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Emissions Sharing Observations from a Diverse Range of Countries

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Abstract: The Paris Agreement is set to come into effect from the year 2020. With this, the issue of emission sharing responsibility has gained momentum. This paper discusses the future emission allowances of various countries based on different sharing principles. Twelve countries from six continents were chosen for observation based on attributes such as past emissions, extent of development, and population. The aim was to find the implication of different sharing principles in future emission quota of a diverse range of countries. Four different budgeting periods were employed for increased certainty. Future cumulative and per capita emission allowances were estimated. The results prove that longer budgeting periods are more advantageous for developed countries while shorter budgeting periods favor developing countries more. The study brings forth some new developments in emission distribution research, primarily concerned with the low emitting countries. Overall, the study contributes to the field of emission sharing science to meet global climate targets.

Keywords: emission budgets; sharing principles; developed countries; developing countries; least developed countries

1. Introduction

The 25th session of the Conference of the Parties (COP) is scheduled to take place in November, 2019 [1], where the Paris Agreement's two degree target [2] will be the central issue. Responsibilities of countries (parties to UNFCCC) will be negotiated in the wake of "the transient climate response to cumulative carbon emissions" [3]. This session will add momentum to the ongoing discussion of emission sharing among the countries. Many researches are going on aiming to develop different methods for sharing the remaining emission budget, called sharing principles [4–7]. In continuation of this, many researches are going on to find the implications of these sharing principles on different countries of the world [8,9]. Meanwhile, there are other studies exploring the efforts required by the developing and developed countries to meet the climate targets [10,11]. The most discussed principles are inertia sharing and equity sharing. Inertia sharing (also known as grandfathering) is based on the theory that future emissions should be allocated depending on the past emissions of the country/region [12,13]. Equity sharing is based on the theory that each person on Earth deserves an equal share of the carbon emissions budget [14], hence future emissions should be allocated based on the population count. However, these principles are considered unjust by the research community [15,16]. Many alterations have been proposed to these principles and many new principles have been proposed [7,17–19]. In spite of that, none of the sharing principles were accepted globally until the 24th meeting of Conference of Parties, held in December 2018.

The first Assessment Report by Intergovernmental Panel on Climate Change (IPCC) in 1990 proposed a relationship between emissions and global temperature [20]. Since then, this field has attracted attention of many disciplines and a lot of work is being done in this direction. However, mostly, the countries with high past cumulative emissions have been the target of such studies. Many countries, which have had small shares in past cumulative emissions but might significantly contribute in the future, have only been studied as a part of large regions where they currently serve negligible roles. Their contribution in future emissions has not attracted much attention. To account for this, the paper presents a study of 12 countries with diverse characteristics (in terms of past emissions, population and development). In the study, the future emission budgets allocation of these countries were estimated. Their per capita emissions and mitigation rates required to meet the Paris Agreement's 2 °C goal were analyzed. The purpose was to compare the significance of budget distribution to low emitting countries with high-emitting countries and apprehend their probable contribution in the future. Depending on the allocations, the most advantageous sharing principle and budgeting period for each country was also determined. This research can be significant to identify the target countries for global emission reduction strategies with a wider focus. The study therefore contributes to the scientific knowledge in the field of climate change governance and emission sharing.

Certain terms used in this study which need to be explained for this context are

i. "Budgeting period" is the span of years for which the countries are held accountable for anthropogenic emissions. In this study, four different budgeting periods are considered (details are given in Section 2).
ii. Most advantageous/favorable principle (or budgeting period) is the one which is allocating highest emission budget to the country.
iii. 'Combinations' refers to the combination of one sharing principle with one budgeting period. For example, inclusion principle with the first budgeting period is one combination.

For observation, the countries were divided into two groups: a high-emitting group and a low emitting group (Figure 1). In the high-emitting group are the top emitters of the world. According to the World Resource Institute's Climate Data Explorer [21]. China, the Unites States, the European Union 28 (EU 28), India, Russia, and Japan are the six highest emitting countries of the world. Similarly, six countries were selected for the low emitting group (Table 1). This group was further divided into three subgroups. The first subgroup includes Kiribati and Samoa; the lowest emitting countries of the world. The second subgroup comprises of Ethiopia and Afghanistan; the least developed countries [22]. Third subgroup includes Vanuatu and Iceland; the least populated countries [23]. The high-emitting group contains the most developed countries of the world (the United States, the EU 28, and Japan); economies in transition—Russia [24]; and developing countries with the highest population (China and India). Hence, in total, both groups represent a heterogeneous mix of countries with diverse attributes (Table 1).

