Fairness in NDCs: comparing mitigation efforts from an equity perspective

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1. Introduction

The debate for the distribution of collective climate change objectives inevitably raises issues related to ethics and responsibility. Along with efficiency, equity is indeed a key element of an effective international climate policy agreement (Carraro, 2000; Müller, 2001). By involving value judgement and national interests, the matter represents a point of disagreement among countries that has been accompanying the whole UNFCCC process since the beginning of climate negotiations in the 1990s. Although UNFCCC Parties agreed on the Common But Differentiated Responsibilities and Respective Capabilities (CBDR-RC) as the guiding principle to equitably share commitments, there is no a unique interpretation of how it should implemented practically.

With the introduction of the Nationally Determined Contributions (NDCs) and the new bottom-up approach to the definition of emission reductions launched with the Paris Agreement, the issue gained even more relevance. In its article 2, the Paris Agreement confirms its purpose of implementing the commitments in order "to reflect equity and the principle of common but differentiated responsibilities and respective capabilities, in the light of different national circumstances" (UNFCCC, 2015). However, each country implicitly or explicitly includes an own interpretation of how the burden should be fairly distributed or justifies why the proposed contribution should be considered equitable. Indeed, single countries strongly differ in terms of current and historical emission levels, vulnerability to climate impacts and economic capabilities. These differences are fully reflected in their NDCs. According to the objectives of the Paris Agreement, however, the sum of the self-determined domestic emission reduction contributions needs to be consistent with the emissions pathway required to limit global temperature increase to 2°C by 2100.

Against this background, this essay aims to combine these two aspects (equity and stringency) to assess the mitigation component of the NDCs provided by different countries. It enriches the emerging literature aimed at providing a benchmark for the evaluation of the NDCs mitigation effort including also equity principles, and going beyond a quantitative assessment of the emission required to stay under the 2° C target. More broadly, our findings will be able to inform the UNFCCC negotiating debate within

the first facilitative dialogue in 2018, which will be followed by the first global stocktake to take place in 2023.

2. Implementing equity principles in the climate change debate

The academic literature discussing equity in the context of environmental governance is vast and interdisciplinary, encompassing philosophy, economics, political and social sciences.

Overall, the research community agrees quite unanimously in considering the equity principle essential for the establishment of any global climate change regime and its effective sustenance. Although the inherent complexity and fuzziness of the concept make its operationalization elusive (Aslam, 2002; Fleurbaey, et al., 2014; Howard, et al., 2016) it is recognized that greater cooperation is likely to emerge if the main elements of the climate change regime, including the policy process, implementation decision and outcome, are perceived to be fair (Morrisette & Plantinga, 1991; Kverndokk & Rose, 2008; Winkler & Beaumont, 2010).

Against this background, a consensus emerged on the need to find plausible mechanisms to convert abstract principles into a form to be used in international climate negotiations and that could possibly be easily applicable and transparent (Bretschger & Zue, 2013). In particular, through effort-sharing approaches the costs (and benefits) associated to mitigation actions can be distributed differently across countries without affecting the overall efficiency of the global abatement effort (Edenhofer, et al., 2014). However, in the real world countries have very different views of what can be deemed equitable, being the perspective strongly influenced by single country's self-interest. Some have, indeed, argued that emphasizing equity in climate negotiations can raise a trade-off with efficiency and encourage countries to exploit ethical justifications in order to avoid stringent commitments (Keohane, 2016).

Among the early studies that contributed to the understanding of the issue, Rose (1992) provides a comprehensive overview of various principles for sharing costs and benefits of climate change and discusses their transformation into operational rules for distributing tradeable greenhouse gas emission permits. In particular, the author classifies different equity criteria into three major categories: allocation-based, outcome-based and process-based, which have become the most-commonly used categorization in the literature on fairness in climate change policy (Rose, 1992). The distinction refers to the different rules applied to decide the initial allocation of emission permits (e.g. proportional to countries, population or wealth), the final outcome of the implementation of the policy instruments (e.g., how the net impact on welfare is shared), or to the process of allocating or trading permits (e.g. stable negotiations process or fair market rules). As noticed by Müller (2001), however, allocating emission quotas and sharing out the burden of climate change actions are different from a moral perspective. If the former includes some assumption on the proportionality, the outcome of the latter can indeed be independent from the origin of the costs and benefits to be distributed (Müller, 2001).

