



Comparison of Greenhouse Gas Emissions Per Capita Per Year Among Countries Considering Methane Emissions

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Abstract: The cumulative emissions of CO₂ and CH₄ had a great impact on the global climate, and the responsibility of countries around the world to achieve greenhouse gas (GHG) emission control goals should be based on the concept of fairness and sustainable development. In this paper, from the perspective of interpersonal equity, based on the annual GHG emissions per capita, using the CO₂ and CH₄ emissions data of 23 major countries from 1961 to 2017, the ratio for GHG emission per capita per year and the ratio for carbon dioxide emission per capita per year in various countries were calculated with 1961 and 1990 as the starting years, the countries were also sequenced and sorted to analyze the extent to which major countries occupy limited global emissions space at different time scales and GHG ranges. The results showed that the ratio of GHG emission per capita per year in developed countries such as the United States and Canada were far higher than the world average, China was significantly lower than the average, India was much lower than the average. In addition, lengthening the time scale and incorporating the methane emissions from the planting and breeding industry (agriculture activities) had a significant impact on the the ratio of GHG emission per capita and national classification. It can be more conducive to judge the world's average annual GHG emissions, reflect the global emission space occupied by each countries comprehensively and objectively, and scientifically support policymakers in formulating action plan for GHG emission reduction and control, which was of practical significance.

Keywords: GHG Emissions Space Use Ratio, Emission Per Capita Per Year, Carbon Emissions, Methane Emissions from Agriculture

1. Introduction

Climate change is a global challenge that matters for the living environment of humans and the development as well as prosperity of all countries. Effective adaptation and mitigation of climate change requires international cooperation, as well as long-term joint action for emission reduction and control on a global scale based on the concept of fairness and sustainable development. The increase of total GHG emissions, including CO₂, has resulted in global warming, glacier melting, reduction of sea ice area, and acceleration of sea level, which poses a catastrophic risk to small island countries. CH₄, the second largest GHG only

after CO₂, accounts for 16% of the global GHG emissions [1]. The global warming potentials (GWP) of CH₄ within 20-year and 100-year after emissions were about 84 times and 28 times that of CO₂ respectively [2], which has contributed to 25% of the global warming [3]. In China's national GHG emission inventories, CH₄ is listed among the major GHG emissions, mainly from agriculture, coal mining, oil and gas production. According to the Third National Communication of the People's Republic of China on Climate Change and China's National Greenhouse Gas Emissions Inventory 2010, CO₂ and CH₄ represented 80.4% and 12.2% of China's total GHG emissions (with land use, land-use changes, and forestry, i.e. LULUCF) in 2010 respectively. CH₄ emissions from agriculture reached 22,414 million tons, of which

enteric fermentation accounted for 26.2%, rice planting 22.1%, and manure management 16.6%. In light of this, it is of great significance to study the accounting of GHG emissions in various countries, especially the space of GHG emissions. At present, most studies on annual per capita GHG emissions only cover CO₂ emissions from energy and industrial activities, and fail to include the high CH₄ emissions with strong greenhouse effect.

In order to reflect the space of GHG emissions of various countries and the share in global limited emission allowance more comprehensively and objectively, this paper examined GHG emissions per capita per year in major countries between 1961 and 2017, including CH₄ emissions from breeding industry and CO₂ emissions from energy activities and industrial processes. Based on the study of Su Mingshan [4] while taking into account interpersonal equity, this study calculated the ratio of GHG emissions and only for CO₂ emissions in major countries of the world, and extended the calculation year of termination from 2013 to 2017, to analyze the extent to which major countries occupy the world's limited emission of global space. Changes in the ratio for GHG emissions and the ranking of various countries with 1990 and 1961 as the starting years were also discussed. The study will facilitate equitable allocation of global emission allowance and provide more scientific support for decision makers to formulate action plans for GHG emission reduction and control.

