Effects of emissions allocations and ambition assessments immediately based on equity

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Abstract (No references, up to 150 words)

National emissions targets are collectively insufficient to align with the Paris Agreement. The literature quantifying national emissions trajectories based on equity principles will inform the Global Stocktake on the ambition of national 2030 targets. Ambition assessments based on trajectories that start at present-day emissions levels inherently reward past inaction thus far, and increasingly do so into the future. Here we quantify emissions trajectories based on equity principles applied with immediate effect. We find national targets of G7 countries, Russia and China responsible for most of the global ambition gap, while only those of some countries in the Global South align with their 1.5°C allocation. Discontinuous trajectories not starting at current emissions levels imply stronger international support that can mobilize the capital needed to implement the 1.5°C trajectory globally. The difference between allocation with or without discontinuity has remarkable consequences for the relative implied contributions among high-income countries to international support.

Main text (up to 5000 words)

Introduction

The Global Stocktake under the United Nations Framework Convention on Climate Change (UNFCCC) will review at the end of 2023 the potential aggregated impact of the 2030 countries' pledges towards achieving the goals of the Paris Agreement[1]. Based on existing intergovernmental assessments, the expectation is that the pledges are not sufficient and need further strengthening[2]. In this process, assessing the fairness of individual countries' emissions targets is critical for the stocktake and negotiations on ratchetting up ambition. Recent literature has suggested several frameworks to compare the ambition of national emissions pledges against fair distributions of the emissions from global scenarios that limit global warming to 1.5°C and well below 2°C, to align with the Paris Agreement[3–7]. Here, 'fair' or 'equitable' allocations do not refer to the personal view of any authors, but to emissions allocations in the scientific literature that quantifies the distribution of the global effort to reduce emissions, referring to principles of distributive justice and "common but differentiated responsibilities" in the Framework Convention and Paris Agreement[1]. Literature on fair emissions levels can contribute to justifying or even enhancing the ambition of national targets under the Paris Agreement[8–10]. Governments can legislate to adopt emissions targets recommended by independent bodies based on equity-based literature. Additionally, this literature can inform cases at courts of law to establish adequate emissions targets for governments to avoid climate impacts and comply with national and international obligations. Recent literature has compared the ambition of NDCs with possible reduction targets based on fairness principles[3–5,7,11,12]. However, most of the recent approaches rely on allocations of emissions rights following a continuous trajectory starting at current emissions levels, sometimes using a transition period before the allocation is entirely based on fairness considerations[13]. Such a modelling choice of continuous allocation favours in the near-term countries with high current emissions resulting from relatively minor past efforts to reduce emissions[7]. This influence of present-day emissions on near-term emissions allocations also affects the ambition assessment of Nationally Determined Contributions (NDCs). The choice to model continuous emissions trajectories leads to a more lenient ambition assessment of NDCs for countries with high emissions, to the disadvantage of others. Successive future literature updates of continuous emissions trajectories would increase this 'legacy' effect as we approach 2030.

Here we quantify two formulas allocating discontinuous emissions trajectories, starting at emissions levels based on fairness criteria, accounting for countries' historical responsibilities and capabilities referenced in the Paris Agreement, rather than present-day observed emissions levels. We apply these formulae to a range of global emissions scenarios with warming ranging from 1.5°C to over 4°C and compare the resulting allocations to countries' NDCs. We quantify the emissions gaps between these allocations and countries' emissions towards their emissions pledges. Some of the 1.5°C scenarios used here allow temporary overshoot (see Methods). It is an open question how such proposals using a discontinuous approach would compare to continuous approaches.

Approach rationale

The recent literature quantifying emissions allocation based on principles of distributive justice and on the Paris Agreement's CBDR-RC agrees on the insufficiency of NDCs of many of the largest emitting countries[5,6,11,14,15]. However, the differences in emissions allocations across studies imply substantial differences in the amount of additional mitigation effort, which may include international cooperation and climate finance. Despite divergences on the modelling choices of equity concepts[16,17], this literature is mostly based on a 'continuous' allocation of emissions trajectories starting at current emissions levels. In this context, 'continuous' refers to trajectories starting at current emissions levels, rather than equitable levels, to achieve equitable outcomes over the century. Effort-sharing formulas can be designed to directly achieve such continuity[18] (e.g. equal cumulative per capita approach in ref.[4]), or an ad-hoc transition period can be added to ensure continuity[4,13] between current emissions and future levels allocated only on the basis of an equitable effort-sharing formula. Alternatively, the equity formula can allocate a relative change in emissions levels (reflecting an effort to deviate from business as usual) instead of allocating absolute equitable emissions levels directly[3]. This continuity criterion is also applied when national carbon budgets are allocated over time into emissions trajectories[18,19]. Some studies seek to compensate for this early influence through later allocations over the century, to ensure staying within an equity-based emissions budget possibly accounting for historical emissions[3,4,6].

The influence of current emissions levels on near-term emissions allocations[3,4,6] is described here as a 'grandfathering' effect[7] (without any form of judgement) and may affect the ambition assessment of NDCs in 2030, less than 7 years from now. Such iterative updates of ambition assessments based on continuous emissions allocations would iteratively find an insufficient NDC closer and closer to a calculated 'fair' allocation as we near 2030 (Figure 1).

The key motivation for allocating continuous emissions scenarios is to address the need for emissions trajectories that countries can implement domestically[20]. For example, it is unlikely to be considered politically, technically or economically realistic for any country to halve its emissions domestically from one year to the next. However, equity-based allocations do not imply domestic mitigation exclusively and their continuity is therefore not required for the allocations to be implementable. Instead, countries can achieve their equity-based emissions allocations through a combination of domestic effort and international cooperation[20]. Countries can therefore provide an equitable share of the global mitigation effort immediately, beyond the limitations of what is most efficient to implement within their borders. The recent IPCC sixth assessment report calls for research "extending equity frameworks to quantify equitable international support, as the difference between equity-based national emissions scenarios and national domestic emissions scenarios"[17]. International cooperation, possibly through bilateral agreements, financial support or trading of Internationally Transferred Mitigation Outcomes (ITMOs), is now facilitated with the adoption of Article 6 under the Paris Agreement at COP26. Such mechanisms offer a solution to both progress toward an equitable distribution of the mitigation effort (through equitable emissions trajectories suggesting a fair distribution of mitigation costs) and contribute to the funding of mitigation measures in line with the pursued global cost-optimal scenario (that suggests a geographic implementation of mitigation measures without hypothesizing how much each country is funding this effort).

Integrated Assessment Models (IAM) models behind these global scenarios identify the cheapest mitigation option in each region without identifying the source of the necessary funding. Substantial mitigation effort is modelled for countries of the global South, which represents a much greater fraction of their Gross Domestic Product (GDP) than the faction in the global North[21]. In contrast, financial capacity is mostly in the global North. Additionally, substantial differences in financial risks and credit-rating strongly impact the real costs of a given mitigation option across countries[22,23]. Since the IAMs do not factor in the influence of e.g. credit-rating, the cost of the ITMOs could be higher than based on the carbon prices assumed in the model. Accounting for the higher cost of access to capital in developing countries in IAMs would imply greater domestic mitigation in developed countries than resulting from IAMs and lower in developing countries, and thus a lower amount of ITMOs to meet equitable trajectories. The implementation of the IAM scenarios thus requires important international transfers and access to loans. While such international funding may be possible, there are limitations as well possibly leading to a situation that contradicts the “common but differentiated responsibilities and respective capabilities” (CBDR-RC) of the UNFCCC and Paris Agreement.

Considering continuous emissions trajectories that look realistic[20] implies that present-day levels of domestic emissions are an acceptable starting point in terms of mitigation effort. This might hold for domestic emissions reductions, but given the great disparities in countries’ responsibilities and capabilities, large-scale immediate climate finance may be needed to fund the implementation of mitigation options to limit warming to 1.5°C[24,25]. The trading of mitigation outcomes to meet equitable emissions scenarios can deliver funding necessary for the implementation of mitigation measures in developing countries and make the remaining effort politically acceptable[24], though environmental and social safeguards should apply to ensure outcomes are not inconsistent with sustainable development[22]. In practice, the international trading of mitigation outcomes raises implementation issues to ensure the integrity and additivity for the resulting mitigation measures. Assessing the integrity of this international cooperation requires both transparency on the implementation of mitigation measures by countries receiving finance, and transparency on the provision of the pledged finance.

