Research on Using Per Capita Cumulative Emissions for Future Carbon Emission Rights Allocation Scheme Considering Fairness

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Abstract. Previous studies have focused on the convergence of per capita emissions under present emission levels and long-term global emission reduction objectives advocated by some developed countries, mostly based on the principle of realistic sharing, but have overlooked fairness. Assuming that all individuals have equal rights and interests in survival and development, and taking into account historical and future responsibilities, this study proposes a research method for calculating each country's emission ceiling and remaining carbon budget using cumulative CO_2 emissions per capita as an indicator. The analysis discovers that, based on cumulative CO_2 emissions per capita, China's remaining carbon budget could sustain emissions for 22 to 33 years.

Keywords: Developed countries, Carbon emission rights, Per Capita Cumulative Emissions, Carbon budget

1. Introduction

Combating global climate change is imminent. According to the statistics of the World Meteorological Organisation, the global average temperature in 2022 will be about 1.15 ℃ higher than the pre-industrial level. The global average temperature in 2023 once again break the historical extreme value, rising about 1.4 ℃ above the pre-industrial level. The period from 2015 to 2023 has been be the warmest nine years on instrumental record.

Carbon emissions rights are the right to emit greenhouse gases into the atmosphere, granted by nature or by law for the needs of survival and development. It is the right to use climate resources and a new type of development right [1]. The distribution of carbon emission rights is to split the future development space if the goal of carbon emissions accounting is to make historical responsibilities clear. Theoretically, these nations or areas with higher carbon emission rights will have greater room for development [2-3]. Thus, "how to allocate countries' carbon emission rights" can be simplified to the core issue of global carbon emission reduction.

The 1.5 ℃ temperature control objective is already struggling to support with the remaining global carbon budget. In December 2023, the Global Carbon Project team, International Institute for Climate Science, released the Global Carbon Budget Report 2023. According to

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the report, the world is expected to have emitted approximately 2.57 trillion tons of CO_2 by 2023. Based on a probability estimate of 50%, the global carbon budget under achieving the temperature control targets of 1.5°C, 1.7 ℃ and 2.0 ℃ is estimated to be 2.82, 3.17, and 3.72 trillion tons, and the remaining carbon budget is only about 250 billion, 600 billion and 1.15 trillion tons, respectively, representing approximately 10%, 20%, and 30% of the total carbon budget. Based on the global CO_2 emissions in 2022 (about 41.5 billion tons), it is estimated that the global carbon budget under the 1.5 ℃, 1.7 ℃ and 2.0 ℃ temperature rise scenarios will be exhausted around 2030, 2040 and 2050 respectively.

2. Modelling

2.1. Per capita cumulative CO_2 emissions

Summarise the various emission allowance allocation schemes that have been put forth both domestically and internationally [4–7], basically belonging to two categories. One is advocated by some developed countries, based on the current emission status quo and the convergence of per capita emissions under the long-term global emission reduction target [8-10]. This approach disregards fairness and is based on the principle of shared reality; the other is advocated by some developing countries, based on the per capita cumulative emissions, taking into account the historical responsibility, and emphasising the principle of fairness [11-12].

Taking into account the fair rights and interests of all individuals to survive and develop, as well as historical and future responsibilities, we utilize cumulative CO_2 emissions per capita as an indicator to calculate the emission caps and remaining carbon budgets of countries.

Cumulative CO_2 emissions per capita refers to the average (or total) of annual per capita CO_2 emissions over a period of time. For convenience of identification, this paper utilizes average instead of cumulative. For example, worldwide CO_2 emissions in 1850 and 1851 are 2.84 and 2.93 billion tonnes, respectively, while the population during the same period is approximately 1.279 and 1.281 billion people respectively. This means that per capita CO_2 emissions are approximately 2.22 and 2.29 tons respectively, with an average of about 2.25 tons for both years combined. To put this into perspective at the national level, if China's population in 1850 was estimated at around 410 million people with CO_2 emissions of roughly 240 million tons, then based on the principle of equivalent per capita CO_2 emission rates, China should have emitted around 910 Mt (2.22 * 4.1), resulting in an actual difference between what is emitted versus what should have been emitted of -670 Mt.

In order to estimate global and national CO_2 emission caps as well as remaining carbon budgets from1980 to2050, the following boundary conditions are taken into account:

(1) Assuming that net zero CO_2 emissions will be achieved globally by 2050;

(2) The remaining carbon budget, under the global temperature control targets of 1.5 ℃, 1.7 ℃ and 2.0 ℃, is approximately 250 billion, 600 billion, and 115 trillion tons, respectively. This means that, from 2024 to 2050, the annual average CO_2 emissions must be less than 9.3 billion, 22.2 billion, and 42.6 billion tons, respectively. They represent 22.2%, 53.3% and 102.3% of 2019 (pre-pandemic) emissions (41.6 billion tons) respectively.