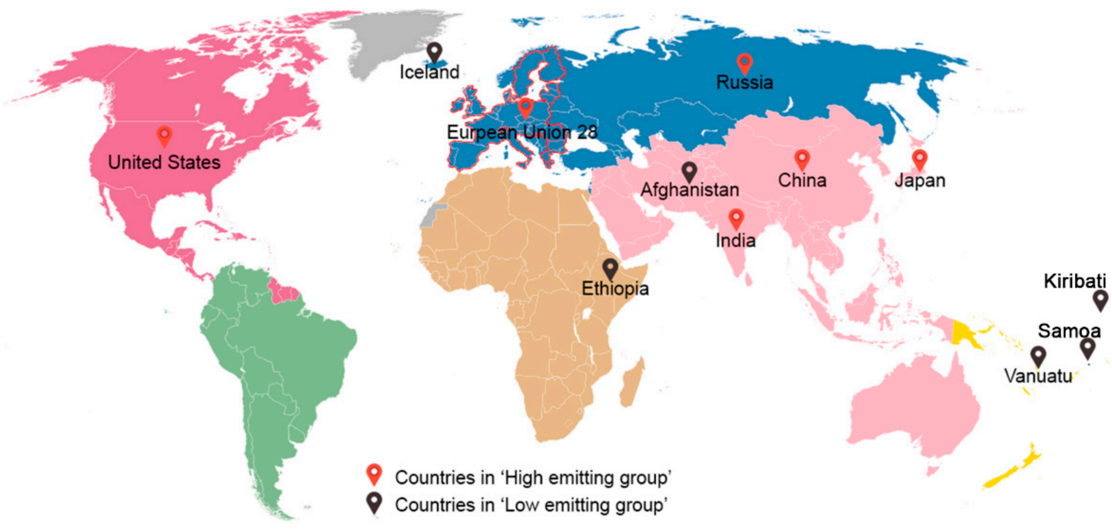

Figure 1. Location of countries selected for observation.

Table 1. List of countries observed in this study representing their basis of selection.

Countries	Highest Emitting Countries	Lowest Emitting Countries	Developed Economy	Developing Economy	Least Developed Countries	Economy in Transition	Most Populated Countries	Least Populated Country	Small Island Developing States
China	✔			✔			✔		
United States	✔		✔						
EU 28	✔		✔						
India	✔			✔			✔		
Russia	✔					✔			
Japan	✔		✔						
Kiribati		✔			✔				✔
Samoa		✔			✔				✔
Ethiopia					✔				
Afghanistan					✔				
Vanuatu					✔			✔	✔
Iceland			✔					✔	

There is a large debate on the question of when countries should be held accountable for the increasing greenhouse gases in the atmosphere. Some researchers argue that the founding of the United Nations Environmental Program in the early 1970s should serve as the start of the budgeting period [25], while most researchers prefer the early 1990s, when anthropogenic climate change science was well established and negotiations leading to the founding of the UNFCCC began [26–28]. Yet another group of researchers claim that the year 2005, when Kyoto Protocol agreements regarding emission reduction by Annex I countries began, should mark the start of the budgeting period. In order to circumvent uncertainties, each of these three time periods were used as the start of budgeting period in this study. Another budgeting period, starting from the year 1960 was also employed as the emission data for most of the countries is available from the year 1960. All the budgeting period end in the year 2016 which is the last year for which emissions data are available from UNFCCC. Thereafter, four different budgeting periods are employed in this study: first is the 57-year budgeting period which starts from 1960 and ends in 2016; second is the 47 years budgeting period which starts from 1970 and ends in 2016; third is the 27 years budgeting period which starts in 1990 and ends in 2016; and the fourth, and last, is the 12-year budgeting period which starts in 2005 and ends in 2016.

Also, Messner [29] explained that more recent is the reference year (the year on which the future emission calculations are based), the higher are the chance that countries with larger populations benefit through equity sharing, while countries with higher emissions benefit through inertia sharing. To neutralize this effect in the current study, the average of all the budgeting years was used as the reference year. For example, for the 57-year budgeting period, the reference emission is the average of emissions in all 57 years, and reference population is the average of population of all 57 years. The same applies to the other budgeting periods. This counterbalances the advantages that highly populated countries and high-emitting countries might have gained with equity and inertia sharing respectively.

2. Methodology

2.1. Data

The past emissions data were taken from the Global Carbon Atlas that sources its data from the Carbon Dioxide Analysis and Information Centre [30], UNFCCC National Inventory Submissions [31], and the British Petroleum Statistical Review of World Energy [32]. In October 2018, IPCC released a special report in which the remaining emission budget was consistent with the 1.5 °C and 2 °C warming limits previously published [33]. In October 2018, IPCC released a special report entitled 'Mitigation Pathways Compatible with 1.5 °C in the context of Sustainable Development' [33] in which the remaining emission budgets consistent with 1.5 °C and 2 °C warming limits were published. In this study, the remaining budgets, consistent with the 2 °C warming limit with 67% probability, were used from this report.