The relevance of equity concepts and their implementations in effort-sharing formulae show various consistency with international law[7]. Here we quantify two equity-based methods to allocate emissions trajectories that do not start at current emissions levels and in that respect immediately reflect the principles of the UNFCCC and the Paris Agreement, notably CBDR-RC (see Methods). These two methods also extend the findings of a recent paper[25] that suggested approaches to allocate the negative emissions of global scenarios (including LULUCF emissions unlike in the present study) on the basis of capability or historical responsibility. This study alone could not be used as a metric to inform economy-wide emissions targets nor assess the ambition of NDCs as it “assume[d] that positive emissions follow least-cost pathways (that is, no equity principle is applied to gross emissions)”[25].

Building upon this study, Fyson et al. 2020, we suggest two extensions of this approach to derive an allocation of economy-wide emissions to countries. A first extension, named Approach 1, allocates global negative emissions across countries based on their capability, assessed through GDP or Human Development Index (HDI, in Supplementary Information), and allocates global positive emissions to equalize historical responsibilities over the net emissions (positive + negative, see Methods). The second extension, Approach 2, conversely allocates global positive emissions based on countries’ capabilities and global negative emissions based on their responsibilities. Approach 1 ensures equal cumulative per capita emissions by 2100, and the capability considerations affects the use the emissions budget over time, but not its total. In Approach 2, historical responsibility does not define countries’ cumulative emissions alone. Looking at the global emissions scenarios, the positive emissions refer here to the projected physical emissions (e.g., fossil fuels, agriculture). The negative emissions here refer to emissions captured through Carbon Dioxide Removal (excluding those from LULUCF, unlike Fyson et al. 2020) and Direct Air Capture.

Here, we present results based on a parameterization that uses GDP for capability and accounts for responsibility through emissions since 1990. As an example of equity considerations in policy making: a capability approach based on GDP per capita drove a 'fair' allocation of mitigation effort across member states for the EU to implement its first NDC targets[26,27] (using a different methodology) and drove most of the effort-sharing discussion under the new “Fit for 55” package[28]. For an example from a different area of policy making: capability approaches of effort-sharing can also be seen to reflect nations of progressive income taxation that many countries have implemented[29]. The capability component overwhelms the allocation of Approach 2 in the near term, which therefore can be seen to reflect a capability driven allocation of financial resources to fund mitigation globally and alleviating poverty inequalities[30]. Additional results using Human Development Index and emissions accounted since 1950 are available as Supplementary Information. Responsibility can be related to the principle of 'polluter-pays' principle that many countries recognized in the Rio 1992 declaration. The indicators of GDP per capita, HDI and historical emissions per capita were identified to support the CBDR principle[7].

By contrast, Approach 1 is mainly driven by responsibility in the near term. Here, countries' responsibility is studied solely based on territorial emissions accounted under UN frameworks. Other emissions frameworks account for emissions linked to consumption, fossil fuel extraction, or carbon intensity of countries' income[31]. Such accounting could lead to more stringent allocations for countries with higher responsibilities, compared to territorial emissions, regarding their consumption footprint (the EU, Switzerland, Japan, Singapore), income footprint (Norway, Switzerland, Saudi Arabia, Australia) and extraction-based emissions (Canada, Saudi Arabia, Norway, Australia)[31].

Results

Under both approaches, emissions allocations start at levels that only depend on the global emissions scenario and countries' historical responsibilities and capabilities (see results for individual countries in Supplementary Data). Over time, the emissions allocations for all countries under a 1.5°C scenario follow a rapid decrease and plateau in the second half of the century, under both approaches. As the need for continuous allocations is absent in this model, the emissions allocations of countries follow the dynamic of the underlying global scenario and have decreasing allocations under a 1.5°C scenario. This dynamic is weaker in magnitude for countries with higher responsibility and capability, that have allocations starting at very low levels compared to today's emissions. The USA, Canada and Australia have immediate negative allocations before 2035 under both Approaches. While Approach 1 constraints countries' budgets based on the responsibility, which often overlaps with high capability[32], Approach 2 is more stringent in the near term for countries with high GDP. Approach 2 is less stringent for countries with very low capability (sub-Saharan African countries), and for countries with high historical responsibility (USA, Russia, Qatar and other fossil fuel extracting countries, Figure 2). The absence of zero or negative allocations for some countries results from fairness indicators as well as the absence of negative emissions in the 1.5°C scenarios-set with strong near-term mitigation, excluding LULUCF emissions. Following net-zero targets based on these allocations are consistent with 1.5°C only if near term mitigation also matches the related discontinuous levels. The near-term allocation of some countries, mostly sub-Saharan countries, may exceed their current emissions and business-as-usual trajectory beyond 2030 implying mitigation efforts only later[11]. Staying within such decreasing allocation beyond 2030 implies earlier investments, possibly with international support. Financial support, possibly ITMOs, can enable recipient countries to implement mitigation measures in line with the underlying socio-economic scenario in the near term and keep their emissions within their fair allocations in the future. Approach 2 follows a modelling allocation inversely proportional to GDP per capita[4,33] (see methods), resulting in high emissions allocations, compared to current emissions and literature based on business-as-usual trajectories[3,11], for countries with very low GDP per capita (e.g., Ethiopia, Democratic Republic of Congo). The implementation of this approach could imply financial transfer going beyond needs-based considerations and contribute to poverty reduction through climate action[30]. The absence of continuity criterion highlights important sensitivities in emissions allocation across equity-based formulae that are otherwise dampened by the need for continuity and given the declining global emissions space.

The IPCC indicated that, on average across a set of scenarios, a 43% reduction in global GHG emissions by 2030 (here taken below 2020 levels) would align with a 1.5°C trajectory with no or limited overshoot. This global target of 43% reduction below 2020 levels (met in 2035 for the global emissions scenarios used here with possible overshoot, excluding bunkers and LULUCF emissions) is met at different dates for the emissions allocations calculated here (Figure 3). Under both approaches, a majority of countries' allocations are immediately below that 2030 target, unlike those of sub-Saharan countries that do not reach such level over century.

The effect of adding a transition phase to ensure the continuity of an emissions allocation on the countries' tradeable emissions budgets and on the potential ambition gap of its NDCs is schematized in Figure 1, using Approach 2. For a country with emissions higher than its allocation, the ambition gap of its NDC is reduced and its cumulative near-term mitigation effort may include international support. Conversely, a country with an allocation higher than its current emissions may find its NDC insufficient and lose emissions space that could have been traded to receive the finance to curb future emissions. We could not model the addition of a transition period to Approach 1 that did not affect the allocation past that period. Results of Approach 1 can be compared to the continuous modelling of the Equal Cumulative Per Capita allocation of ref.[4] to review the effect of a continuity criterion, even when both methods pursue equal historical responsibility.

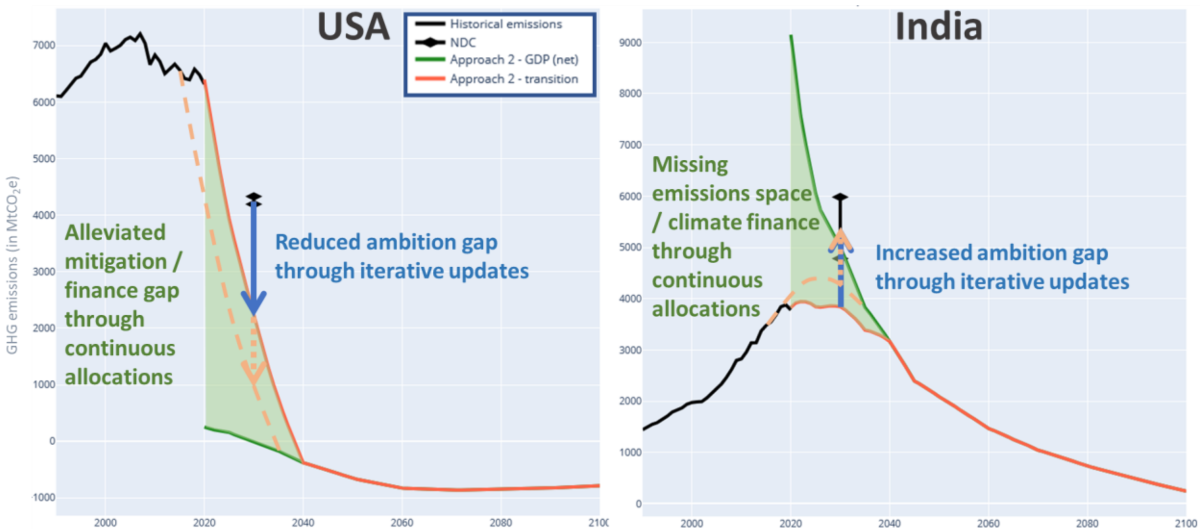

Figure 1 | Schematic figure showing the effect on countries' emissions budgets and NDC assessment of allocating a continuous emissions trajectory, here by adding a 20-year transition phase since 2015 (dashed red) and since 2020 (solid red) towards an equity-based trajectory (green line). The difference between trajectories with and without a transition period affects the 2030 ambition gap that increases with successive ambition assessment updates (dashed red and blue arrows), thus (left panel) 'rewarding' preceding emissions that were too high given the applied fairness allocation. Cumulated over the transition period, the emissions difference affects the effort, possibly through climate finance, that countries could provide or receive (green area).

