



# NOTA DI LAVORO

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Equity: Carbon Gini Index  
Based on Historical  
Cumulative Emission Per  
Capita**

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# SUSTAINABLE DEVELOPMENT Series

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### Summary

This paper uses Lorenz Curve and Gini Index with adjustment to per capita historical cumulative emission and constructs Carbon Gini Index to measure inequality in climate change area. The analysis using Carbon Gini Index shows that 70% of carbon space in the atmosphere has been used for unequal distribution, which is almost the same as that of income in the country with the biggest gap between rich and poor in the world. The carbon equity should be an urgency and priority in the climate agenda. Carbon Gini Index established in this paper can be used to measure inequality in the distribution of carbon space and provide a quantified indicator for measurement of carbon equity among different proposals.

**Keywords:** Climate Change, Carbon Equity, Long-term Mitigation Goal, Cumulative Emission Per Capita, Carbon Gini Index

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# How to Measure Carbon Equity: Carbon Gini Index Based on Historical Cumulative Emission Per Capita

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**Abstract:** This paper uses Lorenz Curve and Gini Index with adjustment to per capita historical cumulative emission and constructs Carbon Gini Index to measure inequality in climate change area. The analysis using Carbon Gini Index shows that 70% of carbon space in the atmosphere has been used for unequal distribution, which is almost the same as that of income in the country with the biggest gap between rich and poor in the world. The carbon equity should be an urgency and priority in the climate agenda. Carbon Gini Index established in this paper can be used to measure inequality in the distribution of carbon space and provide a quantified indicator for measurement of carbon equity among different proposals.

**Key words:** climate change; carbon equity; long-term mitigation goal; cumulative emission per capita; Carbon Gini Index

## 1.Introduction

One of the key issues of addressing climate change is to enact a reasonable global long term emission reduction target and implement the equal allocation of carbon dioxide emission space. The quantitative global long term target will certainly limit the global carbon dioxide emission space. The unequal allocation of the limited carbon dioxide emission space would largely restrict the future emission space of developing countries. The earth's atmosphere is human's public nature resource, reasonable emission space is indispensable for human development. Therefore, we should allocate and use the emission space under the principle of global carbon equality. This is the cornerstone of global addressing climate change cooperation.

Chinese scholars<sup>[1-5]</sup> employed the cumulative carbon dioxide emission per capita as index, revealed the different historical responsibility of developed countries and developing countries. Moreover, the scholars proposed the principle of cumulative emission per capita convergence as the guideline. Under the principle of cumulative emission per capita convergence, Chinese scholars proposed the carbon budget and carbon emission account methods<sup>[6-7]</sup> as the emission space allocation system design. Although the cumulative emission per capita reveals the different historical responsibility of different countries, it cannot provide a comprehensive index which covers every country's cumulative emission per capita, nor can it provide a general

measurement of emission space allocation equality. Therefore, many studies used income equality measurement method, measured emission equality with different income equality index. Hedenus and Azar<sup>[8]</sup> measure emission inequality across countries by the well-known Atkinson index. Duro and Padilla<sup>[9]</sup> apply the decomposable Theil index of inequality to emissions and show convincingly that global inequality in per capita emissions is largely due to inequalities in per capita income across countries. Heil and Wodon<sup>[10-11]</sup> use the Gini-index to measure the inequality of emission across countries. Groot<sup>[12]</sup> established the carbon Lorenz curves and carbon Gini coefficient based on the annual per capita emission. The literatures above measured the emission space equality with income equality measurement indexes, but these literatures are all based on the annual per capita emission. The contribution of this paper is to reestablish the carbon Lorenz curves and Gini indexes based on the historical cumulative emission per capita which has essential difference with the annual per capita emission measurement. Firstly, the existence time of GHG in atmosphere is more than a century, the cumulative emission can show a certain country's climate change historical responsibility more clearly than annual emission. Consequently the historical cumulative emission per capita can represent the carbon equality more. Secondly, the emissions within a certain period determine the temperature rise. The definition of equality is to measure the overall emission allocation in the certain period, rather than annual emission allocation.

