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The Start Matters: A Comparative Analysis of Climate Equity Among UNFCCC Country Parties and Country Groups

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Abstract

Incorrect indicators and starting years for emission cumulation can lead to confusion regarding the concepts of climate equity and climate responsibility. This article examines the variations in the results obtained by using different indicators and starting years to calculate climate equity and climate responsibilities among country parties and country groups of the UNFCCC. The article utilizes historical greenhouse gas (GHG) emissions data from 193 countries spanning the period 1850 to 2021. The data is aggregated from various sources including EDGAR, Climate Watch, and Global Carbon Budget (GCB). The article calculates cumulative GHG emissions and cumulative GHG emissions per capita, with starting years 1850, 1970, and 1990. By highlighting differences in various indicators, the article aims to provide a better understanding of climate responsibilities, climate beneficiaries, and climate equity. The results demonstrate that cumulative emissions and cumulative emissions per capita are scientific indicators that reveal a country's level of climate responsibility and climate equity. Negotiators can achieve consensus more easily in the complex system if they have a comprehensive and scientific understanding of climate equity. It is suggested that country groups under the UNFCCC use scientific indicators and methodologies to reveal climate responsibilities and climate equity.

Keywords

climate equity; climate governance; cumulative GHG emissions; cumulative GHG emissions per capita; UNFCCC

1. Introduction

China and other emerging economies are often accused of being the world's largest emitters (Friedrich et al., 2023; Ritchie, 2019; Tiseo, 2023). From a scientific perspective, this is a critical issue that is relevant to major disputes in global climate talks: Who should reduce greenhouse gas (GHG) emissions and who should bear the cost of climate mitigation and adaptation? This issue concerns climate responsibility and equity. Developed countries are attempting to persuade emerging economies, such as China, to take responsibility for the loss and damage caused by climate change (Lo, 2022). However, they are doing so by reclassifying country groups as "wealthy" and "poor" instead of "developed" and "developing," which may mislead some developing countries.

1.1. What Is Historical Responsibility and Why Is It Relevant to Climate Equity?

Cumulative anthropogenic GHG emissions, which are notably concentrated in earth's atmosphere, provide fundamental scientific evidence of global climate change. To address equity issues, it is important to clarify the indicators used to convey facts and stories. When discussing climate ethics and equity, it is important to consider the concept of sustainable development. This is defined as ensuring that the development of the current generation does not hinder future generations from developing. The issue of climate equity is closely linked to historical responsibilities. GHGs, such as CO2, N2O, and some F gases have a long-life expectancy in the atmosphere. As a result, their concentration will persist for centuries and continue to have an impact until the end of the 21st century. It is important to note that current emissions will inevitably be considered historical emissions in future discussions. Therefore, historical responsibility encompasses both past actions and future consequences. Several scholars argue that developed nations have emitted four times more than their fair share, which limits the developmental space available to developing countries (BASIC experts, 2011; Pan & Chen, 2010). If historical responsibilities continue to be ignored, developing nations may be compelled to follow the precedents set by developed countries, which could result in irreversible climate catastrophes. Therefore, it is crucial to tackle these inequalities within the wider context of global climate policy.

The parties to the United Nations Framework Convention on Climate Change (UNFCCC) have not yet reached a consensus on fundamental concepts such as climate responsibility and climate equity (Bogojević, 2015; Toivanen, 2023). Climate change has become a complex regime with low governance efficiency. Divergent perceptions of climate equity between developed and developing nations are a principal obstacle to effective climate governance.

Discourse on climate equity involves multiple legal and moral standards. The key disputes about how to interpret "common but differentiated responsibilities" arise from different understandings of historical responsibilities. The principle that "polluters pay" means that those who cause pollution should bear the cost of externalities. This principle is often used to impose sanctions on environmental laws (Barthakur, 2021). In climate talks, those who emit GHGs should take responsibility for mitigating the impact of climate change and provide financial support to others in their mitigation and adaptation efforts. The UNFCCC identifies developed countries as the primary polluters and requires them to take the lead in mitigation efforts and provide financial, technical, and institutional support to developing countries. The emissions have been accumulating in the atmosphere since the beginning of the Industrial Revolution in the 1840s.

On the other hand, the "beneficiaries pay" principle is based on a belief in autonomy (Lindstad, 2021). It states that if a third party benefits from the wrongful behavior of another, they are responsible for compensating the victims of the wrongdoing. In the context of the nationally determined contributions under the Paris Agreement, this principle could be considered as a supplementary principle of climate equity.

The "grandfathering principle" allocates carbon credits based on past emissions, thereby increasing entitlements to future emissions (Knight, 2013). Developed countries may evoke this principle to excuse themselves from the historical responsibility of the UNFCCC. This may involve their responsibilities of reducing GHG emissions and providing financial and technological support to developing countries. Critics argue that it allows countries with the highest historical GHG emissions to continue emitting the most (Cripps, 2023). Critics also suggest that developed countries neglect their historical responsibilities and that the grandfathering principle removes incentives for them to mitigate climate change (Damon et al., 2019). In the 1990s, once a country signed and ratified the UNFCCC, it had no excuse not to take responsibility for its emissions. However, if responsibility only began to be assigned from the 1990s onward, there is a gap between the start of industrialization and the 1990s. In relation to the UNFCCC, the grandfathering principle should be considered with specific limitations, taking into account national circumstances, and a specific time frame.

1.2. Country Parties, Country Groups, and Their Perspectives on Climate Equity

According to the UNFCCC (1992), country parties to that convention are typically classified into Annex I and non-Annex I countries. This is meant to differentiate the common responsibilities of global climate change between developed and developing countries, where "the developed country parties should take the lead in combating climate change and the adverse effects thereof" (3.1), "with the aim of returning individually or jointly to their 1990 levels these anthropogenic emissions of carbon dioxide and other greenhouse gases" (4.2(b)). According to the Kyoto Protocol (1997), Annex I countries shall "reduce their overall emissions of such gases by at least 5 percent below 1990 levels in the commitment period 2008 to 2012."

Developing country parties typically collaborate through the "Group of 77 plus China" (G77) to establish common negotiating positions. However, since the 15th Conference of Parties to the UNFCCC was held in Copenhagen in 2009, a spectrum of country groups has been formed to intervene in debates jointly or individually due to identified diversified vulnerabilities among developing countries (Pan et al., 2016). The developing countries are divided into several major groups, including the African Group of Negotiators (AGNs), the BASIC countries (BASIC), the small island developing states (AOSIS), the group of least developed countries (LDCs), the Bolivarian Alliance for the Peoples of our America (ALBA), the Arab Group, and others.

It is important to note that these groups represent different regions and interests (see Table 1). BASIC comprises Brazil, South Africa, India, and China. They insist on the principle of "common but differentiated responsibilities," emphasizing the historical responsibilities and obligations of the developed countries (Hallding et al., 2013; Qi, 2011). The group calls for balance between mitigation and adaptation.

The AOSIS and LDCs are both vulnerable to extreme climate events. LDCs face additional challenges due to extreme poverty, which leaves many people without access to basic provisions. As a result of their vulnerable situation, both AOSIS and LDCs are actively advocating for financial support for adaptation, as

well as compensation for loss and damage (Ashe et al., 1999; Klöck et al., 2012). ALBA opposes neoliberal economic policies and rejects market-based carbon trading schemes under UNFCCC. ALBA advocates for social equity and a balance between human development and nature conservation. The Arab Group consists of most of the member states of the Organization of the Petroleum Exporting Countries (OPEC), who are calling for a just transition and response measures to climate mitigation (Aarts & Janssen, 2003; Alao et al., 2021; Barnett, 2002).

The Paris Agreement brought all parties together with the National Determined Contributions. New country groups have emerged as a result. From these, the Independent Alliance of Latin America and the Caribbean (AILAC) calls for comprehensive climate actions that reduce the differentiation between developed and developing countries. Meanwhile, the Like-Minded Developing Countries (LMDCs) adhere to "common but differentiated responsibilities" (Castro, 2020).

Table 1. Major country groups of parties to the UNFCCC.