2.2. Methods

As discussed earlier in the paper, equity and inertia sharing are the two most discussed principles but have not been globally accepted. Raupach et al. [34] proposed a factor called sharing index (w), aimed to create a balance between the two principles. Neumayer [35] proposed the inclusion of historical emissions in the calculations. The current study uses these four sharing principles to estimate the share of global carbon budget allowance to be allocated to each country. The following are the equations for each of the sharing principles.

i. Inertia sharing—Based on the past emissions of the country.

$$E^t{}_c = (E^b{}_c/E^b{}_w) \times E^t{}_w, \quad (1)$$

ii. Equity sharing—Based on the population of the country.

$$E^t{}_c = (P^b{}_c/P^b{}_w) \times E^t{}_w, \quad (2)$$

iii. Blended sharing—This includes a factor called 'sharing index (w)' which can have a value between 0 and 1, where w = 0 indicates inertia sharing and w = 1 indicates equity sharing. With different values of 'w' this sharing principle may lie anywhere between inertia and equity sharing. However, for the purpose of analysis, blended sharing combines equal parts of inertia and equity sharing, with sharing index = 0.5 (as developed by Raupach et al. [34] and used by Sahu & Saizen [36].

$$E^t{}_c = [(1 - w) \times (E^b{}_c/E^b{}_w) + w \times ((P^b{}_c/P^b{}_w)] \times E^t{}_w, \quad (3)$$

iv. Inclusion sharing—Adds the factor of historical responsibility (in the form of compensation) to the population-based emissions sharing criteria. Compensation is the debt/credit a country owes to the world (or other countries) depending on its past emission trajectory (developed by Neumayer [35] and used by Gignac & Matthews [37] and Sahu & Saizen [36]).

$$HED_c = \Sigma\, [E_c - (P^b{}_c/P^b{}_w)] \times E_w, \quad (4)$$

$$C^n{}_c = (1/N) \times HED^n{}_c, \quad (5)$$

$$E^t{}_c = [(P^b{}_c/P^b{}_w) \times E^t{}_w] - C^n{}_c, \quad (6)$$

where:

- $E^t{}_c$ ($E^b{}_c$) = Emission of region C in target year t (base year b)
- $E^t{}_w$ ($P^b{}_w$) = Emission of the world in target year t (base year b)
- $P^b{}_c$ = Population of the region C in base year b
- $P^b{}_w$ = Population of the world in base year b
- HED_c = Historical emission debt (or credit) of the region C
- $C^n{}_c$ = Compensation that the region C agreed in N years (where n = 1, . . . N)

For this study, calculations were done for compensating all the years that are considered for budgeting period, hence Compensation ($C^n{}_c$) = Historical emission debt (HED_c) for the inclusion sharing principle.

3. Results and Observation

Figure 2 graphically demonstrates the possible number of results for one country. With four budgeting periods and four sharing principles, a total of 16 combinations are possible for each country. This was done for 12 countries and observations were made.

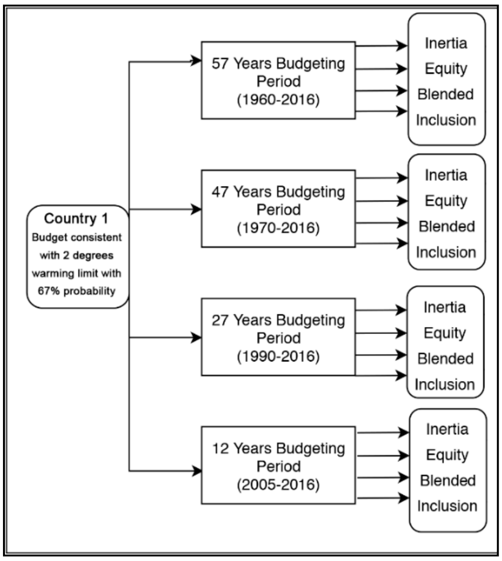

Figure 2. Demonstration of possible number of cases for one country.

Huge differences in HED (discussed in inclusion sharing) of the countries were observed. Figure 3 shows HED of all the countries. Among the 'High-emitting Group', developed countries were found to have positive HED, implying that they owe some credit to the world. China had negative HED in the initial years of observations. However, after 2005, HED drastically changed. India's HED decreased with time. The countries in the 'Low Emitting Group' were found to have negligible HED. However, Ethiopia and Afghanistan were found to have a slight decrement in HED (i.e., from positive HED to negative HED).