Building on Rose's analysis, many studies have reviewed the alternative equity principles advanced for defining common but differentiated responsibilities, mainly focusing on the impact of different

approaches on the distribution of emission allowances at a global or regional level (Ringius, et al., 1999; Clarke, et al., 2014; Robiou du Pont, et al., 2017) or assessing the implications of each principle on social welfare (Cazorla & Toman, 2000; Mattoo & Subramanian, 2012; Rapauch, et al., 2014)

For the purpose of this essay, we focus on recent studies that used equity principles and indicators to analyze the first category, namely the different effort-sharing approaches to define the initial allocation of emissions. It should be noted that academic contributions go hand in hand with the developments in the UNFCCC negotiations. With the objective to analyse one of the novelties in the Kyoto Protocol's architecture, earlier studies mainly framed their research questions in terms of finding an equitable distribution of tradable emission permits, which would be able to provide flexibility and reduce the cost of the collective target's achievement (Rose, 1992; Ott & Sachs, 2000). Conversely, more recent studies largely aim at understanding what would be an ideal fair distribution of future abatement quotas between developed and developing country groups or at comparing the different contributions offered by national governments in the context of the more recent bottom-up approaches adopted in the post-Kyoto international negotiations (Tavoni, et al., 2013). In this more recent approach, the allocation of emissions is therefore often linked to a carbon budget, which is the area under a GHG emissions trajectory consistent with the limits on cumulative emissions estimated to avoid a certain level of global mean surface temperature rise (Allwood, et al., 2014).

A recent review, conducted by Höhne et al. (2014), recalled also in the IPCC's fifth Assessment report (Clarke, et al., 2014), groups such literature into seven categories. Overall, three basic equity principles emerge as the most frequently applied: i) *equality*, based on individual rights and asserting that each individual has the same right to pollute or to be protected from pollution; ii) *responsibility*, which claims that a greater mitigation effort should be imposed to those who have contributed the most to climate change (polluter pays principle, historical responsibility); iii) *capacity*, suggesting that each country's contribution should be proportional to its ability to bear the costs of mitigation (ability to pay) and should not prevent a legitimate right to development (needs, right to development). A fourth category is represented by the *cost-effectiveness*, which allocates emissions according to mitigation potential or other costs–effectiveness rules (equal marginal abatement costs, triptych approach). The remaining three categories are composed by a mix of the above-mentioned principles. In particular, an interesting approach combines the equality and responsibility principles to compute *equal cumulative per capita emissions* and therefore weigh historical emissions of countries according to their population; other authors prefer a *responsibility, capability, and need*, which includes the principles of responsibility and capability plus an indicator of the need for sustainable development; finally, the so-called *staged approaches* provide a compromise over several principles that are applied to different countries in various stages (Höhne, et al., 2014). Overall, the authors find that what matters the most is how the equity principles are implemented. Parameters, data, and methods used can lead to very different results also within the same principle category. As a general rule, the group of countries part of the OECD in 1990s are required deep cuts in emissions (either by 1990 and 2010 levels) under all categories,

especially for the more stringent stabilization objectives. They would get relatively lower allocation if the emissions are shared according to the *responsibility, capability and need* principle as well as to the *equal per capita cumulative emissions* compared to other approaches. On the contrary, for the same categories the Asiatic region would be allowed to increase its emissions the most, especially South Asian countries. Africa and Middle East are more favoured respectively by the *equality* and *capability* principles. Allocation for Latin America would be lower than either 1990 or 2010 levels over all effort-sharing categories, but particularly for *equal per capita cumulative emissions* and *equality* categories (Höhne, et al., 2014).

More recent research efforts started to focus on the Nationally Determined Contributions (NDCs) submitted by more than 190 UNFCCC Parties under the Paris Agreement. Besides those focusing on the consistency of the proposed mitigation actions with long-term temperature targets affirmed by the Paris Agreement (Rogelj, et al., 2016), some studies apply the effort-sharing methodologies described above to assess NDCs both in terms of ambitiousness and fairness.

In particular, Peters et al. (2015) allocate remaining emissions to keep global warming below 2 °C by 2100 according to two approaches: an 'equity' approach based on population, and an 'inertia' approach based on current shares of global emissions. By comparing these results with the emissions pathway resulting from the (I)NDCs of the three major emitters (EU, US and China) they find that the EU and US pledges are close to the 2°C target only under the inertia approach. Interestingly, under current Paris Agreement's contributions, the US would exceed its equity quota already in 2020, China in 2027 and the EU in 2032. Clearly an effort sharing based on the equity approach would require more stringent targets (Peters, et al., 2015).