AOSIS (39)	Antigua and Barbuda, Bahamas, Barbados, Belize, Cuba, Dominica, Dominican Republic, Grenada, Guyana, Haiti, Jamaica, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Nauru, Niue, Palau, Papua New Guinea, Republic of the Marshall Islands, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu, Cabo Verde, Comoros, Guinea Bissau, Maldives, Mauritius, Sao Tome and Principe, Seychelles, Singapore, Timor Leste
AILAC (8)	Chile, Colombia, Costa Rica, Guatemala, Honduras, Panama, Paraguay, Peru
AGN (54)	Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cape Verde, Cameroon, Central African Republic, Chad, Comoros, Congo, Côte D'Ivoire, DR Congo, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Eswatini, Gabon, Gambia (Republic of The), Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, São Tomé and Príncipe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, South Sudan, Sudan, Togo, Tunisia, Uganda, United Republic of Tanzania, Zambia, Zimbabwe
LDCs (46)	Angola, Benin, Burkina-Faso, Burundi, Central African Republic, Chad, Comoros, D.R.Congo, Djibouti, Eritrea, Ethiopia, Guinea, Guinea-Bissau, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Niger, Rwanda, SãoTomé and Príncipe, Senegal, Sierra Leone, Somalia, South Sudan, Sudan, Tanzania, The Gambia, Togo, Uganda, Zambia, Haiti, Afghanistan, Bangladesh, Bhutan, Cambodia, EastTimor, Laos, Myanmar, Nepal, Yemen, Kiribati, SolomonIslands, Tuvalu
ABU (3)	Argentina, Brazil, Uruguay
ALBA (10)	Antigua and Barbuda, Bolivia, Cuba, Dominica, Grenada, Nicaragua, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Venezuela
BASIC (4)	Brazil, South Africa, India, China
UMBRELLA (11)	Kazakhstan, Ukraine, Australia, Canada, Iceland, Japan, New Zealand, Norway, United States, Israel, UK (UK joined UMBRELLA in 2023)
LMDCs (24)	Algeria, Bangladesh, Bolivia, China, Cuba, Ecuador, Egypt, El Salvador, India, Indonesia, Iran, Iraq, Jordan, Kuwait, Malaysia, Mali, Nicaragua, Pakistan, Saudi Arabia, Sri Lanka, Sudan, Syrian Arab Republic, Venezuela, Vietnam
EU (27)	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden
OPEC (13)	Algeria, Angola, Republic of the Congo, Equatorial Guinea, Gabon, Iran, Iraq, Kuwait, Libya, Nigeria, Saudi Arabia, United Arab Emirates, Venezuela

Developed country parties usually present their positions through the EU and the Umbrella group. The EU is taking a leading role in advocating for equal mitigation ambitions for 1.5-degree targets (Holz et al., 2018, 2023; Torney, 2015). Additionally, the EU is also using an internal effort-sharing approach to ensure fairness in both process and distribution (Kulovesi & van Asselt, 2020). The EU is also advocating for a just transition as a new working stream on climate equity. This approach neglects historical responsibilities and shifts the focus of equity issues to the present burden of mitigating fossil fuel emissions. Umbrella emphasizes the importance of equality of climate ambitions, actions, and support among all countries, particularly with the condition of full participation of the emerging countries. Additionally, Umbrella considers domestic federal-state balance a crucial aspect of climate equity. The EU and Umbrella argue for a competitive environment for domestic industries, disregarding the ethical necessity of addressing global climate change.

1.3. How do People Measure Climate Responsibility and Equity?

According to UNFCCC, the term "emissions" lacks specificity regarding its indicators. There are three main indicators: annual emissions, which represent carbon flow; cumulative emissions, which represent carbon stock; and cumulative emissions per capita, which represent carbon benefits. Annual emissions are the most commonly used indicator. Social media and prominent data tools sometimes use indicators to show carbon flow in a certain year to identify the top emitters.

However, it is important to note that different indicators can lead to contradictory implicit meanings, and therefore, it is crucial to consider all perspectives. It is also important to use precise language and avoid ambiguous terms. For instance, using the indicator of annual carbon flow, China and India are often identified as the biggest polluters (Vazhayil et al., 2011). However, it is a misinterpretation of climate science to suggest that annual emissions alone are responsible for the historical impact of global climate change. Annual emissions only contribute to a very small fraction of the GHG concentration in the atmosphere. The US and EU are among the top polluters when considering historical cumulative emissions, which better represents historical responsibilities (BASIC experts, 2011).

Emissions can be accounted for by country groups, country parties, and subnational regions. They can also be accounted for by multiple stakeholders, such as corporations, families, and individuals. Country groups are commonly used in international multilateral negotiations. During the negotiation of the Kyoto Protocol of the UNFCCC, country parties were required to join country groups to reach a consensus on global targets and other climate actions. Environmental organizations often monitor a country's annual emissions to assess its progress in climate governance. Similarly, corporations measure, report, and verify their emissions to facilitate cap-and-trade schemes. Emissions of individuals are often used to discuss disparities and vulnerabilities among different groups of people.

Consumption side emissions indicate the welfare increase resulting from the consumption of products with carbon embodied and transmitted through international trade (Grubb et al., 2022). People argue that importing countries should take responsibility for the emissions they consume. People also argue that exporting countries should take responsibility for carbon reduction from the supply side. Some countries are implementing cross-border measures to make unilateral carbon adjustments (Meng et al., 2023).

Methods for calculating the relationship between carbon emissions and social identities include assumptions about the emission elasticity of incomes of people, which can result in a significant disparity in carbon

footprints among different income groups (Golley & Meng, 2012; Ivanova et al., 2020; Oxfam, 2015). Given that the cost of climate loss and damage may be significantly underestimated (Newman & Noy, 2023), it is increasingly important to identify vulnerable populations in order to make appropriate arrangements for climate financing.

1.4. Research Questions and Scope of Analysis

What are the differences in weighing historical responsibility for global climate change using different indicators among country parties and country groups? Based on these differences, which countries should reduce GHG emissions, and which should provide all kinds of support? Additionally, what is the total amount of emissions by countries since the UNFCCC was put in force? Finally, how would the cumulative emissions differ if different starting years were used? This article aims to study the cumulative emissions and cumulative emissions per capita of 193 countries from 1850 to 2021. This article considers both country parties and country groups.

2. Methodology and Data

2.1. Cumulative Emissions of Country Parties

Cumulative emissions indicate a country's historical responsibilities (Meyer, 2013). This is calculated by adding up all of the country's annual emissions over time:

$$E_{ct} = \sum_{t_0}^{t_n} E_t$$

E_{ct} represents cumulative emissions of a country party at time t. It is calculated as the sum of the country's emissions of the country from year t_0 to year t_n. The length of time over which emissions are accumulated significantly affects the ranking of countries (Yu et al., 2020). In this article, the cumulative emissions are calculated using three sets of starting years: 1990, 1970, and 1850. This article aims to demonstrate the importance of the starting year of emission cumulation in discussions of climate equity. The most commonly used starting year for emission cumulation is 1990, which aligns with the starting year of the UNFCCC. However, a time series with all Kyoto gases is available from 1970, which serves as a medium-level reference to identify the differences using various lengths of time series for emissions cumulation. The best available time series of emissions starts in 1850, which is relevant to the beginning of industrialization in the 1840s. Historical emissions of 193 countries and the EU from 1850–2021 are sourced from Global Carbon Budget (GCB), EDGARv7.0 (1970–2021), and Climate Watch (1990–2020). The emissions data from EDGARv7.0 and Climate Watch include all Kyoto GHGs but exclude land use, land-use change, and forestry (LULUCF). On the other hand, the data from GCB only includes CO2 emissions from fossil fuel combustion.

Previous studies have acknowledged the significance of cumulative emissions. However, many of these studies only calculate emissions of a limited number of selected countries (BASIC experts, 2011; Pan & Chen, 2010; Yu et al., 2020), or they only calculate cumulative emissions starting from a single year in 1990 (Lamb et al., 2021). Research on GHG emission inventories shows historical annual emissions for all countries and country groups starting from 1850, without calculating cumulative emissions (Jones et al., 2023). Some popular data-driven climate action trackers only present annual emissions instead of

cumulative emissions starting from 1990, such as Climate Action Tracker, and Climate Watch. It is noticeable that some media blog articles have already pointed out the importance of historical responsibility of countries (Evans, 2021). This article calculates the cumulative emissions of all 193 countries, over three different periods, which enlarges the country coverage and time coverage of the climate equity studies and provides a comprehensive dataset on cumulative emissions accordingly.