2. Literature Review

The calculation of cumulative CO₂ emissions per capita was based on the premise of insisting on "common but differentiated responsibilities", requiring developed countries to take the lead in fulfilling emission reduction commitments and assume a higher proportion of long-term emission reduction responsibilities. By allocating global limited space of emissions in a fair and reasonable manner, the principle ensures that each country can make the same proportion of contribution to addressing global climate change.

In Poznan climate talks held in December 2008, the Chinese delegation [5] clearly proposed, for the first time, the concept of "cumulative per capita emissions" in the climate negotiations to look at the issue of reduction of global GHG emissions. Miao Xuming [6] proposed the concept of cumulative CO₂ emissions per capita, and believed that it reflected emissions both historically and currently. Pan Jiahua *et al.* [7] investigated the correlation between carbon emissions per capita and economic development in major countries, and analyzed per capita emissions and cumulative per capita carbon emissions. He Jiankun *et al.* [8] systematically discussed the issue of "equity" in global climate change from different perspectives, and proposed the allocation principle of carbon emission rights featuring convergence of per capita carbon emissions towards the target year and cumulative per capita carbon emissions during the transitional period in countries based on the criteria of equitable carbon emission per capita rights. From

the perspective of interpersonal equity and historical responsibility for carbon emissions, Liu Qiang *et al.* [9] measured the carbon emission allowance of various countries based on the principle of equitable carbon emissions per capita per year, which takes full account of historical demographic changes. Wang Huihui *et al.* [10] probed into intergenerational and intra-generational equity in carbon emissions using the data of population, gross domestic product (GDP) and carbon emissions of 132 countries around the world from the perspective of historical cumulative emissions. With "cumulative per capita emissions" as the criteria, Ding Zhongli *et al.* [11] calculated the carbon emission allowance and spatial allocation of countries (1900 – 2050), and divided countries or regions with population of more than 300,000 into four categories.

Su Mingshan [4] defined the ratio of GHG emissions space usage, and from the perspective of interpersonal equity, presented the country ranking by the ratio of GHG emissions space usage and analyzed the country share in global emission allowance, based on comparison of GHG emissions per capita per year of 142 countries with the global level. The results showed that the United States and other Annex I countries unduly occupy the world's limited resources, while the GHG emissions per capita per year of India, Indonesia and other non-Annex I countries were far below than those of the Annex I countries, which was more in line with national historical and current situation, also reflected fairness and therefore has guiding significance. However, the GHG studied only considered CO₂ and fluorinated gas (F-gas), and the CH₄ gas produced by the agricultural process, which took up a high proportion, has not been calculated. In addition, from the analysis of the results, F-gas has little effect on country classification and ranking results of the ratio for GHG emissions space usage.

3. GHG Emissions per Capita Per Year and Space Use Ratio

3.1. Research Method

The calculation formulas for the volume of GHG emissions per capita per year and the ratio of GHG emissions space usage of a participant within the studied time frame were shown as Equation 1 [9] and 2 [4] respectively:

$$\text{GHG emission per capita per year} = \frac{\sum_{\text{starting year}}^{\text{Ending year}} \text{Carbon Emission}}{\sum_{\text{starting year}}^{\text{Ending year}} \text{Population}} \quad (1)$$

$$pi = \frac{ei}{e} \quad (2)$$

Wherein, pi is the ratio for GHG emissions of party i in the studied time frame; ei indicates the volume of GHG emissions per capita per year of party i in the studied time frame; e indicates the volume of GHG emissions per capita per year of all parties in the studied time frame. In this study, party i

represents a country.

3.2. Research Objects and Data Sources

Considering the significant impact of GHGs such as CO₂ and CH₄ on global climate change and the availability and completeness of relevant data, this paper examined GHG emissions from energy activities, industrial processes, and agriculture activities of 23 major countries in the period from 1961 to 2017. These countries included the G20 members, 10 largest carbon emission countries which ranked according to the 2017 International Energy Agency (IEA) data of annual CO₂ emissions, and world's top 10 largest agricultural countries. The calculation scope of GHG emissions includes energy activities, industrial production processes, and agricultural activities. GHG emissions from energy activities calculated CO₂ emissions from fossil fuel combustion; industrial production processes calculated CO₂ emissions from by cement clinker production; agriculture activities calculated CH₄ emissions from animal enteric fermentation, manure management and rice planting.

