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The global carbon budget and the Paris agreement

Olga Alcaraz, Pablo Buenestado, Beatriz Escribano, Bàrbara Sureda, Albert Turon and Josep Xercavins

Group on Governance of Climate Change of the Research Group on Sustainability, Technology and Humanism, Barcelona East School of Engineering – EEBE, Polytechnic University of Catalonia, Barcelona, Spain

Abstract

Purpose – The main purpose of this paper is to introduce the concept of global carbon budget (GCB) as a key concept that should be introduced as a reference when countries formulate their mitigation contributions in the context of the Paris Agreement and in all the monitoring, reporting and verification processes that must be implemented according to the decisions of the Paris Summit.

Design/methodology/approach – A method based on carbon budget accounting is used to analyze the intended nationally determined contributions (INDCs) submitted by the 15 countries that currently head the ranking of global emissions. Moreover, these INDCs are analyzed and compared with each other. Sometimes, inadequate methodologies and a diverse level of ambition in the formulated targets are observed.

Findings – It is found that the INDCs of those 15 countries alone imply the release into the atmosphere of 84 per cent of the GCB for the period 2011-2030, and 40 per cent of the GCB available until the end of the century.

Originality/value – This is the first time the INDCs of the top 15 emitters are analyzed. It is also the first analysis made using the GCB approach. This paper suggests methodological changes in the way that the future NDCs might be formulated.

Keywords Paris agreement, Carbon budget, Cumulative emissions, Global carbon budget, Long-term mitigation goal, NDCs

Paper type Research paper

1. Introduction

One of the main problems on a global scale that humankind is facing nowadays is climate change. From now, and in the coming years, the Paris Agreement (PA) (UN, 2015), which entered into force on November 4, 2016, is destined to play a central role in the multilateral actions against climate change. For this reason, an in-depth analysis of the agreement from scientific, methodological and political perspectives is extremely necessary.

In terms of mitigation, the main objective of the PA is set out in paragraph *a* of the article 2.1, which is quoted below:

The authors want to thank Pepe Antequera, who unfortunately is no longer among us, for the time they spent together.

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a. Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change.

The formulation of a global goal is not new in the policies on mitigation (UNFCCC, 2011), but in the context of the new agreement it is, and will be, the unique real concretion of the mitigation long-term goal.

To achieve this goal, the agreement defines a methodology based on the nationally determined contributions (NDCs). The agreement makes the first and main reference to these NDCs in Article 3. According to this article, the NDCs will be, in practice, the only operational instrument, that will always be in the hands of state-parties from now on and will define the national efforts with a view to achieving the goal of the PA. On the road toward Paris in COP19 and COP20, a call was made for countries to elaborate their intended nationally determined contributions (INDCs) and to send them to the UNFCCC (UNFCCC, 2013, 2014).

According to the package of decisions of the COP21 (UNFCCC, 2015a), this set of INDCs is likely to be the first official set of NDCs in the context of the PA, when the state-parties ratify the agreement (see decision 22). Currently, most countries have already sent their INDC to the UNFCCC, when they ratify the PA mostly they confirm their INDC as their first NDC (only 6 of the first 172 countries that ratified the PA have announced that they will submit a new NDC) (UNFCCC, 2016a, 2016b). This allows very accurate analysis about what these INDCs imply referring to the temperature objective. It should be emphasized that the reports published both before (UNEP, 2015; UNFCCC, 2015b) and after the Paris Summit (UNEP, 2016; UNFCCC, 2016c), present worrying results.

Still considering the methodology established by the PA, another key point is Article 14, where the "global stocktake" is defined as the way to assess the collective progress toward the objectives and the long-term goals of the Agreement. Paragraph 3 of the same article makes it clear that the global stocktake will only be for information purposes for the state-parties (UN, 2015). But it is clear that the global stocktake will be the only reference clearly and objectively showing the real state of the fight against climate change. Therefore, it will provide essential information that will help stakeholders to make any necessary policy changes (always according to their capacities and responsibilities).

According to the decisions 23, 24, 26 and 28 of the COP21, the second set of NDCs will arrive during 2020. And, from now on, the Ad Hoc Working Group on the PA has to elaborate the guidelines for the information to be provided and for accounting of the future NDCs. These guidelines will be considered and approved by the Conference of the Parties serving as the meeting of the Parties to the PA when it finishes its first session, in 2018. This session started in November 2016 in Marrakesh.

In summary, the PA establishes a bottom-up methodology, based on the NDCs that countries should prepare every five years. The UNFCCC, will perform the global stocktake to assess the aggregate effect of these contributions, and how far we are from achieving the target temperature. On November 4, 2016, the agreement entered into force, and we have a first set of INDCs playing, in practice, the role of the first set of NDCs that can be assessed. In addition, before countries begin to prepare the second set of NDCs, it is necessary to establish guidelines for very important aspects of their future structure.

The aim of this paper is to link scientific knowledge to policy proposing a new method that allows scientists and policymakers to monitor whether humankind is progressing adequately toward the goal of keeping the temperature rise below 2°C and also, how far it is from this goal. This method is based on the concept of global carbon budget (GCB), which is discussed and defined below. The authors apply it to study the aggregate effect of the

INDCs presented by the fifteen countries that currently lead the ranking of global emissions. This allows them to focus on the structural format of future NDCs. This format should facilitate objective and easily comparable analyses, of both domestic and global effects, and it should especially facilitate an aggregate assessment.

