Environment, Development and Sustainability (2020) 22:5465–5481
https://doi.org/10.1007/s10668-019-00433-1

Global carbon budget allocation based on Rawlsian Justice by means of the Sustainable Development Goals Index

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Received: 22 January 2019 / Accepted: 24 July 2019 / Published online: 8 August 2019

Abstract
Despite the efforts to mitigate the effects and adapt to the global warming, the inequality in sharing of carbon emissions benefits and costs among the world population has given rise to the "Climate Justice" concerns which currently remain as an unresolved issue. It is expected that this issue may significantly be improved by deploying the Justice-based allocation of carbon budget between countries. Aside from this budget, the remaining budget is limited by mitigation scenarios. In recent decades, some egalitarian, responsibility-based, right-based and capability-based approaches have been presented for carbon budget sharing, which in this study, some of their major deficiencies have been listed. These deficiencies help the politics and business having a stronger hand in international decision-making processes. Then, as a pure Justice-based effort for global carbon budget sharing, the extent to which countries have achieved sustainable development goals has been considered as the only yardstick for differences among the peoples in the world. It is noted that the costs imposed on countries have implicitly been considered. A statistical methodology based on the proximity to development levels of countries has been used, with countries being stratified into the "Developed" and the "Developing." Furthermore, taking into account these strata and Climate Action of each country, in this article the Rawlsian theory of Justice has been applied to allocate carbon budget among countries. As a result, the fair carbon budget share (FCB) model has been introduced as a dynamic and forward-looking mechanism for determining the annual share of countries of the global carbon budget. The fair share of countries, resulting from the FCB model, has been calculated based upon the available statistical data. The results have shown significant differences between actual carbon emissions of countries and their fair share for years 2017 and 2018. Moreover, for comparison purposes, the FCB-derived shares had a significant difference with the shares provided by the egalitarian approach. Furthermore, as expected, it was observed that the FCB model does not provide a predetermined and foreseeable trend for countries' shares. This removes the biasedness criticism (commonly shared in all other approaches) for FCB model. Without any adjustment to the FCB model, the fair share of 2017 showed a significant balance between countries in debt or in credit when compared with their actual greenhouse gas emissions, which is indicative of the FCB's readiness to enter a market mechanism.

Keywords Carbon budget · Climate Justice · Rawls theory of Justice · Sustainable development goals · SDG index

Extended author information available on the last page of the article

Abbreviations

BAT	Best available techniques
BEP	Best environmental practices
CAT	Cap and trade
CB	Carbon budget
GHG	Greenhouse gas
FCB	Fair carbon budget
GCB	Global carbon budget
LULUCF	Land use, land-use changes and forestry
MCJ	Model of Climate Justice
PPP	Polluter pay principle
SDG	Sustainable development goal
SDSN	Sustainable development solutions network
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America

1 Introduction

In the last two decades, in particular, widespread efforts with different success rates have been made to mitigate and adapt to climate change. Nevertheless, the GCB allocation remains an open case in the climate change debate. Inadequate literature and scientific resources in this area, in comparison with similar cases (common waters, oil and gas resources and so forth), have strengthened the power of politics and business in the international decision-making processes. Therefore, there is a need for more robust scientific studies in this field.

Besides theoretical discussion of fair division or allocation of resources, Justice in social choices and the fundamentals and concepts of Climate Justice, there are a number of pragmatic proposals for carbon budget (CB) allocation, which may conveniently be categorized in five approaches. A thorough description of various concepts of Climate Justice and distributional Justice may be found in Okereke and Dooley (2010). In his book, Schlosberg (2007) provided comments and practical applications on environmental Justice. A number of useful references can be found in Bergson and Samuelson studies about welfare economics (Bergson 1938; Samuelson 1954), Arrow and Maskin (2012) works in social choice and no-envy scheme by Foley (1967) as well as unfinished discussions about social choice and definition of Justice in the works of Sen (1970), Rawls (1971) and others. A good source for fair division, with an axiomatic approach, can be found in Moulin (2003). Also Endriss (2010) provided additional complementary dimensions of fair division as well as its mathematical translation by Thomson (2007).

The aforementioned five pragmatic proposals/approaches for CB allocation are:

First, Darwinism, in combination with the market mechanism, suggesting that, similar to the beginning of industrialization (the beginning of consumption of GCB), each country, in a competitive atmosphere, based on its willingness and ability to win over others, took some of the budget in his possession. Then, there is still a weak sense of Justice in the budget allocated to countries even with some market-oriented adjustment efforts such as cap and trade (CAT). This approach uses the power of market mechanism to allocate resources, as well as its steady and popularity in the current world economy. However, it

is criticized for its weakness in Justice as it is not inherently Justice-oriented. Some ideas about this can be found in Lohmann (2006) and Chinn (1999). An illustrative example of the application of this approach is the clean development mechanism (CDM) under the Kyoto protocol (Yamin et al. 2001).The CDM faces more issues such as local resistance, carbon leakage and market deflation. Other attempts such as the CAT also suffer from policy uncertainty (Teeter and Sandberg 2016).