Meeting the discontinuous emissions allocations derived in this study would require important international support, and a faster scale-up of mitigation than implied by current NDCs. In the longer term, beyond the timeline of current NDCs, the approach analyzed here informs discussions on fairer reductions targets, by directly and transparently accounting for inequities preceding the present day.

The ‘warming maps’ (Figure 2) show the warming alignment of countries’ NDCs, that is the warming associated with the most ambitious global scenario underlying the allocation that is above their NDC in 2030. The differences in terms of emissions allocations across the two approaches do not translate into important differences for countries’ ambition assessments. Most countries have an ambition assessment either 1.5°C aligned or not aligned with even 4°C aligned. The effect of the current inequities across countries on 2030 allocations overwhelms the relative spread in numerical targets across countries. The polarization of results reflects the extreme disparities of the current situation considering countries responsibilities and capabilities. This effect would increase as we delay climate action and near 2030 since all global scenarios start at the same level and as inequality increases. Many countries have committed to NDCs much more ambitious than their 1.5°C allocations here, mostly sub-Saharan countries (under Approach 1). Under Article 6, these countries could still sell the emissions space towards their allocations (possibly through a conditional NDCs) and while progressing towards implementing the mitigation measures domestically implied by the cost-optimal scenarios[34]. Based on Approach 2, the assessment of the NDCs of the UK, Sweden and Switzerland is more stringent given their relatively low historical responsibility compared to their relatively high capability. Approach 2 also yields a more stringent assessment for multiple developing countries, mostly in Latin America, Northern Africa, and South and Southeast Asia.

The absence of continuity in emissions allocations also changes the ranking of countries in terms of additional mitigation effort needed to align with their allocation, which potentially affects their share of the climate finance. Figure 4 provides an illustrating case, of the influence of adding a 20-year transition period on the emissions allocation of G20 countries and the United Arab Emirates as a comparison to their respective NDCs. In theory, each country’s contribution to total international climate finance can be proportional to how much each country's NDC deviates from its fair-share level, relatively to other climate-finance providing countries.

We show that by adding a 20-year transition period to ensure continuous allocation, countries move up or down within the ordering very substantially in terms of additional mitigation gap. Compared to a traditional continuous approach, applying a discontinuous approach can implies a much higher obligation to contribute to international finance for Canada (moving up 9 positions), Australia (8), USA, Japan and South Korea (each 7 positions). Countries such as United Arab Emirates and Saudi Arabia would need to be among the largest contributors to international finance under both variants, but even more without continuity. Meanwhile, in terms of ranking, either approach makes very little difference for the EU, or for some lower-income countries, such as Brazil and India. This implies for the latter countries, the deviation of recent emissions from levels consistent with the equity principles, is more representative of the 'average' deviation of efforts by all countries.

Whereas discussions about climate finance in the context of the UNFCCC have often referred to the perceived obligations of, for example, high versus low-income countries, the comparison between continuous and discontinuous fairness allocation within the category of high-income countries alone, illustrates how within that category there are fairness arguments for ramping up climate finance much more for some countries than for others, if recent lack of action were rewarded less.

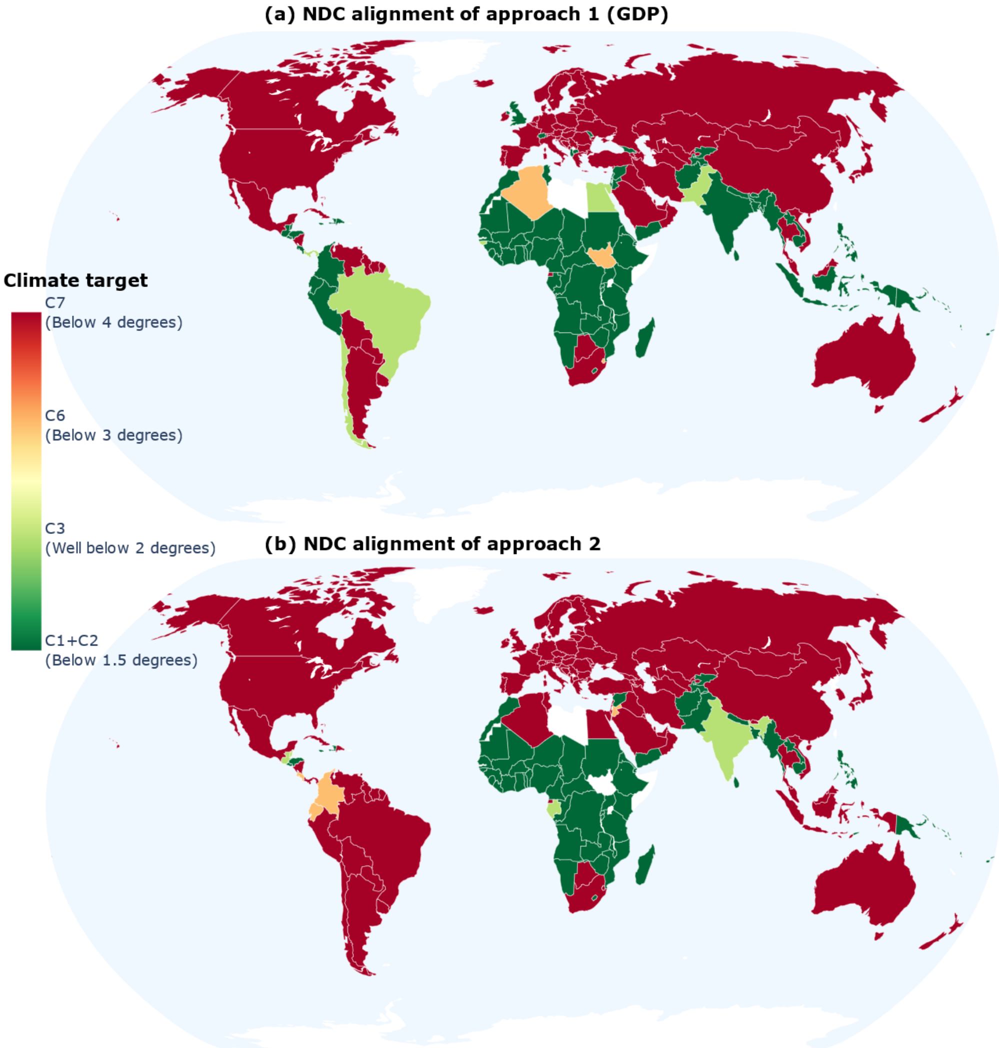

Figure 2 | Alignment of NDCs with the respective national allocation of emissions from global scenarios implying 1.5°C (with possible overshoot), likely below 2°C, below 3°C or below 4°C warmings, calculated with Approach 1 **(a)** and Approach 2 **(b)**. Colours at the edges of the legend range can reflect values outside the range, either more ambitious than a 1.5°C allocation or less ambitious than a 4°C allocation.