In accordance with this general objective, the layout of this paper is as follows: in Sections 2 and 3 the concept of GCB is introduced, and it is proposed a definition of GCB specially adapted to policies on climate change mitigation. In Section 4, the authors analyze individually and collectively the INDCs of the 15 countries that are leading the world's emissions and they determine the percentage of the GCB that these INDCs imply. Finally, in Section 5, the authors discuss the results and make some suggestions concerning the format and the method that the CMA should approve for the future calculation of NDCs. In Section 6, the main conclusions are presented.

2. The global carbon budget concept applied to the objectives of climate change mitigation policies

The concept of GCB is used, often referred to as cumulative emissions, when different future scenarios of emissions are built to foresight the increase of the concentration of CO_2 in the atmosphere and the effect that this increase will have on the Earth's radiative forcing and on the rise of the planet's surface mean temperature (Clarke *et al.*, 2007; Riahi *et al.*, 2007).

When considering CO_2, the specialized literature (Frölicher *et al.*, 2013; Herrington and Zickfeld, 2014; Matthews *et al.*, 2009; Zickfeld *et al.*, 2012) and specially the last IPCC report (IPCC, 2014) establish very clearly that cumulative CO_2 emissions are the main agents responsible for global warming and show that the proportional relationship between cumulative CO_2 emissions and the long-term temperature increases.

Although CO_2 is the main gas responsible for global warming of anthropogenic origin, the contribution of other greenhouse gases (GHG) is not negligible. In 2010, the non-CO_2 gas emissions, excluding land-use change and forestry (LULUCF), made up 24.7 per cent of the total CO_2 equivalent (World Resources Institute, 2015). For some years, determining the effect of the non-CO_2 gas emissions accumulated from now until the end of the century has been somewhat controversial because the specific nature and the time it remains in the atmosphere varies for each gas; in other words, their impact on the Earth's radiative forcing is diverse (Rogelj *et al.*, 2015, 2016). Fortunately, Meinshausen *et al.*, 2009 have shown some light on the relationship between cumulative emissions of a mix of GHG and the probability of keeping the temperature rise below a specific limit. At a practical level, for policy-making, the need to define the GCB for a mix of GHG, i.e. including non-CO_2 gas contributions, is already recognized (Meinshausen *et al.*, 2009).

In the authors' opinion and coinciding with other authors (Kanitkar *et al.*, 2013; Peters *et al.*, 2015; Raupach *et al.*, 2014), the concept of GCB can play a key role in the climate change mitigation policies and the definition and quantification of this concept are the main objectives of this study. And so, the authors begin by defining the GCB with respect to mitigation policies. Moreover, they show how this concept can be useful for the methodology accepted in the PA to check how close we are or not to achieving the 2°C goal, defined in the Agreement.

The GCB for CO_2, and also for a combination GHG, is defined as the cumulative emissions of anthropogenic origin permissible from 2011 until the end of this century (2100) to maintain the increase of the average temperature of the Earth's surface below 2°C. Using the definition of Rogelj *et al.*, 2016 this is an example of a "Threshold avoidance budget", i.e. a Carbon Budget (CB) that prevents crossing a specific temperature threshold, specifically 2°C. From now on, the authors will use the initials GCB to refer to the total World cumulative emissions and they will use CB to refer to cumulative emissions of one country or a group of countries over specific time periods. It is important to mention that the authors propose restricting these terms only to future emission scenarios that are compatible with maintaining the temperature rise below 2°C and therefore the historical emissions have not been included.

It is also important to point out that at the same time it is possible to extend these definitions to scenarios that limit the temperature rise to 1.5 °C, and this extension would be called the GCB for 1.5 °C ($GCB_{1.5}$). At the moment, it is only possible to quantify this $GCB_{1.5}$ for CO_2 (IPCC, 2014), and not for all the GHG. For this reason, these scenarios will not be included in this article, and the authors will wait for the IPCC report on the 1.5 °C scenarios that according to the decision 21 of the Paris COP21 (UNFCCC, 2015a) will be published in 2018.

Nowadays, in the literature, a wide range of future emissions scenarios can be found, (Meinshausen *et al.*, 2011; van Vuuren *et al.*, 2011) some of which are compatible with the 2°C goal. One of these is the RCP2.6 scenario (van Vuuren *et al.*, 2011), published in the last IPCC report (IPCC, 2013), which has more than 66 per cent probability of achieving the 2°C goal. The figures from this scenario, for each one of the GHG, are available on the Potsdam Institute for Climate Impact Research database (RCP Scenario data group, 2010) and the authors have used them in this article, both for CO_2 and for all the Kyoto GHG.

In Figure 1, the RCP2.6 scenarios updated to the latest emission records available are shown. The blue shaded area shows the GCB related to these scenarios. It is necessary to point out that the database contains historical records up to 2005, when the future projections start. As we now have historical data up to 2012 (World Resources Institute, 2015), the authors have slightly shifted the original scenario by 0.6 per cent in order ensure the continuity of the emission curve from 2012 to 2013.