Second, the egalitarian approach. Here, basically, the total GCB is evenly allocated among the world population. One example is the "Fair Share Model" of Singer (2004). Also, Westing 'Law of the Air" can be considered as another example for this approach. In this work, the countries areas are replaced by their population (Westing 1989). The main point of this approach is its simple explanation along with its broad fairness. One major advantage of this approach comes from its ultimate level of equality. It is also the simplest approach to present and understand besides the fact that there are not many different interpretations about egalitarians ideas. On the other hand, this simplicity can be considered as a disadvantage. When egalitarians deal equally with almost everyone, it can be incompatible with the existing definitions of Justice. In other words, from the perspective of many philosophies, Justice is not necessarily equality. An appropriate analysis of some egalitarian efforts is conducted by Schuppert and Seidel (2015) from the German Advisory Council on Global Change (WBGU).

Many recent researches highlighted the problem of Climate Justice, i.e., unequal distribution of climate change costs and benefits between the peoples of the world, e.g., an International Monetary Fund (IMF) work by Acevedo et al. (2017) which emphasized that while the global warming consequences hurting the poorest people the most (Burke et al. 2015), domestic solutions can help but only to some extent and a global solution is needed.

As another example, Puaschunder (2017) has mapped Climate Justice using an index which estimates winners and losers of climate change until 2100. It showed that many African, southeastern Asian, Latin American and the Middle East countries are mainly among the losers. On the other hand, north American (USA and Canada), European and some Asian countries (including Russia) are mainly the winners of climatic changes. So contrary to the two abovementioned approaches, the need for such Justice-oriented approaches which considers the differences between countries will be felt.

Third, responsibility-based approach. Here, the main emphasis of these models and mechanisms is on punishing countries based on their carbon footprint from the past and present. In other words, the polluter pay principle (PPP) can be considered as the basis of this approach (Hayner and Weisbach 2016; Luppi et al. 2012). Where, according to the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report climate change mitigation scenarios (Pachauri and Meyer 2014), the most of the greenhouse gases (GHGs) have already been emitted before any successful agreement. It can be argued that the common but differentiated responsibilities (CBDR) principle, formalized in the 1992 by the United Nations Framework Convention on Climate Change (UNFCCC), Earth Summit in Rio de Janeiro, is also based on PPP (Rajamani 2002). Moreover, the "loss and damage principle" in the Kyoto protocol can be considered under this approach. Some solutions of this approach are aimed at converging the cumulative pollution of all countries to the same value, such as the Baer et al. (2000) and Garnaut (2011).

The responsibility-based approach has several major drawbacks; (1) countries with the highest historical pollution are among the largest contributors to scientific and technological progress since the 1850. As an example and based on a report by PwC and UBS (2018), 80% of the 40 main breakthrough innovations over the last 40 years have been driven by billionaires. They can argue that this higher carbon emission has been

inevitable for the pursuit of science, technology and industry which is an acceptable claim and difficult to reject. Moreover, punishing countries because of their lead in industrialization cannot be justified. (2) This approach punishes peoples of countries mainly due to the behavior of previous generation in those countries. However, taking into account high rates of migration to industrialized countries, they are not necessarily considered to be the descendants of the past generation of that country. In other words, the current people of a country do not have sufficient connection with the past generation of that country, so that they can be expected to bear their obligations. Furthermore, many governments (and, consequently, their political, economic and social systems) have collapsed during this period of time. (3) Human knowledge of the climate change and the certainty that these changes are predominantly anthropogenic is relatively new referring mainly back to the last few decades. Therefore, punishing a nation by virtue of its predecessors' behaviors who did not know the damages of their actions is a kind of ex post facto. Therefore, this approach is too far-fetched into the past which is one of its problems. (4) The legacy of many nations has been deteriorated due to natural and human disasters (especially armed conflicts), so punishment of current people of such countries because of what they have not even achieved (the legacy that was lost before the heirs are inherited) seems unjustified.

Besides the aforementioned disadvantages of this approach, there are also some advantages. The main advantage of this approach is its simplicity in presentation, explanation and also its application. It is easy to present and interpret because the responsibility-based approach is mainly based upon punishment and penalties instead of fairness and Justice, for which simpler interpretations have been offered. The latter means that the calculations required to apply this approach are very straightforward. Since the losses from pursuing this approach are mainly toward the rich countries, it can also be said that it mainly affects those who have the capabilities. An example of the rich people capability to adapt and mitigate climate change has been presented by Otto et al. (2019).

Fourth, right/capability-based approaches. In these approaches, the idea is to ensure that the CB is shared so that individuals or countries all benefit from their rights (including the Right to Development), while the real opportunities and the ability to develop are understood and are considered as the criteria for share.

While, according to their fundamental principles, in these approaches, there is a greater degree of Justice compared to the three previous approaches, but what rights are considered and the amount of capabilities is still controversial. More about capabilities can be found in Caney (2005a, b) and Nussbaum and Sen (1993), also the concept of meta-capability has been presented by Holland (2008).

It can be said that, the in-depth look at the human and societies, besides the comprehensiveness of these approaches, their main advantages are in the comparability with the other approaches. At the same time, the difficulties lie in their understanding and interpretation, because of the complexity in applying these concepts (right and capability). Also, as mentioned earlier, the process of selection and composition of rights/capabilities can be controversial.