The CO₂ emission data was sourced from National GHG Emission Inventories, IEA, Carbon Budget Project, and Carbon Emission Information Analysis Center (CDIAC) [12-15]; The CH₄ emission data from the Food and Agriculture Organization (FAO) of the United Nations [16].

The demographic data came from the United Nations Department of Economic and Social Affairs [17].

4. Calculation Results and Analysis

Firstly, this paper calculated the average GHG emissions per capita per year of major countries between 1961 to 2017, and then calculated the space use ratio of GHG emissions and only CO₂ emissions. Based on the calculation results, the changes in the ratio of GHG emissions space usage and ranking of various countries were compared between calculations with 1990 and 1961 as the starting years respectively.

4.1. Research Objects and Data Sources

Using the aforementioned formula, the ratio for GHG emissions space usage during 1961–2017 was calculated for the 23 countries. Then, a country ranking by the value of ratio is produced, as shown in Figure 1. It can be seen that industrialized developed countries such as the United States, Canada, and Australia have a larger ratio for GHG emissions space usage than emerging economies such as India, Brazil, and China. In particular, the ratio for GHG emissions space usage of the top two countries, i.e. the United States and Australia, exceeded 4, and equals to 15.25 and 14.78 times that of the lowest ranking India respectively, indicating that the ratio for GHG emissions space usage of developed countries such as the United States and Australia were greater than the world average and far higher than that of developing countries, which occupied excessively limited global emission space.

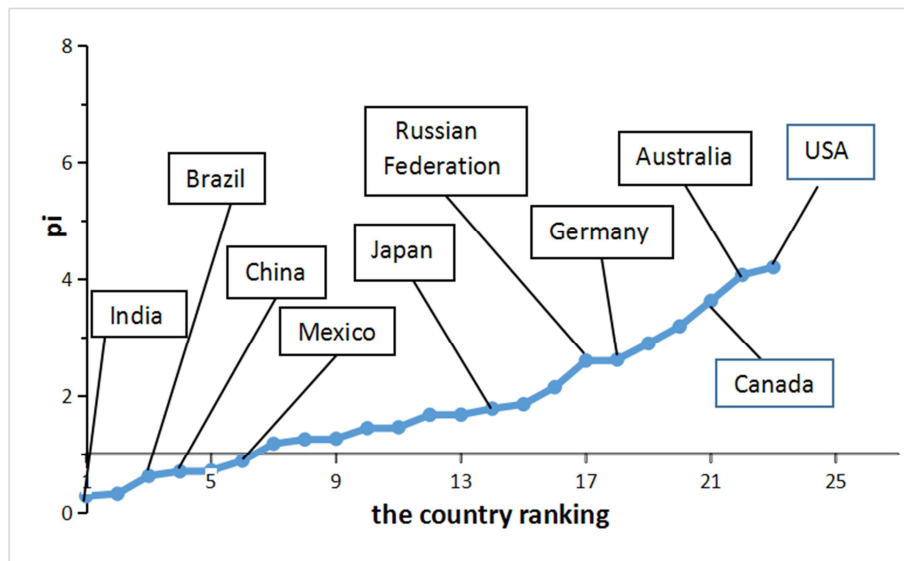


Figure 1. Ratio for GHG emission space usage of major countries in 1961-2017.

Adopting the classification method for the ratio for GHG emissions space usage proposed by Su Mingshan [6], the 23 countries were classified into nine categories according to the value of ratio: LLLL, LLL, LL, L, E, H, HH, HHH and HHHH, as shown in Table 1, and the world average annual GHG emissions per capita per year was taken as E.

LLLL: $pi < 0.30$. GHG emissions per capita per year were far below than E. One country fell into this category.