The remaining carbon budget, under the global temperature control targets of 1.5 ℃, 1.7 ℃ and 2.0 ℃, is approximately 250 billion, 600 billion, and 115 trillion tons, respectively. This means that, from 2024 to 2050, the annual average CO_2 emissions must be less than 9.3 billion, 22.2 billion, and 42.6 billion tons, respectively. Of the 41.6 billion tons of emissions in 2019 (before to the pandemic), they account for 22.2%, 53.3%, and 102.3 percent respectively.

2.2 Global economy-energy-power-environment model

The self-developed Global Energy Modelling System (GEMS-4E) is adopted to carry out research on carbon emission allocation for medium and long term.

With the challenge of reaching the 1.5°C temperature control target, this study uses the global excess carbon budget as a restriction. the baseline scenario, net zero commitment scenario and 2 ℃ scenario are proposed to be set, and the outlook period is 2023-2060. Among them, The baseline scenario is mainly based on the history and current progress of energy transition in each country. The net zero commitment scenario assumes that each country's net zero emission commitment and intended contribution target are fulfilled on time, and explores what effect the net zero ambition of each country is expected to achieve in controlling global temperature rise. The 2 ℃ scenario is a path for global energy transformation under the 2 ℃ temperature rise control target of the Paris Agreement, with the remaining global carbon budget as the main constraint, and the nationally determined contribution targets and net zero emission commitments fulfilled ahead of schedule and over schedule.

3. Results and discussion

3.1. Analysis of the current situation

As shown in Table.1, In 2022, China will rank first in terms of total carbon emissions, while Canada will rank first in terms of per capita emissions. The findings indicate that China's total CO_2 emissions reached 12.38 billion tons, securing its position as the global leader. The United States ranked second with 5.20 billion tons, followed by India, Russia, and Japan to complete the top five countries.

Regarding per capita emissions, Canada takes the lead with 17.1 tons, closely followed by the United States with 15.6 tons; South Korea, Russia, and Japan occupy third to fifth positions respectively. China's per capita emissions stand at 8.8 tons ranking seventh globally. Nigeria and India have lower carbon emissions than two tons per capita.

China's cumulative carbon emissions per capita are below the global average level; however, it is worth noting that the United States holds the highest cumulative carbon emissions worldwide which are approximately 5.1 times higher than the global average on a per capita basis. In contrast to this figure, the manufacturing powerhouse China has a relatively low historical cumulative emission rate accounting for only about 13.7 percent of that of the United States.

Table 1. Carbon emissions

Country	Population (billion people)	Cumulative carbon emissions (billion tons)	Cumulative carbon emissions per capita (tons)	2022 emissions (billion tons)	Carbon emissions per capita (tons/people)
Global	79.5	25703.0	323.3	414.6	5.2
America	3.3	5547.9	1664.6	52.0	15.6
EU27	4.5	3119.1	696.3	26.4	5.9
Russia	1.4	2260.7	1574.8	19.7	13.7
China	14.1	3226.6	228.5	123.8	8.8
India	14.2	994.2	70.2	28.6	2.0
Britain.	0.7	784.8	1171.9	3.3	5.0
Brazil	2.2	1327.8	616.7	16.0	7.4
Indonesia	2.8	938.0	340.5	16.5	6.0
Nigeria	2.2	151.2	69.2	1.3	0.6

3.2 Future Carbon Credits Allocation

As seen in Table.2, historically, from 1850 to 2022, among the major countries, China's, India's, and Nigeria's actual CO_2 emissions have been respectively 225.2, 325.8 and 30 billion tons lower than their expected levels. These figures are respectively 18 times higher for China, 114 times higher for India, and 223 times higher for Nigeria compared to their actual CO_2 emissions in 2022. On the other hand, the United States', Russia's, the United Kingdom's Brazil's and Indonesia's actual CO_2 emissions in this period have exceeded their expected levels by respectively 431,152.7 ,42 ,75.6,and 25.1 billion tons . These values are respectively 83 times higher for the United States,78 times higher for Russia，126 times higher for the United Kingdom，47 times higher for Brazil，and 15 times higher for Indonesia compared to their actual CO_2 emissions in 2022.