Fifth, mixed approaches. To compensate the shortcomings of four previous approaches, especially egalitarian and responsibility-based, a number of mixed approaches are proposed. Examples of these models and mechanisms are the model of Climate Justice (MCJ), presented in a study by Alcaraz et al. (2018). It is a combination of responsibility-based (emitter's historical emissions for the period 1971–2010) and egalitarian approaches. Contraction and convergence (C&C) is a combination of right-based and egalitarian approaches (Meyer 2004). "An alternative approach"

is presented by Caney (2005a, b), works of Rose et al. (1998) and Rowlands (1997), based on egalitarianism taking into account some local differences between countries.

Furthermore, this approach still faces the main issues faced by the other approaches. For example, the MCJ suffers from oversimplification in the egalitarian approach, with the difference that it takes into account the differences between the responsibilities of countries, while other aspects of the differences between countries remain neglected. Similarly, the model suffers from the same problems in the responsibility-based approach. The attempt to comply with international treaties and existing political context seems to have led to this compromise. Another major disadvantage of mixed approaches is the mode of mixing process of the criteria, which increases the probability of being biased in the formation of a solution. In other words, the weight of the criteria in their mixing process is the point of conflict.

One common major disadvantage in all abovementioned five approaches is their very simple and one-dimensional view of the differences among the peoples of the world. In other words, when each of these approaches strives to be fairer in terms of CB by taking into account the differences among the peoples of the world, they mainly reduce differences solely to economic conditions. This is mainly done using income or production indicators, gross domestic production (GDP) and its derivative, gross national income (GNI) and similar indicators. The most important exception here is egalitarian approaches that essentially exclude any difference between peoples in the world.

Also it is necessary to point here that for some reasons like the novelty of the Climate Justice debate, a few of these approaches have been succeeded to come from an idea to a practice. The egalitarian approach shares CB between the world peoples equally while mixed approaches (e.g., MCJ) are among those few that provided solutions. Other approaches still remain as ideas and philosophies. Therefore, the outcome of this study's presented sharing model is compared with the egalitarian as a competitor in the following.

The main purpose here is to introduce a model for equitable sharing of carbon budget among the peoples of the world in a dynamic, forward-thinking way, and away from the mistakes of existing methods. This pure Justice-based approach is based on one well-defined theory for the concept of Justice, and a very acceptable solution for the social distribution of goods and interests. The Rawls theory of Justice seeks equality and liberty at the same time and has a special look at the differences among the least-advantaged members of society (Rawls, A Theory of Justice, 1971). Another unique feature of this study is using a comprehensive multidimensional composite index to reflect differences between nations based on developmental SDGs indicators and came from a study by Jabbari et al. (2019). As shown in Fig. 1, to have a fair share of the GCB, in general, seven major steps should be taken, of which the first two steps were taken by Jabbari et al. (2019) already, and this study covers the third and part of the fourth step.

In this article, following the introduction, a review on the works of Jabbari et al. (2019) to introduce the development index (DEVI) and differentiating countries based on their development levels have been presented including a brief to Rawls theory of Justice. Then, the main contribution of the current study such as the FCB model for GCB allocation, application of the model to world countries and the respective results have been presented. The paper concludes with a Climate Justice-based shares of CB in line with egalitarian approach adopting the Rawlsian Justice.

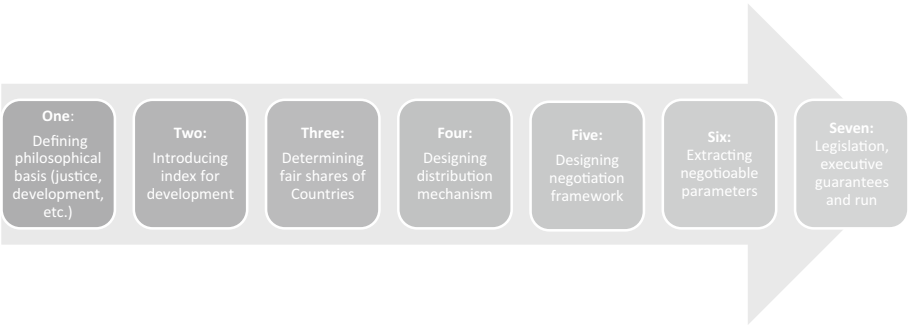

Fig. 1 Seven steps to achieve a global fair carbon budget allocation

2 Rawlsian Justice and its perquisites

2.1 What is Rawlsian Justice?

From utilitarianism to egalitarianism, there have been many philosophical perspectives to the concept of Justice. John Rawls as a liberal political philosopher, subsequent to his idea of "Justice as Fairness", introduced an institutional form of his concept vis-a-vis the following two lexically ordered principles (Rawls and Kelly 2001):

First principle Each person has the same indefeasible claim to a fully adequate scheme of equal basic liberties, which scheme is compatible with the same scheme of liberties for all;

Second principle Social and economic inequalities are to satisfy two conditions:

a. They are to be attached to offices and positions open to all under conditions of *fair equality of opportunity*;
b. They are to be to the greatest benefit of the least-advantaged members of society (the *difference principle*)

A thorough description of Rawls ideas and works may be found in Wenar (2017).