2.2. Cumulative Emissions Per Capita of Country Parities

The cumulative emissions per capita are the cumulative emissions divided by the annual population of a country. Cumulative emissions per capita are calculated from 1990 to 2021 due to the grandfathering principle:

$$e_t = \frac{E_{at}}{P_{tn}} = \sum_{t_0}^{t_n} \frac{E_t}{P_{tn}}$$

P_{tn} represents the population of country n in year t. Cumulative emissions per capita represent the humanitarian development level of a country where carbon emissions have not been decoupled from economic growth. It represents an equal share of the carbon budget on an individual basis, regardless of location or time. Some scholars use cumulative emissions per capita to study global carbon budgets (Pan, 2022; Pan & Chen, 2010; Yu et al., 2020). Most of the studies have found an unfair allocation of carbon budget between developed and developing countries. Equitable access to sustainable development is crucial, and everyone should have a fair share of carbon emission rights to survive and develop from birth. In the end, global climate governance should ensure fairness for all. This article tries to demonstrate the disparity in carbon benefit increases among country parties by comparing the differences in cumulative emissions per capita. The historical population data for 193 countries from 1960 to 2050 is sourced from the World Bank Population Estimates and Projections. Population data of Niue and Cook Islands are sourced from an alternative database as they are not included in the World Bank dataset. Previous studies have used either the number of populations in a certain year (Pan & Chen, 2010), which lacks a comparison in time, or a sum of the population over a time range (Yu et al., 2020), which may not be physically addable. This article uses the number of population in a range of time from 1990 to 2021 for 193 countries, which provides a comprehensive time series of cumulative emissions per capita.

2.3. Cumulative Emissions of Country Groups

This article uses the country groups listed on UNFCCC webpages, which have submitted documents as a country group. These country groups include EU, Umbrella, AOSIS, BASIC, LMDCs, AG(N), LDCs, AILAC, ABU, OPEC, and ALBA. Emissions of G77 are not provided in this article as G77 is divided into many smaller-scale country groups. It is worth noting the UK recently joined the Umbrella in 2023, and therefore we provide the results of Umbrella both with and without the UK. The detailed country lists of the country groups are provided in the Appendix. Some of the countries appear in more than one country group, and therefore this article does not compare any aggregations of the emissions of country groups to the world total emissions:

$$E_{cgt} = \sum_{i}^{j} E_{ct}$$

E_{cgt} represents the cumulative emissions of a country group in year t, which equals the sum of the cumulative emissions of countries from i to j in that country group. Due to calculation capacity limitation, this article uses the average value of each value of the cumulative emissions per capita of the country group to represent the cumulative emissions per capita of the country group.

3. Results and Discussion

3.1. Results and Implications for Country Parties

Annual emissions are not a reliable indicator for determining who should take the historical responsibility for global climate change. The contributions of emerging countries are overestimated with annual emissions. And the contributions of developed countries are increasingly underestimated. It is evident that the ranking of the top 10 emitters varies significantly. Table 2 displays that the emerging large economies, such as China, India, Brazil and Indonesia are seemingly taking on more and more responsibilities. It also shows that the developed economies, like US, EU, Germany, and UK are taking less and less responsibilities.

Table 2. Top 10 emitters with annual emissions in 1990, 2000, 2010, and 2020, using total emissions of GHGs, excluding LULUCF form Climate Watch (unit: MtCO2e).

No.	TOP 10 emitters in 1990		TOP 10 emitters in 2000		TOP 10 emitters in 2010		TOP 10 emitters in 2020	
1	US	5855.54	US	6810.66	China↑	10211.64	China	12942.87
2	EU	4423.62	China↑	4567.27	US↓	6454.24	US	5505.18
3	China	3238.86	EU↓	4094.39	EU	3882.53	India↑	3200.82
4	Russia	2969.78	Russia	2137.89	India↑	2569.05	EU↓	3061.69
5	India	1237.96	India	1719.66	Russia↓	2249.52	Russia	2331.48
6	Japan	1181.86	Japan	1278.17	Japan	1234.82	Japan	1094.56
7	Germany	1129.74	Germany	959.12	Brazil↑	999.92	Brazil	1064.71
8	Ukraine	825.87	Brazil↑	772.34	Germany↓	881.69	Indonesia↑	976.49
9	UK	749.51	UK	690.36	Indonesia↑	788.13	Iran↑	844.65
10	Brazil	592.50	Indonesia↑	666.12	Iran↑	756.07	Saudi↑	712.59

The cumulative emissions of a country provide insights into its historical responsibility for climate change. However, it is important to avoid tricks such as manipulating the length of the time series of emissions for accumulation. To some extent, this can correct the underestimation of the results obtained with annual emissions. When using 1990 as the starting year, the ranking of the countries varies compared to the results in Table 2. Table 3 displays the top 10 emitters with cumulative emissions since 1990, which is the starting year for the grandfathering principle. Although it is not a correct starting point for accumulating emissions, changes indicate that the developed countries, like Russia, Japan, Germany, and Canada, are taking a higher ranking compared to their performance in Table 2. China is still growing fast, but not as much as indicated in Table 2.

With the starting year 1970, it is more apparent that, in Table 4, large emerging economies like India and Brazil are ranking lower and later comparing to Table 3.

Table 3. Top 10 emitters with cumulative emissions in 1990, 2000, 2010, and 2020, using total emissions of GHGs accumulated since 1990, excluding LULUCF from Climate Watch (unit: MtCO2e).

No.	TOP 10 emitters in 1990		TOP 10 emitters in 2000		TOP 10 emitters in 2010		TOP 10 emitters in 2020	
1	US	5855.54	US	68881.03	US	135153.30	China↑	238376.40
2	EU	4423.62	EU	46288.48	China↑	118317.50	US↓	195609.30
3	China	3238.86	China	44135.71	EU↓	87270.77	EU	122429.20
4	Russia	2969.78	Russia	26274.07	Russia	48538.24	Russia	71640.83
5	India	1237.96	India	16149.11	India	36926.97	India	67996.43
6	Japan	1181.86	Japan	13677.88	Japan	26305.88	Japan	38811.47
7	Germany	1129.74	Germany	11433.71	Germany	20686.30	Germany	28897.80
8	Ukraine	825.87	UK↑	7941.27	Brazil↑	16367.92	Brazil	27112.47
9	UK	749.51	Brazil↑	7449.25	UK↓	14520.30	Indonesia↑	22666.63
10	Brazil	592.50	Canada↑	6450.16	Indonesia↑	13604.91	Canada↑	20313.47

Table 4. Top 10 emitters with cumulative emissions in 1990, 2000, 2010, and 2020, using total emissions of GHGs accumulated since 1970, excluding LULUCF from EDGAR 7.0(unit: MtCO2e).

No.	TOP 10 emitters in 1990		TOP 10 emitters in 2000		TOP 10 emitters in 2010		TOP 10 emitters in 2020	
1	US	123627.85	US	188700.62	US	256243.95	China↑	348950.63
2	EU	104109.42	EU	148978.33	China↑	199113.56	US↓	322077.81
3	China	62399.339	China	112372.94	EU↓	192669.65	EU	233891.7
4	Russia	52395.497	Russia	75065.581	Russia	96439.207	Russia	121436.28
5	Germany	27598.618	Germany	38516.332	India↑	59171.983	India	95685.813
6	Japan	23480.615	India↑	36992.214	Japan↑	50106.439	Japan	64283.049
7	India	20814.241	Japan↓	36737.318	Germany↓	48201.638	Germany	57656.146
8	Ukraine	18247.196	Ukraine	24137.709	UK↑	30583.954	Brazil↑	43282.633
9	UK	16906.581	UK	24109.373	Brazil↑	29527.926	UK↓	35862.362
10	France	12939.335	Brazil↑	19167.255	Ukraine↓	28485.906	Canada↑	32328.992

Starting in 1850, the results indicate that developed countries are the largest contributors to global climate change. Table 5 displays the top 10 emitters with the cumulative CO2 emissions since 1850. The majority of the Annex I countries dominate the list, while large emerging economies rank far behind. China remains a fast-growing emitter but with a significant gap in total cumulative emissions compared to the US. This highlights the difference in industrialization history over the past centuries.