## **2. Carbon Equality and Measurement**

The essence of carbon equality is to measure the difference of each emission allocation plans. Although allocation difference is a new topic in climate change studies, it has been thoroughly investigated in the income allocation equality researches<sup>[13-14]</sup>. The commonly used resident income allocation difference indexes are variation coefficient, Gini coefficient, Generalized Entropy index, Atkinson index. The Gini coefficient is most widely used index. Such indexes are usually used to statically mapping the wealth allocation and social stability of a certain country or district.

The Lorenz curve had been initially proposed by Lorenz in 1907. It indicates the relations between population shares and income shares. Cumulative emission shares on the vertical and cumulative population shares on the horizontal axis. The curve reflects the relations between emission shares and population shares. If the population shares are not equal to the income shares, the inequality exist. If the allocation is perfect equal, then Lorenz curve is the straight line with the slope of 45 degree. That is the "perfect equal allocation curve"(Fig.1). Based on the Lorenz curve, Gini proposed the equality level measurement index which is Gini index. Defined the area between the actual allocation curve and perfect equal allocation curve as X, the area below the actual allocation curve as Y. Then the Gini index equals to  $X/(X+Y)$ . The economical meaning of Gini index is that the inequality level of the income allocation

equals to the income used for unequal allocation among total residential income. Gini index is a real number between 0 and 1. The perfect equal allocation's Gini index is 0, while the perfect unequal allocation's Gini index is 1. Gini index is a general index, reveal a general level of the allocation equality. According to the UN's definition, Gini index  $< 0.2$  corresponds perfect income equality, 0.2-0.3 corresponds relative equality, 0.3-0.4 corresponds adequate equality, 0.4-0.5 corresponds big income gap. Above 0.5 corresponds severe income gap. Therefore, the warning level of Gini index is 0.4. This paper used the division above to investigate the carbon inequality issue. How to use Gini index to provide a more meaningful division is still an issue which need further research, since this involves the welfare meanings of the carbon space allocation.

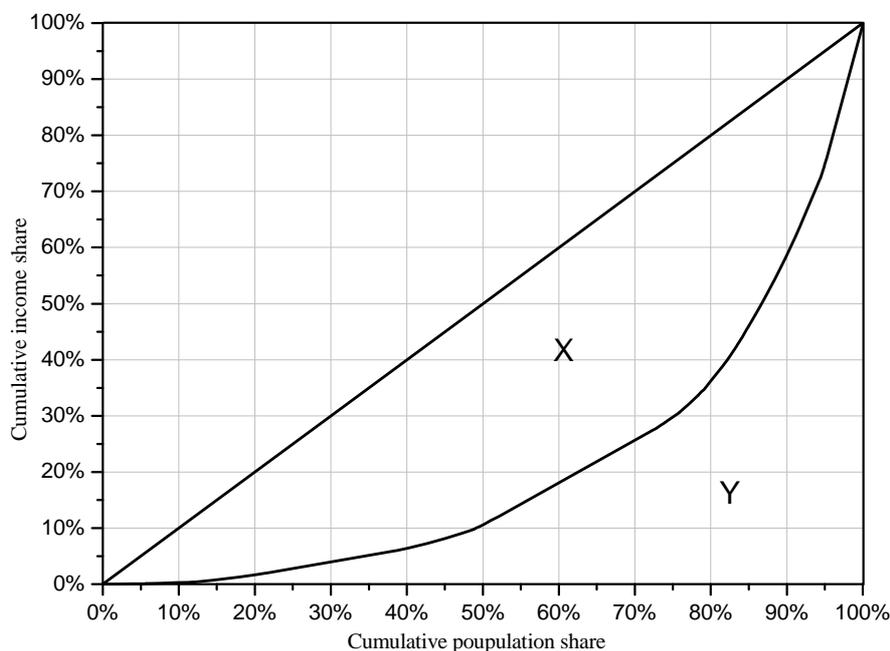


Fig.1. Lorenz Curve and Gini Index

Lorenz curve and Gini index reflect the relations between income shares and population shares. Whenever the income shares and population shares are not equal to each other, inequality exists. The convergence of cumulative per capita proposed by Chinese scholars reflects this equal principle. This idea applied with the Lorenz curve and Gini index means that everyone has the same cumulative emission space, no carbon inequality.