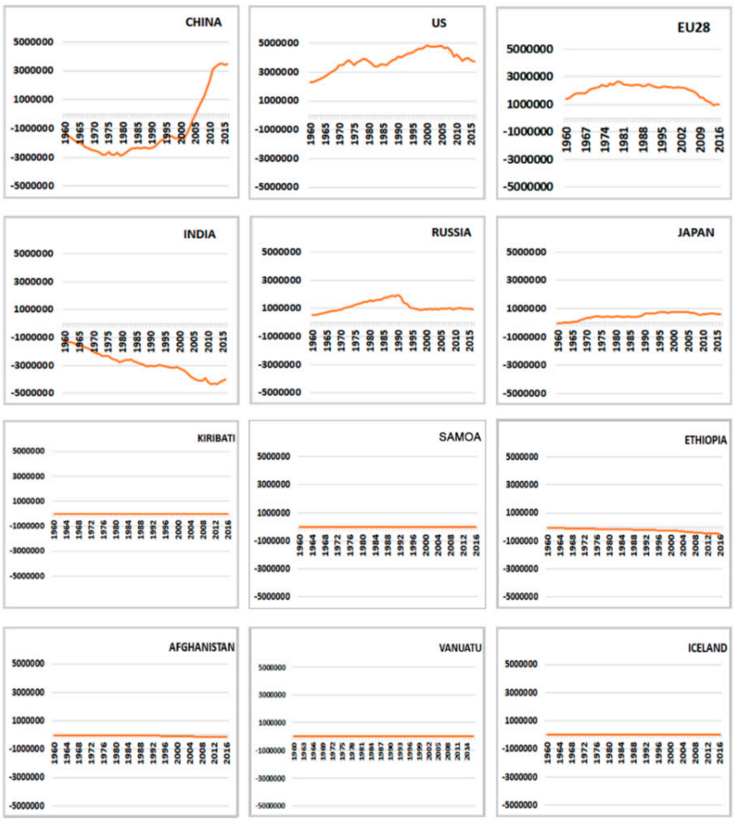

Figure 3. Historical emission debt (HED) of countries selected for observation.

3.1. Cumulative Emission Budget

According to Rogelj et al. [33], the world is left with a budget of 1170 $GtCO_2$ to limit the rise in global temperature to 2 °C above the pre-industrial level with 67% success probability. Using this quota as target emissions for the world, future emission allowance to countries was calculated in this study. Figure 4 shows the comparison of cumulative remaining emissions of all the countries. In addition, the results are discussed separately for the two different groups because of the huge difference in magnitudes.

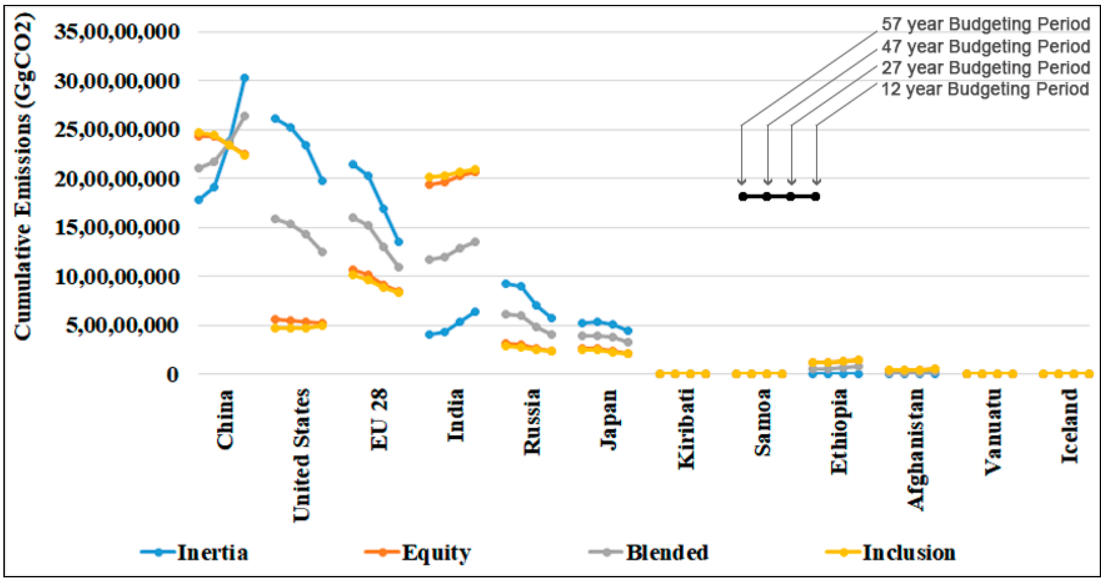

Figure 4. Remaining cumulative emissions allocated to countries according to the different sharing principles.

3.1.1. High-emitting Group

The results of emission allowance for the 'High-emitting Group', calculated using the above equations (Equations (1)–(3) and (6)), are presented in Table 2. The table shows results for four different budgeting periods for each country.

Table 2. Emissions quota allowed to countries in the high-emitting group ($GgtCO_2$).

Sharing Principles	57 Years	47 Years	27 Years	12 Years	57 Years	47 Years	27 Years	12 Years
	CHINA				United States			
Inertia	152.66	163.34	203.32	259.08	222.83	215.39	199.68	169.30
Equity	208.36	207.32	200.56	192.20	48.59	47.36	45.41	44.43
Blended	104.18	103.66	100.28	96.10	24.29	23.68	22.70	22.21
Inclusion	211.48	209.56	200.43	190.97	38.68	38.68	40.05	42.14
	EU 28				INDIA			
Inertia	183.28	173.46	144.19	115.25	34.83	36.90	46.08	54.23
Equity	91.47	86.73	77.60	72.24	16.58	16.79	173.49	177.29
Blended	45.75	43.36	38.80	36.12	82.93	83.97	86.74	88.64
Inclusion	86.14	82.22	75.27	71.45	173.35	174.73	177.93	179.54
	RUSSIA				JAPAN			
Inertia	78.62	76.50	60.17	49.45	58.14	44.72	44.06	37.52
Equity	27.13	25.56	22.86	20.53	29.74	22.02	19.90	18.29
Blended	13.56	12.87	11.43	10.26	14.87	11.00	9.95	9.14
Inclusion	24.18	23.12	21.55	20.09	28.75	20.78	19.06	17.94

For every country, the results from Table 2 are explained below.