LLL: $0.30 \leq pi < 0.50$. GHG emissions per capita per year

was considerably below than E. One country fell into this category.

LL: $0.50 \leq pi < 0.70$. GHG emissions per capita per year was moderately below than E. Two countries fell into this category.

L: $0.70 \leq pi < 0.90$. GHG emissions per capita per year was slightly below than E. Two countries fell into this category.

E: $0.90 \leq pi < 1.11$. GHG emissions per capita per year was equivalent to E. No country fell into this category.

H: $1.11 \leq pi < 1.43$. GHG emissions per capita per year was

slightly higher than E. Three countries fell into this category

HH: $1.43 \leq pi < 2.00$. GHG emissions per capita per year was significantly higher than E. Six countries fell into this category.

HHH: $2.00 \leq pi < 3.33$. GHG emissions per capita per year was

absolutely higher than E. Five countries fell into this category.

HHHH: $pi \geq 3.33$. GHG emissions per capita per year was much higher than E. Three countries fell into this category.

Table 1. National Classification about GHG Emission Space Usage Ratio in 1961-2017.

category	country
LLLL	India
LLL	Indonesia
LL	Brazil, China
L	Turkey, Mexico
E	
H	Iran, Argentina, Spain
HH	Republic of Korea, Italy, Israel, France, Japan, South Africa
HHH	United Kingdom, Russian Federation, Germany, New Zealand, Saudi Arabia
HHHH	Canada, Australia, USA

If only the CO₂ emissions were considered to calculate the ratio for CO₂ emissions of various countries during 1961–2017, the country ranking and classification results were as shown in Figure 2 and Table 2, respectively.

Table 2. National Classification about carbon dioxide Emission Space Usage Ratio in 1961-2017.

category	country
LLLL	India, Indonesia
LLL	Brazil
LL	
L	Turkey, China, Mexico, Argentina
E	
H	Iran, Spain
HH	Italy, Republic of Korea, New Zealand, France, Israel, Japan, South Africa
HHH	United Kingdom, Germany, Russian Federation
HHHH	Saudi Arabia, Australia, Canada, USA

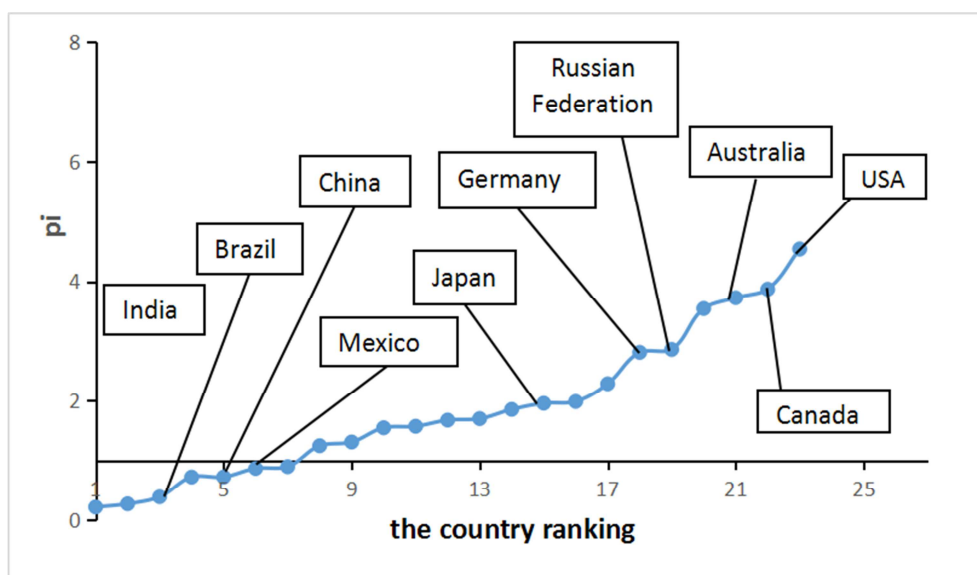


Figure 2. Ratio for carbon dioxide emission space usage of major countries in 1961-2017.