Cumulative emissions per capita indicate who benefits from carbon emissions. However, it can be misleading if the calculation is based on a shorter time series. A shorter time series of emissions for accumulation makes the actual emitters underestimated. Cumulative emissions per capita are meant to show how much benefits a country take on an individually average level. Figure 1 and Tables 6 and 7 present different information. Starting in 1850, the cumulative emissions per capita of a country could decrease as shown in Figure 1. This contradicts the assumption that longer accumulation leads to larger cumulative emissions per capita. The top 10 smallest emitters have a cumulative emission per capita of less than 3 metric tonnes of CO2 in 2021. This

Table 5. Top 10 emitters with cumulative emissions in 1990, 2000, 2010, and 2020, using emissions of CO2 accumulated since 1850 from GCB (unit: MtCO2).

No.	1990		2000		2010		2020	
1	USA	249044.87	USA	304224.93	USA	363636.67	USA	416729.34
2	EU	185005.53	EU	221178.16	EU	257156.13	EU	287514.61
3	Germany	66552.07	Russia	83522.49	China↑	136923.60	China	237880.45
4	Russia	66515.84	Germany↓	75972.45	Russia↓	99228.14	Russia	115792.04
5	UK	59123.88	China↑	75692.22	Germany↓	84647.72	Germany	92376.24
6	China	43404.61	UK↓	64895.62	UK	70427.61	UK	74581.22
7	Japan	28813.90	Japan	41012.36	Japan	53584.98	Japan	65643.68
8	France	27146.62	France	31155.85	France	35159.33	India↑	54395.70
9	Ukraine	20834.44	Ukraine	24979.09	India↑	31668.51	France↓	38479.00
10	Poland	17775.25	Canada↑	22183.91	Ukraine↓	28074.57	Canada↑	33569.39

is exemplified by the performance of the US in Table 7. The per capita cumulative emissions of the US are 1257 metric tonnes of CO2 in 2020.

Starting in 1990, Table 6 shows the top 10 emitters; EU as one economy is not on the list, and neither is China, India, and other emerging large countries. Oil producing and exporting countries rank high on the list. USA ranks in the middle among the top 10 emissions, and lower than Australia in 2020. With starting year 1850, Table 7 shows a list of the top 10 emitters where US ranks first in 2020. EU as one economy is still not

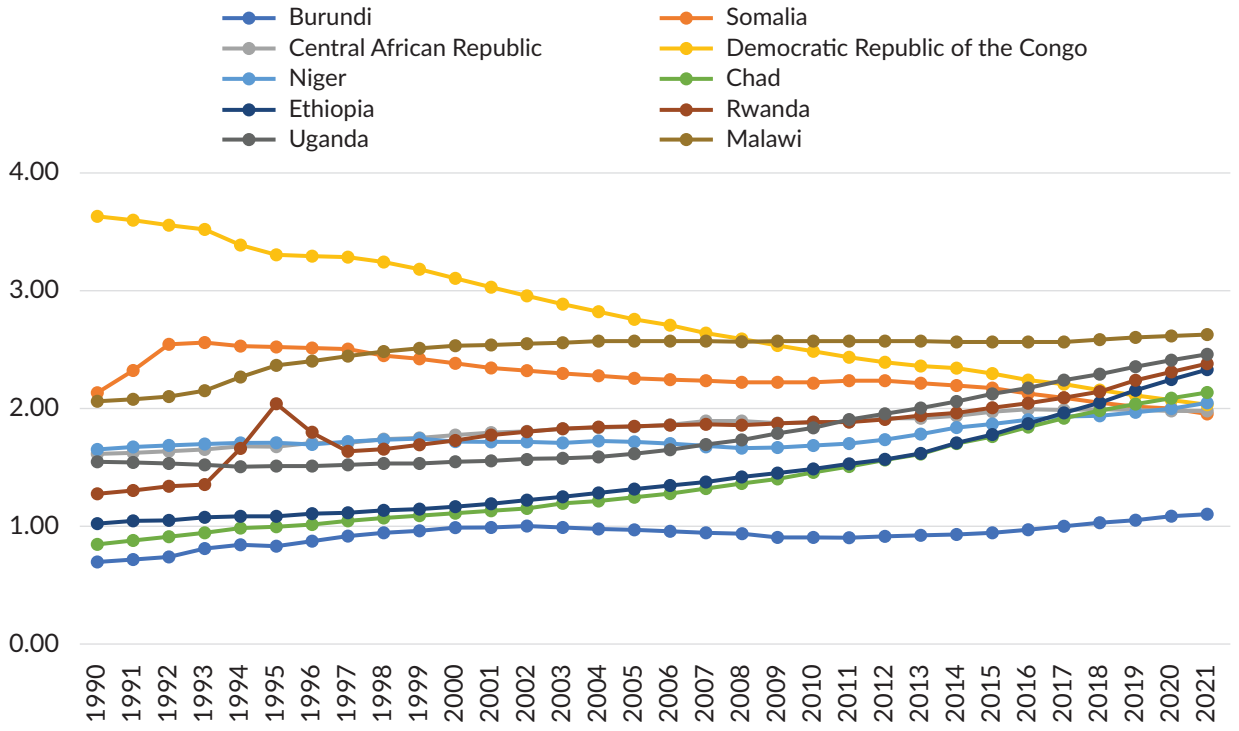

Figure 1. Top 10 smallest emitters in 2021 and the cumulative emissions per capita from 1990 to 2021, using emissions of CO2 accumulated since 1850 from GCB (unit: MtCO2/person).

Table 6. Top 10 emitters with cumulative emissions per capita in 1990, 2000, 2010, and 2020, using total emissions of GHGs accumulated since 1990, excluding LULUCF from Climate Watch (unit: tCO2e/person).

No.	1990		2000		2010		2020	
1	UAE	41.37	Qatar	472.80	Australia	533.17	Qatar	742.59
2	Turkmenistan	41.25	UAE	335.92	Qatar	529.83	Turkmenistan	736.98
3	Qatar	36.77	Bahrain	316.01	Turkmenistan	498.86	Bahrain	707.24
4	Belize	35.71	Australia	301.34	Kuwait	496.90	Australia	703.59
5	Luxembourg	31.92	Kuwait	281.64	Luxembourg	463.10	Kuwait	626.77
6	Bahrain	30.83	Luxembourg	267.91	Bahrain	459.55	USA	590.05
7	Australia	28.74	Turkmenistan	247.69	USA	436.93	Brunei	556.64
8	Estonia	24.94	USA	244.12	Canada	389.03	UAE	556.13
9	Kuwait	23.49	Belize	224.66	Brunei	378.71	Luxembourg	538.86
10	USA	23.46	Canada	210.20	Grenada	377.24	Grenada	535.49

on the list, and neither is China, India, and other emerging large countries. However, European industrialized countries rank very high among the top 10. Oil producing and exporting countries rank much lower.

A shorter time series for cumulations hides the real carbon beneficiaries. Table 6 suggests that the fossil fuel export-dependent countries are cumulating carbon benefits together with the Annex I industrialized countries. Countries like UAE, Qatar, and Kuwait are among the top 10 emitters. However, Table 7 indicates that, the top 10 countries does not include any OPEC countries, and the developed countries once again dominate the list.

Table 7. Top 10 emitters with cumulative emissions per capita in 1990, 2000, 2010, and 2020, using emissions of CO2 accumulated since 1850 from GCB (unit: tCO2/person).

No.	1990		2000		2010		2020	
1	Luxembourg	1169.47	Luxembourg	1252.65	Luxembourg	1294.72	USA↑	1257.06
2	UK	1032.78	UK	1101.93	UK	1122.06	Estonia↑	1226.01
3	USA	997.68	USA	1078.19	USA	1175.57	Luxembourg↓	1195.39
4	Belgium	896.46	Belgium	993.88	Belgium	1047.29	Czech ↑	1119.84
5	Germany	837.84	Czech ↑	944.03	Czech	1042.91	UK↓	1111.80
6	Czech	807.78	Estonia↑	924.90	Estonia	1098.67	Germany↑	1110.81
7	Estonia	694.53	Germany	924.11	Germany	1035.11	Belgium↓	1075.28
8	Qatar	663.84	Qatar	920.52	Qatar	666.52	Trinidad ↑	1035.77
9	Canada	619.91	Canada	722.94	Canada	819.92	Canada	883.24
10	Brunei	619.03	Kuwait↑	645.68	Kuwait	667.77	Brunei↑	816.77

3.2. Implications for Country Groups

With the emissions accumulation starting in 1990, results indicate that the emerging country groups contribute more emissions to the world. However, this misleads the media and the public in their understanding of climate responsibilities. Figure 2 shows that LMDCs have taken a leading role in cumulative emissions for over a decade. It exceeded Umbrella around 2007. BASIC has ranked second since

2015. The EU has not ranked high since the beginning of the 1990s. The EU has a flatter curve compared to the top 3 groups of countries above. All other country groups are positioned much lower near the horizontal axis.