China: It was observed that allocation through inertia sharing and blended sharing increased with decreasing budgeting period, while the opposite occurred for the equity and inclusion principles. Hence, inertia and blended principles allocated highest budget in 12-year budgeting period and equity and inclusive principles allocated highest in 57-year budgeting period.

United States: Inertia sharing was found to allocate highest budget to US while inclusion sharing allocates the lowest. For lesser number of budgeting years, the budget allocation was observed to decrease for inertia, equity, and blended sharing principles. However, for the inclusion principle, the budget increased by a small percentage for each consecutive budgeting period (Table 2). According to this, it can be said that a longer period of budgeting years allocates higher emission allowances to US if HED is not factored into emissions sharing calculations.

EU 28: Like the United States, budget allocations were found to be highest in the 57-year budgeting period which decreased steadily with decreasing number of budgeting years. Also, the highest budget was allocated by the inertia sharing principle, followed by blended sharing and equity sharing. The lowest budget resulted from the inclusion sharing principle.

India: Highest allocation was through inclusion sharing principle, closely followed by equity. Lower budget was allocated by blended and lowest by inertia principle. With an increase in the number of years in the budgeting period, the share increased but only nominally. The 12-year budgeting period is allocating higher emission allowances.

Russia: Past emissions have been high and population share has been low for Russia. The 57-year budgeting period was observed to allocate highest budget. Also, inertia allocation was the highest for all the budgeting periods, followed by blended, equity and inclusion sharing.

Japan: Figure 3 shows that HED of Japan has been low compared to other high-emitting countries observed in this study. The 57-year budgeting period allocated highest budget to Japan. Inertia sharing proves most beneficial followed by blended sharing. Allocation by inclusive and equity are lowest.

3.1.2. Low Emitting Group

The cumulative carbon budget allocated to the low emitting group observed in this study ranged from 1.5×10^{-4}% to 4×10^{-1}% of the world's total emission share, which is a very small proportion. Only Ethiopia's budget was found to be slightly higher, but the magnitude was still very small. Table 3 presents results of emission allocation for the 'Low Emitting Group'. The results are calculated using Equations (1)–(3) and (6) for the four different budgeting periods.

Table 3. Emissions budgets allowed to countries in low emitting group ($GtCO_2 \times 10^{-3}$).

Sharing Principle	57 Years	47 Years	27 Years	12 Years	57 Years	47 Years	27 Years	12 Years
	KIRIBATI				**SAMOA**			
Inertia	2.11	1.80	1.74	1.73	6.62	6.43	6.05	5.73
Equity	17.35	16.70	16.38	16.36	31.39	32.81	35.57	36.55
Blended	9.73	9.25	9.06	9.04	19.01	19.62	20.81	21.14
Inclusion	17.58	17.14	17.09	17.07	31.78	33.59	36.86	38.03
	ETHIOPIA				**AFGHANISTAN**			
Inertia	285.74	229.86	191.58	181.64	260.31	166.69	159.71	153.40
Equity	14,950.9	13,523.5	12,180.4	11,797.7	4960.3	4271.2	3923.7	3875.8
Blended	7618.3	6876.7	6185.9	5989.6	2610.3	2218.9	2041.7	2014.6
Inclusion	15,180.6	13,921.8	12,715.1	12,370.7	5034.0	4394.8	4092.2	4059.2
	VANUATU				**ICELAND**			
Inertia	4.0	3.8	3.79	3.9	115.7	118.5	115.3	117.4
Equity	40.1	37.4	34.9	33.9	53.4	53.9	56.1	57.3
Blended	22.0	20.6	19.3	18.9	84.5	86.2	85.7	87.4
Inclusion	40.7	38.4	36.2	35.4	52.4	52.0	53.4	54.4

Kiribati: It is a country with increasing population and comparatively low emissions. The highest budget was allocated by inclusion, closely followed by equity. Blended, followed by inertia sharing principle allocated lowest budget. Also, the 12-year budgeting period was found to allocate highest budget to Kiribati and with increasing budgeting years, the budget decreased.

Samoa: Like Kiribati, the highest budget was allocated through the principle of inertia, closely followed by blended, and then equity and inclusion principles allocated the lowest budget to Samoa. However, with the decreasing budgeting years, the budget decreased.

Ethiopia: This country was allocated the highest budget in the group of low emitting countries through blended and inclusion principle. This is a country with rapidly increasing population. With a decreasing number of budget years, the carbon budget allocated to Ethiopia was observed to increase. Henceforth, the 12-year budgeting period was found to allocate highest budget to Ethiopia. The highest budget was allocated by the inclusion sharing principle, followed by equity sharing, and then blended, while the lowest budget was allocated by the inertia sharing principle.

Afghanistan: The population of Afghanistan is less than that of Ethiopia, however past emissions are higher compared to Ethiopia. With a lesser number of budgeting years, the carbon budget was observed to increase. The highest budget was allocated by inclusion sharing, closely followed by equity sharing. Blended sharing and inertia sharing allocated the lowest budget.

