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Uncompensated claims to fair emission space risk putting Paris Agreement goals out of reach

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Abstract

Addressing questions of equitable contributions to emission reductions is important to facilitate ambitious global action on climate change within the ambit of the Paris Agreement. Several large developing regions with low historical contributions to global warming have a strong moral claim to a large proportion of the remaining carbon budget (RCB). However, this claim needs to be assessed in a context where the RCB consistent with the long-term temperature goal (LTTG) of the Paris Agreement is rapidly diminishing. Here we assess the potential tension between the moral claim to the remaining carbon space by large developing regions with low per capita emissions, and the collective obligation to achieve the goals of the Paris Agreement. Based on scenarios underlying the IPCC's 6th Assessment Report, we construct a suite of scenarios that combine the following elements: (a) two quantifications of a moral claim to the remaining carbon space by South Asia, and Africa, (b) a 'highest possible emission reduction' effort by developed regions (DRs), and (c) a corresponding range for other developing regions (ODR). We find that even the best effort by DRs cannot compensate for a unilateral claim to the remaining carbon space by South Asia and Africa. This would put the LTTG firmly out of reach unless ODRs cede their moral claim to emissions space and, like DRs, pursue highest possible emission reductions, which would also constitute an inequitable outcome. Furthermore, regions such as Latin America would need to provide large-scale negative emissions with potential risks and negative side effects. Our findings raise important questions of perspectives on equity in the context of the Paris Agreement including on the critical importance of climate finance. A failure to provide adequate levels of financial support to compensate large developing regions to emit less than their moral claim will put the Paris Agreement at risk.

1. Introduction

The 2015 Paris Agreement contains a global objective to hold warming 'well below 2 °C and to pursue efforts to limit warming to 1.5 °C' (UNFCCC 2015). The scientific community has modeled a large number of mitigation scenarios that demonstrate different pathways to achieve this objective, many of which are developed using integrated assessment models (IAMs) (Keppo *et al* 2021). Pathways modeled using IAMs form a large proportion of the low carbon emission scenarios assessed by the Working Group III (WGIII) of the intergovernmental panel on climate change (IPCC) in its sixth assessment report (AR6) (IPCC 2022b). Given the prominent role these pathways play at the science-policy interface, it is unsurprising that a number of critiques and proposals for improvement have been raised (McCollum *et al* 2020, Keyßer and Lenzen 2021, Peng *et al* 2021, Schultes *et al* 2021). Such critiques and the blind spots they highlight in the design of scenarios can be consequential, precisely because they map out the solution space for policymakers (Keppo *et al* 2021, van Beek *et al* 2022). This raises profound questions around perspectives that are currently excluded from the existing suite of scenarios, limiting the perceived solution space seen by policymakers (Beck and Oomen 2021).

One such perspective that is largely missing in the existing suite of IAM scenarios is equity of regional emission reductions as highlighted by the IPCC, which notes the following about the scenarios assessed in AR6: '[m]ost do not make explicit assumptions about global equity, environmental justice or intra-regional income distribution.' (IPCC 2022b). This absence is concerning because equity is a central theme of international efforts to tackle climate change (and an important pillar of the Paris Agreement). In simple terms, using an equity lens to evaluate contributions to addressing climate change helps to account for one of the key moral dilemmas of climate change—that developed countries have contributed the most to causing the problem, but action to meet global climate targets will also require emission reductions from developing countries, some of which have contributed very little to causing the problem (Gardiner 2010, Dooley *et al* 2021).

Some contributions to the literature have tried to bridge the gap between cost-optimization (e.g. Rogelj *et al* (2018), Riahi *et al* (2021)) and equitable mitigation assessments (e.g. Winker *et al* (2013), Meinshausen *et al* (2015), Rajamani *et al* (2021)), and there are broadly two approaches suggested. The first approach is to *interpret* the gap (in emission terms) using the analytical separation between efficiency (cost optimality), and equity, assuming seamless international financial transfers to facilitate mitigation (Leimbach and Giannousakis 2019). The second approach is to *design and implement* scenarios with regionally differentiated carbon prices (Bauer *et al* 2020). The first approach is potentially difficult to apply directly to the current international climate policy context—international climate finance is continually highlighted as a failed promise, and is proving to be an ongoing challenge in international climate negotiations (Roberts *et al* 2021, Pauw *et al* 2022). The second approach, which we term 'heterogenous scenario construction' lends itself well to answer research questions that assume regionally differentiated mitigation actions—however, differentiation need not necessarily occur due to differences in the assumed regional carbon prices, as applied in Bauer *et al* (2020). Other examples of such an approach are papers that aim to evaluate the warming outcomes of current country-level emission reduction pledges, to track progress towards the collective achievement of the Paris Agreement's long-term temperature goal (LTTG) (Geiges *et al* 2020, Höhne *et al* 2021, Meinshausen *et al* 2022).