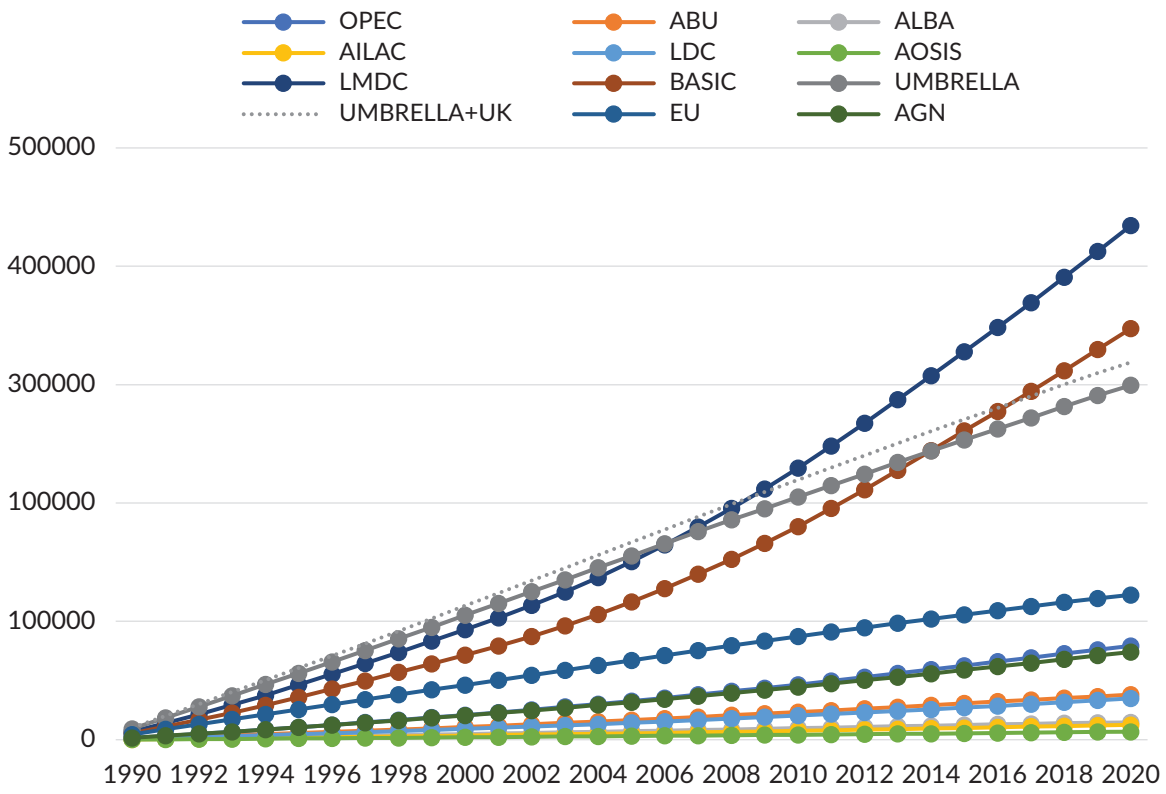

Figure 2. Historical cumulative emissions of major country groups of UNFCCC from 1990 to 2020, using total emissions of GHGs accumulated since 1990, excluding LULUCF from Climate Watch (unit: MtCO2e).

Starting in 1970, the contribution of emerging country groups decreased while the EU became more prominent. As shown in Figure 3, LMDCs still rank high in 2020, but the time when it exceeded the Umbrella is 2013, which is about six years later than in Figure 2. BASIC did not surpass Umbrella until 2021, which is about seven years later than in Figure 2. The EU is much closer to the top 3 country groups in Figure 3, with a steeper curve of increase, and it also drifted away from the lower-ranking country groups. It is still difficult to distinguish between the country groups that are close to the horizontal line.

Starting in 1850, emerging country groups fell from the top positions. Figure 4 shows that the Umbrella group ranks much higher than other country groups, emitting more than twice than the EU in 2021. The emission curve of the EU in Figure 4 is flatter but still shows a slight increase, while Umbrella's emissions are on the rise. The increase rate of the emission accumulation of Umbrella is significant, and the increase rate of emission accumulation of LMDCs and BASIC are exponential. This indicates that Umbrella is not only the biggest emitting country group, but it is also still contributing its emissions to the atmosphere. Meanwhile, LMDC and BASIC will probably surpass Umbrella very quickly. LMDCs and BASIC rank second and the third in 2021, where LMDC exceeds EU in 2013 and BASIC exceeds EU in 2017. The EU emits much more than the other country groups. Other country groups appear to be flattened near the horizontal line, indicating more inequality. Figure 4 illustrates the disparity of climate historical responsibility more

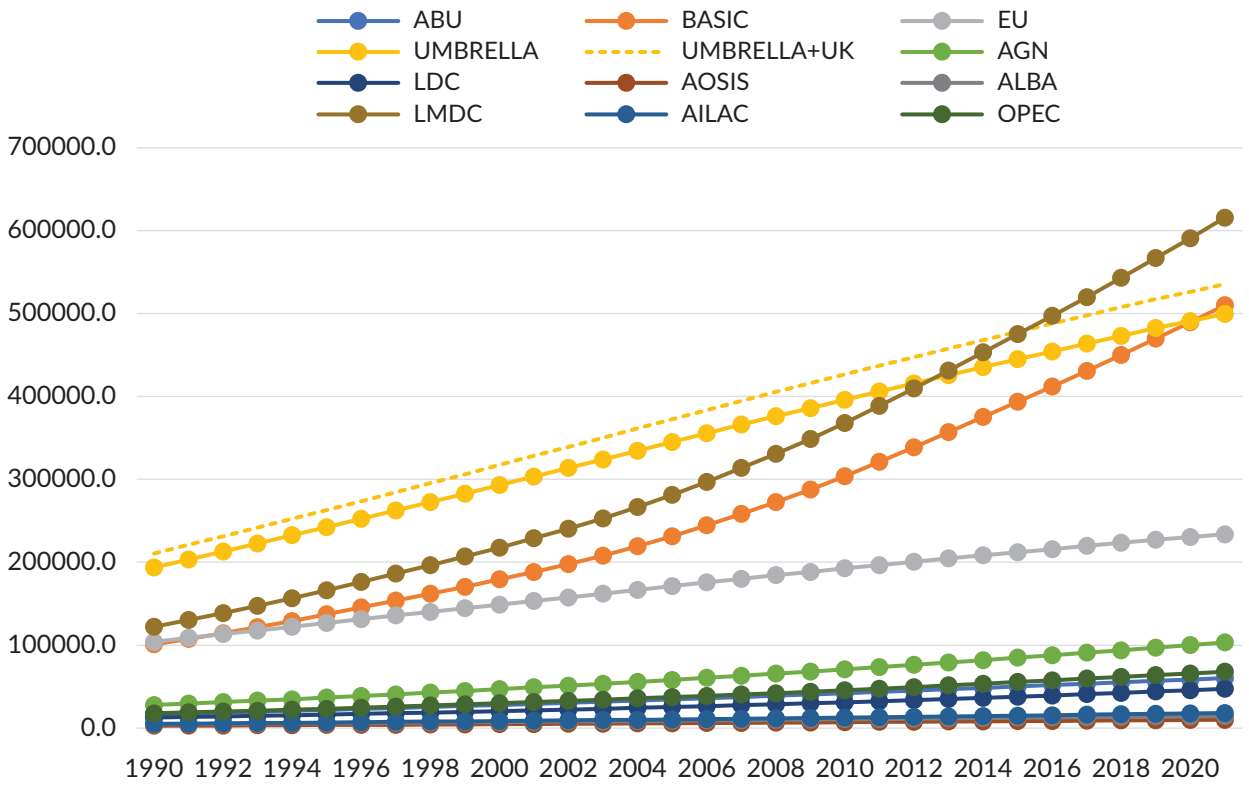

Figure 3. Historical cumulative emissions of major country groups of UNFCCC from 1990 to 2020, using total emissions of GHGs accumulated since 1970, excluding LULUCF from EDGAR 7.0(unit: MtCO2e).