Vanuatu: For this low population, low emissions country, the highest budget was allocated by the inclusion sharing principle, followed by equity sharing, and blended sharing. The lowest budget allocation was by the inertia sharing principle. The budget allowance was found to increase with decreasing number of budgeting years.

Iceland: This is a low population, high emissions country. The number of budgeting years do not make a significant effect on the budget allocation. For all the budgeting years, the allocation is approximately same. Inertia sharing is allocating the highest budget, followed by blended sharing. Equity sharing and inclusion sharing are allocating the lowest budget to the country.

3.2. Per-Capita Emission Budget

Per capita emission budget allowance was calculated using the population of countries in the year 2016; 2016 was chosen for the calculations because this is the last year, common for all the budgeting periods.

Figure 5 presents the comparison between cumulative budget and per capita budget per year allocated to the countries. Figure 5a presents inertia allocation, Figure 5b presents equity allocation, Figure 5c presents blended allocation while Figure 5d presents inclusion allocation. In whole, the figure shows that the calculated per capita emissions of some 'Low emitting countries' is higher than some 'High-emitting countries'. Cumulative emission budget of low emitting countries is negligible compared to high-emitting countries, which is quite obvious. But the per capita emission budget of low emitting countries is not very low compared to all the high-emitting countries. According to inertia principle, the per capita emission allocation of Iceland is close to EU 28. India's per capita budget is comparable to Samoa's budget. United States gets highest per capita allocation according to inertia principle.

The comparison gives more interesting results for the equity and inclusion principle. The per capita emissions are very similar for all the countries. This is because the basis of equity and inclusion principle is population based allocation. The blended principle also gives Iceland higher per capita emission then China and India. In the low emitting group, Equity, blended and inclusion principle allocate Ethiopia the highest cumulative budget, but per capita budget is low. However, for Kiribati, Samoa, Afghanistan, and Vanuatu, the cumulative emissions are too low but per capita emissions are comparatively higher.

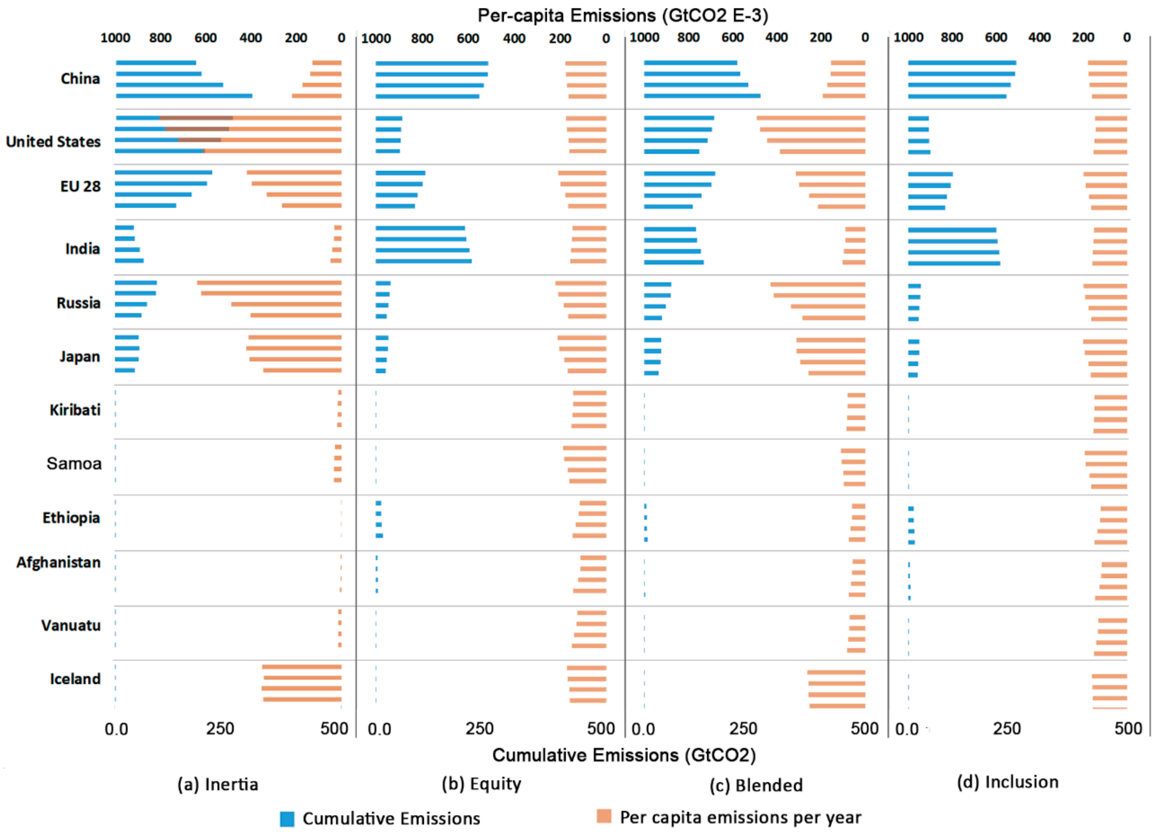

Figure 5. Cumulative and per capita carbon budget allocated to countries to meet the 2 °C climate target with 66% probability based on different sharing principles.