Compared with Figure 1 and Table 1, the ranking changed for 14 countries, involving every category, but the lowest- ranked and highest-ranked countries and their categories remain the same, i.e. India (LLLL) and the United States (HHHH). The number of LLLL category

increased from 1 to 2 country as Indonesia moved from LLL category. While number of LLL category does not change with Brazil's joint (formerly in LL category). China and Argentina fell into L category (from LL category and H category, respectively), which made the number of LL

category reduced from 2 to 0, L category increased from 2 to 4, and H category decreased from 3 to 2. In addition to the changes in the country classification already explained above, the number of HH category reduced from 6 to 7 countries as New Zealand joined from HHH category. With the addition of Saudi Arabia (formerly in HHH category) and the withdrawal of New Zealand, the number of HHH countries declined from 5 to 3, while the number of HHHH countries changed from 3 to 4. Hence, the inclusion of CH₄ emissions from agriculture activities (enteric fermentation, manure management, rice cultivation) has a greater impact on the calculation results of the ratio for GHG emissions space usage and classification in various countries, and can more comprehensively reflect the country share in global emission allowance.

4.2. Ratio for GHG Emissions Space Usage During 1990-2017

Taking 1990 as a starting point to calculate the ratio for GHG emissions of 23 countries during 1990 – 2017, the country ranking and classification results were as shown in Figure 3 and Table 3, respectively. It can be seen that GHG emissions per capita per year of emerging economies such as India, Indonesia, and Brazil were considerably lower than the world average level. China as the largest developing country, has an emission level close to Mexico, which was equivalent to the the world average, so both fell into E category. Saudi Arabia, Canada, the United States, and Australia belonged to the HHHH category as GHG emissions per capita per year far exceeded the world average and the level of developing countries.

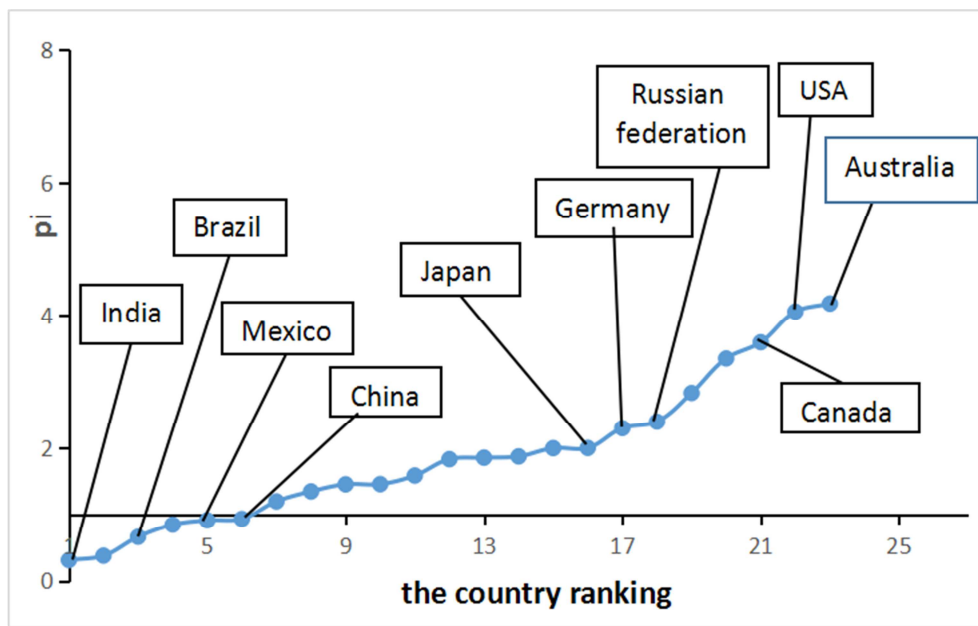


Figure 3. Ratio for GHG emission space usage of major countries in 1990-2017.