Robiou du Pont et al. (2016) come to very similar conclusions. They quantify the emission allocation which would be consistent with five of the above-mentioned equity principles and compare them to the mitigation component of (I)NDCs submitted by a set of countries and regions. Their methodology aligns aggregate emission allocations with different cost-optimal global emissions scenarios consistent with the 1.5 and 2°C long-term limits. Overall, they show that the aggregate emission reduction tabled by major economies is already 39 percentage points above their averaged allocation under a 2°C scenario with a pre-2020 peak, whereas the aggregated (I)NDCs of the other economies fall short only by 8 percentage points. Focusing on major emitters, China's current target falls outside the range estimated for any of the five equity approaches. The US' and the EU's NDCs are in line with the allocation based on current emission ratios (*staged approach*) and within the range under the *responsibility, capability, need* principle. Both the EU's and India's mitigation objectives are coherent with the *equality* approach, with the latter also consistent with the equal cumulative per capita (including the '1.5°C pre2020peak' scenario). At regional level, most developing countries' conditional NDCs are more ambitious than the average of the five equity approaches under the 2°C goal, but only Middle East and Africa's aggregated (I)NDCs are consistent with some 1.5° C allocations. According to all equity approaches, except for the

current emission ratios, OECD countries should further decrease their emissions with respect to what announced in their NDCs. The NDCs of transition economies are not consistent with the *responsibility, capability and need* principle as well as the *current emission ratios*, but they comply with the *equal cumulative per capita emissions* (Robiou du Pont, et al., 2017). In an analogous exercise, Pan et al. (2017) assess the NDCs' mitigation objectives of eight among major emitting countries against six equity principles of effort-sharing. Also in this case, the study highlights the need for most countries to increase the ambition of their 2030 emissions reduction policy. A particularly large emission gap characterizes Russian NDC, which is estimated will be almost the double of its maximum 2030 allowances (available under the *responsibility, capability and need* approach). An exception to the general rule is India, whose conditional target falls within the range of all the selected approaches under a 2°C scenario and the majority of them under a 1.5°C. The upper bound of South Africa's mitigation contribution is consistent with the *responsibility* and the *responsibility, capability and need* principles. (Pan, et al., 2017).

The topic raised a relevant debate also outside the pure academic domain. Interesting analytical contributions are indeed offered also among think tanks and international non-governmental organizations. Among the most relevant contributions, Climate Action Tracker evaluates the coherence of the mitigation plans in the (I)NDCs and a set of indicators including a fair effort sharing allocation budget obtained through the aggregation of estimate ranges coming from pertinent studies (Climate Action Tracker, 2016). In advance for COP21, also Oxfam International (2015) and the French press agency Novethic (2015) released their own indexes of (I)NDCs' fairness, which rate countries' target according an equitable share in line with the 2°C threshold and based on *responsibility* and *capacity* principles. Even though some differences, both studies confirm that the pledges of developed countries and major emitters are far from being a fair contribution, especially for Russia. According to Oxfam (2015), Japan's effort averages a tenth of a fair distribution, and the (I)NDCs of the EU and the US are approximately a fifth of their estimated fair portion. Brazil represents an exception among emerging economies, covering about two thirds of its equitable part of the global effort, whereas the targets proposed by India is approximately in line with its fair share (Oxfam, 2015). By contrast, in both assessments developing countries' contribution generally corresponds to their fair share or even exceed it.

3. Methods

Our assessment consists in a comparison of the cumulative emissions resulting in the period 2015 - 2030 from the implementation of the mitigation targets included in the NDCs against the cumulative emissions for the same period consistent with the path for the <2°C, allocated according three equity indicators. The analysis is conducted at the global level, covering 45 countries and regional aggregations. It is divided into the following steps:

3.1 The Global Carbon Budget

A crucial element of the analysis is the remaining global carbon budget (CB_G) for the period 2015-2030. As mentioned above, the carbon budget is computed as the area under the emission trajectory in line with a specific temperature objective (Allwood, et al., 2014). As we consider the goal to keep the increase in average temperature below 2°C by 2100, we use the global cumulative emissions for the period 2015-2030 consistent with this objective. GHG emission (excluding land use) estimates are provided by the IPCC AR5 database (Kriegler, et al., 2013). We select the stabilization scenarios consistent with the long-term climate objective of both 450 and 500 ppm CO2-eq projected by seven different energy-economy and integrated assessment models. These scenarios are associated with a likely (probability > 70%) achievement of the 2°C target in 2100 (Kriegler, et al., 2013). As the dataset provides emissions in 5-year intervals we interpolate them in order to have annual emissions. The resulting median of world's annual emission levels for the years 2015 to 2030 are then summed up to obtain the cumulative emissions that compose the global carbon budget:

3.2 Equity-based indicators

In order to have a benchmark for the evaluation of the NDCs emission levels, the carbon budget for the period 2015 – 2030 obtained from step 1 is then distributed according to three equity criteria.