In Figure 1(a), the RCP2.6 for only CO_2 emissions produced by the burning of fossil fuels and cement production is shown. In this scenario, the cumulative emissions between 2011 and 2100 amount to 1,000 $GtCO_2$ (in other words, this is the integral area of the curve between these years). This is the value of the GCB for CO_2, and it is currently widely accepted by the scientific community (Friedlingstein *et al.*, 2014; Peters *et al.*, 2015).

The quantification of the cumulative CO_2 emissions included in the IPCC AR5 Synthesis Report (IPCC, 2014) is extremely relevant. It shows that, calculating from 1,870, the cumulative CO_2 emissions allowable to reach the 2°C goal, amount to 2,900 [2,550 to 3,150] $GtCO_2$. Of these emissions, 1,900 [1,650 to 2,150] $GtCO_2$ were released before 2011, leaving

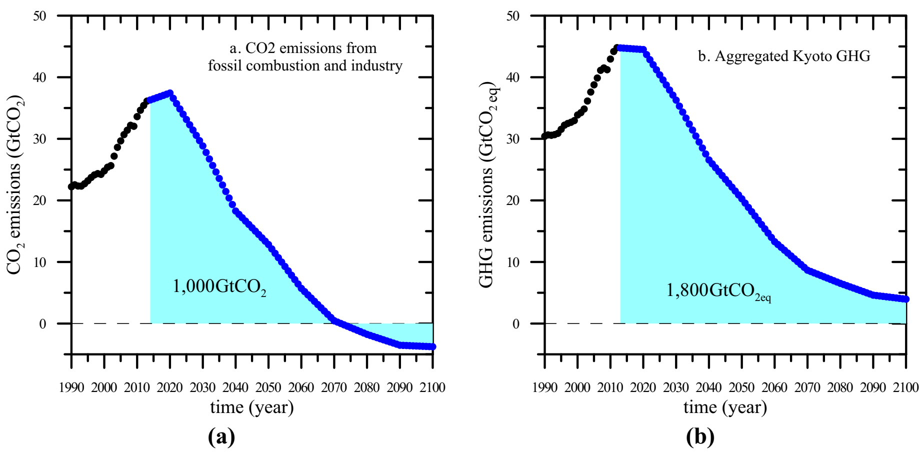

Figure 1. RCP2.6 scenarios; (a) CO_2 from fossil fuel combustion and industry; (b) aggregated Kyoto GHG weighted with IPCC AR4 Global Warming Potentials of a 100-year time horizon. Black dots represent historical data and blue dots the future scenario. The blue area under the blue line represents the GCB

about 1,000 $GtCO_2$ to emit from 2011 onwards. In summary, in line with the objectives and analysis of this paper, it can be stated that the GCB for CO_2 from 2011 to 2100 is 1,000 $GtCO_2$. This figure will offer a 66 per cent likelihood that the temperature rise will not go above 2°C with respect to the preindustrial era.

Fortunately, this figure of 1,000 $GtCO_2$ has finally been included in the evaluations of the aggregate effect of the INDCs carried out in different studies (UNEP, 2015, 2016) and it also appears in the synthesis reports (UNFCCC, 2015b, 2016c) elaborated by the UNFCCC itself. These synthesis reports will insure that this concept will finally take its place in the political world.

One of the objectives of this paper is to emphasize the importance of incorporating the concept of GCB in mitigation policies and also of the political analysis of their effect. It is also necessary to monitor how the GCB is being spent over the years. A simple look at the curve shown in Figure 1(a) quickly makes us aware that if humankind wants to be faithful to the Paris 2°C goal, it must achieve the end of fossil fuel combustion during this century and ensure that these 1,000 $GtCO_2$ are the last CO_2 emissions released into the atmosphere.

However, even though CO_2 is the main gas responsible for the greenhouse effect, it is not the only one. Because of this, and taking into account that at the moment nearly all the countries who have presented their INDCs, have included CO_2 along with other GHG (and have not separated the figures for CO_2), it is even more obvious that it is very important to extend the GCB concept, which was initially only used for CO_2, to all the GHG.

In Figure 1(b), the same RCP2.6 scenario for all the GHG included in the Kyoto Protocol is shown, aggregating the different contributions using the AR4 GWP100 (IPCC, 2007). Here, the integral area between 2011 and 2100 amounts to 1,800 $GtCO_{2eq}$. Although it is important to be aware that, when non-CO2 gases are also considered, the relationship between accumulated emissions and temperature rise is, to a certain point debatable (Rogelj *et al.*, 2015, 2016), this figure also fits perfectly with the GCB values for all the GHG that appears in the paper of Meinshausen *et al.*, 2009. According to this paper, and after using straightforward algebra (Appendix), it can be stated that a GCB of 1800 $GtCO_{2eq}$ involves a probability higher than 62 per cent (ranging between 43 per cent and 81 per cent) that the 2°C limit will not be exceeded. Therefore, the authors think, for both practical and operative reasons that, in a policy-making context, it is important to also identify the integral area of the RCP2.6 scenario curve, with the GCB for all the GHG.