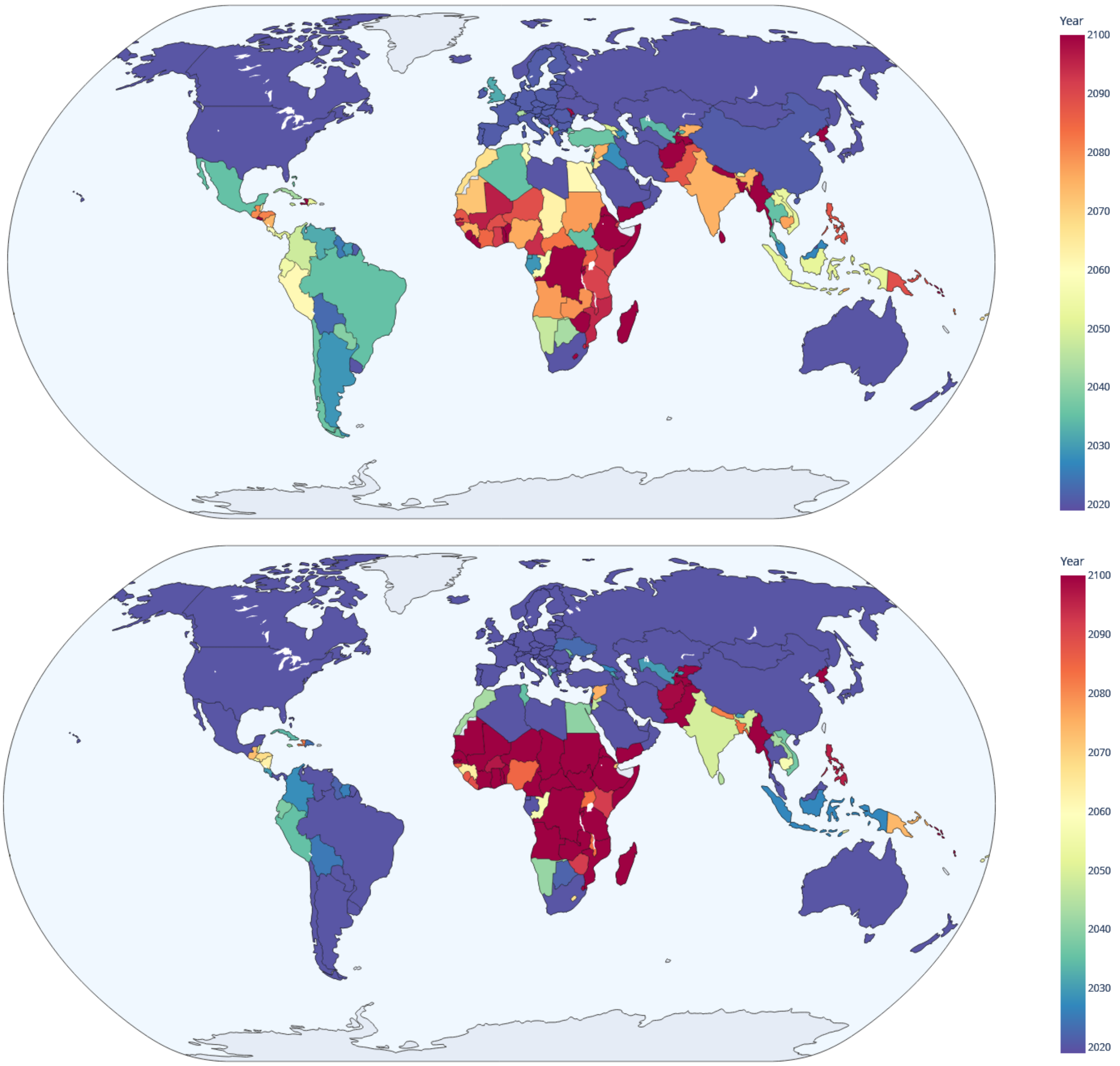

Figure 3 | Dates when emissions allocations first reach 43% below 2020 as suggested as global goal for 2030 by the IPCC based on Approach 1 **(a)** and Approach 2 **(b)**. The global emissions shared across countries, excluding LULUCF and bunkers reach 43% in 2035.

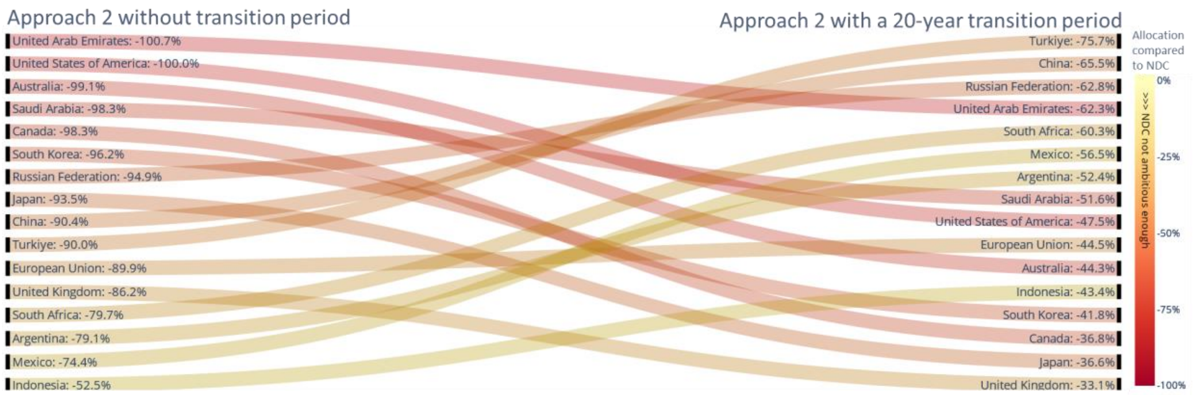

Figure 4 | Effect on 2030 emissions allocations of G20 countries and United Arab Emirates of adding a 20-year transition period (right side) from current emissions levels to the allocations calculated in Approach 2 (left side), expressed as a percentage reduction below countries' respective NDCs. Adding a transition period changes the relative differences between countries' NDCs and their emissions allocation. The ranking of additional mitigation effort needed for countries to align their NDC with their 1.5°C allocation changes when using a transition period.

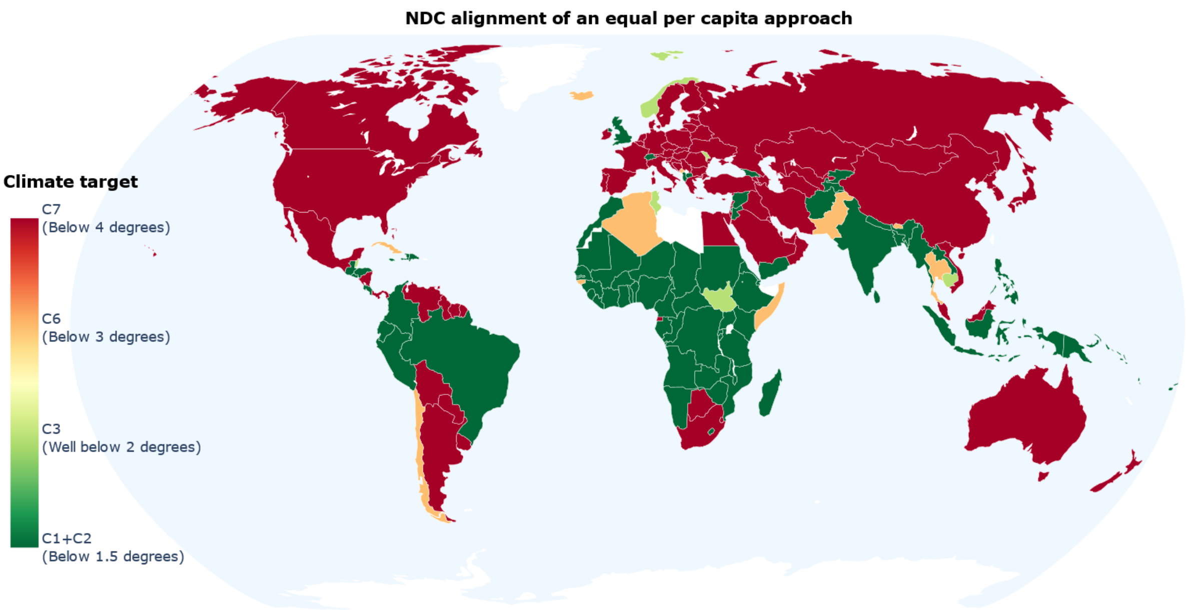

Figure 5 | Alignment of NDCs with the respective national equal per capita allocation of emissions from global scenarios implying 1.5°C (with possible overshoot), likely below 2°C, below 3°C or below 4°C warmings. Colours at the edges of the legend range can reflect values outside the range, either more ambitious than a 1.5°C allocation or less ambitious than a 4°C allocation.

The egalitarian approach of equal perc capita emissions is not directly anchored in the Paris Agreement or international environmental law[7], but can reveal the unequal emissions space claimed through NDCs. Figure 5 shows the equal per capita allocation of the emissions space at every point in time[11], each country's emissions allocation is proportional to its population. This map shows a quantification of the third equity principle highlighted by the IPCC[16], although not mentioned in the Paris Agreement. Even discarding countries' CBDR-RC, as modelled in approaches 1 and 2, this equality-based assessment yields similar ambition assessments for the largest emitters. In other words, the NDCs of many sub-Saharan countries are below the equal per capita levels of a 1.5°C scenario. However, NDCs of many countries with high responsibility and capability meant to reflect their 'highest possible ambition'[1] and account for CBDR-RC do not reflect an equal per capita share of a business-as-usual trajectory itself yielding warming impacts that hit some countries much harder than others.