Developed countries had emitted large amount of GHG in their industrialization process. These GHG cumulated in the atmosphere, not only enhanced the green house effect, but also led to global warming and many other climate changes. Moreover, GHG of developed countries occupied the emission space and made developing

countries face a more restricted emission limit. Therefore, Gini index can also measure equality situation of different emission allocation plans. When using the Lorenz curve and Gini index, horizontal axis is changed from households to population, while vertical axis is changed from income to emissions. This paper calculated the carbon equality with historical cumulative emission statistics. Based on such statistics we established the “carbon Lorenz curve” to reflect different counties unequal emission allocation level. According to “Carbon Lorenz Curve”, we can calculate the “Carbon Gini Index” to quantitatively measure the emission inequality of different countries.

### 3. Carbon Lorenz Curve and Carbon Gini Index Calculation

When investigating different countries’ historical cumulative emission situation, this paper focused on the carbon dioxide emission from energy activities. Baumert<sup>[15]</sup> suggested that CO<sub>2</sub> is the main GHG, CO<sub>2</sub> emission from energy activities contribute more than 2/3 of the world GHG total. This paper calculated the historical cumulative emissions by simply add the emissions, this is a widely used method.

In order to understand how the historical cumulative emission per capita Lorenz curve is established, firstly we define country  $n$  as followings:

$G_i^n$  is the  $i$  th year CO<sub>2</sub> of country  $n$ ,  $P_i^n$  is the  $i$  th year population of country  $n$ ,

$p_i^n = \frac{P_i^n}{\sum_m P_i^m}$  is the  $i$  th year population share of country  $n$ .

Consider the period between  $i$  th year and  $j$  th year,  $C_{ij}^n = \sum_{k=i}^j G_k^n$  is the country  $n$ ’s

historical cumulative CO<sub>2</sub> emission from  $i$  th year to  $j$  th year,  $c_{ij}^n = \frac{C_{ij}^n}{\sum_m C_{ij}^m}$  is the

country  $n$ ’s historical cumulative CO<sub>2</sub> emission share from  $i$  th year to  $j$  th year,  $\bar{C}_{ij}^n$  is the country  $n$ ’s historical cumulative CO<sub>2</sub> emission per capita from  $i$  th year to  $j$  th year.

$\bar{C}_{ij}^n$  is the important emission equality measurement index which is proposed by this paper. It also helps to sort the data when establishing the Lorenz curve. There are two ways to calculate  $\bar{C}_{ij}^n$ . One is to add up the annual emission per capita. Another is to

add up the CO<sub>2</sub> emission  $C_{ij}^n$ , and divide  $C_{ij}^n$  with population  $P_j^n$ . Although two method have different output, they are essentially the same. Moreover, this paper will use population share. It is not suitable to calculate the cumulative population. Accordingly, we adopt the latter method:

$$\bar{C}_{ij}^n = \frac{C_{ij}^n}{P_j^n} \quad (1)$$

Table.1 provides from 1850 to 2006 the main countries historical cumulative CO<sub>2</sub> emission, population and the historical cumulative emission per capita according to the function (1) calculation. The all data are from Climate Analysis Indicators Tool (CAIT), Version 7.0, (see World Resources Institute). From Table.1 we can see that USA is the world biggest CO<sub>2</sub> emission country from the industry revolution, the historical cumulative emission of USA is 30% of world total. Developed countries, such as USA and Britain, had the historical cumulative emission per capita which was more than times bigger than developing counties such as China and India. The historical cumulative emission per capita can reflect the inequality of carbon space allocation. Comparing to developed countries, developing countries' industrialization is latter and on the low level. Developing countries are allocated with less resource in the constrained carbon space, but developing countries are having large population, these results to the developing countries' residents can not enjoy an equal emission right.