In particular, considering the purposes of the article 2 of the Paris Agreement we selected the following equity principles:

1. Historical responsibility (HR);
2. Economic capability (EC);
3. Equal individual rights (ER).

As already mentioned, the methodologies reported in the literature to build these indicators are many and each of them implies different levels of detail. We opt for those that represent feasible options for countries (excluding therefore results implying immediate negative emissions), that are relatively simple to use, and that allow for transparency.

3.2.1 Historical responsibility

The proposal to share emissions using an indicator of historical responsibility was firstly advanced by the Brazilian delegation in 1997 during the Kyoto Protocol's consultations (UNFCCC, 1997). Since then, a vast debate has followed both in negotiations and academia to understand what is the best way to operationalize the principle and what are the implications of applying such an approach (Höhne & Blok, 2005). In particular, the assumptions that may influence the results are many and they involve an interpretation of the historical responsibility concept. Among them, the choice of the timeframe is certainly one of the most important along with the source and measure of emissions. As for the first, the debate has been mainly divided between those affirming that countries responsible for climate change should bear the costs of solving the problem (as stated by the Polluter Pays Principle) (UNFCCC, 1997; Neumayer, 2000; Botzen, et al., 2008) and those suggesting that countries should not be hold responsible

of something they were unaware of (Grubb, et al., 1992; Grubb, 1995; Singer, 2002; Miller, 2009). The practical consequence is that in the first case historical responsibilities date back to time of the industrial revolutions, in the other case to much later, when the first IPCC's assessment report has been published or at the beginning of the UNFCCC process. It is straightforward that the first approach will put a higher burden to the developed countries whereas in the second the contribution of emerging economies will be more relevant. Another important issue to take in to account are the emission sources, and in particular those from land-use and forestry. Exclusion of these significant CO_2 sources would give less relevance to the contribution of countries where the deforestation rate is high. A further aspect regards how the contribution is expressed: in terms of cumulated emissions, global temperature increase or radiative forcing. In addition to all these aspects, the measure of cumulative emissions is often equalized, according to population or GDP, in order to reflect the size of countries (Neumayer, 2000). Only few studies, however, fully describes how they implement this principle (Matthews, et al., 2014).

For the allocation of the Carbon Budget according to our historical responsibility indicator (CB_{HR}) we use the cumulative emissions 1850 – 2014 of each country or region to first compute a Historical Responsibility Share (HRS). We then use the inverse of this share to assign each country an inversely proportional share of the global carbon budget (CB_G).

Including more recent years to the considered timeframe allow us to take into account also the growing "responsibility" of current emerging economies. Historical emissions are derived from the PRIMAP database, which provides a comprehensive set of national greenhouse gas emission pathways with worldwide coverage (Gütschow, et al., 2017). To compare our estimates with the emission levels deriving from the NDCs assessment we do not include historical land-use, land cover change and forestry (LULUCF) emissions.

3.2.2 Economic capability

The intuition behind the economic capability approach derives from the interpretation of the CBDR-RC principle in a way that assigns a larger share of the emission reduction to countries that can afford the cost. On the contrary the poorest, and usually most vulnerable, countries are still free to prioritize their development objectives. Used also in the Kyoto Protocol to differentiate commitments between Annex I and non-Annex I countries, the implementation of this principle usually relies on a quantified measure of wealth or wellbeing, including the Gross Domestic Product (GDP) per capita or the human development index (Jacoby, et al., 2010; Tavoni, et al., 2013; Winkler, et al., 2013).

In order to account for the current most affluent countries to take the lead and bear a higher share of mitigation costs, we use the 2015 national GDP (PPP) per capita (International Monetary Fund, 2017) as a measure to allocate them calculating an inversely proportional share ($IECS_r$) of the global Carbon Budget for the period 2015 – 2030 (CB_G).

3.2.3 Equal individual rights

The third of our equity indicators is based on the assumption that available allowances should be equally shared among the global population. A key approach is the "Contraction and Convergence" concept. Presented as a global solution to climate change that integrates precaution, equity and efficiency, it was conceived by the Global Commons Institute (GCI) (Meyer, 2000) since the mid 90's in several political fora. This plan suggests that global CO_2 emissions significantly decrease (contraction) up to an agreed target in a given date and each year's emission budget is allocated in order to achieve equal per capita emissions across world's countries (convergence). The concept has been since then further refined, developing various approaches to distribute the available carbon budget on per capita basis (Singer, 2002; Chakravarty, et al., 2009).

