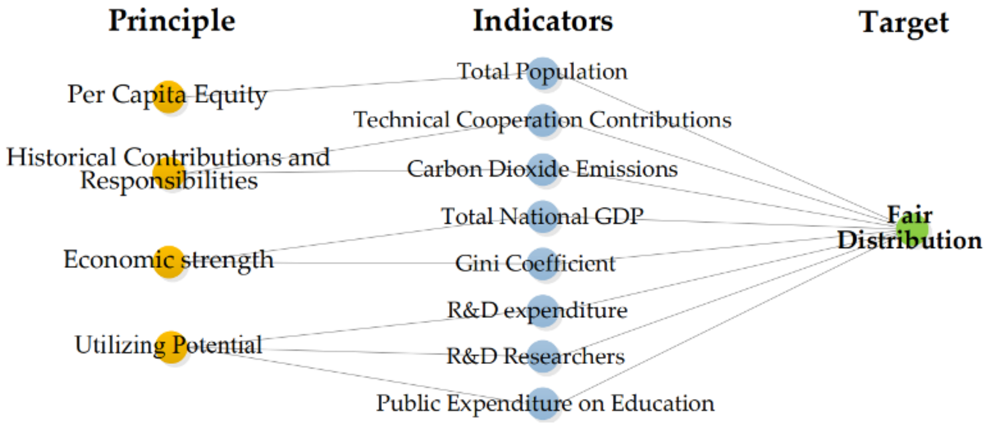

Fig. 2. Four Principles Basic Indicator System.

The data of the eight major indicators such as GDP and population of each country are derived from the online database of the World Bank. We select the data in 2018 for calculation, and impute the missing data in some countries and regions according to the rate of change over the years.

4.2 Weight calculation

After constructing the indicator system for the allocation of global carbon emission rights, it is necessary to calculate the weight of each indicator. Common weighting methods include subjective weighting and objective weighting. For the subjective weighting method, the indicator weight is judged by decision-making experts based on experience, which reflects the importance of the indicator itself, and is generally not affected by the value of the indicator; for the objective weighting method, the indicator weight is calculated from the actual value of each indicator, which reflects the degree of discrimination of the indicator on the specific evaluation object, and generally cannot directly reflect the importance of the indicator itself.

In this paper, we combined the advantages of these two types of methods, use FAHP method to solve the subjective weight W_s, and EWM to solve the objective weight W_o. The final combined weight W_f is shown in equation (4.1):

$$w_f = \alpha \times w_s + \beta \times w_o \tag{4.1}$$

In order to reasonably determine the proportion of subjective and objective weights, so that the final indicator weights can take into account the advantages of both, we use the level difference minimization method to optimize W_f .The process is as follows:

- **Objective function:** In order to reduce the difference in the share of carbon emission rights among countries and reflect the concept of fairness as much as possible, the objective function is to minimize the variance of the scores of all countries under the combined weight.

  The calculation steps of the objective function are as follows:

The attribute value matrix X is the standardized result of various indicators (positive type, negative type, interval type), as shown in equation (4.2), the comprehensive evaluation result Z is shown in equation (4.3), and the variance of the comprehensive evaluation result is shown in equation (4.4).

$$X = \left(x_{ij}\right)_{mn} = \begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix} = \left(x_1, x_2, \cdots, x_n\right) \tag{4.2}$$

where m=70, n=8

$$Z = w_f X = \left(w_f x_1, w_f x_2, \cdots, w_f x_n\right) \tag{4.3}$$

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(w_f x_i - w_f \overline{x})^2 \tag{4.4}$$

To sum up, the level difference minimization is shown in equation (4.5).

$$\min \frac{1}{n-1}\sum_{i=1}^{n}(w_f x_i - w_f \overline{x})^2$$
$$s.t.\begin{cases} w_f = \alpha \times w_s + \beta \times w_o \\ \alpha + \beta = 1 \\ 0 < \alpha < 1 \\ 0 < \beta < 1 \end{cases} \tag{4.5}$$

Use Matlab to solve the optimization model, and get the optimal proportions of subjective and objective weights:

$$\alpha = 0.61, \beta = 0.39$$

Subsequently, the subjective weights obtained by FAHP and the objective weights obtained by EWM are linearly weighted to obtain the final weights. The specific results are shown in Table 2.

Table 2. Detailed indicator weights.

Indicator	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8
W_s	0.35	0.05	0.11	0.06	0.05	0.21	0.11	0.06
W_o	0.1898	0.0474	0.0025	0.0029	0.6149	0.0722	0.0455	0.0203
W_f	0.2875	0.0499	0.0885	0.0681	0.2703	0.1563	0.0848	0.0445

4.3 Allocation share calculation

The TOPSIS model can use the optimal and worst distances to construct an evaluation system to score the carbon emission rights of 70 countries. After obtaining the scores of each country, we use the normalization operation to calculate the carbon emission share of each country, as shown in Table 3.

Table 3. Carbon emission rights allocation results.