Table.1. historical cumulative emission of major countries from 1850 to 2006  
(Data source: CAIT V7.0)

Country	Historical cumulative CO <sub>2</sub> emission (M t)	Historical cumulative CO <sub>2</sub> share(%)	2006 population (10 <sup>3</sup> )	Population share(%)	Historical cumulative CO <sub>2</sub> emission per capita (t per capita)	Kyoto Annex I (Y/N)
UK	68235.8	5.96%	60226	0.94%	1133	Y
USA	333747.8	29.14%	296507	4.60%	1125.6	Y
Germany	80377	7.02%	82469	1.28%	974.6	Y
Russian Fed	93081.6	8.13%	143150	2.22%	650.2	Y
Australia	12715.8	1.11%	20400	0.32%	623.3	Y
France	32278.6	2.82%	60873	0.95%	530.3	Y
Japan	44535.2	3.89%	127773	1.98%	348.5	Y
South Africa	12793	1.12%	46892	0.73%	272.8	N
Mexico	11768	1.03%	103089	1.60%	114.2	N

China	99204.2	8.66%	1304500	20.25%	76	N
Brazil	9457.5	0.83%	186831	2.90%	50.6	N
India	27433.6	2.40%	1094583	16.99%	25.1	N

When we focusing on the every country's CO<sub>2</sub> emission from  $i$  th year to  $j$  th year, we have to sort the countries by historical cumulative emission per capita  $\bar{C}_{ij}^n$  and give the countries sequence number  $s$ . After sorting the countries in ascending order, set cumulative population of  $j$  th year on the horizontal axis, set cumulative historical cumulative emission per capita form  $i$  th year to  $j$  th year on the vertical axis. It should be noted that the “cumulative” in this part is referring to the adding up of countries which's sequence number is less than  $s$ . Therefore, the coordinates  $(p_s, c_s)$  refer to

$$p_s = \sum_{t \leq s} p_j^t, c_s = \sum_{t \leq s} c_{ij}^t.$$

Connected the different countries' points in the coordinate system with a smooth curve, we established the Lorenz curve based on the historical cumulative emission per capita form  $i$  th year to  $j$  th year. Fig.2 shows the carbon Lorenz curve stated from 1850 and lists the positions of different countries. As the Lorenz curve is sorted by the historical cumulative emission per capita, the country's position is more close to the upright, the higher historical cumulative emission per capita is and the bigger historical responsibility one country should take in climate change issue. Moreover, from Fig.2 we can learn that developing countries have the 82% population of world's total, but merely occupy 25% cumulative emission of world's total. As to developed countries, they have the 18% population of world's total, but occupy 75% cumulative emission of world's total.