To this purpose, we build on Singer (2002) and estimate an equal per capita emission quota by using the ratio between the emissions budget for 2015-2030 consistent with the pathway limiting warming to below 2°C by 2100 (CB_G) and the summation of global population in the same period (SSP2 scenario as for O'Neill, et al., 2017).

3.2.4 Combining the indicators

Finally, the three indicators are combined in order to have a single carbon budget that takes into account all the dimensions considered. Since the object of our analysis is a homogeneous divisible good, such as the global carbon budget, and it is very unlikely that countries agree on one of our candidate equity-based indicators, an acceptable compromise may be to compute a new distribution obtained by aggregating the emission levels associated to our three different indicators.

We use two methods to accomplish this task. The first is a simply averaged combination (CB_A), justified by the fact the CBDR-RC principle does not specify how responsibilities and capabilities should be weighted.

The second aggregation method relies on a population-based voting approach as proposed by Müller (2001) in his global preference score procedure. According to this method, each country expresses its preference for one of the options (the one which allocates the largest amount of carbon budget emissions) that is then multiplied by the number of people it represents (Müller, 2001). This sort of 'demographic weights' for each candidate option (w_{HR}, w_{EC}, w_{ER}) allows to include also a dimension of representational equity in the definition of the carbon budget (CB_{Dr}).

We use population data for the year 2015 (World Bank, 2017). The distribution of emissions linked to the *equal individual rights* approach received the highest scores, with 85% of world population preferences. The *economic capability* and *historical responsibility* follow, chosen by 9 and 7% of global population respectively. The weights are computed accordingly (Table 1).

Table 1: Population-based voting approach: results and assigned weights

Preferred option	HR	EC	ER
Population	500,850,535	621,746,035	6,186,218,054
Weights (w)	0.07	0.09	0.85

3.3 Emissions reduction in the NDCs

The emission levels 2015-2030 resulting from the NDCs submitted by the selected countries are finally estimated. We run a modelling exercise, using the conditional mitigation objectives stated in the NDCs. The emissions in 2030 are computed by using data from CAIT (WRI 2016) for countries committing to an emission reduction with respect to a base year, whereas the SSP2 baseline scenario is used as a reference when the reduction is relative to the BAU scenario (O'Neill, et al., 2017).

We perform our modelling exercise with the recursive dynamic Computable General Equilibrium model ICES (Inter-temporal Computable Equilibrium System) (Eboli, et al., 2010; Parrado & De Cian, 2014, see Appendix I for further details).

4. Results

The main results of the equity-based indicators are summarized in the figures below. In particular, Figure 1 illustrates the emission debt (positive difference) or credit (negative difference) that countries have for the period 2015-2030 when their NDCs' emissions are compared with the budgets consistent with the 2°C limit and allocated according to each one of our ideal equity indicators. China, United States and Europe have the highest emissions debt for all the three categories. In all the three cases the gap generated when the criteria to distribute emissions allocation are *historical responsibility* and *economic capability* is approximately at the same level, whereas the emissions allocated taking into account the *equal individual rights* would allow them to emit a bit more by 2030. Other developed countries show a gap in all three approaches, even though the size is lower. These include the Middle East and North African region (RoMENA), where GDP and historical emissions have the major impact, followed by Russia, Japan, and Canada.

At the opposite side of the picture there are the less developed countries, whose NDC's are well below what they would be allowed to emit according our equitable distributions of carbon budget. In particular, Ghana, Uganda, Bolivia, Mozambique, Kenya, and Chile, have the largest emissions credit in terms of *historical responsibility*. If the *economic capability* is used as a benchmark, Mozambique, Ethiopia and Uganda have the widest remaining credit. Interestingly, India and is the only country among major emitters to show a credit in one of the allocation criteria. Specifically, Indian emission intensity reduction objective is more ambitious than the allocation according to equal per capita emissions.