2.2 Introducing DEVI as the criteria for the differences between the peoples in the world

Further to the aforementioned *difference principle*, understanding and differentiating between the peoples' differences are prerequisites for Rawlsian Justice. There are several aspects of differences between the peoples of the world, including economic, sustainability, development, ethnic, gender, geographical and ecological circumstances in their homeland, vulnerability to natural disasters, and so on. Moreover, the level and progress rate in each of these variables is itself a measure of difference. However, the current study focused on the level of development in coherence with sustainability.

In a cooperation between Bertelsmann Stiftung and sustainable development solutions network (SDSN), a very comprehensive multidimensional index, namely the SDG index (a number from 0 to 100), has been introduced. SDG index describes countries' progress toward achieving the SDGs and the global SDG index score can be interpreted as the

percentage of achievement. The difference between 100 and countries' scores can therefore be interpreted as the distance in percentage that needs to be completed to achieve the SDGs. Also the SDG index can be used as comparable scores and rankings.

By introducing some corrections to the SDG index, hence separating *developmental SDGs* from the *environmental SDGs*, Jabbari et al. (2019) introduced an index to evaluate and monitor the development level of countries that incorporate many aspects of the differences between human by aggregation of more than 100 indicators. This comprehensive composite index, DEVI, illustrates human differences by measuring the countries' different progress toward achieving the *developmental SDGs* consistent with the United Nations (UN) SDGs.

It can be said that the method of construction of DEVI by Jabbari et al. (2019) is almost similar to the method of SDG index by Bertelsmann Stiftung & SDSN (2017a) with a difference that the indicators of 5 SDGs out of 17 SDGs have been excluded during the aggregation of indicators. They argued that, inclusion of the indicators of these 5 SDGs in the super aggregation of SDG index results in rising the development score of least developed countries in a superficial manner. These 5 SDGs known as non-socioeconomic SDGs are SDG 12, 13, 14, 15 and 17. The first four are *environmental SDGs* while the latter is about partnerships for the goals (Table 1).

2.3 Differentiating countries based on their development levels

Also an algorithm for differentiating countries based on their proximities in DEVI has been provided by Jabbari et al. (2019), which they designated it "Combined Criterion Algorithm," with more or less a statistical method. So they aligned countries with a cluster,

Table 1 The 17 SDGs. All these SDGs indicators have been included in SDG index while the indicators of five mostly non-socioeconomic SDGs have been excluded during construction of DEVI

SDGs		SDG index	DEVI
SDG 1	No poverty	✓	✓
SDG 2	Zero hunger	✓	✓
SDG 3	Good health and well-being	✓	✓
SDG 4	Quality education	✓	✓
SDG 5	Gender equality	✓	✓
SDG 6	Clean water and sanitation	✓	✓
SDG 7	Affordable and clean energy	✓	✓
SDG 8	Decent work and economic growth	✓	✓
SDG 9	Industry, innovation and infrastructure	✓	✓
SDG 10	Reduced inequalities	✓	✓
SDG 11	Sustainable cities and communities	✓	✓
SDG 12	Responsible consumption and production	✓	✖
SDG 13	Climate action	✓	✖
SDG 14	Life below water	✓	✖
SDG 15	Life on land	✓	✖
SDG 16	Peace, Justice and strong institutions	✓	✓
SDG 17	Partnerships for the goals	✓	✖

including all developed countries, consistent with the common practices for developed countries and a number of other clusters that encompass the developing countries. Another advantage in using the concept of proximity rather than equality is to reduce sensitivity of using the DEVI to the process of aggregating indicators as well as statistical data. For details on the criteria for choosing countries refer to Bertelsmann Stiftung & SDSN (2017a), and for indicators that are included in the DEVI refer to Jabbari et al. (2019).

Given these clusters, and the inequality and dispersion of indicators that shaped the DEVI, it can be said that based on the achievements of SDGs, the world population is divided into a number of groups of people and the people of each group have almost the same level of development, and the difference lies only in the name of countries. With the aim of CB allocation in mind, other parameters that differentiate countries may include the indicators under SDG 13 (climate action). These indicators or parameters include those related to their annual carbon emissions and climate change vulnerability as a reflection from their commitments to global climate change.

In short, only two criteria are considered for differentiating people in the world: first, their development levels highlighting the membership of the corresponding clusters in accordance with their DEVI scores, and second their effectiveness in the Climate Action, that is the respective scores in SDG 13. In other words, in this study two distinct individuals are assumed to be the same if and only if they are put in the same cluster, in terms of their country's DEVI score, and their climate action equals. Of course, as mentioned earlier, and as a practical tool, the proximity was replaced by equality at the developmental levels.

2.4 Countries instead of peoples

The ultimate goal of the FCB sharing model presented here is to determine the share of each person from the GCB. Now, due to the two shortcomings, this ultimate ideal will not be possible:

First, lack of individual statistics indicators, for people of the world. This means that SDGs statistics are currently being collected nationwide, with the exception of a few countries that provide statistics for indicators on a smaller scale (state-to-state, etc.).