Here, we apply such a heterogenous scenario construction approach, by performing a reanalysis of the IPCC AR6 WG III scenarios (Byers *et al* 2022), to assess the potential tension between the moral claim to the remaining carbon budget (RCB) for 1.5°C by large developing regions, and the collective obligation to achieve the LTTG of the Paris Agreement. More specifically, we aim to answer the following research question: is the global achievement of the 1.5°C goal of the Paris Agreement still possible if South Asia and Africa (R10INDIA+, and R10AFRICA respectively following IPCC AR6 WGIII nomenclature—see supplementary information for the regional definitions following IPCC AR6 WGIII nomenclature) emit as much as they could claim to be morally entitled to, in the absence of adequate international transfers to compensate them for this moral claim? This research question is informed by the calls by some developing countries from those regions to 'operationalize equity' including through an 'equitable distribution of the carbon space' (LMDC Group 2022).

2. Methods

The focus on South Asia (R10INDIA+) and Africa (R10AFRICA) stems from the fact that these are the two world regions with the lowest historic per-capita emissions and thus, arguably, the largest moral claims to carbon space (depending on the equity principle applied). To answer the research question, we need to make two key assumptions to inform the design of long-term emission scenarios. First, we need to assess how much of the RCB for 1.5 °C these two regions have a moral claim to. Second, we need to make assumptions around the emission reductions that occur in the other world regions. Combining these two groups of emission pathways yields a global emission pathway that can be compared to the RCB assessed by the IPCC. We first present the two approaches we use to operationalize the moral claim—an equal cumulative per capita emission approach, and a capability-based approach. We choose these two approaches to reflect notions of 'responsibility' and 'respective capabilities', which are present in the Paris Agreement (see, for e.g. Article 2(2)).

2.1. Equal cumulative per capita emissions—historical responsibility and equality

This approach aims to represent notions of historical responsibility and equality (Höhne *et al* 2014). Following van den Berg *et al* (2020), we first calculate a 'carbon debt' for each region—this is defined as the CO_2 emissions per region, which exceeds a counterfactual equal per capita emission pathway (equation (1)):

$$Debt_r = \sum_{t=t_{\mathrm{start}}}^{t_{\mathrm{end}}} \frac{pop_{r,t}}{POP_t} \times E_t - e_{r,t} \tag{1}$$

for $Debt_r$, the historical carbon debt for region r, t_{start} and t_{end}, the time period (historical) for the assessment, $pop_{r,t}$, the population of region r in timestep t, POP_t, the global population in timestep t, E_t, the global emissions in timestep t, $e_{r,t}$, the actual regional emissions in timestep t.

A key decision while calculating the carbon debt is the starting year of the analysis, which is not only a matter of scientific judgment (e.g. data availability and quality), but also an ethical choice (Dooley *et al* 2021). We choose a starting year of 1990 to calculate the carbon debt because this was the year when the IPCC started providing science-based guidance to policymakers on climate change (Nauels *et al* 2019, Beusch *et al* 2022). For historical CO_2 emissions (fossil fuel and industrial, as well as land use emissions), we use the dataset published by Minx *et al* (2021). For population estimates, we use the population projections from the World Development Indicators database (World Bank 2022). To evaluate the implications of choosing a much earlier starting date (1850), we calculate the carbon debt using the PRIMAP-hist dataset (Gütschow *et al* 2016, 2021), which extends back to 1850 (albeit, without land use, land use change, and forestry emissions), and a composite population dataset from (Our World in Data 2022). We then proceed to calculate the regional fair shares of the RCB b_r (equation (2)), assuming that future population projections follow the middle of the road Shared Socio-Economic Pathway (SSP2) (Samir and Lutz 2017):

$$b_r = \sum_{t=2020}^{t_{\mathrm{peak}}} \frac{pop_{r,t}}{POP_t} \times B + Debt_r \tag{2}$$

where t_{peak} is the year of peak warming and B the global carbon budget. For the RCB (B in equation (2)), we use a value of 500 Gt CO_2 (from 2020), which the IPCC AR6 WGI assesses as providing a 50% chance of keeping warming below 1.5 °C (Canadell *et al* 2021).

2.2. Capability using GDP per capita as a proxy

A different approach to equitable allocations is to use a 'capability to contribute' metric. Here, we use the GDP per capita of each region in 2015 as a proxy to allocate the RCB (equation (3))—this proxy (GDP/capita) has been used in other studies in the literature as a metric to operationalize the notion of capability (du Pont and Meinshausen 2018):

$$b_r = \left[\frac{pop_{r,2015}/gdp_{r,2015}}{POP_{2015}/GDP_{2015}}\right] \times B \tag{3}$$

where $pop_{r,2015}$ is the regional population in 2015, $gdp_{r,2015}$ the regional GDP in 2015, POP_{2015} the global population in 2015 and GDP_{2015} the global GDP in 2015. We use the GDP/capita estimate for 2015 from the IMAGE SSP2-baseline scenario reported in the AR6 scenario database (Dellink *et al* 2017, Samir and Lutz 2017, van Vuuren *et al* 2021).