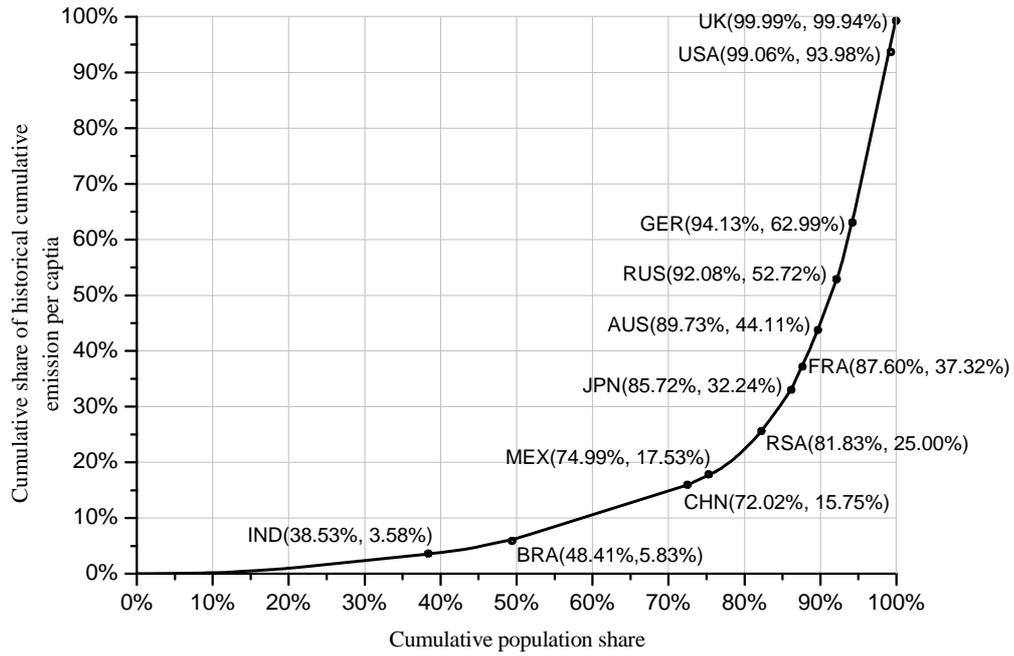


Fig.2. Carbon Lorenz Curve using 1850 as starting year

Based on the carbon Lorenz curve, this paper calculated the Gini index. Similar to the income Gini index calculation, this paper used two methods. One is the area method, the other is mean variance method.

The area method is according to the definition of Gini index. As mentioned before, since  $(X + Y) = 0.5$ , therefore:

$$G = \frac{X}{X + Y} = \frac{0.5 - Y}{0.5} = 1 - 2Y \quad (2)$$

The main difference between various area calculation methods is the area  $Y$  calculation. One way is to select a suitable fitting Lorenz curve, and then use integration to calculate the area. Another way divides  $Y$  into several trapezoids. The sum of the trapezoidal area is near to area  $Y$ .

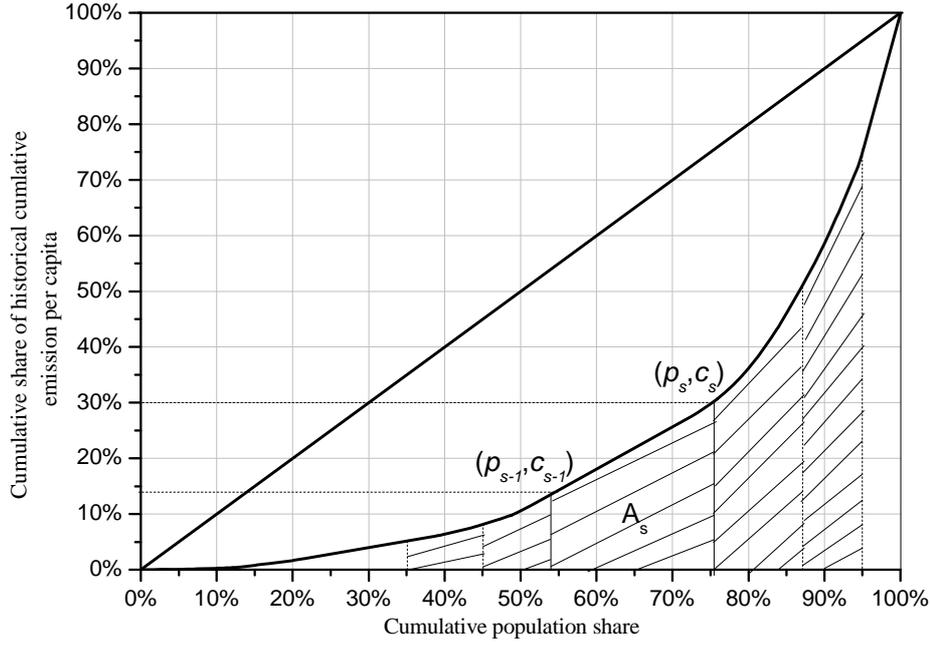


Fig.3. Gini index calculation using trapezoid method

We assumed that there are  $S$  countries and we can divide the total area into  $S$  trapezoids:

$$Y = \sum_{s=1}^S A_s = \sum_{s=1}^S \frac{(c_{s-1} + c_s)(p_s - p_{s-1})}{2} = \frac{1}{2} \sum_{s=1}^S (c_{s-1} + c_s) p_j^s \quad (3)$$

Apparently, when the  $S$  is big enough, the result above is almost the same as real value.