Discussion

Incidentally, literature on fair emissions allocations that informs international negotiations on a fair implementation of the Paris Agreement also serves as a basis to inform courts[7,35] on legal emissions levels[36]. A transparent disclosure on inclusion or not of a continuity criterion in the literature can inform courts on how the modelling assumptions affect the assessment of whether or not a country's targets is legally sufficient[7,37].

The combination of effort-sharing allocations representing different equity dimensions of the CBDR-RC can be used to derive a single ambition metric reflective of different countries' positions. However, combining dissonant interpretations of the CBDR-RC into a single metric of ambition can affect the consistency of the allocations with the underlying equity principles. Averaging[3,38] or applying weighting factors[3] to equity formulas may reflect a numerical compromise where none of the approaches are met rather than a multidimensional vision of equity[39]. Likewise, the online tool Climate Action Tracker (CAT) can assess or suggest targets to reflect a broad selection of fair-shares available in the literature[14]. The underlying studies considered may have inconsistent hypotheses, including different starting dates strongly influencing near-term emissions allocations, different pursued warming outcomes using different global scenarios or budgets used differently over time. Combining this literature to ensure collective consistency with the global objectives and growing historical emissions inherently requires additional calibration and harmonization of the emissions levels from the underlying studies[7,37]. The reliance of the underlying literature on continuous approaches, and the iterative aggregation updates over time, can increasingly impact the ambition assessment of countries, likely in favour of parties with rapidly shrinking allocations. Alternatively, other studies apply different equity formulae to each country[5,40,41] distinctively, possibly reflecting a self-differentiated approach of equity reflective of the Paris Agreement bottom-up architecture[5] rather than a single principle applicable to all. Under this differentiated combination, each country's fair-share formula does not affect how the share of another country is calculated, instead it affects the global goal applied to all countries' formulae. While these combinations of equity concepts often rely on underlying continuous allocations, this is not a methodological requirement. The combination modelled in the present paper is also conceptual rather than numerical. It differentiates the application of different equity principles across the type of emissions, positive and negative. The combination suggested here seeks to provide a simple and transparent method to combine responsibility and capability with few arbitrary parameters, whose relevance and fairness implications can be discussed by climate actors. The approaches we model illustrate this sensitivity of allocations to illustrative implementation of interpretation of a combination of capability and responsibility in the absence of continuity criteria. Other ambition assessment frameworks and effort-sharing formula could consider discussing and quantifying the influence of the continuity component on their results.

A recent study[37] called for transparency regarding "ethical choices behind quantifications of fair contributions under the Paris Agreement". It categorized existing literature based on whether a grandfathering "perspective or approach had been used" explicitly or through the addition of a transition period. Here we identify a broader form of grandfathering influence that results from the modelling equity principle relying on continuous emissions allocations[7], which aligns with existing identification of a grandfathering effect contradicting ethical[37] and legal considerations[7]. However, several studies[3,42] previously found not to have a grandfathering influence[37] are continuous and hence feature a grandfathering influence, sometimes through the allocation of emissions budget as a continuous emissions trajectory[19,43,44]. Allocating emissions budgets requires making additional assumptions regarding the dynamic use of this budget. Even equity-based budgets could theoretically be used mostly in the near-term by countries and not collectively reflect any of the global 1.5°C mitigation scenarios underpinning the global budget. Budgets may not adequately track near-term ambition and progress on emissions reductions without additional assumptions. Furthermore, ad-hoc assumptions regarding the use of an emissions budget over time make the global aggregation of national trajectories inconsistent with the underlying global scenario, including its warming threshold and its socio-economic feasibility. Additionally, emissions budgets are not suitable for addressing the knowledge gaps identified in the IPCC AR6 of "extending equity frameworks to quantify equitable international support, as the difference between equity-based national emissions scenarios and national domestic emissions scenarios"[17]. Finally, the advantage of 'flexibility' identified in the use of carbon budgets over emissions pathways[11] comes at the expense of the ability to track progress over time against a decarbonization trajectory. Ensuring the continuity of the emissions trajectory when using an emissions budget or using a transition period towards equitable emissions levels[13,37] is an ad-hoc choice that brings a grandfathering influence[7]. In other models, the continuity of the emissions trajectory can result from the allocation of mitigation burden to depart from a business-as-usual trajectory rather than allocating emissions space independently of current levels[3]. Such an approach based on business-as-usual trajectories can be adequate to assess the ambition of an emissions target provided with a corresponding reference scenario. The 'grandfathering' effect can also occur when the ambition of an older target is assessed against newer emissions allocation based on newer business-as-usual scenarios that can no longer reflect the effort the target represented when adopted. With successive updates, the equitable emissions trajectory will come closer to even a business-as-usual target, and an assessment-update the year prior to the target will find it to be close to equitable. Therefore, such an approach may not be suited as a single metric to assess the ambition of several targets adopted at various times by countries[3,45]. Furthermore, this approach requires assuming counterfactual business-as-usual scenarios that are often not provided by countries that do not frame their targets as an effort to depart from a reference scenario[5].

The literature agrees on the insufficiency of most NDCs under the 1.5°C goal but diverges on the ambition gaps across countries. Here, only substantial improvement including international climate support can improve the warming assessment of many NDCs. Compared to a previous warming assessment[5] (visible on Paris-Equity-Check.org), Approach 1 finds NDCs to be more ambitious (1.5°C aligned) for a few countries (including India, Indonesia and Egypt) and less for Norway. Both Approach 1 and 2 have more polarized results with fewer NDC between 1.5°C and 3°C, partly because the previous warming assessment[5] relies on continuous approaches[4,13]. Looking at the CAT 'fair shares', the part of the CAT assessments that serves to assess the ambition of the overall mitigation effort in countries' NDC, results of our study are more stringent for G7 countries (in particular Australia, Canada and the USA, partly due to not rewarding a relative lack of emissions reduction efforts) and South Africa, and less for India and Brazil. The Climate Equity Reference Calculator (CERC)[15], published an NDC assessment[3] in 2017 that notably differed in finding China's NDC to be 1.5°C aligned, unlike most other assessments[4,5,11,14], including from Chinese institutions[6]. In terms of emissions allocations, the CERC finds much larger allocation for middle eastern fossil-fuel exporting countries (Saudi Arabia, United Arab Emirates, Qatar) indicating a need for international climate support despite their high GDP per capita. Under its default setup (responsibility since 1950), the CERC is more stringent for the EU with net-zero dates before 2030 (before 2035 in our study with responsibility since 1950) India, and LDCs collectively since their allocations are capped by their reference scenario. This capping disserves finance recipient countries for the calculation of potential climate finance compared to the present study. Capping finance based on a reference scenario can inform the UNFCCC streams on needs-based finance to fund efforts deviate from business-as-usual (for countries with the lowest responsibility and capabilities). However, updating reference scenarios may reset the starting point for calculating fair-efforts and may not account for the mitigation effort already conceded, by both countries providing and receiving finance, thereby rewarding inaction.

A recent study[24] quantified the interregional financial transfers, additional to domestic investment, that enable an equitable distribution of the mitigation costs by 2030. Alternatively, it is possible to calculate the amount of finance that country could provide to align its NDC with a fair emissions allocation, or receive when improving an NDC that is already within the country's fair share[46]. Implementing equitably the global IAM trajectory can imply that countries' domestic emissions trajectories follow cost-optimal scenarios – that can be downscaled at the national level[34] – and provide (or receive) climate finance needed to mitigate the difference with their equitable allocation. Compared to the equity-based emissions allocations of IAM trajectories, countries could pursue greater domestic mitigation to reap important co-benefits not accounted for, which can cover a substantial share of the mitigation costs[47]. Importantly, top-down effort-sharing formula such as used here may lose relevance for countries with small populations. Such countries may have limited technical options to mitigate emissions and limited access to some options given the small size of their economies.

The two approaches modelled in the present paper exemplify numerical outcome of combining modelling frameworks based on the recent literature to account for countries' responsibilities and capabilities with simple formulae. Beyond the countries' allocations derived here, this study highlights how iterative updates of ambition assessments based on continuous emissions allocations reward lack of action and result in shrinking amounts of implied provision of Internationally Traded Mitigation Outcomes by 2030. The ratcheting-up mechanism of the Paris Agreement is partly informed by assessments ratcheting-down the importance of near-term equity criteria. With the removal of an important near-term grandfathering effect, this methodology informs on both the amount that some countries could request to fund conditional NDCs, and the respective magnitude of finance that developed countries could provide, in light of their recent progress in reducing domestic emissions. Further studies could refine discontinuous emissions allocation framework in light of discussions on ambition and fairness under the Global Stocktake.