Table 1 and Table 3 clearly indicated the differences between cumulative emissions measured with 1990 and 1961 as the starting point. Overall, 17 countries's ranking have varied, the country on the top rank has changed from the

United States to Australia, while the bottom ranked country remained India. In addition, countries included in each category were also varied, specific alterations were as follows.

Table 3. National classification about GHG Emission space usage ratio in 1990-2017.

category	country
LLLL	
LLL	India, Indonesia
LL	Brazil
L	Turkey
E	Mexico, China
H	Argentina, Iran
HH	France, Spain, Italy, South Africa, Israel, United Kingdom, Republic of Korea, Japan
HHH	Germany, Russian Federation, New Zealand
HHHH	Saudi Arabia, Canada, USA, Australia

India moved to LLL category from LLLL category, which reduced the number of LLLL countries to 0 and increased the

number of LLL category from 1 to 2. With the addition of China (formerly in LL category) and Mexico (formerly in L

category), the number of E category rose from 0 to 2, while both LL category and L category decreased from 2 to 1. Spain moved from H category to HH category, declined the number of H category countries from 3 to 2. HH category grew in number from 6 countries to 8 countries, in addition to the above-mentioned changes in country rankings, the United Kingdom moved from HHH category to HH category. As a result of Saudi Arabia moved from HHH to HHHH and the United Kingdom's alteration, the number of HHH countries

reduced from 5 to 3, while the number of HHHH countries increased from 3 to 4. It was not difficult to see that when calculating GHG emissions per capita per year of various countries, the expansion of time scale has a significant effect on the country ranking results of the ratio for GHG emissions and classification. By taking full account of historical emissions, the results can more scientifically and objectively reflect the degree of global emission space occupied by each country.

Table 4. National classification about carbon dioxide emission space usage ratio in 1990-2017.

category	country
LLLL	India
LLL	Indonesia, Brazil
LL	
L	Turkey
E	Mexico, Argentina, China
H	
HH	Iran, France, Spain, Italy, New Zealand, South Africa, United Kingdom
HHH	Israel, Republic of Korea, Japan, Germany, Russian Federation
HHHH	Saudi Arabia, Canada, Australia, USA

If only CO₂ emission was considered, the ratio for CO₂ emissions space usage of various countries during 1990 – 2017 can be calculated, the country ranking and classification results were as shown in Figure 4 and Table 4, respectively. Compared with Figure 2 and Table 2, the ranking of 13 countries has changed, involving every category except LL, but the names and categories of lowest-ranked and highest-ranked countries remain the same. As Indonesia

moved from LLLL to LLL category, the number of LLL countries increased from 1 to 2, while the number of LLLL countries decreased from 2 to 1. There was no change in the LL category. With the move of Argentina, Mexico, and China from L category to the originally empty E category, the number of L countries decreased from 4 to 1, while E category increased to 3.