2.3. Translating equitable carbon budgets into emission pathways

Now that we have derived equitable carbon budgets for R10INDIA+ and R10AFRICA, we need to translate these budgets into emission pathways. There are multiple emission pathways that can potentially correspond to a cumulative emissions constraint (Raupach *et al* 2014). Here, we employ a simple two-stage process. First, we set a 2030 waypoint at the median of the 2030 CO_2 emissions across pathways assessed in AR6 WG III that pass through emission levels consistent with the nationally determined contributions (Byers *et al* 2022, Riahi *et al* 2022, IPCC 2022a). We interpolate linearly between the last historical year and the 2030 waypoint. Second, we proceed to identify a post-2030 rate of reduction per region that would result in the achievement of the regional carbon budgets identified above.

2.4. Constructing synthetic emission scenarios at the global level

After constructing the equitable emission pathways, we now need to determine the emission reduction pathways in other regions. In this paper, we choose to operationalize the notion of 'highest possible ambition' (see, for example, Article 4(3) of the Paris Agreement). In order to do so, we perform a re-analysis of the pathways assessed by AR6 WG III, at the R10 region level. We first filter for modeling frameworks that report more than three pathways in the C1 climate category of pathways—this is the lowest warming category available in the AR6 WGIII database. We group the R10 regions (except R10INDIA+, and R10AFRICA) into two groups—DRs (R10NORTH_AM, R10PAC_OECD, R10EUROPE, R10REF_ECON), and developing regions (R10CHINA+, R10REST_ASIA, R10MIDDLE_EAST, R10LATIN_AM). The metric we choose to select scenarios is the cumulative CO_2 emissions until the regional year of net zero CO_2 emissions.

For DRs, we select regional scenarios for each modeling framework, which have the lowest cumulative CO_2 emissions across the C1 category of AR6 WG III pathways to represent the highest possible ambition. For developing regions, we choose two pathways per region: (a) a maximum case, with the highest cumulative CO_2 emissions across the C1 and C3 category of AR6 pathways, and (b) a minimum case with the lowest cumulative CO_2 emissions across the C1 and C3 category of AR6 pathways. For reference, the C1 category of pathways limit warming to 1.5 °C (>50%) with no or limited overshoot, and the C3 category of pathways limit warming to 2 °C (>67%) (IPCC 2022b). The reason we select regional scenarios per modeling framework is because there are significant differences between each modeling framework (Harmsen *et al* 2021). Since we apply a cumulative CO_2 emission metric, calculated up to the regional net zero year, to select the emission pathways per region, this means that a given region (both developed, and developing) can contribute with net-negative CO_2 emissions if the regional year of net zero CO_2 occurs before the global year of net zero CO_2 of the synthetic scenario.

For each modeling framework, we assume that the AR6 WGIII pathway ensemble is comprehensive, and complementary, in terms of regional decarburization efforts, so that a recombination of different regional decarburization pathways is possible for the purpose of constructing 'synthetic emission scenarios'. We construct four such synthetic emission scenarios (scenario labels: ecpc_minc1_maxc3, ecpc_minc1_minc1, cap_minc1_maxc3, and cap_minc1_minc1) to answer our research question. These scenarios combine the two equity schemes, as well as the two sets of emission pathways for the developing regions, chosen to represent the range of 'highest possible ambition' outcomes. Each scenario is labeled using the following scheme that consists of three parts, with each part separated by an underscore. The first part indicates the equity scheme underlying the pathways for R10INDIA+ and R10AFRICA (ecpc—equal cumulative per capita, and cap—capability). The second part indicates the assumption underlying the pathway selection for DRs (in this case, the minimum cumulative emissions across the C1 pathways, or, minc1). By design, this is the same across all the four scenarios. The final part indicates the assumption underlying the pathway selection for developing regions, which varies between the minimum across the C1 pathways (minc1) for each region, and the maximum across the C1 pathways (maxc3) for each region.

2.5. Formal assessment of the warming implications of the pathways

The primary point of reference we use to assess the consistency of the scenarios with the LTTG of the Paris Agreement is the 1.5 °C RCB. However, a more complete assessment of the scenarios is necessary to compare the warming outcomes of the scenarios to criteria that have been suggested to operationalize the two textually linked elements of the LTTG ('hold warming well below 2 °C' and 'pursue efforts to limit warming to 1.5 °C') (Schleussner *et al* 2022). This requires assumptions to be made about the non-CO_2 emission trajectories, and the use of an appropriately calibrated simple climate model to capture uncertainty in the response of the climate system to emissions (Brecha *et al* 2022, Kikstra *et al* 2022). In this paper, we first infer the methane (CH_4) and nitrous oxide (N_2O) emissions using a quantile-based infilling method (Lamboll *et al* 2020), and then proceed to use the sequence of harmonization, infilling, and climate assessment steps applied in AR6 WG III (Kikstra *et al* 2022), with one key difference. We use the FaIR simple climate model (Smith *et al* 2018) with the solar cycle forcing estimates removed from 2016, so that we only assess the anthropogenic warming contribution of these emission pathways (Rogelj *et al* 2017). FaIR v1.6.2 uses a simple state-dependent carbon cycle and representation of atmospheric chemistry coupled to an energy-balance module, and calculates global mean temperature change, effective radiative forcing and concentration of greenhouse gases for a given emission pathway (Millar *et al* 2017, Smith *et al* 2018). The probabilistic setup we employ here is consistent with assessed ranges of equilibrium climate sensitivity, historical global surface average temperature, and other critical metrics assessed by IPCC AR6 Working Group I (Forster *et al* 2021). FaIR was chosen as it is open source and efficient to run. For further details on the calibration performed for AR6 WG III, please refer to Kikstra *et al* (2022).