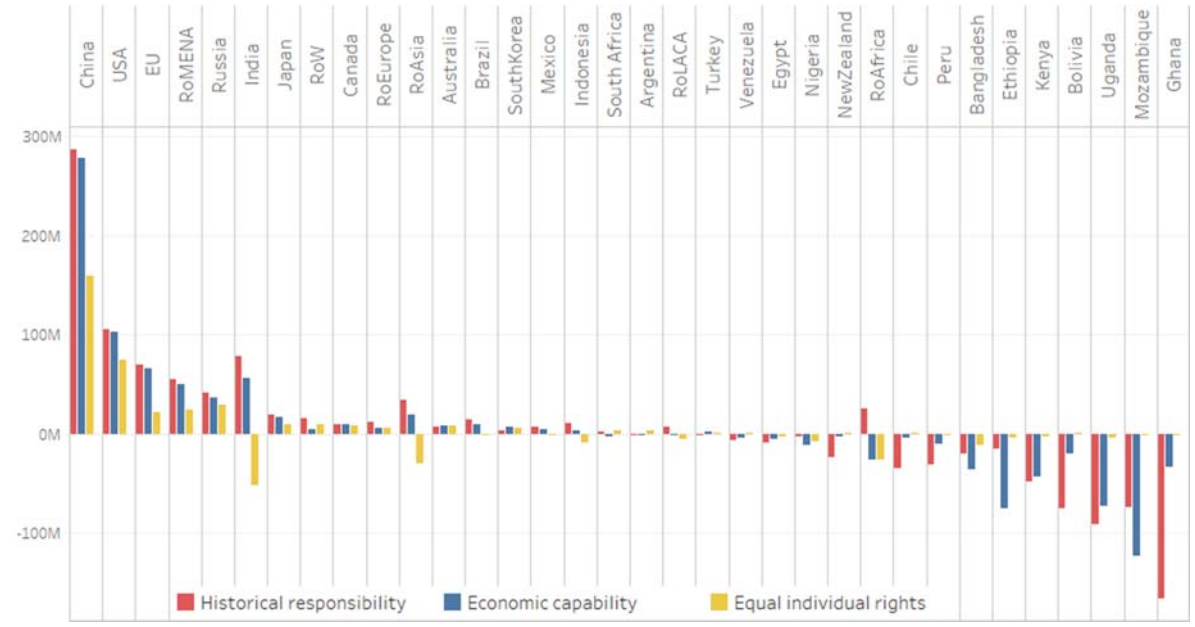

Figure 1: Difference between 2015 – 2030 NDCs emissions and equity-based allocation approaches (cumulative GHG, excl. LULUCF).

When the individual carbon budgets derived from the three approaches are aggregated in one single allocation, the results are strongly influenced by the chosen methodology (Figure 2). Overall, countries that receive a broader share of emissions under the *equal individual rights* approach are more favoured by the population-weighted voting method, which in some circumstances manages to lead to opposite results compared to the averaged aggregation.

Figure 2: Difference between 2015 – 2030 NDCs emissions and aggregated equity-based carbon budgets (cumulative GHG, excl. LULUCF)

This is the case of India, RoAsia, Indonesia and the Rest of Latin American countries, which show an emission debt in the case of the averaged carbon budget (CB_A) and a carbon credit when the demographic weights (CB_D) are applied.

The reduction objectives of Turkey and Brazil are in line with our ideal equity-based benchmarks aggregated respectively using the average and the population voting approach. Overall, China, United States, the EU, the MENA region and Russia, are expected to run out their equitable allocation well before 2030, under both aggregation approaches. The sum of their NDC emissions represents alone 80% of the total available budget to keep the global temperature increase below 2°C. On the contrary, the carbon credit of less developed countries results wider under the averaged aggregation mainly because of the greater relevance this method gives to both *economic capability and historical responsibility* approaches.