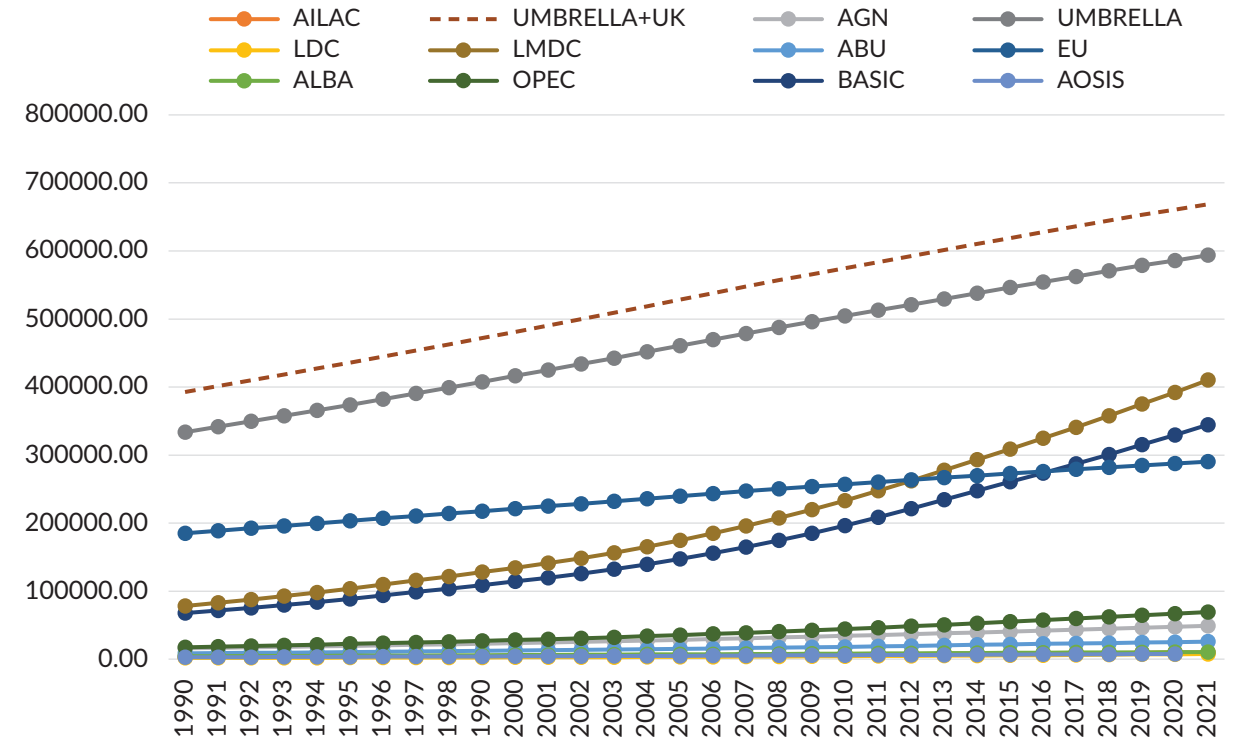

Figure 4. Historical cumulative emissions of major country groups of UNFCCC from 1990 to 2021, using emissions of CO2 accumulated since 1850 from GCB (unit: MtCO2).

clearly and may be the closest representation to reality. If LMDCs and BASIC are required to reduce emissions without financial and technological support from Umbrella and EU, all the us will lose the opportunity to achieve a fair and equitable share of sustainable development.

Meanwhile, if the world continues to accumulate emissions in the atmosphere at the current rate, emerging economies will eventually surpass the emission levels of the industrialized countries. It is crucial to establish a reasonable pathway for these economies to transition from the traditional industrialization pattern. Failure to do so would perpetuate the historical trend of industrialized countries colonizing the rest of the world.

Figures 5 and 6 identify the true beneficiaries of carbon emissions. Even with starting year 1990, as shown in Figure 5, Umbrella is leading in taking the most benefits from global carbon emissions. Umbrella has over 10 times the cumulative emissions per capita on average than LDCs and AGN. EU, OPEC, ABU, and ALBA, have cumulative emissions per capita higher than the world average. AOSIS, LMDCs, and BASIC are close to or below the world average. AOSIS may benefit from its small-scale population, while LMDCs and BASIC have large populations that lower their average emissions. Figure 5 shows that LMDCs and BASIC do not truly benefit the most from carbon emissions.

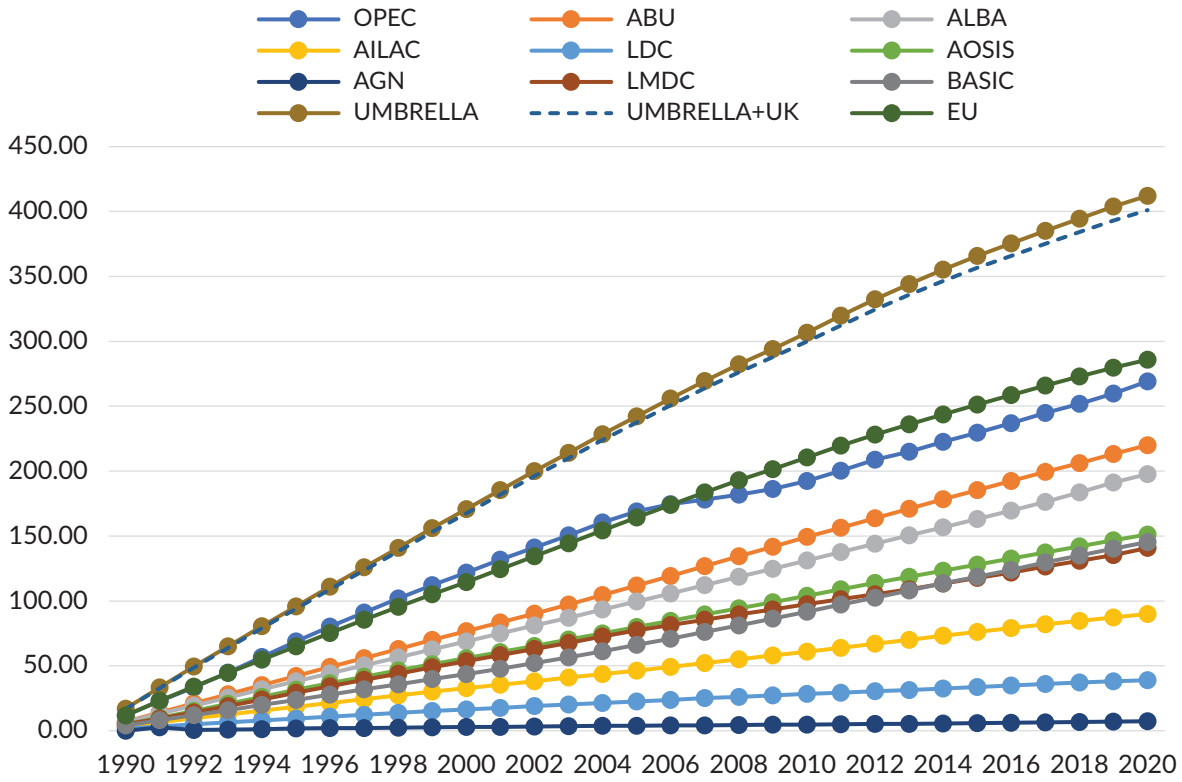

Figure 5. Average historical cumulative emissions per capita of major country groups of UNFCCC from 1990 to 2020, using total emissions of GHGs accumulated since 1990, excluding LULUCF from Climate Watch (unit: tCO2e/person).

With starting year 1850, Umbrella benefits the most from carbon. Umbrella countries are still cumulating their carbon benefits with a rise in the curve of their cumulative carbon emissions per capita. They emit five times more than developing country groups like ALBA, AOSIS and OPEC, and more than 100 times more than LDCs.