3. Results

3.1. Focusing on the RCB

Determining whether the fair share of emission space should be based on the RCB, or the total carbon budget (the RCB plus historical cumulative CO_2 emissions from a pre-industrial reference) is an open question. When we apply the equal cumulative per capita emission scheme (equation (1)) to historical CO_2 emissions between 1850 and 2019 (excluding LULUCF emissions—see section 2), we calculate that R10INDIA+ and R10AFRICA have together emitted around 430 Gt CO_2 less than a counterfactual equal per capita emission pathway for the two regions (figures S1(a) and (b)). If the two regions were to lay claim to this 430 Gt CO_2, even without considering their claim to the 1.5 °C RCB, this would leave around 70 Gt CO_2 for all other regions to emit to remain within a no-overshoot 1.5 °C RCB, or around 220 Gt CO_2 for a low overshoot 1.5 °C RCB. If, in addition, the two regions were to claim their fair share of the RCB (equation (2)), then we cannot generate any synthetic scenarios that would stay within the 1.5 °C RCB. Since such an allocation puts the climate objectives of the Paris Agreement out of reach, we focus on the application of equity schemes to the 1.5 °C RCB (equations (2) and (3)), to investigate

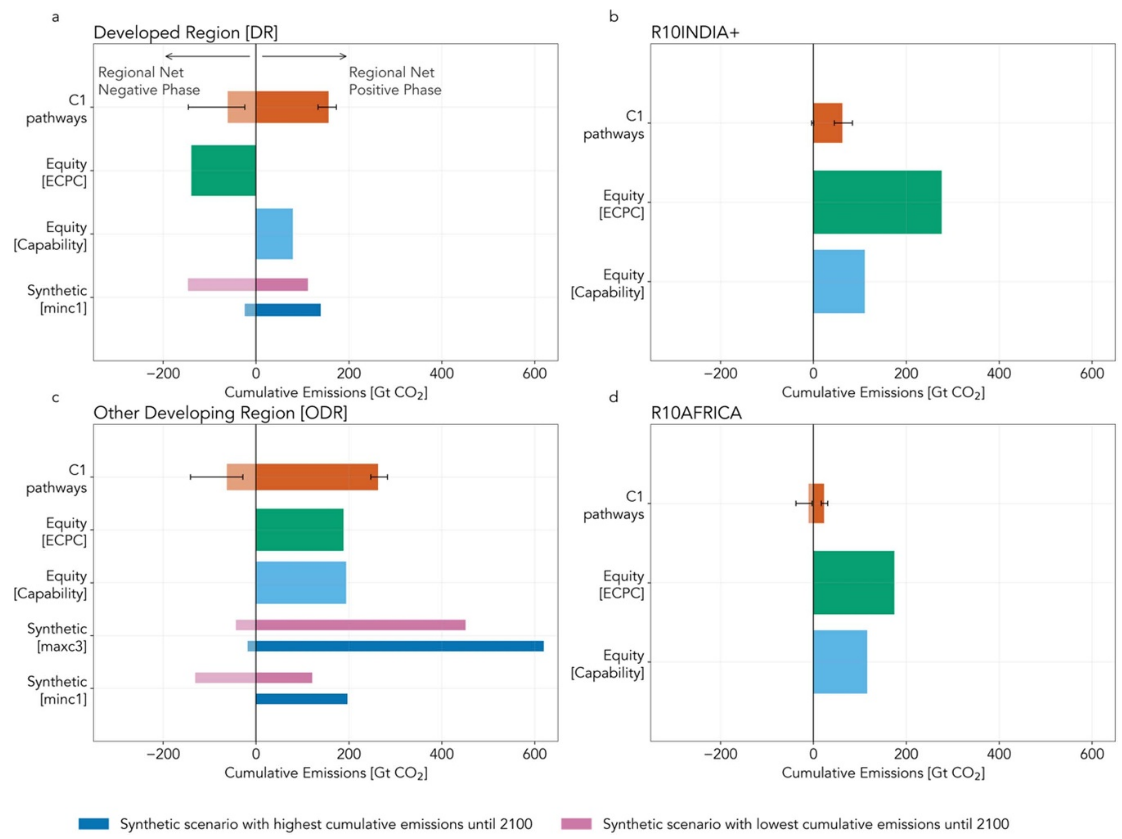

Figure 1. Cumulative emissions until the regional year of net zero CO_2. We compare the typical emissions across the C1 pathways (median, interquartile range indicated by the error bars) from the AR6 scenario database with the computed equitable emission allocations, and the emission allocations across the synthetic emission pathways (a) For the developed region [DR] (R10NORTH_AM, R10PAC_OECD, R10EUROPE), (b) R10INDIA+, (c) for the other developing region [ODR], which excludes R10INDIA+ and R10AFRICA, and (d) R10AFRICA. The C1 pathways limit warming to 1.5 °C (<50%) with no or limited overshoot. We illustrate how the net-positive and net-negative phases are defined in figure S3.