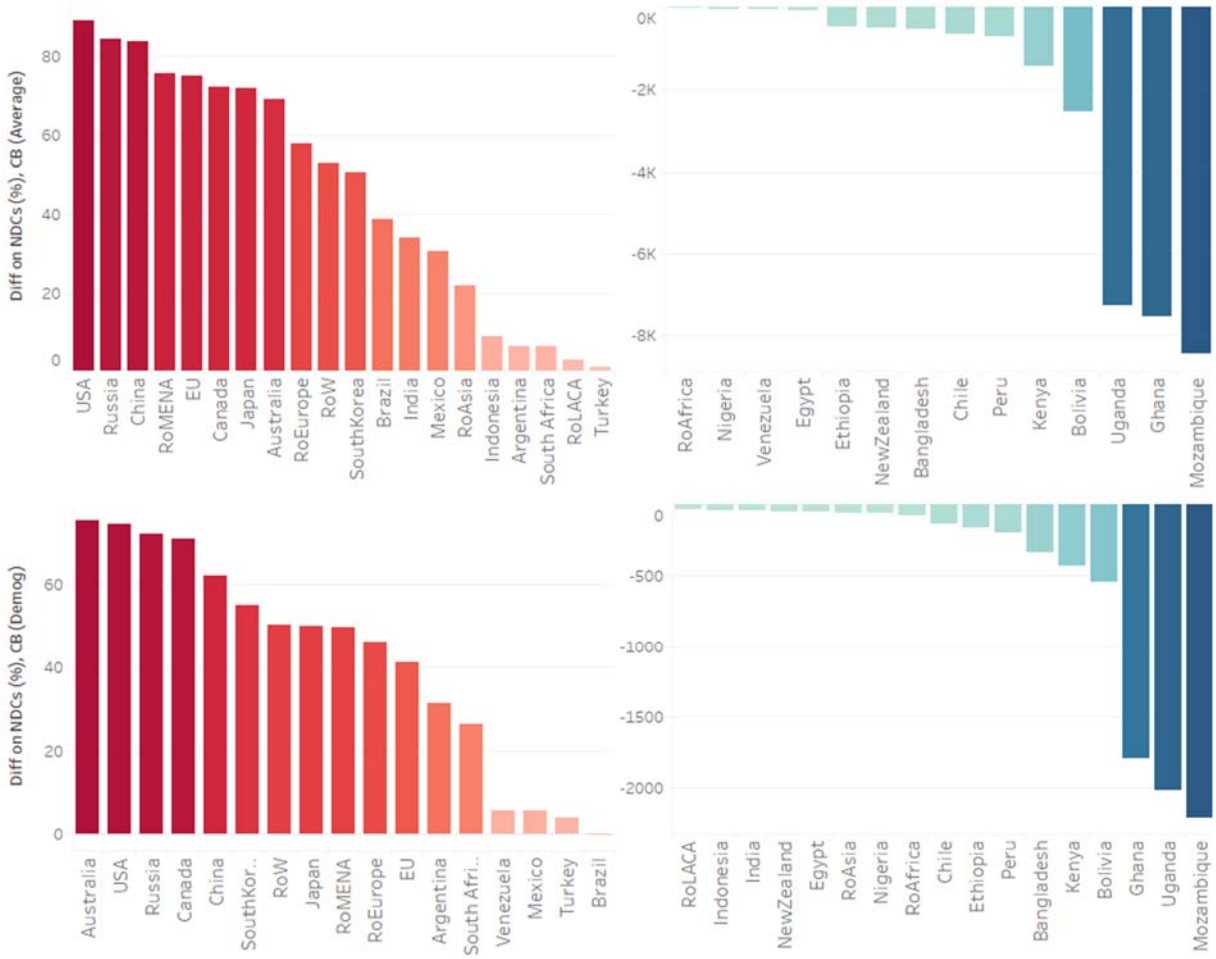

Figure 3: Difference (%) between NDC cumulative emissions and averaged CB (top panel) or demographic weighted CB (bottom panel)

As showed by the Figure 3, which reports the difference in percentage terms between the cumulative emissions projected under the NDCs and our combined equitable carbon budgets, the US should further increase the ambition of their NDC by 90% (CB_a) – 75% (CB_D) whereas Russia and China by about

85% if they would like to match the averaged equity allocation (CB_A) or 72 and 62% in the case of the weighted allocation (CB_D). In other words, the emissions that US, Russia and China plan to release in their NDCs are respectively in the range of about 9-4, 6.5-3.5, and 6-2.5 times higher than their equitable allocations. Interestingly, the countries that experience a relevant difference in adopting one aggregation approach than the other are India, whose NDC results 43% lower than it should be according to our population weighted carbon budget (CB_D)and 34% higher if the average aggregation (CB_A) is used; the RoAsia region, that similarly shows a 22% surplus respect to their CB_A and, on the contrary, a 58% credit under the CB_D; and Brazil, whose CB_D distribution is perfectly in line with the NDC submitted.

Both Middle East and North Africa (RoMena) and the EU proposed a mitigation objective that is 75% higher than their CB_A, but that decreases at 50% and 40% respectively if the CB_D is considered.

Canada, Japan and South Korea would be anyway required to submit a mitigation contribution in the range of 70% - 50% more ambitious than the current one.

On the contrary, among the countries that show a credit between the NDC emissions and the equitable average budget, Mozambique, Ghana and Uganda experience the largest difference in relative terms whatever the aggregation method, even though the size of their advantage is reduced under the CB_D (**Errore. L'origine riferimento non è stata trovata.**). The credit that these countries have is about 90 to 70 times the emissions they plan to release in their NDC. Smaller but anyway relevant is the carbon budget still available for Bolivia, Kenya, Bangladesh, Peru, Ethiopia and Chile, which can ideally increase their 2015-2030 emissions by a consistent amount.