Methods

Approach 1 combines a capability-driven allocation of global negative emissions with a historical responsibility-driven allocation of global positive emissions to correct for historical responsibility and equalize per capita emissions rights over the considered period. The 'historical' period to account for responsibility here starts in 1950 to reflect recent historical emissions or in 1990 to account for observed emissions since the first IPCC report. In this approach, the capability of countries does not affect their total net emissions budget by 2100, only how the budget is used over time (its dynamic use). The capability driven allocation of growing global negative emissions (under the most ambitious global pathways) requires greater negative emissions from richer countries, mostly occurring after 2030. Achieving future negative emissions requires technologies (here excluding LULUCF) yet to be developed and that do not provide the important co-benefits of positive emissions reductions (e.g., energy security, health co-benefits). Since the responsibility-driven allocation of positive emissions ensures a given total emissions budget for each country, the capability-driven allocation of negative emissions results in an increase of near-term net emissions allocations for richer countries as it otherwise reduces their longer-term net allocations. Many of these richer countries would have negative emissions budgets in 2020 already under a pure equal cumulative per capita allocation of global net emissions. An alternative parameterization of this Approach 1 uses HDI instead of GDP to better reflect the development of countries and their potential needs for development, supported by a view of development that is not purely economic (see Supplementary Information). The HDI spans multiple development indicators wherein GDP is only one factor. A country with higher HDI is allocated a greater effort as a share of negative emissions. Comparing two countries with equal population and equal GDP, the country with higher HDI (that may result from better governance or potentially ill acquired wealth) will have greater effort to provide. Results based on HDI are available in the supplementary information.

Practically, the first step of this approach is to annually allocate to countries negative emissions (excluding LULUCF) of the global scenario proportionally to their respective GDP projection (and thus indirectly based on their populations). Unlike Fyson et al. 2020, the current approach does not filter out countries below the global mean of GDP per capita. As a second step, the positive emissions of the global scenario are then allocated to equalize per capita emissions over the considered period and reflect historical responsibility (in terms of emissions since 1950 or 1990). The budget is equal to the cumulation of equal per capita emissions over that period. This modelling accounts for historical responsibility dynamically as the sum over time of equal per capita share of the global emissions. The resulting budget matches that of a theoretical situation where countries had equal per capita emissions. This 'dynamic' modelling of historical responsibility differs from a more 'integrated' modelling where total emissions over the period considered are proportional to the total cumulated population over the same period. This budget can be negative for countries that had high emissions levels. Note that past emissions are first discounted by 1.5% each year in the past to account for technological improvement[48]. Each country is then allocated at every point in time (2020 to 2100) a fraction of the positive part of the global scenario proportional to its remaining budget. As a result, the first year's allocation differs from current emissions, and it may require IMTOs and very rapid scaling up of mitigation efforts to reconcile actual emissions with allocations over the period to 2030. The use of HDI, an indicator that does not depend on the population of a country, instead of GDP requires accounting for the population of a country. Here, we simply multiply HDI by the population of the country and use this indicator instead of GDP. Each country is allocated at every point in time a share of the global negative emissions proportionally to its share of the sum of all countries' HDI (2020 value) times their population projection.

Approach 2 models a capability driven allocation of the global positive emissions and responsibility driven allocation of negative emissions. This modelling can reflect a funding of the near-term transition mostly by countries with the most financial capacities. Following the results allocations can help mobilize the high investments needed to implement the mitigation measures across countries. Practically, the allocation of positive part of the global scenario follows the approach of prior studies[4,33], where each country gets a share of global emissions proportional to its population divided by its GDP per capita dynamically (that is at every point in time). This approach yields significant differences in emissions allocations across countries; which reflects the important differences across countries' GDPs (often proportionally greater than the differences of their historical contributions). This results in the allocation of important mitigation effort for richer countries as a share of a global mitigation effort, which remains minor compared to global GDP[2].

As a second step, the allocation of the global negative emissions is proportional to countries' respective contributions to cumulative emissions dynamically (since 1950 or 1990 consistently with Approach 1 parameterization). Countries are allocated a share of the effort to contribute to remove emissions proportionally to their contribution to global warming at every point in time. This contribution to negative emissions is thus linked with their past population through their emissions, but not linked to their future population. The influence of the responsibility component is entirely bounded by the levels of global negative emissions that grow over time. The starting point of the emissions allocation is thus hardly influenced by the responsibility component. The capability allocation contributes to reducing the difference of historical emissions across countries given the frequent correlation between countries' responsibility and capability.

The emissions allocations in the near term are driver by the GDP per capita of each country which yields very large allocations for poor countries. For example, the Democratic Republic of Congo has a large share of global emissions allocation compared to its current share. This is a result of its GDP (in purchasing power parity) per capita is 1/16th of the global value, and 1/115th of Luxembourg's[49]. For such countries, climate finance informed by Approach 2 allocations in this paper could increase their GDP indicators and thus reduce their allocation in turn. In practice, many of the poorest countries have committed to unconditional targets much lower than the equity-based allocations.

Ambition alignment of global emissions scenarios

Here, the warming alignments of a country's pledge reflects the global warming resulting from the emissions of the global scenarios whose allocation to that country is matched by its pledge. We use the representative scenarios from the IPCC-AR6 called C-scenarios, with warming outcomes ranging from 1.5°C to 4°C. The respective emissions levels, including their negative emissions components, are not necessarily ordered according to their warming outcomes given their underlying socio-economic assumptions. As a result, their respective emissions trajectories cross over time, which brings limitations in assessing ambition of the NDCs of a small number of countries (see supplementary information).

The reference to a 1.5°C alignment corresponds here to an alignment with the distribution of emissions of the average of scenarios of the IPCC Categories C1 ('below 1.5°C with no or limited overshoot'), itself averaged with the distribution of C2 ('below 1.5°C with high overshoot'). The 2°C alignment here follows the definition based on emissions scenarios C3 ('likely below 2°C') category. Otherwise considered are scenarios that fall outside 1.5/2.0°C to reflect alignment with symbolic warming thresholds, with the scenario categories C6 ('below 3°C') and C7 (below 4°C) reflecting current policies. Countries that do not align with their fair allocation of C7 scenarios can be considered dragging even the insufficient ambition current policies that do not track towards NDC. Avoiding any 1.5°C overshoot and ensuring a higher likelihood of achieving that warming threshold thereby implies smaller emissions allocations still than the ones presented in this article.

The alignment of an NDC with a given emissions scenario is based on the unconditional part of the NDC as it represents the mitigation effort provided by the country. When the emissions quantification of the NDC was provided with an uncertainty range, the alignment with a pathway (the colour grading in Figure 2, 4 and 5) is based on the average of the high and low values.

The absence of monotony between the warming response of the C-scenarios and their negative emissions can also result in non-monotonous 2030 allocations for some countries under Approach 1. In other words, some countries may have less stringent allocations under a 3°C scenario than under 2°C in 2030. While this paradox is compensated over time, such warming assessments are not relevant for these countries (list of countries in Supplementary Information).

Data sources

The global emissions scenarios whose emissions are allocated to countries are the average of ensembles of scenarios of the categories C1 to C7 from the IPCC AR6 database[50] (accessible here). The GDP data (in purchasing power parity, ppp) is taken from the Social Socioeconomic Pathways[51] associated with the global emissions scenarios (available here), specifically assuming the SSP2 scenario, describing a middle of the road between adaptation and mitigation challenges. Taking GDP without purchasing power parity correction could widen the difference in allocations between rich and poor countries. Historical emissions data is from the Potsdam Real-time Integrated Model for the probabilistic Assessment of emission Paths (PRIMAP)[52,53]. The population data is from the UN population prospects 2022 (available here). The HDI data (for 2020 only as projections are not available) is from the UN Development Programme (available here). The quantification of NDCs is taken from a recent publication[54,55] (updated in March 2023). The country level results are contingent on the limitations of the methods discussed above and on the limitation of the data projections used here. Population and especially GDP projections have intrinsic uncertainty that varies from country to country. In particular, GDP projections for small countries should be seen as best guesses and the resulting emissions allocation are indicative. Considering groups of small countries, possibly as their negotiating groups, can reduce the sensitivity of their emissions allocation to underlying data uncertainty. Additionally, the accounting of LULUCF emissions, here excluded, in reported data and emissions projections towards NDC target can bring high uncertainty for countries with important forest coverage. Here, the data is coming from single sources for all countries while the accounting of LULUCF in NDCs may differ from country to country and is often vaguely defined[54]. The allocation methods described here could be applied using other data projections, including governmental ones.