whether the climate objectives of the Paris Agreement can be attained (and, under what conditions). When we apply equation (2) (the equal cumulative per capita emission allocation) to the 1.5 °C RCB, we derive an emission allocation of 276 Gt CO_2 for R10INDIA+ and 174 Gt CO_2 for R10AFRICA. When we apply equation (3) (the capability-based allocation) to the 1.5 °C RCB, we derive an emission allocation of 111 Gt CO_2 for R10INDIA+ and 116 Gt CO_2 for R10AFRICA.

3.2. Assessing cumulative CO_2 emissions to regional and global net zero years

Given the lack of explicit equity assumptions in the mitigation pathways assessed in AR6, it is unsurprising that the typical emission allocation across the C1 pathways for R10INDIA+ (figure 1(b)) and R10AFRICA (figure 1(d)) are much lower than the emission allocations that would be consistent with the two equity schemes. We aggregate the emissions across the DRs into a composite DR, and the corresponding emissions across the developing regions into a composite other developing region (ODR) to present the results. For the DR (figure 1(a)), the synthetic scenarios have net positive CO_2 emissions that range between 80–153 Gt CO_2, compared to a median of 156 Gt CO_2 across the C1 pathways in the AR6 WG III scenario database. In the net-negative CO_2 phase, cumulative emissions span −146 to −23 Gt CO_2, compared to a median of −61 Gt CO_2 across the C1 pathways. We already observe that even the 'highest possible ambition' by the DR cannot make up for the increased emissions by R10INDIA+ and R10AFRICA (figures 1(b) and (d)), indicating the importance of the ODR (and its constituent regions) in determining whether the Paris Agreement's LTTG can be kept in reach.

None of the synthetic scenarios constructed using the maximum cumulative emissions across the C1 and C3 categories for the developing regions (ecpc_minc1_maxc3, and cap_minc1_maxc3) keep cumulative emissions until net zero CO_2 within a low overshoot 1.5 °C carbon budget. This finding holds irrespective of the quantification of the moral claim for R10INDIA+ and R10AFRICA, with the remaining low overshoot 1.5 °C carbon budget exceeded by 237–517 Gt CO_2 for the Equal Cumulative Per Capita (ECPC) case, and 97–343 Gt CO_2 for the Capability

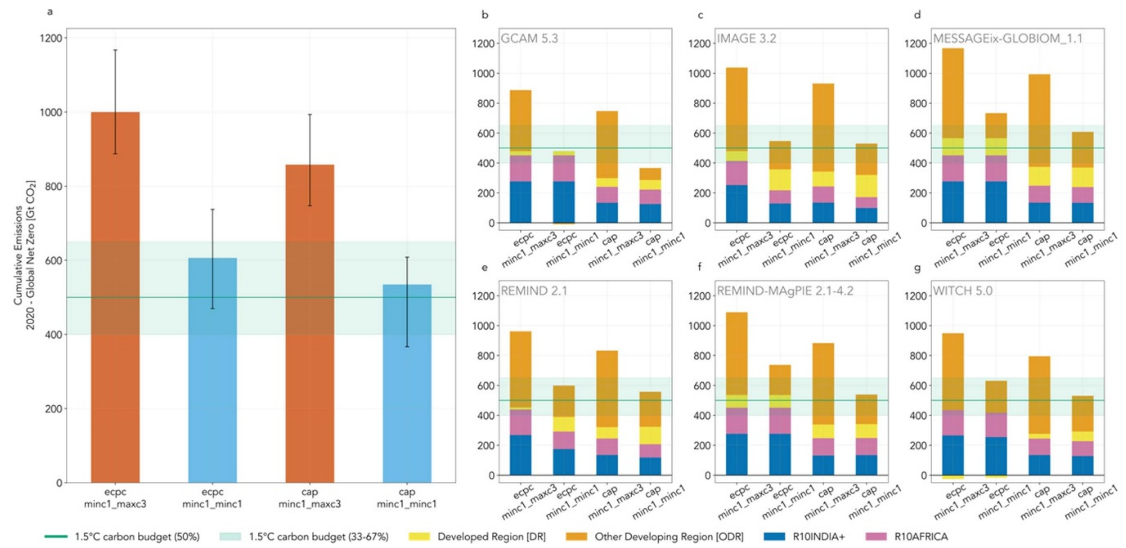

Figure 2. Comparing cumulative emissions until global net zero CO_2 with the remaining carbon budget for 1.5 °C. (a) Across the four sets of scenarios, where the error bar shows the range of outcome across the individual synthetic scenarios, (b)–(h) Across each synthetic scenario for a single modeling framework. The modeling framework is indicated in the top-left corner of each panel. The horizontal line and the shaded region indicate the median, and the 33rd–67th percentile of the remaining carbon budget for 1.5 °C assessed by the IPCC (Canadell *et al* 2021).