This comparison shows that the ranking of countries based solely on higher emission allocation is very different from per capita budget allocation. To determine this difference, the highest per capita budget that can be allowed to each country (irrespective of budgeting period) was determined. In Table 4, the 12 countries studied in this paper are ranked from 1 to 12 based on per capita emissions. The country allocated maximum per capita budget is at rank 1, while the country allocated minimum per capita budget is rank 12. For example, according to inertia sharing, the highest per capita budget that can be allocated to US (under any of the four budgeting periods) is 31.32, which is the highest of all the 12 countries. Highest budget that can be allocated to Ethiopia (under any of the four budgeting periods) is 2.79, but it the lowest of all the 12 countries. Observation showed that the first three ranks were always occupied by the four top emitters of the world (US, EU 28, Russia and Japan); implying that in any possible condition, these countries will have the highest per capita emissions in future. On the contrary, China and India which are also in the list of top emitters of the world, hold lower platforms in the list of per capita emissions. Some low emitting countries are ranked higher than China and India as per every budgeting principle. Table 4 shows that in the low emitting group, the highest per capita emissions allowed to Iceland are higher than India's highest per capita emissions for every sharing principle and higher than China's highest per capita emissions for inertia and blended principles. Per capita emissions of Samoa are also higher than both China and India for equity, blended and inclusion principles. Afghanistan and Ethiopia hold the lowest platforms in every sharing principle. Under equity sharing, the US is at sixth rank; implying that population based sharing is disadvantageous to US. In inclusion sharing, US is at the ninth rank; implying that the factor of historical inclusion is even more disadvantageous to US. However, EU 28, Russia, and Japan are not affected by these factors and continue to hold top ranks in the per capita emissions.

Table 4. Ranking of countries based on highest per capita emission allowance (GtCO$_2$ E-3). The cells in grey shade show that the country has highest per capita emission in 57-year budgeting period and cells in white show that the country has highest per capita budgets in the 12-year budgeting period.

Ranking	Inertia		Equity		Blended		Inclusion	
	Country/Region	Per Capita Emissions	Country/Region	Per Capita Emissions	Country/Region	Per Capita Emissions	Country/Region	Per Capita Emissions
	World	157.17	World	157.17	World	157.17	World	157.17
1	US	806.16	Russia	219.93	US	490.98	Japan	200.90
2	Russia	637.28	Japan	210.81	Russia	428.61	Russia	199.50
3	EU 28	419.48	EU 28	209.35	EU 28	314.42	EU 28	198.99
4	Japan	412.07	Samoa	187.35	Japan	311.44	Samoa	194.92
5	Iceland	350.03	China	176.83	Iceland	260.56	China	179.09
6	China	219.87	US	175.80	Samoa	108.37	Iceland	162.36
7	India	47.90	Iceland	171.09	India	102.28	India	158.35
8	Samoa	33.97	India	156.65	China	91.49	Kiribati	153.76
9	Kiribati	18.46	Kiribati	151.67	Kiribati	85.06	US	153.68
10	Vanuatu	14.89	Vanuatu	148.46	Vanuatu	81.67	Vanuatu	150.55
11	Afghanistan	7.51	Ethiopia	146.00	Afghanistan	75.32	Ethiopia	148.24
12	Ethiopia	2.79	Afghanistan	143.13	Ethiopia	74.40	Afghanistan	145.26

Also, for every country, the highest per capita emissions are either held by the 57-year budgeting period or the 12-year budgeting period. In Table 4, the cells are in grey shade if the highest per capita emission is in the 12-year budgeting period and are in white shade if the highest per capita emission is in the 57-year budgeting period. It can be seen that all the developed countries have highest per capita emissions in the 57-year budgeting period and are of higher rank too. All the developing countries have highest per capita emissions in the 12-year budgeting period and are mostly at the lower ranks. However, the two countries, China and Samoa are observed to be deflecting from the trend and are found to have highest per capita emissions in different budgeting periods for different sharing principles.

3.3. Obligation to Mitigation

The countries are obliged to reduce certain amount of emissions each year to successfully meet the remaining emission budget. This required reduction in emissions is termed 'mitigation rate'. Raupach et al. [34] formulated the following method for estimating mitigation rates.

$$\text{Mitigation Rate (m)} = \frac{1 + \sqrt{1 + \text{rT}}}{\text{T}} \tag{7}$$

where,

$$\text{r} = \text{initial proportional growth rate} = 1/\text{f}_0 \times \frac{df}{dt} \tag{8}$$

$$\text{T} = \text{emission time (defined by quota q)} = \frac{\text{q}}{\text{f}} \tag{9}$$

where:
f = capped emission trajectory (and f_0 = initial cumulative emissions),
q = emission quota.