Taking a different perspective and comparing the amount of emissions derived from the NDCs as a share of the equitable average budget give us a better idea of the measure of developing countries' largest emission credit. The NDCs of Mozambique, Ghana and Uganda represent, indeed, only less than 5% of the budget at their disposal under the CB_D (or even less than 1.5 under the CB_A). Also Bolivia, which does not propose any quantitative emission reduction target, is projected to emit only 16% (or 4% if CB_A is used) of its total budget in 2030 if our three equity principles are applied jointly using the demographic weights.

5. Discussion and conclusions

Through the NDCs, countries, among other things, propose how they are planning to contribute to the global emission reduction by 2030. NDCs reflect a national view on what the single country's contribution should be, both in terms of capability and fairness. As a flexible tool, the NDCs allow a regular update to be prepared also in the light of the periodic UNFCCC review of the progress toward the Paris Agreement's objectives. With the aim to contribute to this process, this essay compares the mitigation objectives included in the NDCs with a carbon budget consistent with the 2°C pathway and allocated according to three different equity approaches. Overall, we find that only a small number of countries proposed a NDC in line with our alternative equitable allocation of the carbon budget until 2030. Our results confirm that the mitigation contributions submitted by most of developed countries are far from being consistent with the objectives of the Paris Agreement in terms of either stringency or

equity. A significant gap affects the NDC of major emitters and in particular those of US, China and Russia, whose equitable budget is expected to expire well in advance of 2030. India is the exception, with an emission gap relatively smaller than the other key players and the NDC above of only one of the selected equity principles. Also Middle Eastern regions and the EU countries are required to propose more stringent emission reductions. On the contrary, the least developed countries will accumulate a consistent credit, accounting for a very small portion of emissions in each of our criteria.

From a methodological point of view, by including an approach based on more than one criterion and able to adjust responsibilities, capabilities and national circumstances over time, our framework represents a transparent and relatively easy way to measure NDCs efforts. As highlighted by the existing literature, however, the results are strongly influenced by how these principles are implemented and the methods to do it are many. This is confirmed by fact that the two alternative methods we use to aggregate the equity-based criteria lead to different – or even opposite - results for some countries.

We are also aware that, compared to other studies (Winkler, et al., 2013), our approach assigns a heavier burden to emerging economies in terms of historical responsibility and in the same way, influences positively the emission contribution of some developed countries. This is because of our choice to include also the most recent years in accounting for historical emissions (1850 – 2014). In fact, when looking at data, 50% of China's share of historical GHGs and more than 30% of India's have been emitted in the years from 2000 to 2014. For the same period, cumulative emissions of US and EU range between 19-15%. Nevertheless, we found no convincing reasons to exclude recent years' emissions, as they will represent future historical responsibility. And if part of the literature affirms that carbon emissions at the beginning of the industrial revolution were released without knowledge of the consequences, current emissions should be considered even more important as both awareness of the problem and availability of technology have improved. In the same manner, the fact that we exclude land use change and forestry emissions implies an underestimated contribution of Brazil and Indonesia. On a more fundamental level, intrinsic in ethical considerations about climate change there is a choice concerning social equity and income parity across countries (Ott & Sachs, 2000). If it is true that, as prescribed by the Paris Agreement and confirmed by our analysis, developed countries should bear the heaviest burden, they also have limited mitigation opportunities, while developing countries, which should have fewer obligations in tackling climate change, present greater opportunities of emissions reductions. This approach can be, therefore, useful to assess climate finance obligations, to be provided in the form of international support from developed to developing countries. Nevertheless, the impact of climate funds are difficult to disentangle from other forms of development assistance as, by increasing investments, they can contribute to the economic growth of host countries. Implicit in the considerations about climate equity there is also a political choice about the ultimate economic and social goal to be reached at the international level, namely if convergence and eradication of socio-economic disparities across countries would be the common objective in the climate policy arena. While the convergence approach offers a consistent way to take into account for equity concerns, some have claimed that aiming

at a world with equal GHG emissions, exactly as aiming at a world with equal GDP per capita, leads to standardization and represents a threaten to diversity (Ott & Sachs, 2000). In addition, the vulnerability aspects and the strong disparity on how they will affect countries are often disregarded in these kinds of evaluation. How to take into account all these aspects in the assessment of the Paris Agreement's future progress, certainly offer interesting insights for further research and methodological improvements.

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