(CAP) case (figure 2(a)). The quantification of the moral claim becomes important when we assess the scenarios where the developing regions instead follow the lowest cumulative emission trajectories across the C1 and C3 categories (ecpc_minc1_minc1, and cap_minc1_minc1).

For this subset of scenarios, all scenarios constructed using the capability-based equity approach (cap_minc1_minc1) keep cumulative emissions until global net zero CO_2 within the low overshoot 1.5 °C RCB (figure 2(a)). We also note that many of the scenarios in this subset (figures 2(b), (c), (f) and (g)) have cumulative CO_2 emissions that are close to a RCB associated with limiting peak warming to 1.5 °C (>50%). However, in the ECPC case (ecpc_minc1_minc1), two out of six scenarios have cumulative CO_2 emissions that exceed the low overshoot 1.5 °C RCB (these scenarios are constructed using the scenarios reported by MESSAGEix-GLOBIOM 1.1—figure 2(d), and REMIND-MAgPIE 2.1–4.2—figure 2(f)). The reason these two synthetic scenarios demonstrate this behavior is because they do not achieve net zero CO_2 emissions globally, to compensate for the increased emissions in R10INDIA+ and R10AFRICA. This is an issue which we explore in further detail in the following section.

3.3. A waterbed effect—regional net zero timings and net negative emissions sensitivity case

In the previous section, we have established that there are two key features of the scenarios that would place future emissions on a 1.5 °C low overshoot trajectory. The first, is a scenario design input, which is that the DR minimizes its net emissions (figure 1(a)). The second is that other regions comprising the ODR in our analysis are also required to minimize net emissions, which is not a fair outcome for those regions. Across the synthetic scenarios we observe that the latter also results in a convergence between the net zero CO_2 timings between DR, and ODR (figures 3(a)–(f)). Note that we calculate this metric for the aggregate region, and not across the individual sub-regions.

Only 5 out of 24 synthetic scenarios have a net zero CO_2 year for the ODR, which is later than the global net zero CO_2 timing (see figure 3 for the ranges in the regional and global net zero timings). Across the other 19 scenarios, the ODR has global net zero CO_2 timings, which are around two decades on average (range: 0–6 decades) ahead of the global net zero CO_2 year. This indicates that, by the time of global net zero CO_2 emissions, the ODR is already contributing negative emissions, which raises further questions around equity and fairness related to negative emissions (Fyson *et al* 2020). Among the developing regions that constitute the ODR, R10LATIN_AM has negative emissions in the year of global net zero CO_2 across all the synthetic scenarios (table S3). For R10LATIN_AM, the negative emissions in the year of global net zero CO_2 can span from 3%–5% (REMIND-MAgPIE 2.1–4.2) to 59%–161% of the 2015 emission levels (WITCH 5.0) (table S3). To assess the potential implications of this regional reliance on negative emissions, we construct a set of sensitivity scenarios, where