The countries considered are the 198 Paris to the UNFCCC. Parties for which data is missing are summarized in the Supplementary Information. Emissions allocations are run amongst countries with available data, and the emissions allocation of the EU is the sum of the allocations of its member states. Its allocation as a single entity would yield different results given the non-linearity of the effort-sharing formulae derived here. The same considerations apply to country groups.

Data availability

All the material part of the submission, including data contained in the figures of the main manuscript and described in the supplementary information are accessible for all countries online under the DOI 10.5281/zenodo.8003393

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Author contributions

Y.R.d.P. modelled the approaches. M.D. coded the implementation of the equity approach and provided the figures and derived the results. All authors contributed to the data review and wrote the manuscript.

Competing interests

The authors declare no competing interests.

Supplementary Information

Summary

1. Request from the Climate Vulnerable Forum and influence on the study
2. Description of additional material
3. Description of data limitations

1. Request from the Climate Vulnerable Forum and influence on the study

This work was co-funded by the CVF to inform the following request. The modelling presented in this article is not restricted to answer the following request. The rationale presented in the request represents one of the possible understanding of equity and of the Paris Agreement. The model develops in this study informs this request, amongst other possible parameterizations and interpretations.

Request as formulated by the CVF:

"This study was partly funded by the Climate Vulnerability Forum (CVF). The CVF secretariat aimed to provide guidance based on over a decade of forum member deliberations on climate policy issues, especially equity considerations, to identify key parameters and concepts that could guide an assessment of NDCs' alignment, or not, with the Paris Agreement temperature goal that might be considered broadly consistent with CVF views. Specifically, the CVF requested that the burden-sharing approach models a combination of a principle of capability and responsibility as per Article 2 of the Paris Agreement.

CVF Parameters for Evaluating NDC Alignment

In order to contribute to discussion and debate on the adequacy of any national climate change mitigation efforts under the Paris Agreement, this paper aims to transparently document key concepts of relevance to the CVF's appreciation of such concerns. Within this context, the following three chief *equity* parameters have, in particular, been proposed to guide this present papers' assessment of all countries NDCs for alignment with the Paris temperature goal:

1. Distribution - the issue of evenly distributing emissions' responsibilities to all countries, whereby everyone has an equal right and responsibility to ensuring a safe climate. This parameter manifests as conferring "common" or shared responsibility to not exceed a given global carbon budget (or, inversely: access rights to this budget) needed to keep within the Paris Agreement temperature goal, implying here country emission allocations are by population scale relative to one another.

2. Interval - the interval or time period over which any countries' per person responsibility for emissions should prevail. The CVF members have generally viewed responsibility to have a historical quality. The text of the UN Framework Convention on climate change (UNFCCC) itself called on developed countries to "lead", noting that "the largest share of historical and current [prior to 1992] global emissions of greenhouse gases has originated in developed countries". The CVF's broader research project is, for now, thereby exploring timeframes to 2100 and commencing in 1990, when the first IPCC report and first UN General Assembly resolution on climate change were adopted, as well as 1950.

3. Capability - the ability of any country to respond to climate change, especially as conditioned by available capacities and resources, which may be measured in a variety of ways, including economic (such as using Gross Domestic Product, GDP) or in human development terms (such using the UNDP Human Development Index).

The mandate provided to experts responsible for the present paper was to resolve the foregoing parameters - and not other - factors in a framework and approach that enabled comparable evaluation of countries' present national climate action pledges (NDCs) with the Paris temperature goal.

Data on developing countries' unconditional and conditional NDCs have been requested in order to contribute and enable discussion, bearing in mind that unconditional NDCs represent what a government is promising to deliver independently, whereas conditional NDCs depend on various forms of international cooperation and support, such as finance, technology, and capacity building."

Discussion of CVF's request in light of the available literature:

The three criteria detailed by CVF are comparable to the considerations influencing the literature on effort-sharing approaches.

The distribution criterion was implemented as part of effort-sharing formula allocating emissions to countries on a per capita basis, in line with the literature referenced in the manuscript.

The interval criterion was implemented by accounting for past emissions since 1990 (referred to as "observed" emissions by the CVF) and since 1950 (referred to as "historical" emissions by the CVF). In the absence of consensus under the UNFCCC on a period to account for countries' responsibilities, the literature referenced in this paper has modeled responsibility for past emissions since 1850, 1950, or starting at current dates. The 1950 and 1990 dates selected here are commonly used in literature.

The capability criterion implies that the approaches modelled here reflect considerations of capability (through GDP), jointly with considerations of responsibility. These considerations are explicitly present in Article 2 of the Paris Agreement and are already modelled in several studies and discussed in the 6th chapter of the Working Group 3 of IPCC AR5. Upon CVF's request, HDI was considered as a capability indicator, in addition to GDP.

The modelled choices to derive the novel approaches (Approach 1 and Approach 2) were developed by the authors independently of further consideration from CVF.

2. Description of the additional material

The supplementary data includes results for all countries visible as a HyperText Markup Language (HTML) file through different interactive figures. These two files contain emissions allocations data for all countries arranged in five figures, one file with responsibility accounted since 1950, one since 1990. To view the file content, the file needs to be downloaded and can then opened in a web-browser.

List of Supplementary figures (labelled Fig.1 to Fig. 5 in the file):

- Figure S1 | Greenhouse gases emissions allocation towards 1.5°C. (a) Emissions allocations of the 1.5°C scenario-set are shown in 2030, (b) cumulated budgets over the century, and (c) dynamically.
- Figure S2 | Emissions allocations of various global scenarios from 1.5°C to 4°C, under Approach 1 - GDP (left panel), Approach 1 - HDI (central panel), Approach 2 - GDP (transition) (right panel).
- Figure S3 | Warming assessment of NDCs for various effort-sharing allocations
- Figure S4 | Emissions allocation of the 1.5°C in 2030 under various effort-sharing allocations
- Figure S5 | Differentiated dates for national allocations to equal the global objective of 43% reduction below 2020

3. Description of the data limitations

Missing data

The unavailability of data necessary to calculate some countries' allocation has a minor impact on the global picture (Table S1) and results in the exclusion of some countries in the analysis (Table S2). In this section, countries are referred to by their iso-Alpha 3 codes.

Table S1 | Overview of missing data. If we weigh by population, the population data will always be fully complete. Hence, no data in cells filled with (*).

Variable	Percentage of countries missing (Number of countries)	Fraction of countries missing, weighted by population	Data source (references in main article)
Population (past)	0% (0)	*	UN population estimates
Population (future)	0% (0)	*	UN population prospects
GDP (past)	1.91% (4)	0.00075%	SSP2 projections from NAVIGATE
GDP (future)	1.91% (4)	0.00075%	SSP2 projections from NAVIGATE
Emissions (past)	0.48% (1)	0.0639%	PRIMAP
HDI	3.35% (7)	0.243%	UNDP
NDC	0.96% (2)	0.0852%	Climate Resource

Table S2 | Countries with missing data. All countries in this table, except from Libya, were excluded from the calculation of emissions allocations as some necessary data is missing. Their allocations are treated as null, which slightly increases the emissions space available to other countries.

Countries with missing variable	HDI	GDP	Emissions	NDC
COK (Cook Islands)	X	X		
VAT (Holy See)	X	X		X
MCO (Monaco)	X			
NRU (Nauru)	X			
NIU (Niue)	X	X		
SOM (Somalia)	X			
GMB (The Gambia)	X			
LIE (Liechtenstein)		X		
PSE (Palestinian Territory, Occupied)			X	
LBY (Libya)				X

Additional implications of missing data

- Emissions allocations to groups (e.g., SIDS, LDC, G7) are calculated as the sum of their respective members, even when some few members are missing. The resulting SIDS projections may be biased towards the other island states that are part of SIDS.

- For some countries, the GDP projections become extremely low towards 2100, some of which even have missing values in 2100. This may significantly affect calculations in Approach 2. Some countries obtain an erroneously high share of the total because of these GDP projections. These countries' iso-alpha 3 codes are: "AND", "ATG", "DMA", "GRD", "KIR", "MHL", "FSM", "MCO", "NRU", "PRK", "PLW", "KNA", "SMR", "SYC", "SSD", "TUV".

