Equity Assessment of Global Mitigation Pathways in the IPCC Sixth Assessment Report

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Abstract

The remaining carbon budget to restrict warming levels to 1.5℃ or 2℃ is limited and rapidly being depleted, making the assessment of potential mitigation pathways for policymaking for the future, both important and challenging. The Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report (AR6) relies heavily on modelled mitigation pathways to assess policy-relevant outcomes. In this paper, we analyse 556 model scenarios assessed by IPCC's Working Group-III for the 6th Assessment Report, which have an underlying 10-region classification and correspond to restricting warming levels to 1.5℃ and 2 ℃. Our results show that the IPCC AR6 scenarios disregard both the historical responsibility of the global North for carbon emissions as well as the future energy needs of the global South required to meet developmental goals. The burden of climate change mitigation is placed squarely on developing countries, while developed countries continue to increase their energy consumption unhindered by constraints on the use of fossil fuels. Our analysis clearly underlines the need for new frameworks for emissions modelling, scenario building, and constructing ideas of a future that makes the planet "liveable" for all and not just some sections of the global population.

Key Words

IPCC, Mitigation, climate equity, CBDR, climate scenarios, SSPs, modelling, carbon budget, fossil fuel use, net zero emissions, carbon sequestration

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Introduction

The world has warmed by 1.1 ℃ between 1850 and 2019 due to the anthropogenic historical cumulative CO_2 emissions of 2390 (±240) GtCO2 and other greenhouse gases (GHGs), including short-lived climate forcers, during this period (IPCC, 2021). Four-fifths of the global carbon budget to limit temperature rise to 1.5 ℃ (>50% probability), and two-thirds of the global carbon budget to limit temperature rise to 2 ℃ (>67% probability), is already exhausted (IPCC, 2022). Hence the assessment of potential mitigation options and pathways for the future has become even more important for policymaking than in the past.

The recently released Working Group III contribution to the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) relies heavily on global modelled mitigation pathways (or *scenarios*) based on the use of Integrated Assessment Models (IAMs) (IPCC, 2022).

However, for these scenarios to be relevant to policymaking, especially in the climate negotiations under the United Nations Framework Convention on Climate Change (UNFCCC) (hereinafter referred to as the Convention when alluding to its text), it is important to assess them in the light of the foundational principles of the Convention, especially with reference to equity and the principle of common but differentiated responsibilities and respective capabilities (CBDR&RC). Both these principles have a manifest role in the implementation of the Convention and its Paris Agreement, especially in the processes of the periodic Global Stocktake (GST) and in determining the adequacy and need for enhancement of the Nationally Determined Contributions of countries (UNFCCC, 2016; UNFCCC,2019). Equity in the light of the Convention, and in the sense the term will be deployed further in this paper, clearly refers to equity between countries and regions, while intra-country equity is the subject of domestic policies and the sovereign jurisdiction of national governments, outside the scope of the Convention.

In general, the assessments of the IPCC do not consider equity and CBDR&RC or adherence to the responsibilities and commitments of the Convention or its Kyoto Protocol and Paris Agreement to be a requirement in filtering the literature that it finally undertakes to assess. Detailed discussions of equity and CBDR&RC issues are typically relegated to a specific chapter in the Working Group III assessments (in AR6) under the rubric of international cooperation, but even these discussions do not specifically apply to mitigation pathways. There are other references to equity (or climate justice) in the Working Group II contribution to AR6 as well, but none of these carry any specific assessment of equity between countries and regions.

While these qualifications, regarding the lack of assessment of equity, exist in the full report, their representation in the Summary for Policymakers (SPM) of the IPCC report is pithy. It is also completely absent in the material used by the IPCC for the outreach of its results as well as in related presentations by IPCC officials and authors[4].

The Equity Deficit in AR6 Scenarios

The prima facie importance of equity considerations in global scenarios and mitigation pathways is obvious from the data on the wide global disparity in historical responsibility for cumulative emissions and a similar disparity in the current per capita annual emissions.

The WGIII AR6 contribution notes that 57% of the historical cumulative CO_2 emissions from fossil fuel use and industry, from 1850 to 2019, have been from developed countries (not including Eastern Europe), despite their accounting for, currently, only approximately 16% of the global population (IPCC,2022a). A similar situation obtains with respect to current emissions, where again the contribution of developed countries is substantially disproportionate to their share of the global population (IPCC,2022; IPCC, 2022a). These differences in cumulative and current annual emissions are a reflection of the highly unequal energy consumption between the two groups, which in turn also correlates with widely unequal incomes, wealth, and levels of human development across these regions (Martinez and Ebenhack, 2008). In 2019, the median energy consumption in Annex-I countries was 137.6 GJ/person as opposed to 58.85 GJ/person in non-Annex-I regions with corresponding median per capita GNI levels of $43,930 and $10,360 respectively (BP 2021, World Bank).

It has been a long-standing problem in the literature on climate mitigation, especially climate mitigation policy, that while the need for equity between countries and regions is acknowledged, there is little effort to operationalize the same, with notable exceptions (Kanitkar et al, 2013; Baer et al, 2022;). In the same vein, the AR6 includes several calls for climate justice, equitable climate action, and just transitions (IPCC, 2022b; IPCC, 2022c). However, little attention is paid to these issues in specific, especially quantitative terms (IPCC, 2022a) in operationalizing climate action in the near, medium, and long term.

[4] The IPCC outreach material can be found here: https://www.ipcc.ch/outreach-material/. A key word analysis of the transcript shows that the qualifiers on the lack of equity present in the full report and even in part in the Summary for Policymakers, are absent in the outreach material.