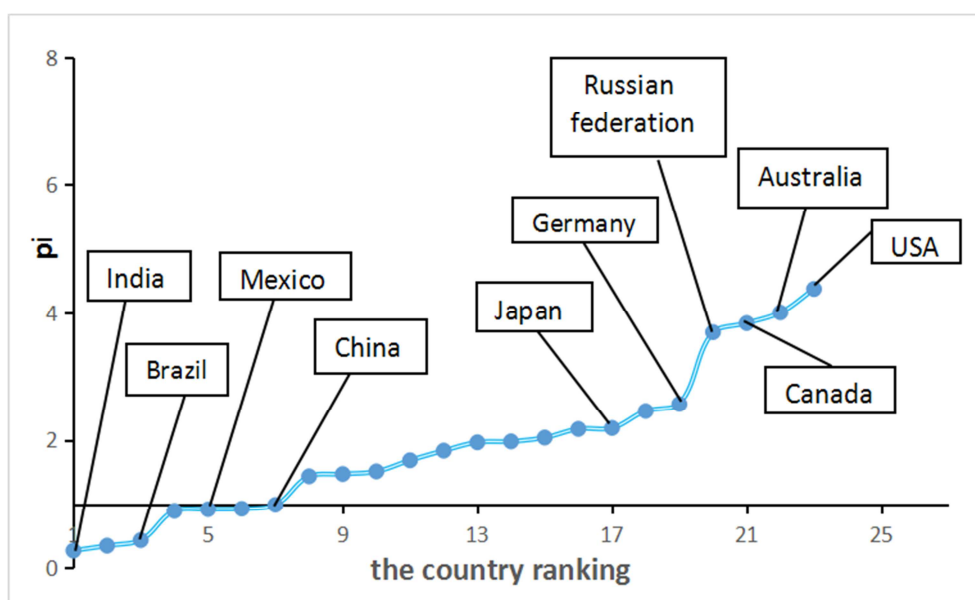


Figure 4. Ratio for carbon dioxide emission space usage of major countries in 1990-2017.

Iran and Spain fell into HH category, instead of H category, but because of the join of the United Kingdom (formerly in HHH category) and the withdrawal of Korea, Japan, Israel (formerly in HHH category) to HH category, the number of HH countries remained the same and HHH countries grew from 3 to 5 considering the rise of Israel into HH category. The same four countries fell into HHHH category, with

variance in the ratio and ranking by per capita CO₂ emissions. The results further proved that a longer time scale that took full account of historical GHG emissions of each country had a significant impact on the ranking results of the GHG emissions space usage ratio per capita per year and country's classification, which can be more conducive to the measurement of GHG emissions per capita per year of

various countries and the equitable distribution of global emission allowance.

5. Conclusions

In summary, the following conclusions can be drawn:

(1) Between 1961 and 2017, the ratio for GHG emissions space usage exceeds 3.33 in the United States, Australia, and Canada, indicating that annual GHG emissions per capita per year of these countries were more than 3.33 times the world average, which excessively took up the limited global emission space. The ratio for GHG emissions ranges from 2.00 to 3.33 in the United Kingdom, Russia, Germany, New Zealand, and Saudi Arabia, absolutely higher than the world average. Within a range of 1.43 to 2.00, the ratio for GHG emissions in South Korea, Italy, Israel, France, Japan, and South Africa, were moderately higher than the world average. The ratio for GHG emissions of Iran, Argentina, and Spain ranges from 1.11 to 1.43, slightly higher than world average. In contrast, Turkey and Mexico (0.70–0.90) had a level slightly below the world average, China and Brazil (0.50–0.70) were moderately lower than the world average, Indonesian (0.30–0.50) was considerably below the world average, and India (less than 0.30) was far below the world average.

(2) Incorporating CH₄ emissions from agriculture activities (enteric fermentation, manure management, and rice cultivation) into the calculation scope of GHG emissions per capita per year and space use ratio of each country had a significant impact on the results that only consider CO₂ emissions. The country ranking and classification results had changed significantly, which can more fully reflect the share to which various countries occupy global emission allowance.

(3) When calculating GHG emissions per capita per year of each country, a longer time scale of the calculation significantly affected country ranking results of GHG emissions space use ratio and the national classification results. By fully taking into account both current and historical emissions of various countries, the approach was more conducive to judge GHG emissions per capita per year, so as to more scientifically and objectively demonstrate the degree of global emission space occupied by countries.

In addition, the calculations and the results of this paper indicated that GHG emissions space use ratio was a scientific and impartial indicator for measuring the primary responsibility of various parties for GHG emissions and their obligation to control GHG emissions. Furthermore, this indicator does not directly show the GHG emission data information of each parties. Therefore, the openness and transparency of information about GHG emissions will not be impaired by the confidentiality of certain data and it can also support policy makers and all sectors of society to understand the degree of global emission space occupied by countries, and facilitate the equitable distribution of global emission allowance, to ensure that each country owns the equitable right to development while making the same proportion of contribution to global climate change, which was of high

practical significance.

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