Category	Country	Allocation Share	Category	Country	Allocation Share
I	India	15.39%	III	Portugal	0.98%
	China	13.74%		Congo	0.95%
	United States	3.54%		Italy	0.88%
	Nigeria	2.85%		Spain	0.87%
	Indonesia	2.51%		Mexico	0.84%
	Pakistan	2.29%		Estonia	0.83%

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	Brazil	2.17%	Poland	0.78%
	South Korea	1.87%	Thailand	0.77%
	Algeria	1.84%	Greece	0.77%
	Russia	1.69%	Argentina	0.75%
	Sweden	1.69%	Hungary	0.73%
	Japan	1.65%	Lithuania	0.70%
	Ethiopia	1.57%	Slovakia	0.62%
	Finland	1.54%	Sudan	0.60%
	Singapore	1.47%	Tanzania	0.60%
	Norway	1.41%	Malaysia	0.60%
	Iceland	1.38%	Colombia	0.58%
	Chile	1.37%	South Africa	0.58%
	Belgium	1.36%	Afghanistan	0.57%
	France	1.32%	Morocco	0.57%
	Denmark	1.29%	Ukraine	0.56%
II	Philippines	1.29%	Belarus	0.55%
	Britain	1.27%	Canada	0.55%
	Germany	1.24%	Australia	0.47%
	New Zealand	1.21%	Croatia	0.47%
	Netherlands	1.21%	Saudi Arabia	0.36%
	Bulgaria	1.19%	Central African	0.35%
	Ireland	1.15%	Libya	0.32%
	Austria	1.14%	Mali	0.31%
	Egypt	1.10%	Romania	0.31%
	Iran	1.08%	Angola	0.29%
	Vietnam	1.06%	kazakhstan	0.29%
	Slovenia	1.05%	Kuwait	0.27%
	Turkey	1.02%	Czech Republic	0.20%
	Switzerland	1.02%	United Arab Emirates	0.15%

From Table 3, it can be seen that the reasonable share of carbon emissions in most countries is between 1% and 2%, which is also consistent with the facts. In order to more clearly show the reasonable share allocation of carbon emissions among countries, we divide the 70 countries into three categories of countries according to the size of the share, using 1% and 2% as the boundary, and plot our results on the map, as shown in figure 3.

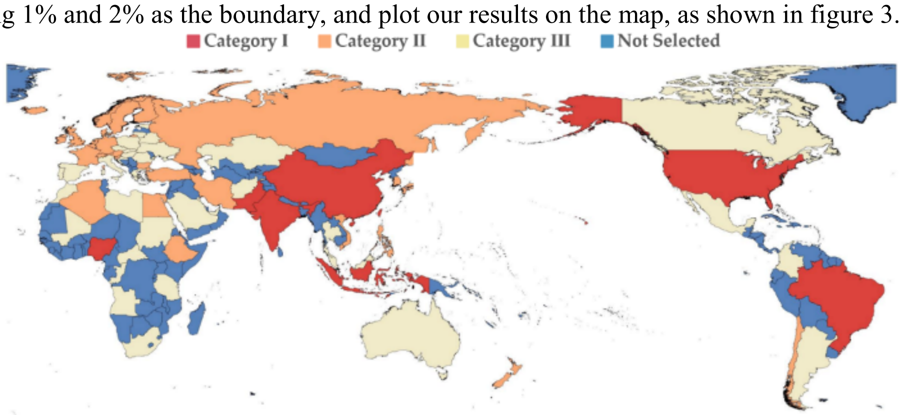

Fig. 3. Carbon Emission Rights Allocation Map.

5 Summary and outlook

The low-carbon economy is in the ascendant. At present, all countries are actively exploring carbon emission reduction technologies and mechanisms, and share the responsibility of reducing greenhouse gas emissions. In this paper, the index method is used to reasonably allocate the carbon emission shares of various countries in the world. While taking into account global equity and social efficiency, the FAHP-EWM-TOPSIS comprehensive evaluation model is applied to the index system of carbon emission allocation. The carbon emission share that each country deserves is scored, so as to optimize the decision-making process, so that the final distribution of carbon emission rights can take into account the interests of all parties, and provide new ideas for global climate governance. Finally, we divided the carbon emission share of the world's 70 major countries into three categories: above 2%, 1% to 2%, and below 1%, and gave the detailed share of each country. Among them, China and India both account for more than 10% in our allocation results due to their huge population base and high proportion of their total economic output.

In the future, when studying the distribution of global carbon emission rights, it is necessary to seek a balance between global equity and social efficiency, and between the total target and individual standards. Excessive pursuit of the principle of fairness will lead to a large degree of waste of carbon emission space in many countries with small economies, which is not conducive to the industrial development of society. Therefore, a reasonable balance between fairness and efficiency is also an idea that is widely used in the current research on carbon emission rights allocation.

However, we also found in our research that the allocation of carbon emission rights is not only a scientific issue, but also a political and social issue, which is related to human well-being and the development space of various countries, and will also have an important impact on the construction of the global governance system. Therefore, it is not only necessary to consider whether the distribution plan is scientific, but also to consider the differences in historical, cultural, economic and other factors between countries and regions and their interest demands. The final distribution plan that can be implemented must be scientific, rational and feasible.

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