The UNFCCC itself, in its report about the aggregate effect of the INDCs, is already considering, among other factors, the consumption of the CO_2 budget that the INDCs will imply (only CO_2, not other GHG). The main results of this report are worrying, because the aggregate effect of the current INDCs would imply the consumption of 53 per cent of the GCB by 2025 and 74 per cent by 2030 (UNFCCC, 2016c). These are percentages of the total CO_2 GCB available for all the century, i.e. the 1,000 $GtCO_2$ above mentioned. In other words, if the unconditional commitments expressed by the countries to the UNFCCC are fulfilled, in 2030 we will already have consumed 74 per cent of the CB we have available until the end of the century. Although the UNFCCC uses the concept of GCB in its report, instead of using this term, it uses the term "cumulative emissions". It is important to point out, that, unfortunately, the concepts of CB and GCB (or cumulative emissions) had not entered the praxis of the UNFCCC before and, consequently, they are not included in the way that countries have formulated their mitigation intentions at the time of elaborating their INDCs, although a few of them have presented their future estimated CB in addition to their mitigation objectives.

This again shows the importance of quantifying and monitoring how this GCB is being consumed and to have this budget as a conceptual and quantified figure of reference.

3. The way the mitigation objectives are presented in the intended nationally determined contributions

When considering mitigation goals, the format of the INDCs is very different. In general, many INDCs express emission reduction targets to be achieved by a given year, but do not specify the pathway they will follow between 2020 and 2030 (or 2025) to achieve this objective. It can be seen that the commitments of countries have not been made based on a method that limits their CB, and would ensure that the GCB is not being exceeded. This is a very worrying fact, confirmed by the reports on the aggregate effect of INDCs that, *a posteriori*, have attempted to assess the CB that these INDCs imply (Iyer *et al.*, 2015; Peters *et al.*, 2015; UNEP, 2015; UNFCCC, 2015b, 2016c). The situation is also aggravated because between 2012 and 2020, the international community is in a period without legally binding commitments and where the consumption of the GCB is not being controlled. The latest data records reach until 2012, and between 2012 and 2020 mitigation commitments expressed by some countries are voluntary. In the meantime, and with a high likelihood that GHG emissions will increase during this period, the world is waiting for the implementation of the PA.

Figure 2 illustrates the uncertainty regarding the consumption of the GCB in the coming years. Again, it clearly shows that a commitment in terms of percentage of reduction with respect to a certain base year does not imply any commitment regarding the mitigation pathway to be followed by the country. And, as well as this, to assess the CB that it will use, it is necessary to know the detailed mitigation pathway. It is worth mentioning that the CB equals the integral area of the mitigation pathway.

4. Results

In this section, the authors present the analysis of the INDCs (UNFCCC, 2015c) of the 15 countries or aggregates of countries (the EU-28 is treated as a single state party) that had the highest levels of emissions in 2010, and which have been given the name "TOP-15". These state-parties contribute 79 per cent of total global emissions (World Resources Institute, 2015).

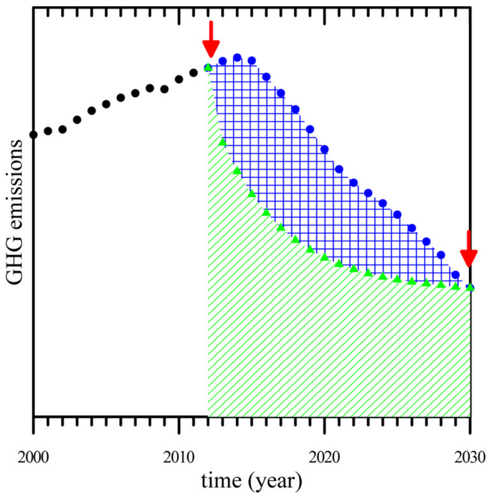

Figure 2.
Example of different possible pathways (in blue dots and green triangles) that fit with the same target (at 2030) and that implies different carbon budgets (areas marked with blue squares and green lines)

The rest of the state-parties, responsible for 21 per cent of global emissions, have initially been treated as a single group, which have been given the name "Rest of the world".

Table I includes the most general characteristics of these INDCs regarding the mitigation issue. The diversity of formats in which these INDCs are presented is more than remarkable. Some state-parties (Iran, Mexico and Indonesia) present two mitigation objectives, an unconditional objective and a conditional one that is more ambitious and depends on external factors. In this paper, only the unconditional mitigation objectives have been considered.

It is worth mentioning that the targets of the INDCs of China and India are given in emissions per gross domestic product (GDP). In relation to this point, and to assess what these contributions might represent in terms of emissions, it is necessary to have some foresight into the future GDP of these countries. For this reason, the authors have used the foresight published in the Economic Outlook No 95 - Long-term Baseline Projections, (2014) OECD, (2014). According to this, the GDP of China in 2020 and in 2030 will be, respectively, three and five times the GDP in 2005. And the GDP of India in 2020 and 2030 will be, respectively 2.6 and around 4.6 times the GDP in 2005. It is important to note there is a level of uncertainty in the long-term GDP estimations.

Table II presents the comparison of the unconditional mitigation contributions of each of these countries with respect to the same base year (2010), and also, the emissions per capita of these countries in 2010. The population data were obtained from UNDESA Population Division (UNDESA Population Division, 2015). A good reference point when making assessments of the different countries' mitigation efforts is emissions per capita. In 2010, GHG emissions per capita in the world were 6.2 tCO_{2eq}. The red line drawn between China and Mexico separates countries that are above the world average from those that are below.