Another commonly used method is mean difference method. We define the absolute mean variance as  $\Delta = E|\bar{C}_{ij}^a - \bar{C}_{ij}^b|$ , relative mean variance as  $\Delta / \bar{C}_{ij}$ ,  $a$  and  $b$  is the sequence number of different countries,  $\bar{C}_{ij}$  is the historical cumulative world emission per capita. Gini index is the half of the relative mean variance. Therefore:

$$G = \frac{E|\bar{C}_{ij}^a - \bar{C}_{ij}^b|}{2\bar{C}_{ij}} = \frac{\sum_a \sum_b p_j^a p_j^b |\bar{C}_{ij}^a - \bar{C}_{ij}^b|}{2 \sum_m \bar{C}_{ij}^m p_j^m} \quad (4)$$

The covariance equation can derive from the equation (4). As following:

$$G = \frac{1}{\sum_m \bar{C}_{ij}^m p_j^m} [2 \text{cov}(\bar{C}_{ij}^a, p_a) - \text{cov}(\bar{C}_{ij}^a, p_j^a)] \quad (5)$$

The most important thing in carbon equality and carbon budget is how to set the starting year. Many researches confirmed that the earlier the starting year was, the more historical responsibility is reflected. But they did not provide a quantitative analysis of the various starting years' impacts on the historical responsibility. This paper try to use the carbon Lorenz and carbon Gini index to quantitatively analyze the impact of the starting year on historical responsibility. Fig.4 shows the Lorenz curves of different starting years. Table 2 shows Gini index results of different starting years in various calculation methods. We can learn that different calculation methods do not affect the Gini index value much, but the different starting years have big influence on the Gini index value. The latter the starting year, the lower the Gini index is. That means as the starting years become bigger, the carbon space allocation inequality has been concealed. On the global level, carbon Gini index do not change much when comparing the 1850 starting year calculation and 1900 starting year calculation. But the 1950 starting year calculation and 1990 starting year calculation have largely underestimate the carbon inequality. 1950 calculation has 4% underestimation of the carbon space allocation inequality, while 1990 calculation has 14% underestimation of the carbon space allocation inequality. From 1850 to 2006, 70% of the cumulative emission space has been allocated unequally, but when starting from 1990 this figure decreases to 60%. No matter what the starting year is, the inequality of carbon space allocation need to be concerned. According to the World Banking statistics, among the 182 countries there are 3 countries income Gini indexes are above 0.6. The biggest income gap is in Namibia which has the income Gini index of 0.74. The Gini index of carbon space allocation is 0.70 from 1850. Even focusing on the 1990 calculation, the carbon Gini index can still reach 0.60 which is on the same level with the biggest income gap country.