Second, the sovereignty of the government over the people of their country, that is, the shares assigned to each person, should usually be allocated through a government that governs his country. Indeed, the sovereignty of states does not allow CB share, even individually assigned, reach the people in a way other than the state. Therefore, as a pragmatic way, the goal here is reduced to determine the contribution of each country in GCB.

3 Method for GCB allocation based on Rawlsian Justice

3.1 How to interact with different countries?

From an environmental point of view, it is ideal that each country uses the best available techniques (BAT) in GHG emissions and also follows the best environmental practices (BEP). Expecting developed countries to follow these will not be considered as unfair while applying this ideal to developing countries is seen as unfair by the Rawlsian theory of Justice. This is unfair, derived from the *difference principle*, because it pays no special attention to the least-advantaged members of the community. Also derived from the *fair*

equality of opportunity, it can be an obstacle to the development of developing countries that have low climate action scores (high GHG emission).

Since there is no specific BEP and BAT for all aspects of the country behavior, and the process of determining BEP and BAT has complexity and can be very controversial, therefore, as a pragmatic approach, the behavior of the best country in terms of GHG emissions is considered to be BEP and BAT. In other words, the developed country emission rate which at the same time has the best performance in climate action is considered as BEP and BAT. It is reasonable to attribute BEP to a developed country that has the best climate action. On the other hand, and for developing countries, based on the Rawls theory of Justice, it is fair that they are permitted to emit GHG as far as they have not exceeded the level of the worst country (i.e., the least-advantaged members of society) in terms of climate action among their similar countries.

Although this can be interpreted as a very lenient interaction with developing countries, when developing countries, due to their failure to reach SDGs, still suffer from the non-achievement of BAT, these are the most stringent conditions for CB sharing which will still keep the right to develop for them. This comes from the Rawlsian Justice perspective for the least-advantaged members of community.

3.2 Fair carbon budget (FCB) sharing model

As depicted in Fig. 2, the innovative methodological approach proposed by the authors (FCB) consists of five major steps: (1) collection of existing statistics, (2) construction of composite index for development level, (3) differentiation of countries, (4) application of Rawlsian Justice principles and (5) fair allocation of CB and their comparison with actual emissions from countries (Fig. 2).

The latest available data for GHG emissions including LULCF have been extracted from World Resources Institute WRI (2018), and the estimated population data from the UNPD and all SDGs indicators have been extracted from the SDG index and dashboard report (Bertelsmann Stiftung & SDSN 2017a, b; Sachs et al. 2018). The same method used to formulate the DEVI was also used to formulate SDG 13 of the indicators. This includes rescaling, normality tests, weighting equally and aggregating using the constant elasticity of substitution (CES) function. For more details about this method, refer to Bertelsmann Stiftung & SDSN (2017a).

$$\mathrm{FCB}_i = \begin{cases} \mathrm{GHG@highestSDG13} & \text{for, Developed cluster} \\ \mathrm{GHG@lowestSDG13} & \text{for, Developing clusters} \end{cases} \tag{1}$$

in which the FCBi is the fair budget of each person in the *i*th country. GHG @ highest SDG13 is the total GHG per capita (including LULCF) for the country in the *i*th cluster that has the best performance in terms of climate action (SDG 13), and the GHG @ lowest SDG13 is the total GHG per capita, including LULCF for a country in the *i*th cluster of the country with the worst climate action performance. The overall fair share of each country is determined by its population (Eq. 2).

$$\text{Total FCB}_i = \mathrm{FCB}_i * \mathrm{Popi} \tag{2}$$

in which Popi is the *i*th country population and FCBi is also the FCB for each person in the *i*th country. In other words, after clustering countries based on their proximity with the DEVI, a lexicographic function is first applied to the development level of countries (DEVI scores) and then to their climate action (SDG 13). Subsequently, by applying the