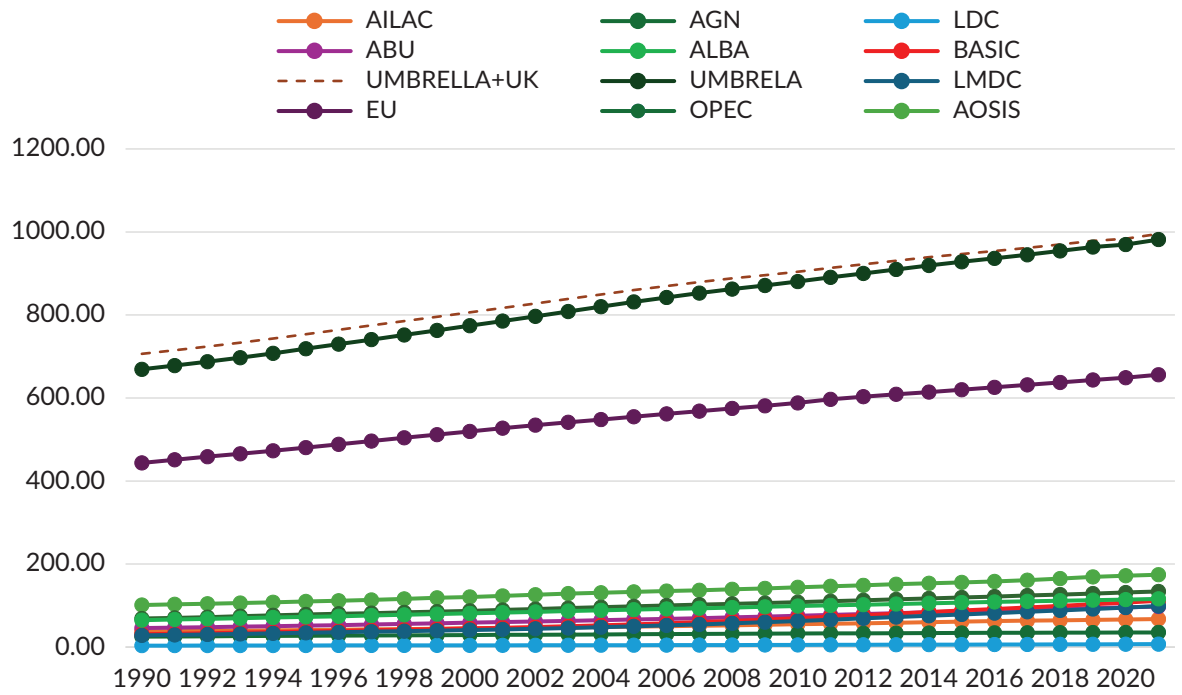

Figure 6. Average historical cumulative emissions per capita of major country groups of UNFCCC from 1990 to 2021, using emissions of CO2 accumulated since 1850 from GCB (unit: tCO2/person).

The EU comes after the Umbrella and ranks much higher than the other country groups. EU also emits nearly 100 times more than LDCs. All the developing country groups do not benefit much from carbon emissions. LMDC and BASIC do not rank high even within the developing countries.

4. Conclusion and Implications

4.1. Available Emission Data Justify Climate Responsibility and Equity

Cumulative emissions and per capita emissions, with a baseline year as early as the start of the Industrial Revolution, should serve as pivotal scientific indicators in assessing climate responsibilities. Different methodologies yield varying results for the top 10 emitters. While annual emissions provide a snapshot of a country's current emission levels, cumulative emissions offer a more comprehensive view of historical responsibilities. It is thus inaccurate to rely solely on annual emissions for assessing climate responsibilities. The selection of the starting year for accumulation significantly influences the portrayal of historical responsibilities.

If emissions have cumulated since 1850, it is evident that Annex I countries are responsible for climate change. The developed countries rank high on the cumulative emissions. They should reduce emissions. According to the principle of "polluters pay," they should also compensate non-Annex I country parties for losses and damages already incurred.

Developed countries also benefit most according to the results on per capita cumulative emissions with a starting year in 1850. Moreover, their emissions per capita are still rising. Other countries are left far behind

and crowded out of sustainable development. The most vulnerable and the poorest countries are being locked in the under-development stage. According to the principle of "beneficiaries pay," developed countries should pay for the loss and damages of the developing country parties and help them adapt to climate change.

Meanwhile, China and other emerging countries will soon become largely responsible for cumulative emissions. However, their cumulative emissions per capita are not guaranteed to grow. Other non-Annex I countries are neither accumulating their emissions nor increasing their climate benefits. They should further identify and diversify their vulnerabilities and bring their calculated loss and damage cost to the negotiations under UNFCCC.

4.2. Revisiting Position to Achieve a Consensus on Climate Equity

Developing countries should recognize their collective similarity that is in contrast with the developed countries, fostering unity in negotiations. EU countries should distinguish their positions from the Umbrella group, understanding that unilateral mitigation efforts are insufficient without addressing the Umbrella group's contributions to global emissions. The Umbrella group must acknowledge their high cumulative emissions and substantial carbon benefits, prompting substantial reductions in emissions, innovations in support of non-Annex I countries for mitigation and adaptation of climate change, and compensation for the most vulnerable countries in line with the Polluter Pays and Beneficiary Pays principles.

4.3. Limitations, Uncertainties, and Future Directions

This analysis acknowledges several limitations and uncertainties. Firstly, the lack of official ratification by developing country governments of existing GHG emissions data may lead to discrepancies with national GHG inventories. Secondly, variance in data sources could introduce bias, although this is considered negligible for this study. Thirdly, cumulative GHG emissions do not perfectly correlate with atmospheric concentrations, but this bias is deemed irrelevant for the comparative analysis conducted.

Due to time limitations, this article does not provide the future scenario analysis of various indicators for climate equity of country parties and country groups. Therefore, future research could extend to projections of emissions and population, utilizing resources like the IPCC-AR6 socioeconomic scenarios and IIASA POP 2.0. Methodologies for calculating individual carbon emissions, including bottom-up consumption pattern analyses and assumptions of emission elasticities relative to socio-economic indicators (such as income level, gender identities, rural-urban identities, and aging disparity), offer potential for exploring the intersection of emissions and social issues, particularly for vulnerable groups.

Interestingly, OPEC countries lead in historical cumulative emissions per capita in Table 6. Distinguishing production-side from consumption-side emissions could further clarify the beneficiaries of carbon emissions.

It is also notable that the UK joining the Umbrella group makes this country group more responsible for historical emissions, but less beneficial on emission stocks in Figure 5. Hopefully, the UK's recent back-pedaling on climate change policies will be temporary, and the British government will be able to stimulate a positive response among members of the Umbrella group.

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Data Availability

1. Global Carbon Budget: https://www.icos-cp.eu/science-and-impact/global-carbon-budget/2022; https://www.icos-cp.eu/science-and-impact/global-carbon-budget/2022
2. EDGARv7.0: https://edgar.jrc.ec.europa.eu/dataset_ghg70
3. Climate Watch: https://www.wri.org/initiatives/climate-watch
4. World Bank Population Estimates and Projections: https://databank.worldbank.org/source/population-estimates-and-projections
5. Population data of Niue and Cook Islands are sourced from an alternative database: https://database.earth/population
6. Climate Action Tracker: https://climateactiontracker.org/global/cat-emissions-gaps
7. Climate Watch: https://www.climatewatchdata.org/ghg-emissions

References

Aarts, P., & Janssen, D. (2003). Shades of opinion: The oil exporting countries and international climate politics. *Review of International Affairs*, *3*(2), 332–351. https://doi.org/10.1080/1475355032000240739

Alao, R. O., Payaslioglu, C., Alhassan, A., & Alola, A. A. (2021). Accounting for carbon dioxide emission effect of energy use, economic growth, and urbanization in the OPEC member states. *International Social Science Journal*, *72*(243), 129–143. https://doi.org/10.1111/issj.12304

Ashe, J. W., Van Lierop, R., & Cherian, A. (1999). The role of the Alliance of Small Island States (AOSIS) in the negotiation of the United Nations Framework Convention on Climate Change (UNFCCC). *Natural Resources Forum*, *23*(3), 209–220. https://doi.org/10.1111/j.1477-8947.1999.tb00910.x

Barnett, J. (2002). Articles 4.8 and 4.9 of the UNFCCC: Adverse effects and the impacts of response measures. *Climate Policy*, *2*(2–3), 231–239. https://doi.org/10.1016/S1469-3062(02)00023-2

Barthakur, A. (2021). Polluter pays principle as the key element to environmental law. *International Journal of Scientific and Research Publications*, *11*(3), 274–277. https://doi.org/10.29322/IJSRP.11.03.2021.p11137

BASIC experts. (2011). *Equitable access to sustainable development: Contribution to the body of scientific knowledge*.