Group/Country	Base year	INDC target year	INDC target (*)	Target at 2020	Particularities
China	2005	2030	60-65	40-45	CO2_Emissions/GDP
United States	2005	2025	26-28	17	
EU 28	1990	2030	40	20	
India	2005	2030	33-35	20-25	GHG_Emissions/GDP
Russia	1990	2030	25-30		
Japan	2005	2030	25.4		
Iran		2030	4		BAU 2030
Korea, Rep.		2030	37	30	BAU 2030
Saudi Arabia		2030	130 MtCO2eq (**)		BAU 2030
Canada	2005	2030	30		
South Africa		2030	398-614 MtCO2eq (***)		Peak, plateau and decline emissions range
Mexico		2030	22		BAU 2030
Indonesia		2030	29	26	BAU 2030
Brazil	2005	2030	43		
Australia	2005	2030	26-28	13	

Notes: (*) % of GHG emissions reduction in the target year in reference to the base year and according particularities; (**) The INDC of Saudi Arabia gives an absolute reduction figure to the BAU scenario at 2030; (***) The South African INDC gives a range of emissions for the target year

Table I.
General characteristics of the INDCs from the TOP-15 group of countries

Group/Country	% of variation at 2030 with respect to 2010 GHG emissions	GHG emissions per capita at 2010 (tCO2eq)	GDP per capita PPP at 2010 (constant 2011 international $)	GHG emissions per capita at 2030 (tCO2eq)
Australia	−29.3	24.4	41,363	13.4
The USA	−42.7 (*)	22.1	49,373	11.0
Canada	−26.3	20.5	40,773	12.8
Saudi Arabia	92.7	17.0	44,247	23.5
Russia	6.0	15.5	21,664	17.0
Korea, Rep.	−18.7	13.4	30,440	10.2
Japan	−17.0	9.9	34,404	8.7
EU 28	−28.9	9.5	34,035	6.6
Iran	26.9	9.2	17,517	9.8
South Africa	10.1	8.9	12,087	8.4
China	31.6 (**)	7.3	9,430	9.1
Mexico	7.8	5.9	15,359	5.1
Brazil	−49.6	4.8	14,406	2.1
Indonesia	6.0	2.9	8,465	2.5
India	128.0	2.3	4,453	4.1
World	−15.5 (***)	6.2	13,070	4.3 (****)

Notes: The mitigation compromises are compared with the emissions per capita of these countries and with the GDP per capita PPP of these countries at 2010. The last column shows the emissions per capita at 2030 of these countries assuming they meet their compromises, and considering the UNDESA population trends. The world emissions per capita at 2030 are estimated from the emissions provided by the scenario RCP2.6 at this year and the population projections given by UNDESA; (*) Estimated emissions at 2030 from emissions at 2025; (**) Estimated GHG emissions from CO2 emissions at 2030; (***) According to RCP2.6 scenario; (****) According to RCP2.6 scenario and UN DESA population prospects

Table II. Comparison of the mitigation compromises of the TOP-15 countries according to their INDCs

Table II also indicates the GDP per capita based on purchased power parity (PPP), measured in constant 2011 international USD, for these countries in 2010, according to the World Bank database (The Worldbank Group, 2016) The global GDP per capita PPP that year was 13070 USD_{2011}. Moreover, Table II shows the per capita emissions of each country in 2030 assuming that the mitigation commitments expressed in their INDCs are met.

For the sole purpose of being able to make a comparison between the countries studied and to analyze the aggregate effect of these INDCs, in this paper, the authors have extrapolated China's commitment (that only refers to CO_2 emissions) to all the GHG. They have also extrapolated the United States' commitment (that only refers to the period from 2020 to 2025) between 2026 and 2030, assuming a reduction of 257 $MtCO_{2eq}$ per year in this period. The annual reduction of the USA in the voluntary first commitment period (until 2020) is 61 $MtCO_{2eq}$ per year, and from 2020 to 2025, 159 $MtCO_{2eq}$ per year.

To estimate the CB that these INDCs involve, the unconditional mitigation contributions have been added on to the historical GHG emissions curve of each country. The LULUCF contribution is not included in this study, mainly because of a lack of reliable historical data at a country level, consistent over time. In the case of countries which have stated INDC commitments for 2020, they have been taken into consideration. Then, the authors have drawn linear mitigation pathways between the last year for which they have real data (2012) and the target year (or years). For those countries (e.g. South Africa) that do not indicate a single value but a range, the mid-range value has been used to draw the pathway.

Starting from these traced mitigation pathways, the authors calculate the CB (i.e. the cumulative emissions) for each of these 15 countries between 2011 and 2030. Figure 3 shows, for the TOP-15, the percentage distribution of 846 $GtCO_{2eq}$ (i.e. the GCB available between 2011 and 2030 according to RCP2.6 scenario) and compares it with the percentage of emissions of these countries at 2010.

A complementary perspective is provided by Figure 4, where the aggregate effect of the mitigation pathways of the TOP-15 countries is presented superimposed on the mitigation RCP2.6 scenario (remember that the integral area under the RCP2.6 curve is the GCB).