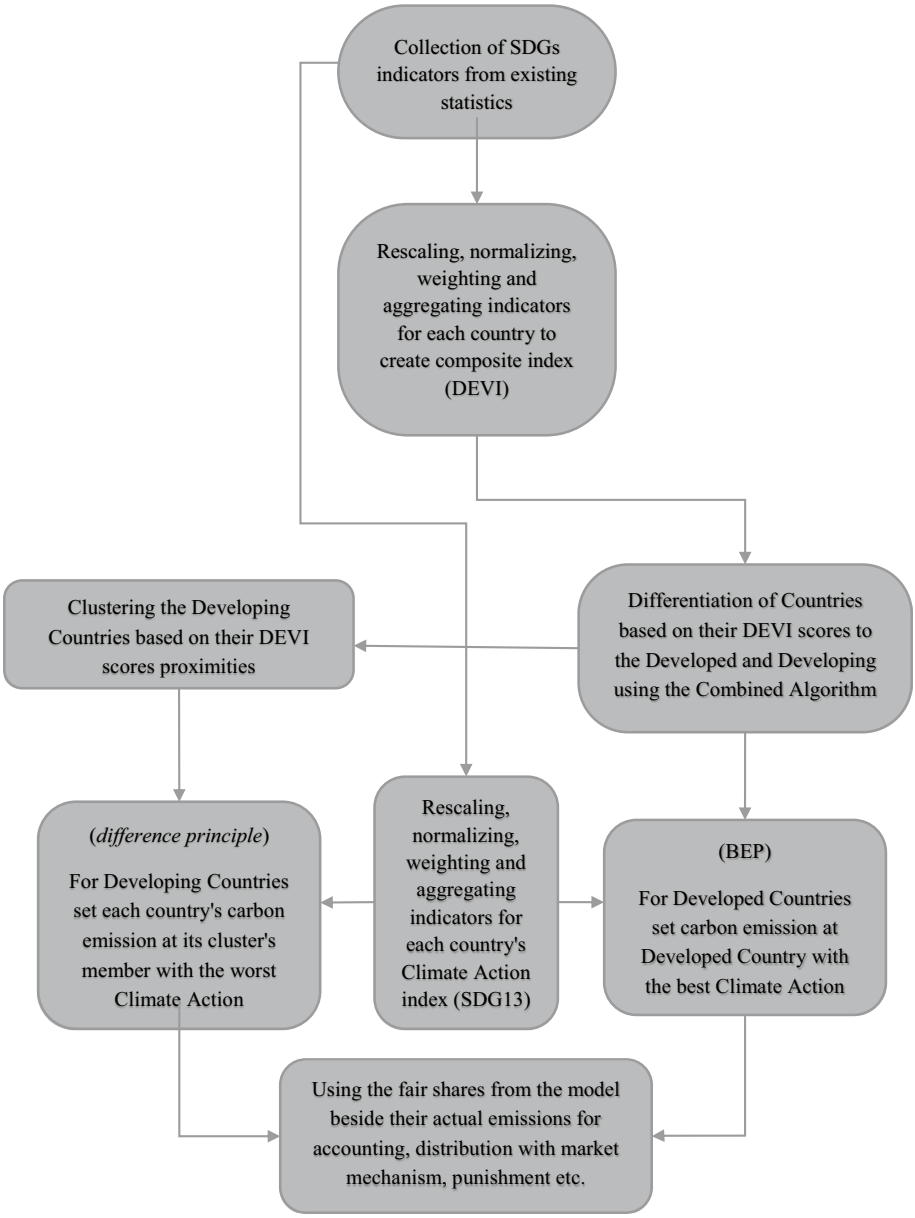

Fig. 2 The fair carbon budget sharing model (FCB)

abovementioned fairness criteria on the ordered list of countries (lexicographic output), the share of each country is determined.

4 Results and discussion on applying FCB for 2017

Eight clusters of countries are identified as the result of applying a combined criterion algorithm to DEVI scores for 157 UN parties for 2017. The developed cluster includes 43 countries, and 114 countries were in the 7 developing country clusters with proximity in development performances (Jabbarieta et al. 2019). For instance, the results of three clusters including the developed countries and the two first clusters of the developing countries have been presented below. The *best* country among the developed countries in terms of climate action is Hungary with a total GHG emissions per capita of 6.275 kt (including LULUCF), hence, according to FCB, all countries in the developed cluster (consisting of all developed countries) have the right to emit a maximum of 6.275 kilotons per capita for 2017.

For the first cluster of the developing countries (based on the DEVI when sorted out in a lowering order), which includes 27 countries, Mauritius had the *worst* climate action with total GHG emissions per capita of 4.607 kt. Therefore, other members of this cluster will have the right to emit a maximum of 4.607 kilotons per capita for 2017. As another example, the *worst* climate action of the second developing cluster belongs to Guyana. Its total GHG emissions per capita was 32.106 kt, then the people of Guyana and the peoples of all the other members of this cluster will have the right to emit a maximum of 32.106 kt of GHG. This approach is similarly applicable to all the reaming five developing clusters.

Figure 3 shows the actual emissions of four major countries in carbon emissions by 2017 statistics. All their actual emission levels are higher than fairly determined shares, and except for India, this is a sharp difference, signifies that the emission figures deviate

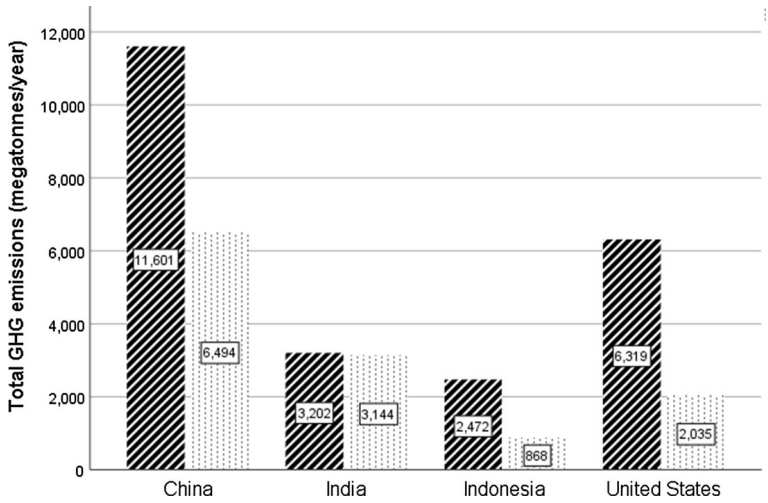

Fig. 3 Comparison of the annual shares of countries with more than 5% contribution on global emissions of greenhouse gases. The darker columns are the actual emission levels for 2014, and the lighter columns are the fair shares for these countries, which are provided by the fair carbon budget sharing (FCB)

from the determined equitable values. Four countries are also important because they are major pollutants, accounting for around half of global GHG emissions in 2014.