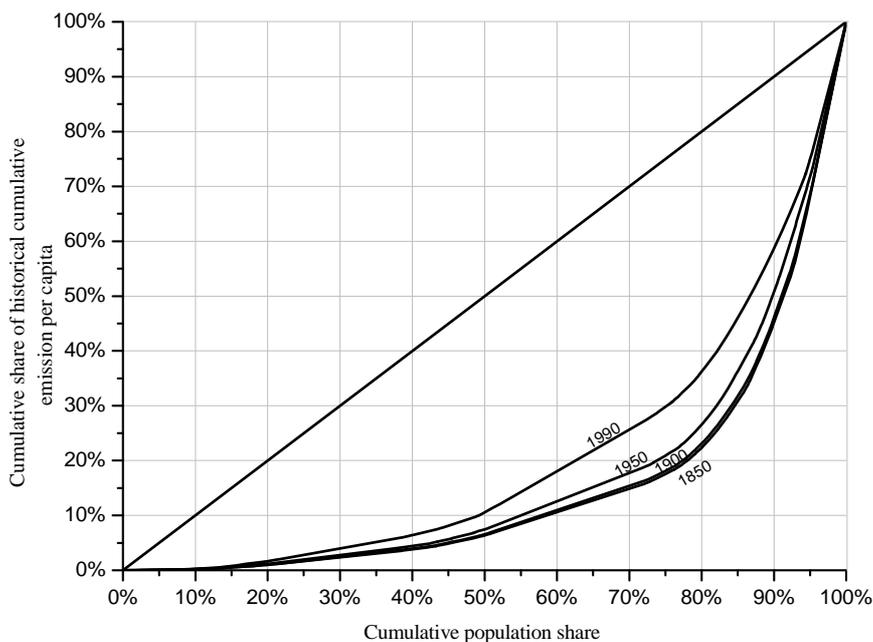


Fig.4. Carbon Lorenz Curve by using different starting years

Table.2. Carbon Gini Index based on the historical cumulative emission per capita

Calculation method	1850—2006	1990—2006	1950—2006	1990—2006
Fitting method	0.70	0.70	0.67	0.60
Trapezoid area method	0.70	0.69	0.66	0.59
Gini mean difference method	0.70	0.69	0.66	0.59
Covariance method	0.70	0.69	0.66	0.59

## 4 Conclusion

Economics and sociology focus more on the economical variances' inequality, especially income inequality. Income is a key factor which determines the welfare. In the field of climate change, the unequal allocation of carbon emission pace is very crucial, but there are few measurement of inequality research on the theory and application. The quantification of the carbon allocation inequality has great significance. According to the quantification, we can investigate the climate change inequality issue in another view. For example, measure the inequality level and trends, and then look for the key factor that affects the inequality. The income allocation related literatures have provided many meaningful indexes and tools for inequality research. After adjustment, such indexes can be applied to the emission space allocation related carbon inequality issue. This paper, based on the historical cumulative emission per capita, established the carbon Lorenz curve and carbon Gini index to quantitatively analyzed the emission space allocation inequality issue.

The historical cumulative emission per capita based carbon Gini index has several values as following: 1) historical cumulative emission per capita based carbon Gini index reflect the severe inequality of current emission allocation in a more general way, it help the policy maker and publics to know the emission allocation inequality level. 2) Carbon Gini index can not only analyze the current situation of the emission space allocation inequality, but also compare the emission space allocation inequality of different future allocation plans, this can reveal the equality mean of different future emission allocation plans. 3) By using the carbon Gini index and carbon Lorenz curve, we can further know the deep-seated factors in carbon inequality by factor decomposition.

The result of the carbon Gini index based on the historical cumulative emission per

capita shows that current emission space allocation is severe unequal. The inequality situation is on the same level with the biggest income gap country. In the 1850-2006 calculation period, carbon Gini index reaches 0.70 which is far beyond the warning level of income inequality. This result indicates that 70% of the world total emission space is allocated unequally and such space has been excessively occupied by developed countries. The carbon Gini index has confirmed that developed countries had excessively occupied the emission space. According to the principle of UNFCCC, developed countries should take the lead to reduce their emissions to redress the unequal situation.

The selection of starting year has great influence on the carbon Gini index. The inequality of carbon space allocation has been concealed as the starting year becomes bigger. Even focusing on the 1990 calculation, the carbon Gini index can still reach 0.60 which is far beyond the warning line. Carbon index can be used as a static index to measure the inequality of emission allocation. It also provides a quantitative index for international carbon equality discussion. At present, many institutes and scholars proposed various future carbon dioxide emission space allocation plans. It is difficult to compare the different plans. The carbon Gini index in this paper can reveal the equality meaning of different allocation plans, compare the different plans in the equality measurement.

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