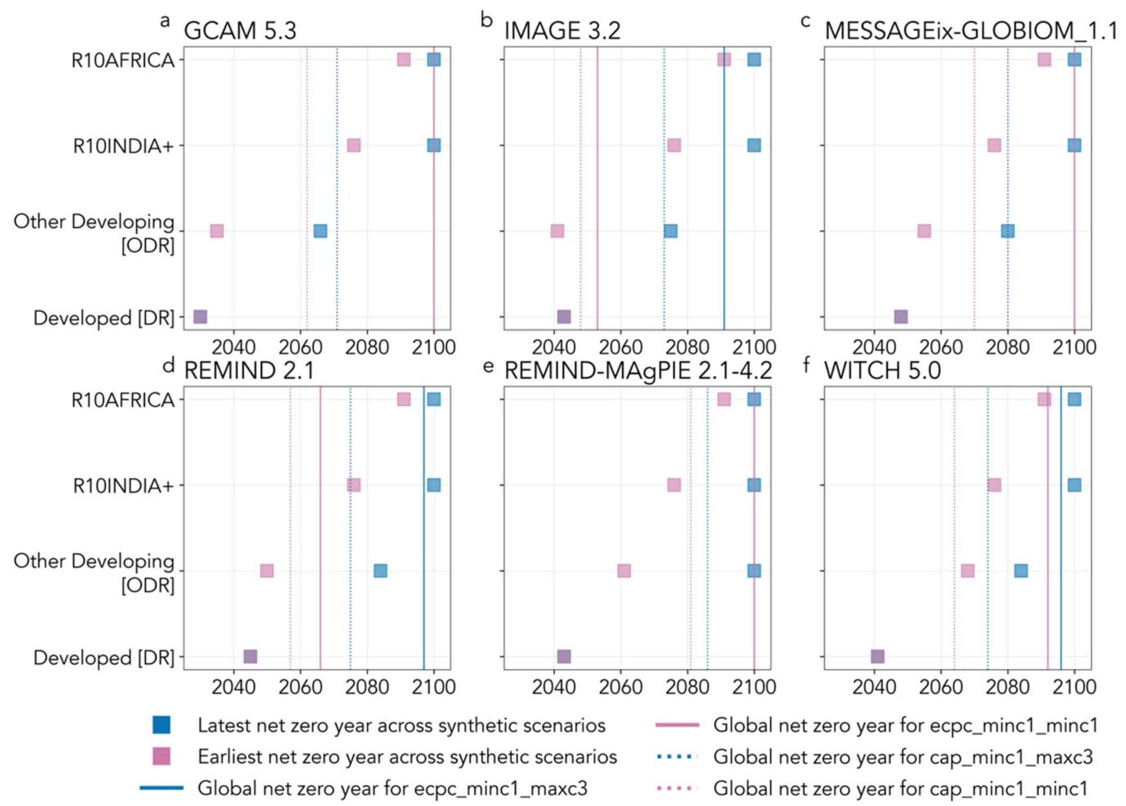

Figure 3. Net zero timings across the synthetic scenarios for key regions. (a)–(f) Across each synthetic scenario for a single modeling framework. Note that the net zero years for DR are in purple because the latest and earliest net zero years coincide.

emissions for R10LATIN_AM are flatlined after achieving zero CO_2 emissions. We evaluate the results of the formal assessment of the warming outcomes of the main, and sensitivity scenarios in the following section.

3.4. Formal assessment of the warming outcomes of the scenarios

So far, we have restricted our scenario assessment to a 33%, or 50% RCB for 1.5 °C—this corresponds to a 'low overshoot' or 'no overshoot' definition respectively, as adopted by the IPCC. Here, we assess the warming outcomes using the simple climate model FaIR (v1.6.2) in a probabilistic setup, which allows us to map these outcomes to pathway criteria that operationalize the LTTG of the Paris Agreement (Schleussner *et al* 2022). In table 1, we highlight scenario characteristics which pass the criteria in sky blue, and those which do not, in red.

We generally observe that the formal warming outcomes of the scenarios map well to the 1.5 °C RCB assessment that we carry out above, with a few exceptions. The first is that the synthetic scenarios for the ecpc_minc1_maxc3 case constructed using the Global Change Assessment Model (GCAM) 5.3 modeling framework keep peak warming below 1.5 °C with at least a 33% chance, while the cumulative CO_2 emissions until net zero CO_2 exceeds the 1.5 °C RCB by a wide margin (figure 2(b))—we trace this difference back to the process of infilling the non-CO_2 gases, especially in the 2020–2030 timeframe (figure S4), reiterating the importance of a formal warming assessment, and associated warming uncertainties. Second, we observe that while many scenarios in the ecpc_minc1_minc1 case keep peak warming below 1.5°C with a greater than 33% chance, they do not bring warming down to 1.5 °C in 2100 with at least a 50% chance, or keep warming below 2°C with at least a 90% chance. For both criteria, the sensitivity cases constructed with no negative CO_2 emissions lead to an increase in the peak exceedance probability (around 3% points increase for 1.5 °C, and around 2% points increase for 2°C), and median end of century warming (around 0.05 °C increase) for the ecpc_minc1_minc1 case. We note that these results, especially those close to the thresholds, are somewhat sensitive to the choice of emulator (FaIR v1.6.2 in this case). Another simple climate model, MAGICC (Nicholls *et al* 2020), which was applied for the scenario categorization in AR6 WGIII, exhibits faster near-term warming, and slightly higher peak temperatures than FaIR, especially for scenarios consistent with a 1.5 °C RCB (Kikstra *et al* 2022). Hence, for some scenarios (e.g. GCAM 5.3 ecpc_minc1_maxc3 in table 1), we would expect them to breach the thresholds

Table 1. Formal assessment of warming outcomes of the scenarios. We compare the warming outcomes to the thresholds outlined in Schleussner *et al* (2022). The cells are colored according to whether they pass the criterion (sky blue) or not (red). For an overview of the criteria applied here, please refer to the table S4.