Since the SDG report of 2017 covers the indicators value for 2016, the GHG emissions statistics are for 2014. These 2 years are considered as negligible priority. The multidimensional nature of DEVI, as well as the growth rate of the GHG emissions, makes this assumption reasonable (Hansen and Sato 2004).

4.1 Comparison between FCB and Egalitarian shares

Since according to the egalitarian approach, the relative percentage of a country's population reflects its share from the GCB, it can also be seen that while the proportionate shares of India, Indonesia and the USA are higher than their fair shares (from the FCB), but for China, the FCB share is above the egalitarian share. This is an example of differences between the shares of countries from the GCB in this approach and the other approaches.

As noted earlier, the other approaches to GCB allocation are accused of supporting particular groups of countries. For example, since the population of nations is the most important criterion in the egalitarian approach to CB allocation, strong support of heavily populated countries for this approach is expected. However, as shown, the FCB does not foresee any specific trend in country shares, and this can be a remedy for the allegation of bias with this approach.

Figure 4 shows the relative differences between the shares from FCB and egalitarian approach for some countries. It can be seen that many industrialized countries and also some oil producer countries are on the right side of the chart (negative values) which means that they have less FCB shares in comparison with egalitarian shares. But FCB in this case also does not foresee any specific trend in country shares, for example Iran and Nigeria as two oil producers are on the left side (positive values) of the chart. Also it can be seen that the China is on the left side while India is on the right side of the chart (as two heavily populated countries).

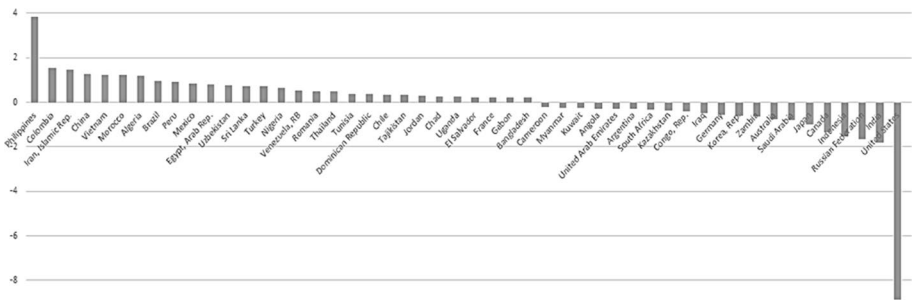

Fig. 4 Relative differences between the FCB shares and egalitarian shares for countries. Countries with higher egalitarian shares compared with their FCB shares are at the left side of the chart (for example China) and countries with higher egalitarian compared with their FCB shares (for example India and the USA) are at the right side. For a better presentation, countries with less than 20% of differences have been excluded from this chart. Negative values mean the FCB share is higher than egalitarian share, vice versa for positive values

4.2 Examining the balance in the FCB determined shares

The fair shares assigned to countries by FCB have been found to be higher for some countries than their actual annual emissions and were lower for others. Therefore, in an accounting system, countries have a range of debts and credits in this comparison. A prestigious tool in these cases is the use of a market-based mechanism for the exchanges of these amounts of debts and credits. The unit price and other details will be determined after the formation of the market and as a result of actual exchanges. However, the point that can be useful at the start of the formation of the market is the existence of a balance between the sum of the debts and credits of the countries. In the fair share of CB presented here, no manipulation has been made to balance the debts and credits, and there have not been any adjustments in this regard (in the final mechanism, the existence of such manipulations is not unexpected, and some settings can be adjusted for this purpose). Nevertheless, and fortunately, for the results of 2017, there was a significant balance between the amount of debts and credits of countries in the actual emission with the amount set by the FCB (with a significant figure in gigatons). As previously mentioned, this can be useful in establishing a market.

Discussing the unit price of emissions before market formation and exchange is not recommended. Even though the countries are expected to develop, there is no prediction of the total amount of debt or credit and how it changes. This is due to lack of information on the behavior of countries in an interactive and competitive environment, and in line with their incentives in the future. In these cases, some scenarios about the future are presented based on the game theory and the like, the discussion of which is beyond the scope of the current study.

4.3 A comparison between the fair shares of CB in years 2017 and 2018

According to the results of clustering based on the DEVI of countries for 2018, Argentina, Cuba, Greece, Kazakhstan and Uruguay were excluded of the list of 43 developed countries in 2017. On the other hand, Moldova and Serbia have been added to this list (Jabbari et al. 2019).

Due to different criteria for CB allocation for the developed and developing countries, significant changes were expected in the budgets derived from the FCB for these seven countries (Fig. 5).