Table 2. Global and major country CO_2 emissions, 1850-2022

Unit: billion tons, ton/person

Region	Total emissions	Among them: 1. Land use change emissions	2. Energy-related emissions	Cumulative carbon emissions per capita
World	25703	8020	17683	4.3
China	3279	667	2611	1.7
United States	5548	1280	4267	24.7
Russia	2298	1105	1193	14.0
India	1021	424	597	1.0
United Kingdom	785	32	752	9.8
Brazil	1370	1198	173	10.3
Indonesia	1054	897	157	8.5
Nigeria	161	117	44	1.9

As seen in Figure 1 and Table 3, looking to the future, under the 1.5℃, 1.7℃ and 2.0℃ scenarios, the upper limit of global CO_2 emissions from 1850 to 2030 is expected to be around

2.8 to 2.9 trillion tons, the upper limit from 1850 to 2035 is around 2.8 to 3.1 trillion tons, and the upper limit from 1850 to 2050 is around 2.8 to 3.7 trillion tonnes.

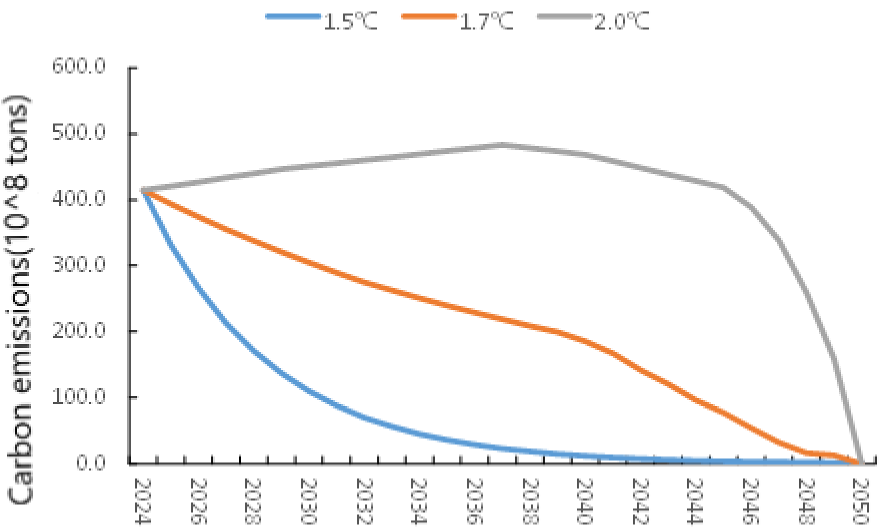

Figure 1. Global year-by-year CO_2 emissions outlook for 2024-2050 under the 1.5 ℃/1.7 ℃/2.0 ℃ temperature rise scenarios

By country, there is a significant gap between the actual share of CO_2 emissions and the share that should be emitted by major countries. Among them, the actual emissions share of China, India and Nigeria is 12.8%, 4.0% and 0.6% respectively, which is much lower than the emissions share that should have been emitted. The actual emissions share of the United States, Russia, the United Kingdom, Brazil and Indonesia is 21.6%, 8.9%, 3.1%, 5.3% and 4.1% respectively, all higher than the emissions share.

Table 3. Projected global and major country carbon budgets, 1850-2050

Unit: billion tons

Starting year	Cut-off year	Temperature rise scenario	World	China	United States	Russia	India	United Kingdom	Brazil	Indonesia	Nigeria
1850	2022	Supposed emission	25703	5530	1238	771	4279	364	614	802	461
	2022	Actual emission	25703	3279	5548	2298	1021	785	1370	1054	161
	Balance	-	0	-2252	4310	1527	-3258	420	756	251	-300
	2030	1.5℃	27765	5889	1324	807	4645	381	669	861	520
		1.7℃	28623	6035	1360	822	4797	389	692	887	546
		2.0℃	29156	6125	1382	831	4892	393	706	903	562
	2035	1.5℃	28060	5937	1336	812	4697	384	677	871	530
		1.7℃	29941	6248	1414	843	5030	399	726	929	588
		2.0℃	31480	6500	1477	868	5303	411	766	977	635
	2050	1.5℃	28200	5958	1342	814	4722	385	680	876	534
	2050	1.7℃	31700	6513	1484	869	5339	413	770	990	649
		2.0℃	37201	7348	1704	953	6304	455	909	1179	838

3.3 Conclusion

According to the estimation of actual emissions in 2022, China's remaining carbon budget can support emissions for 22-33 years. Carbon emissions should be accounted for in terms of "historical accumulation", taking into account China's rapid development of new energy sources, its success in contributing to the global low-carbon energy transition, and the differentiation of emission reduction responsibilities to achieve fair and equitable emission reductions that take into account environmental sustainability and China's economic development.

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