Bogojević, S. (2015). Global imbalances in climate protection, leadership ambitions and EU climate change law. In A. Bakardjieva Engelbrekt, M. Mårtensson, L. Oxelheim, & T. Persson (Eds.), *The EU's role in fighting global imbalances* (pp. 89–108). Edward Elgar Publishing. https://doi.org/10.4337/9781784716738.00012

Castro, P. (2020). Past and future of burden sharing in the climate regime: Positions and ambition from a top-down to a bottom-up governance system.*International Environmental Agreements: Politics, Law and Economics*, *20*(1), 41-60. https://doi.org/10.1007/s10784-019-09465-4

Cripps, E. (2023). *What climate justice means and why we should care*. Bloomsbury Continuum.

Damon, M., Cole, D. H., Ostrom, E., & Sterner, T. (2019). Grandfathering: Environmental uses and impacts. *Review of Environmental Economics and Policy*, *13*(1), 23–42. https://doi.org/10.1093/reep/rey017

Evans, S. (2021, October 5). Analysis: Which countries are historically responsible for climate change? *Carbon Brief*. https://www.carbonbrief.org/analysis-which-countries-are-historically-responsible-for-climate-change

Friedrich, J., Ge, M., Pickens, A., & Vigna, L. (2023). *This interactive chart shows changes in the world's top 10 emitters*. World Resources Institute. https://www.wri.org/insights/interactive-chart-shows-changes-worlds-top-10-emitters

Golley, J., & Meng, X. (2012). Income inequality and carbon dioxide emissions: The case of Chinese urban households. *Energy Economics*, *34*(6), 1864–1872. https://doi.org/10.1016/j.eneco.2012.07.025

Grubb, M., Jordan, N. D., Hertwich, E., Neuhoff, K., Das, K., Bandyopadhyay, K. R., van Asselt, H., Sato, M., Wang, R., Pizer, W. A., & Oh, H. (2022). Carbon leakage, consumption, and trade. *Annual Review of Environment and Resources*, *47*(1), 753–795. https://doi.org/10.1146/annurev-environ-120820-053625

Hallding, K., Jürisoo, M., Carson, M., & Atteridge, A. (2013). Rising powers: The evolving role of BASIC countries. *Climate Policy (Earthscan)*, *13*(5), 608–631. https://doi.org/10.1080/14693062.2013.822654

Holz, C., Cunliffe, G., Mbeva, K., Pauw, P. W., & Winkler, H. (2023). Tempering and enabling ambition: How equity is considered in domestic processes preparing NDCs. *International Environmental Agreements: Politics, Law and Economics*, *23*(3), 271–292. https://doi.org/10.1007/s10784-023-09599-6

Holz, C., Kartha, S., & Athanasiou, T. (2018). Fairly sharing 1.5: National fair shares of a 1.5°C-compliant global mitigation effort. *International Environmental Agreements: Politics, Law & Economics*, *18*(1), 117–134. https://doi.org/10.1007/s10784-017-9371-z

Ivanova, D., Barrett, J., Wiedenhofer, D., Macura, B., Callaghan, M., & Creutzig, F. (2020). Quantifying the potential for climate change mitigation of consumption options. *Environmental Research Letters*, *15*(9), Article 093001. https://doi.org/10.1088/1748-9326/ab8589

Jones, M. W., Peters, G. P., Gasser, T., Andrew, R. M., Schwingshackl, C., Gütschow, J., Houghton, R. A., Friedlingstein, P., Pongratz, J., & Le Quéré, C. (2023). National contributions to climate change due to historical emissions of carbon dioxide, methane, and nitrous oxide since 1850. *Scientific Data*, *10*(1), Article 1. https://doi.org/10.1038/s41597-023-02041-1

Klöck, C., Castro, P., & Weiler, F. (2012). AOSIS in the UNFCCC negotiations: From unity to fragmentation? *Climate Policy*, *12*, 591–613. https://doi.org/10.1080/14693062.2012.692205

Knight, C. (2013). What is grandfathering? *Environmental Politics*, *22*(3), 410–427. https://doi.org/10.1080/09644016.2012.740937

Kulovesi, K., & van Asselt, H. (2020). *Three decades of learning-by-doing: The evolving climate change mitigation policy of the European Union.* Social Science Research Network. https://doi.org/10.2139/ssrn.3859498

Kyoto Protocol, 1997, 2303 U.N.T.S. 162.

Lamb, W. F., Wiedmann, T., Pongratz, J., Andrew, R., Crippa, M., Olivier, J. G. J., Wiedenhofer, D., Mattioli, G., Khourdajie, A. A., House, J., Pachauri, S., Figueroa, M., Saheb, Y., Slade, R., Hubacek, K., Sun, L., Ribeiro, S. K., Khennas, S., De La Rue Du Can, S., . . . Minx, J. (2021). A review of trends and drivers of greenhouse gas emissions by sector from 1990 to 2018. *Environmental Research Letters*, *16*(7), Article 073005. https://doi.org/10.1088/1748-9326/abee4e

Lindstad, S. (2021). Beneficiary pays and respect for autonomy. *Social Theory and Practice*, *47*(1), 153–169. https://doi.org/10.5840/soctheorpract2021129114

Lo, J. (2022, November 29). Who should pay for loss and damage? Spoiler: Not China. *Climate Home News*. https://www.climatechangenews.com/2022/11/29/who-should-pay-for-loss-and-damage-spoiler-not-china

Meng, B., Liu, Y., Gao, Y., Li, M., Wang, Z., Xue, J., Andrew, R., Feng, K., Qi, Y., Sun, Y., Sun, H., & Wang, K. (2023). Developing countries' responsibilities for CO2 emissions in value chains are larger and growing faster than those of developed countries. *One Earth*, *6*(2), 167–181. https://doi.org/10.1016/j.oneear.2023.01.006

Meyer, L. H. (2013). Why historical emissions should count. *Chicago Journal of International Law*, *13*(12), Article 15. https://chicagounbound.uchicago.edu/cjil/vol13/iss2/15

Newman, R., & Noy, I. (2023). The global costs of extreme weather that are attributable to climate change. *Nature Communications*, *14*(1), Article 1. https://doi.org/10.1038/s41467-023-41888-1

Oxfam. (2015). *Extreme carbon inequality*. https://www.oxfamamerica.org/explore/research-publications/extreme-carbon-inequality

Pan, J. (2022). Measuring carbon emissions for basic necessities. In *Climate change economics: Perspectives from China* (pp. 151–164). Springer.

Pan, J., & Chen, Y. (2010). Carbon budget proposal: A framework for an equitable and sustainable international climate regime. *Social Sciences in China*, *31*(1), 5–34. https://doi.org/10.1080/02529200903565046

Pan, J., Wang, M., Zhang, Y., Liu, Z., & Wu, X. (2016). Road to Paris: The changed and unchanged in international responsibility system. *Chinese Journal of Urban and Environmental Studies*, *4*(1), Article 1650006. https://doi.org/10.1142/S2345748116500068

Qi, X. (2011). The rise of BASIC in UN climate change negotiations. *South African Journal of International Affairs*, *18*(3), 295–318. https://doi.org/10.1080/10220461.2011.622945

Ritchie, H. (2019). *Who emits the most CO2 today?* Our World in Data. https://ourworldindata.org/annual-co2-emissions

Tiseo, I. (2023). *World's biggest CO_2 emitters 2022*. Statista. https://www.statista.com/statistics/271748/the-largest-emitters-of-co2-in-the-world

Toivanen, V. (2023). *How does multilateralism occur in global climate negotiations? The common principles and values behind the COP26 negotiations*. Tampere University. https://trepo.tuni.fi/handle/10024/148055

Torney, D. (2015). The normative gap in European, Chinese, and Indian climate relations. In D. Torney (Ed.), *European climate leadership in question: Policies toward China and India* (pp. 73–96). MIT Press.

United Nations Framework Convention on Climate Change, 1992, No. 102-38, 1771 U.N.T.S. 107.

Vazhayil, J. P., Sharma, V. K., & Balasubramanian, R. (2011). A framework for equitable apportionment of emission reduction commitments to mitigate global warming. *International Journal of Energy Sector Management*, *5*(3), 381–406. https://doi.org/10.1108/17506221111169881

Yu, Z., Mingshan, S., & Shanshan, Y. (2020). Comparison of greenhouse gas emissions per capita per year among countries considering methane emissions. *Earth Sciences*, *9*(5), Article 219. https://doi.org/10.11648/j.earth.20200905.18

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