		Exceedance Probability 1.5 C (FaIRv1.6.2)				median warming in 2100 (FaIRv1.6.2)				Exceedance Probability 2.0C (FaIRv1.6.2)			
	Scenario	cap_min c1_maxc 3	cap_min c1_minc 1	ecpc_min c1_max c3	ecpc_min c1_min c1	cap_min c1_maxc 3	cap_min c1_minc 1	ecpc_min c1_max c3	ecpc_min c1_min c1	cap_min c1_maxc 3	cap_min c1_minc 1	ecpc_min c1_max c3	ecpc_min c1_min c1
Model	Case												
GCAM 5.3	Baseline	0.64	0.46	0.66	0.47	1.54	1.36	1.61	1.43	0.13	0.05	0.16	0.07
	Sensitivity_lam	0.64	0.48	0.67	0.53	1.56	1.39	1.62	1.5	0.13	0.06	0.16	0.09
IMAGE 3.2	Baseline	0.73	0.54	0.76	0.57	1.59	1.37	1.68	1.47	0.17	0.06	0.21	0.08
	Sensitivity_lam	0.73	0.57	0.81	0.6	1.63	1.44	1.76	1.54	0.18	0.08	0.27	0.11
MESSAGEix-GLOBIOM_1.1	Baseline	0.72	0.54	0.75	0.6	1.64	1.46	1.71	1.56	0.18	0.08	0.22	0.12
	Sensitivity_lam	0.73	0.53	0.78	0.64	1.67	1.46	1.73	1.6	0.2	0.08	0.24	0.15
REMIND 2.1	Baseline	0.66	0.55	0.71	0.55	1.54	1.35	1.64	1.44	0.14	0.06	0.18	0.08
	Sensitivity_lam	0.66	0.53	0.71	0.57	1.56	1.4	1.65	1.51	0.14	0.06	0.19	0.1
REMIND-MAgPIE 2.1–4.2	Baseline	0.68	0.51	0.79	0.61	1.6	1.45	1.74	1.59	0.16	0.07	0.25	0.14
	Sensitivity_lam	0.68	0.52	0.8	0.62	1.61	1.46	1.75	1.59	0.16	0.07	0.26	0.14
WITCH 5.0	Baseline	0.65	0.51	0.74	0.6	1.56	1.42	1.69	1.56	0.14	0.07	0.21	0.12
	Sensitivity_lam	0.67	0.53	0.78	0.63	1.6	1.47	1.74	1.6	0.16	0.08	0.24	0.15

identified by Schleussner *et al* (2022), if MAGICC was used for the climate assessment.

4. Discussion and conclusion

In the absence of appropriate recognition of equity, and international financial transfers from developed countries, some scholars have suggested a unilateral claim to the remaining carbon space as a last resort (Jayaraman and Kanitkar 2016). In this paper, we have constructed a set of synthetic emission scenarios to assess the implications of such a moral claim by South Asia and Africa using the scenarios underlying IPCC AR6 WG III. We find that there are two possible outcomes across all scenarios, even when DRs minimize their ongoing CO_2 emissions—either the Paris Agreement's LTTG is breached, or ODRs need to minimize their CO_2 emissions as well to compensate for the gap between maximum DRs emission reductions observed in the AR6 WG III scenarios and the 1.5 °C LTTG.

The former case, which is invariant to the specific quantification of the moral claim we assess here is in itself an undesirable and highly inequitable outcome, especially for the populations of South Asia and Africa exposed to the impacts of climate change (Schleussner *et al* 2018, Saeed *et al* 2021). The latter case, which requires ODRs to not only minimize their CO_2 emissions, but also to contribute with negative emissions, risks cascading inequities to ODRs, as well as raising potential sustainability concerns associated with large-scale deployment of negative emissions (Fuss *et al* 2018). The willingness of ODRs to reduce their emissions below their fair share will also be strongly dependent on the provision of appropriate levels of international finance. Looking ahead, based on the scenarios we assess here, we suggest three policy-relevant actions for DRs. First, we propose that DRs commit to not only strengthening their emission reduction commitments to align with the maximum possible ambition, but also to deploy net-negative CO_2 emissions in proportion to the cumulative net-positive CO_2 emissions that they are responsible for (Fyson *et al* 2020). Second, we suggest that DRs recognize the importance of equity in discussions of international climate finance, especially in light of recent work by Pachauri *et al* (2022), which indicates that the current level of financial flows for mitigation are not only insufficient to meet the climate objectives of the Paris Agreement but also unfairly distributed. Finally, we reiterate that DRs should show appropriate haste in facilitating the deployment of international financial transfers at scale to avoid putting the goals of the Paris Agreement out of reach.

4.1. Limitations and outlook for further work

In this work, we have used an ethically, and methodologically transparent approach to construct emission scenarios with heterogenous regional objectives. However, as is true for any work that relies on an unstructured ensemble of opportunity, we cannot draw conclusions on whether the regional bounds assessed here are the actual lowest possible regional emissions (Guivarch *et al* 2022). The scenarios (per modeling framework) constructed here should be understood to represent a potential scenario that could have been constructed by that modeling framework if: (a) regionally differentiated carbon prices were applied to match a pre-defined regional carbon budget, (b) regional carbon budgets are applied. Ideally, a structured ensemble of scenarios using an inter-model comparison project would help evaluate further characteristics of such heterogenous scenarios, including a feasibility assessment (Brutschin *et al* 2021), and quantification of the magnitude of financial transfers.

Data availability statement

The code used to conduct the analysis, prepare the figures, and a README to locate the openly available input datasets is available at: https://gitlab.com/climateanalytics/tradeoff_scenarios.

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Author contributions

G G, C F S, and M J G initiated the study. G G performed the analysis with input from M J G, C F S, and A N. C J S provided the FaIR parameter set used in this study. G G and C F S wrote the manuscript with input from C J S, A N, M J G, K R, and C F. All authors provided contributions to the final draft of the manuscript.

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