5. Discussion

With respect to the INDCs format, the 15 INDCs analyzed are widely diverse. The wide range of formats in which the INDC information is provided makes it difficult to compare them and to assess if we are on track for the 2°C goal.

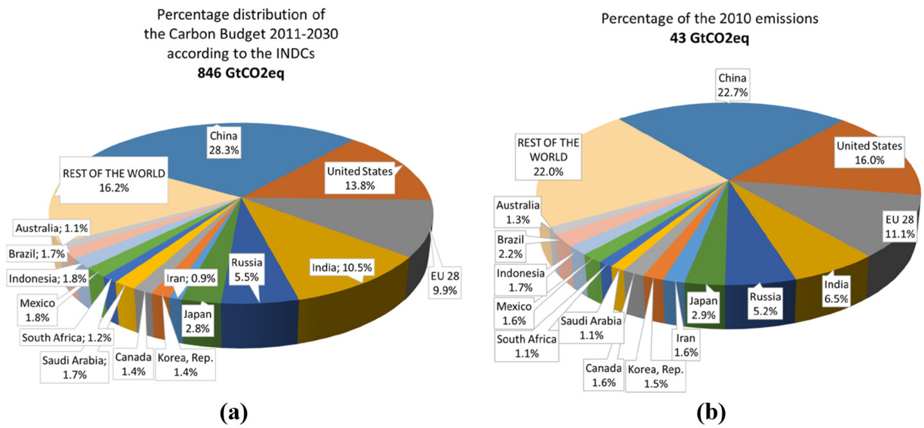

Figure 3.
(a) Percentage distribution of the GCB available in the period 2011-2030, among the TOP-15 state-parties, according to their INDCs and (b) Percentage distribution of the World emissions among the TOP-15 state-parties at 2010

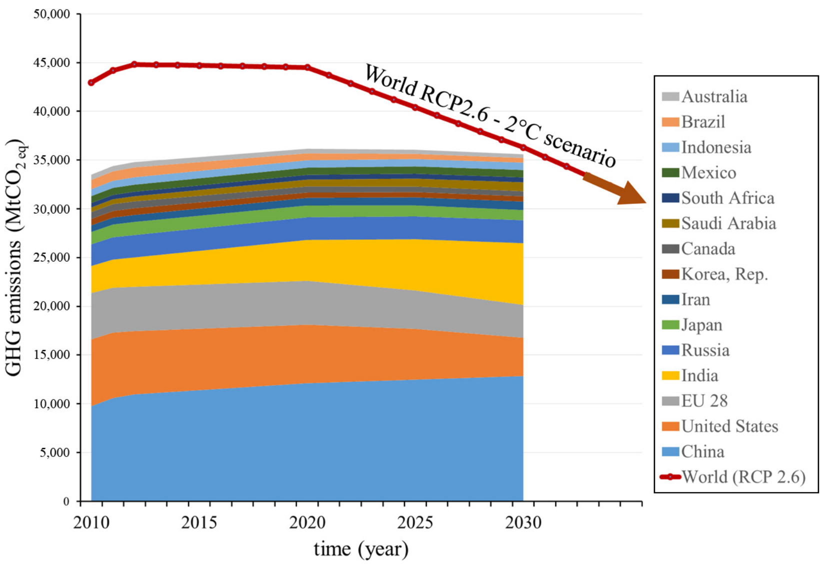

Figure 4.
The GHG trajectories of the TOP-15 countries added together, compared with the RCP 2.6 scenario for the aggregated Kyoto GHG

There is still not an agreement on the base year used by countries in giving their emission reduction percentage. The authors believe it is time to unify this reference year. They think that it could be more convenient to use a relatively recent year and so they have adopted 2010 to compare the different INDCs.

All the countries studied, except the USA, adopted 2030 as the target year. Again, it is time to fix a unique target year.

The set of GHG considered by each INDC is also quite diverse. An extreme case is the case of China, which adopted commitments to reduce only CO_2. Another problem is that most countries adopted commitments related to a group of GHG, without specifying the distribution of these commitments for each gas separately.

Several countries give their mitigation commitments as a specified quantity relative to a projected baseline scenario, sometimes referred to as business-as-usual (BAU) targets. Although this method has been suggested in some documents (Levin *et al.*, 2015), the authors think it should only be used as a relative reference for the future trajectory of the country.

In summary, in relation to the formats and contents of NDCs, an important step forward could be made by using very simple guidelines that would unify some important aspects. For example, a common base year, a common set of GHG and the specification of the mitigation pathway that countries will follow during the implementation period. Detailing the mitigation pathway implies determining the CB the countries will use. It is worth noting that the integral area of the mitigation pathway equals the CB (Section 3).

Table II facilitates comparative assessments between mitigation commitments adopted by the countries studied. To assess the level of ambition that these commitments represent, data of both a country's emissions per capita and GDP per capita PPP for the year 2010 have been included. Emissions per capita can be considered an indicator of the degree of responsibility of countries in relation to climate change. The GDP per capita PPP can be considered as an indicator of the economic capacity of the country to afford mitigation and/or adaptation costs (Baer *et al.*, 2009; Füssel, 2010), and this is not the same as the potential of reducing its emissions. In addition, the last column shows the per capita emissions in 2030 that these countries would achieve if they meet their INDC.