Implications of GDP disparities on Approach 2 allocations

The important disparities in countries' GDPppp per capita result in important emissions allocations for poorer countries with large populations, as a fraction of global remaining emissions (Figure S6).

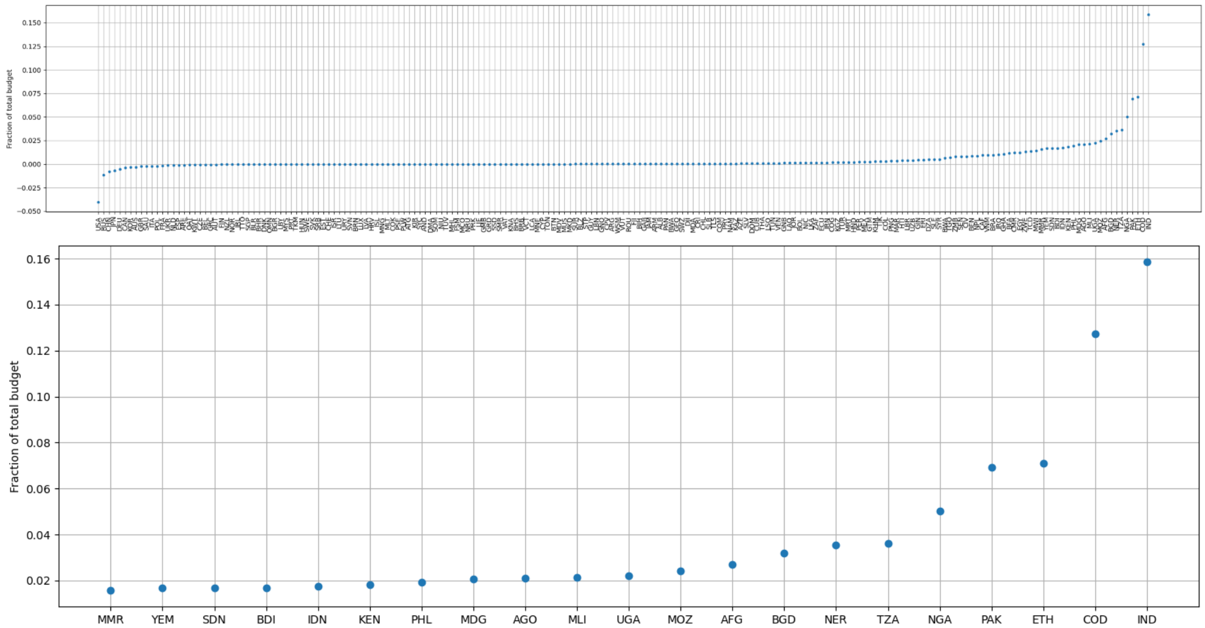

Figure S6 | Cumulative fraction of the global budget allocated to countries under the C1+C2 scenarios. The lower panel shows a zoom on the countries with the highest values. India has about 16% of the global budget (for a population of 1,4 billion people, 17% of the world) while the Democratic Republic of Congo has about 13% (for a population of 100 million people projected to reach around 400 million in 2100).

Monotony of emissions in C-categories

This section discusses the monotony between the warming levels associated with the scenario categories C1+C2, C3, C6 and C7 (1.5°C, 2°C, 3°C and 4°C rise respectively), and their emissions levels. Even though the positive parts of net-emissions are generally increasing with increasing temperature response, the negative parts emissions are not always. In Approaches 1 and 2, positive and negative emissions are separately allocated, and may have opposite effects (increasing or decreasing) on the net emissions allocations. These allocations may not monotonously increase along the warming response of the allocated global emissions scenarios. The check is performed on countries as well as country-groups.

For Approach 1, based on GDP, all of the countries and country groups are monotonous in terms of full-century budgets. The monotony check is performed on the 2030 allocations to ensure that the emissions allocations can be used as an ambition metric. For 2030 allocations (accounting for past emissions since 1990), 21 countries have non-monotonous allocations in 2030 (Figure S2 and S3). For Approach 2, none of the countries have non-monotonous allocations in 2030.

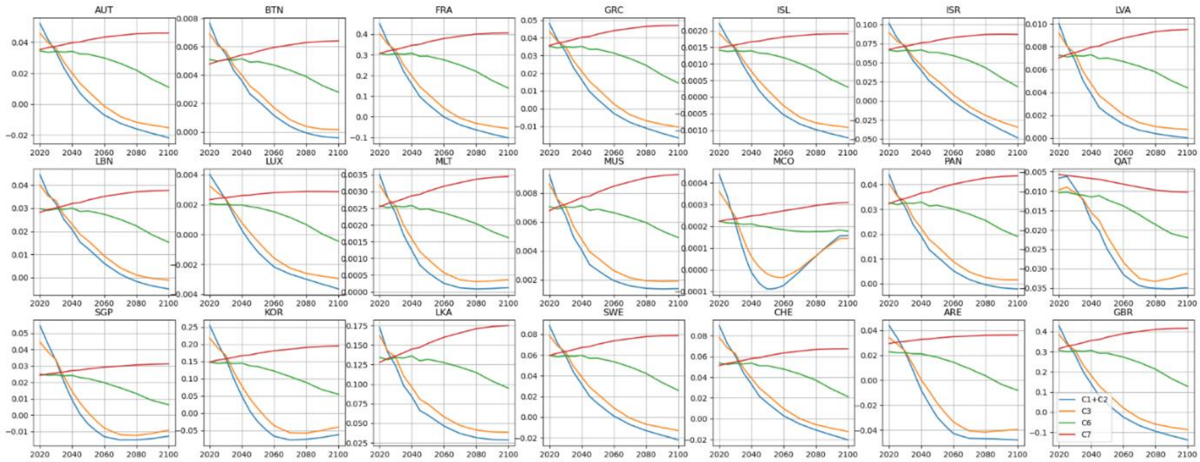

Figure S2 | Emissions allocation of the 4 global scenarios considered for the 21 Countries with non-monotonous allocations in 2030 with Approach 1, based on HDI.

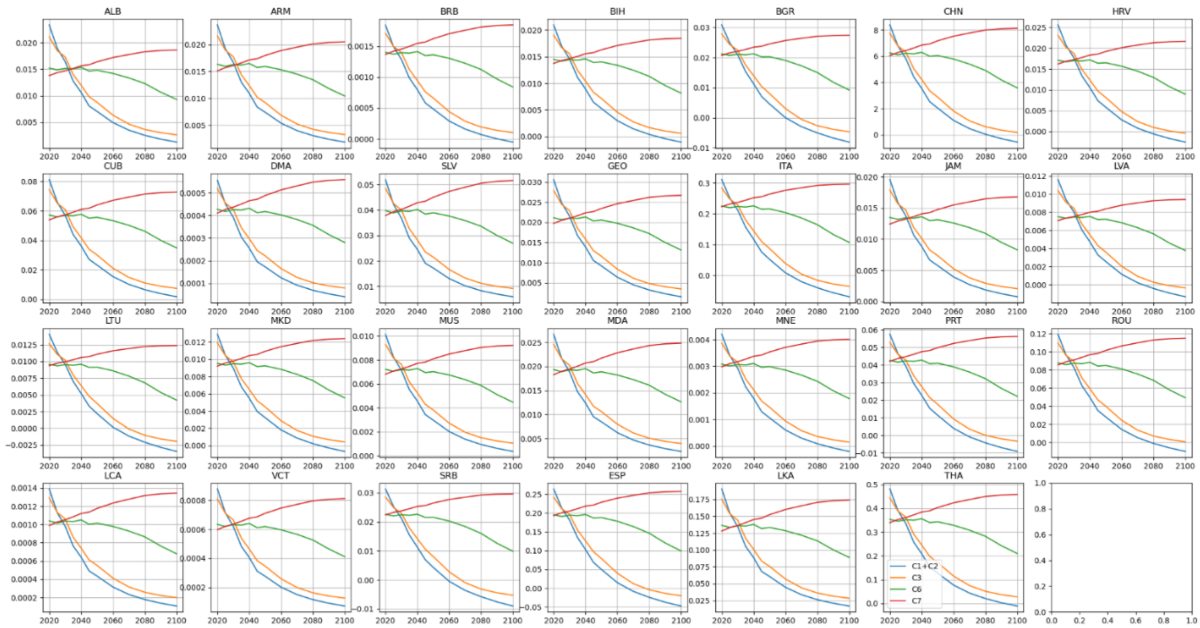

Figure S3 | Emissions allocation of the 4 global scenarios considered for the 27 Countries with non-monotonous allocations in 2030 with Approach 1, based on HDI.