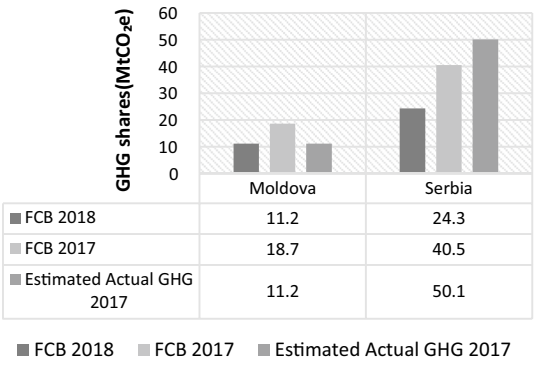

Fig. 5 The fair carbon budget (FCB) for the two new members of the developed countries, and their actual emissions for 2017 and 2018. The graph for 2018 shows an increase in the FCB share for Moldova and also a decrease for Serbia compared to 2017

The climate action aggregated score (SDG 13 score) for Moldova in 2018 was 95.8, which is the best climate action between developed countries (this is also one of the highest scores in the world). Subsequently, based on what is expected from the FCB benchmark, the Moldova GHG emissions are considered as the acceptable level for the developed countries cluster. The accounting of countries shares is beyond the scope of this study due to their annual changes, but it needs to be emphasized. However, the dynamic nature of the proposed model for CB share in this study (the FCB), and as a result, the possibility of a dramatic change in the annual share of countries, give less importance to the focus on further analyzes in the quantitative value of annual shares.

5 Conclusion

The existing and well-known GCB allocation approaches, namely, the egalitarianism, the responsibility-based and the right/capability-based, have fully been examined. These three approaches generally suffer from a number of weaknesses when pursuing Justice, e.g., for the egalitarianism, *firstly,* Justice has been defined as equality and countries different circumstances and capabilities have been ignored. *Secondly,* the right of countries to development has not been recognized and *finally*, it would be biased in favor of the most populous countries. For the responsibility-based approach (which is based on PPP), not only the Right to Development has not been appreciated for countries, but instead the Right to punish others has been recognized! Also, this approach is very retrospective in the sense that it merely puts emphasis on the historical cumulative GHGs emissions of countries regardless of their present and future behaviors. Commonly shared weakness between the aforementioned two approaches is that the promotion of Justice at national level, which stems from the spirit of the SDGs, particularly for goals 3, 4, 5 and 10, is not pursued. *Finally*, for the right/capability-based approach, the high rate of controversy during the process of selecting right/capabilities and weighting them is assessed to be the main drawback.

In order to overcome the abovementioned weaknesses, the Rawls theory of Justice has been adopted as the basis for GCB allocation. Also, (1) the amount of countries' achievements in SDGs and (2) their climate action performance, have been determined as the two main aspects of differences between countries. Additionally, a very comprehensive index (DEVI) to evaluate countries' SDGs achievements has been used, which eliminates oversimplification threats to the differences in countries in the assessment.

The fair share model for GCB allocation between the countries of the world has been presented, known as the FCB model. This model attempts to be fairer in GCB allocation by means of, *firstly*, taking sides with countries, solely based on Justice and in accordance with their development levels. This means that it gives the most benefit to the least developed countries (Rawlsian *difference principle).*S*econdly*, by recognizing the right to development for all countries (Rawlsian *fair equality of opportunity*) and at the same time pursuing the best environmental practices (BEP) by the developed countries in order to promote their mitigation goals, it boosts their ambitions. *Finally*, promotion of Justice at national and international levels by pursuing SDGs, significantly results in a fairer GCB allocation which is in full compliance with the 2015 Climate Paris Agreement along with the 2030 agenda for sustainable development.

Following introduction of the FCB, the fair share of countries was determined for 2017 and 2018 as expected, the results of applying such a fair share model showed a significant difference with the shares from egalitarianism and also actual emission levels of countries.

In 2017, for the three major world pollutants, China, the USA and India, 44%, 68% and 2% reduction in fair share compared with actual emission values (including LULUCF) were identified, respectively. In the same year, for USA and India, respectively, more than 100% and 800% decrease in fair share were observed compared with the egalitarian approach, while, for the China, two were almost equal.

Due to changes in countries development levels for 2018 and application of the FCB, changes in the fair share of all countries were observed compared to 2017. This year, two newcomers to the list of developed countries, i.e., Moldova and Serbia, have witnessed a 40% decline in fair share compared to 2017. In order to transform the fair share method presented in this study into a real-world solution, some additional steps should be taken. Accounting on debt and credit of countries is one of these steps. Then, using a mechanism such as a market, one can provide an infrastructure for exchanging these credits and debt of countries, which can be a duplicate incentive for development and also reducing GHG emissions. In the method presented in this study, without adopting any regulation, an acceptable balance (or a significant gigaton value) between debt and credits of countries for fair shares in 2017 was observed. This can be beneficial at the inauguration of the market. In this study, as a purely Justice-oriented approach, no action was taken to create a kind of adjustment or integration with mitigation scenarios, which could be the subject of future studies.

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