The emissions per capita in 2010 allow a rapid classification of those with per capita emissions well above the world average (6.2 tCO_{2eq}) and those that are below. The former has a higher level of responsibility and would be expected to follow more ambitious mitigation policies. It is remarkable that countries like Saudi Arabia, Russia, Iran and South Africa, with per capita emission levels well above the world average, are still contemplating increasing their level of emissions instead of reducing them. It is interesting to note that Brazil is an example of the opposite, it could increase its emissions per capita but it proposes a reduction. However, the authors must point out that Brazil includes LULUCF in its INDC, and in this paper, LULUCF has not been included. The authors have assumed that the percentage reduction expressed in its INDC would be the same for all sectors, ignoring the fact that the mitigation potential of LULUCF in Brazil is very important (Gebara and Thuault, 2013). This comparison made according to emissions per capita justifies that countries like Indonesia and India, with per capita emissions well below the global average, can increase their level of emissions, although they are currently within the group of 15 countries with a higher level of emissions.

It is also interesting to see what would be the evolution of per capita emissions in these countries at 2030, according to the commitments expressed in their INDCs. In general, we will still be rather far from meeting the figure of 4.3 tCO_{2eq} per capita, which, according to RCP2.6 scenario and the UN DESA population prospects, would correspond to the world emissions at 2030. Although there are a number of countries that will see a reduction in its emissions per capita, they are still far away from the world average. Saudi Arabia, Russia, Iran and China deserve a special mention as countries that are currently above the world average and their INDCs imply that they will still increase their emissions per capita by 2030. Saudi Arabia, Russia and Iran have a GDP per capita above the world average. In their review about equity and climate change, Mattoo and Subramanian (2012) highlighted the proportional relationship between emissions per capita and GDP per capita as an example of inequity. The fact that the commitment of these three countries implies an increase of their emissions per capita, confirms that we are far from implementing the equity paradigm of the PA.

Among the countries that currently have per capita emissions below the world average, India is the only one whose emissions will almost meet the world average in 2030. Some authors suggest that a good way to include equity criteria in achieving emissions reduction could be that the emission pathways of the different countries converge toward the same number of emissions per capita (Gignac and Matthews, 2015; Meyer, 2000).

Moreover, the GDP per capita PPP can be used to gauge the ability of a country to undertake mitigation policies, which in many cases involve investments in the installation of new technologies, for example for renewable energy production or to achieve a higher degree of energy efficiency (Baer *et al.*, 2007; Mattoo and Subramanian, 2012).

Now, the authors would like to discuss the implications of the INDCs with regard to the global mitigation goals. Figure 3(a) shows what the cumulative emissions, the CB, until 2030 would be, according to the INDC of the 15 countries assessed and compared to the GCB for that period according to RCP2.6. It is worth noting that linear mitigation pathways have been used to calculate the CB, but the actual pathways may not be linear, as discussed in Section 3. Therefore, by assuming linear pathways, the authors are making an optimistic analysis of the consequences of the application of the INDCs.

It is particularly worrying that the commitments of only 15 countries add up to 713 $GtCO_{2eq}$ and represent 84 per cent of the GCB (846 $GtCO_{2eq}$) in 2011-2030 and 40 per cent of the budget for 2011-2100. When the 2011-2030 distribution and the distribution in 2010 are compared [Figure 3(b)], a high degree of coincidence can be seen. In other words, the proposed TOP-15 INDCs are a long way from achieving a turnaround from the current distribution of emissions. As the PA states, this turnaround should be led by the developed countries (article 4.4, UN, 2015), but once again it can be seen that, at least for the moment, the inertia of these countries makes this change very difficult. Several studies highlight the contradiction between ambitious mitigation commitments and the reality (Elzen *et al.*, 2016).

Figure 4 compares the aggregated mitigation pathways of the TOP-15 with the RCP2.6 scenario. This scenario presents a very steep slope of emissions reduction from 2020. It is worth noting that the sum of the mitigation pathways, far from presenting a slope similar to that of the RCP2.6 scenario, remains virtually stable from 2020. This means that the two pathways will almost cross in 2030, which in turn means that from that date, the aggregate trajectory of only 15 countries will exceed the total world RCP2.6 scenario. Among other things, these facts would make the PA worthless from 2030.

6. Conclusions

The PA sets a clear target of mitigation: the global temperature increase must not exceed 2° C. It also defines a methodology for achieving this goal. A bottom-up methodology, based on the NDCs. As some authors suggested (Hermwille *et al.*, 2015) the PA has overcome the old paradigm of distinct specific targets for developing and developed countries of the annexes of the Convention, and the NDCs goes beyond mitigation targets. In other words, every five years, countries prepare and approve their own mitigation commitments and send them to the UNFCCC. Every five years the UNFCCC will do a study of the aggregated effect of all these commitments, i.e. a global stocktake or global inventory. The global stocktake will be communicated, but in fact only for information purposes, to all the state-parties for them to take it into consideration when elaborating new NDCs (UN, 2015).