Using these equations, mitigation rate required by all the countries were calculated. All the past recorded emissions (from the year 1960 to 2016) were assumed to be the initial cumulative emissions. And the emission quota (q) was different for different sharing principles. Figure 6 shows the results.

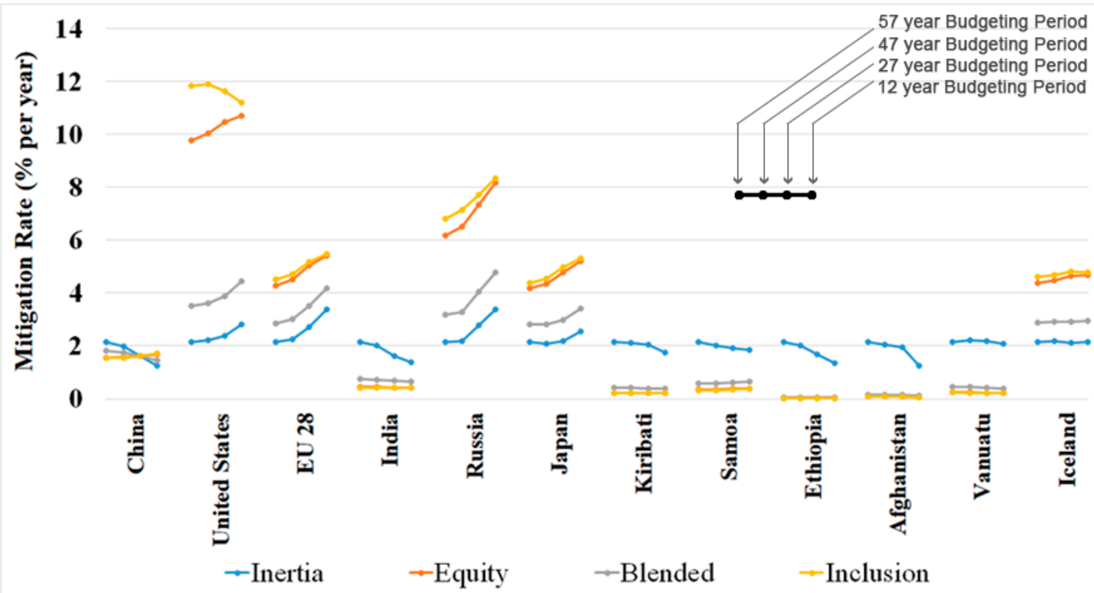

Figure 6. Mitigations rates of countries for different budgeting periods and sharing principles.

The important point that the figure brings out is that mitigation rates of all the countries are inversely proportional to their remaining emission budgets for all the sharing principles, except the mitigation rate for inertia based allocation which is not inversely proportion. Instead, the magnitude of mitigation rate as per inertia sharing is very similar for the countries. It implies that the developing and least developed countries are required to make similar percentage of reduction as the most economically advanced countries of the world.

4. Conclusions

This study intended to explore the remaining emission allowances of different countries to meet the climate targets. Based on these observations the following conclusions can be made.

Firstly, the shorter budgeting period was found to allocate high emission allowance to the developing or least developed countries of the world, while a longer budgeting period was found to allocate higher budget allowance to the developed countries. The reason behind this can be-owing to the UNFCCC commitments, the developed countries are voluntarily reducing their emissions. Therefore, in the recent years these countries have emitted lesser than the past. And in this study, the shorter the budgeting periods is, the more recent years are taken into account. Hence, with shorter and more recent budgeting years, the developed countries get lesser budgets. On the other hand, the developing and least developed countries already had lower emissions in the past, hence, the above theory is not applicable to them. Additionally, the increasing population in the recent years gave an advantage to these countries in shorter budgeting periods over the developed countries which are mostly less populated. This result can further be refined by the finding that the factor of historical accountability (in the inclusion sharing principle) is allocating higher budget to most of the developing countries. Overall, the results depict that the combination of a shorter budgeting period and inclusion principle is most advantageous for the developing countries and the combination of longer budgeting period and inertia sharing is most advantageous for the developed countries.

Secondly, the results of this study show that some countries which have low past emissions (and hence not considered in emission distribution research) may have high per capita emission in future. And hence, they can play an important role in future emission distribution. This can be seen more clearly in Figure 6, which shows the comparison of mitigation rates required by the countries. The figure shows that mitigation required by some low emitting countries is higher than that required by some high-emitting countries. Samoa, Kiribati and Vanuatu require similar (or slightly higher) mitigation than India. Mitigation required by Iceland is higher than China and India. Concluding these results, the authors wish to suggest that emission distribution research should also be based on per capita emissions calculations and not just cumulative emissions. Further research may bring more cases into focus which are currently assumed insignificant considering their small contribution in the current emissions. Also, some studies have reported that the voluntary mitigation targets expressed in the Intended Nationally Determined Contributions are insufficient [38,39], which further enhances the need of discussing emission allowances of the countries. Employing more emission allocation methods can give more robust results in this direction.

The study adds to the research data base of different countries of the world, especially the ones which are mostly not at the center of this field of research. These results are important to understand the significance of a wider focus in the emission distribution science.

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