Currently, as a result of the process that led to the Paris summit, 190 state-parties have sent their INDCs to the climate convention. These documents, which in principle only express their intentions (not commitments), allow a first assessment about what the aggregate effect represents in relation to the global mitigation goals. In fact, the INDC submitted by each state will become in most cases its first NDC, when the state ratifies the PA, unless it expresses its willingness to change it. Currently, only 6 of the first 172 countries that ratified the PA have announced that they will submit a new NDC (UNFCCC, 2016a, 2016b).

Various analyses of the aggregate effect of these INDCs have been carried out (UNEP, 2015, 2016, UNFCCC, 2015b, 2016c), and everyone agrees that there is a "gap" between the mitigation efforts that countries say they will undertake and the actual effort needed to achieve the objective of 2°C. In addition, different proposals of sharing the efforts of GHG reductions have been published (Herrala and Goel, 2016; Kanitkar *et al.*, 2013; Peters *et al.*, 2015). Unfortunately, the Agreement does not define any binding mechanism for feedback; only a communication to inform the parties about the global balance of the aggregate effect of the NDCs, which will be done every five years.

This article identifies the concept of GCB as a key concept that should be introduced as an obligatory reference for NDCs. In this context and mainly for policy purposes, the authors propose that the GCB for all the GHG can be assessed in a very simple way: by calculating the integral area under the curve of the mitigation scenario RCP2.6 for all the GHG. The GCB obtained between 2011 and 2100 amounts to 1,800 GtCO2eq. Being aware that the extension of the GCB concept to all the GHG is an issue still under debate, the authors use the Meinshausen *et al.*, 2009 "2°C Check Tool" to verify that the figure of 1,800 GtCO2eq fits with their estimations. This software verifies that these 1,800 GtCO2eq will result in a higher than 62 per cent probability (ranging between 43 per cent and 81 per cent) that the 2°C limit will not be exceeded.

The authors have shown that it is highly recommended that countries should formulate future NDCs by specifying the mitigation path over all the years that the NDC applies to. The inclusion of this measure would represent an improvement to the current situation because it implies that countries must unambiguously identify the CB (i.e. the cumulative emissions or the integral area of the mitigation path) that they will use during the total implementation period of their NDC. This framework would also facilitate the assessment of the level of ambition and the overall fairness of each NDC, because it would be possible to compare each NDC with the rate of consumption of the remaining GCB that it represents. Despite all of these, it is necessary to be aware that to guarantee the effectiveness of NDCs, further policy tools are needed. And, even more so to achieve an implementation of the PA in the light of equity. To offer an example, the guidelines of the features of the new NDCs could include the strong recommendation that state-parties should take into account the distribution between them of the GCB based on equity criteria as a reference for elaborating the next and the future NDCs.

In this study, the INDCs submitted by the 15 countries that currently head the ranking of global emissions have been analyzed. From a preliminary analysis, it has been seen that the

INDCs have been elaborated with a wide variety of formats and that efforts to unify them are needed. In addition, a diverse level of ambition in the formulated targets has been observed.

These 15 INDCs have been analyzed according to the method proposed in this article. It was found that the commitments of the 15 countries alone imply the release into the atmosphere of 84 per cent of the GCB for this period, and 40 per cent of the GCB is available until the end of the century.

The study also found that the important emission reductions required by the RCP2.6 scenario will not be achieved. This analysis implies that by 2030 it would be impossible for humankind to comply with the only scenario that has a chance of fulfilling the PA.

The world is therefore facing an extremely delicate moment with regard to the necessary mitigation policies to be followed if it wants to achieve the 2°C goal. The PA, ratified in November 2016, provides a methodology for progressing toward the target. This methodology will need to incorporate effective instruments to address a situation that today is far from being under control or on the right track. The incorporation of the concept of GCB for both CO_2 and for all the GHGs is very useful when analyzing the aggregate effect of the contributions of the countries. In addition, it could be interesting to incorporate this concept when a new set of NDCs is formulated, clearly identifying the CB (or its percentage within the GCB) that the NDCs imply. This method could be the only guarantee that we still have to change the course we are on and to.

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Appendix

With the aim of validating the Figure 1(b) and the corresponding quantification of the GCB for all the GHG and also identifying the percentage likelihood that this GCB will meet the 2°C goal, the authors have used the "2°C Check Tool" provided in the additional materials of the paper by Meinshausen *et al.*, 2009. When the accumulated emissions between 2000 and 2049 are introduced into the "2°C Check Tool", the program calculates the probability that the temperature will rise above 2°C by assessing the probability range using several independent references. To use this tool, the accumulated emissions of the RCP2.6 scenario [Figure 1(b)] between 2000 and 2049 have been calculated, and the result is 1790 $GtCO_{2eq}$ (423 Gt from 2000 and 2010 + 1367 Gt from 2011 to 2049). When this result is introduced, the tool gives a probability higher than 62 per cent (ranging between 43 per cent and 81 per cent) that the 2°C limit will not be exceeded. Therefore, it is important to also identify the integral area of the RCP2.6 scenario curve, with the GCB for all the GHG. The GCB between 2011 and 2100 amounts to 1800 $GtCO_{2eq}$ (1367 Gt from 2011 to 2049 + 433 Gt from 2050 to 2100).

Corresponding author

Olga Alcaraz can be contacted at: olga.alcaraz@upc.edu