Frequently in the WGII and WGIII contributions to AR6, references to equity and climate justice are left ambiguous on whether the reference is to equity between countries or restricted to intra-country equity.

Indeed, the WGIII Report does note (IPCC, 2022a) that the mitigation pathways assessed *"do not explore issues around income distribution or environmental justice but assume implicitly that where and how action occurs can be separated from who pays"*. It also states that "*Equity hinges upon ethical and normative choices. As most IAM pathways follow the cost-effectiveness approach, they do not make any additional equity assumptions…. Cost-effective pathways can provide a useful benchmark, but may not reflect real-world developments"* (IPCC, 2022a).

If the key to assessing equity as per the Convention lies in the provision of Annex-based, or development level-based (developed versus developing countries) or at least sufficiently disaggregated regional information, the Summary for Policymakers of the WGIII Report of AR6 explicitly refrains from providing any such differentiated outcomes of the scenarios. The text in Box SPM.1, which introduces scenarios, and is titled, "The Assessment of Modelled Emission Scenarios", states: *Most do not make explicit assumptions about global equity, environmental justice, or intra-regional income distribution. Global emission pathways, including those based on cost-effective approaches, contain regionally differentiated assumptions and outcomes and have to be assessed with the careful recognition of these assumptions. This assessment focuses on their global characteristics*. An accompanying footnote to this Box further notes: *Many underlying assumptions are regionally differentiated. {1.5; 3.2; 3.3; Figure 3.9; Annex III.II.1.4; Annex III.II.3}.* A similar statement is repeated, more briefly, in Table 2 of the SPM: *Global emission pathways contain regionally differentiated information. This assessment focuses on their global characteristics.* It is clear therefore that while the end results contain regionally differentiated information, and indeed depend upon it, the IPCC Working Group III has chosen not to present these details.

That the attitude of the authors on the display of regional results is rather inconsistent is clear from the detailed regional information provided in Chapter 15 of the WGIII Report in Table 15.3, on the assessments of investments required in the electricity sector across regions, based on the scenarios submitted to the database (Chapter 15, IPCC 2022a). In contrast to these results, Chapter 3 of the WGIII Report, has several references to qualitative assessments for specific regions and countries, including China and India, but studiously refrains from any quantitative regional assessment comparable with the details seen in Chapter 15.

Selection and Filtering of Scenarios

Another problematic feature of the WGIII Report is the presentation of the scenario outcomes of key variables in the language of statistical distributions and probability of outcomes, though the Report acknowledges in Annex-III (in the section on statistical uncertainty) that this indeed should not be interpreted as results from a proper statistical distribution. One must therefore be careful while reporting and interpreting the results of the global modeled scenarios in the IPCC report (Rogelj, 2022).

The report of Working Group-III (WG3) of the AR6 states that 2425 scenarios were submitted to the database, of which 2118 scenarios are listed in the Annex-III of the WG-III report[5]. Of these scenarios, 1594 could be assessed in terms of their climate response, and 1202 passed the vetting criteria[6] specified by the IPCC. Of the 1202 scenarios that were finally assessed by the IPCC team of authors, 937 (78%) are from model-intercomparison studies and the remaining are from single-model studies. Of these scenarios, 591 scenarios, over 49% of the total, are from one model intercomparison project, ENGAGE.(Riahi, et. al. 2021). An additional 70 (5.8%) of the scenarios are from the Shared Socio-economic Pathways (SSP) model intercomparison project. It is clear therefore that the scenarios used in the AR6 are not a statistical sample.

The vetting criteria themselves may be considered a performative imposition by the authors of the IPCC, in that they seek to impose criteria eliminating a little over 50% of the scenarios submitted, instead of devising criteria for categorization that took note of all submissions to the scenario database. This does not apply to all criteria of course. For instance, the need for the inclusion of projections of CO2 emissions appears straightforward, but the exclusion of scenarios that go up to only 2050 seems excessively restrictive, excluding potentially useful scenarios from the assessment.

In this paper, we analyse a subset of the model scenarios that are available from the scenarios database of the 6th Assessment Report. We focus our attention on the results for

[5] The scenario database can be found here: https://iiasa.ac.at/models-and-data/ar6-scenario-explorer-and-database

[6] Details of the vetting process and the parameters used for the same can be found in Annex-III on 'Scenarios and Modelling Methods' of the Working Group-III Contribution to the 6th Assessment Report of the IPCC

key variables reported by regions across the scenarios. Though the projections for key variables are only available for a 10-region classification, the differentiation between regions is sufficient to make key estimations regarding equity. Thus we will regard the four regions labelled North America, Western Europe, Pacific OECD, and Reforming Economies to be Annex-I regions and others will be referred to broadly as non-Annex-I regions or by their individual names as required. In the absence of any consistent labelling of regions by development level or Annex-based UNFCCC classification by the IPCC, this is the closest approximation that enables us to make the assessment that we seek from the available data of the scenarios.

This paper thus examines regional disparities in per capita GDP and consumption of goods and services, energy consumption, fossil fuel consumption, and CO_2 emissions projected in the scenarios, demonstrating how current inequalities are perpetuated into the future. We also analyse the region-wise allocation of the remaining carbon budget for different temperature targets. The regional differences in carbon sequestration and the time of reaching of net-zero CO_2 emissions in the modelled scenarios are also analysed.

For several key countries, both non-Annex-I and Annex-I, the average regional results may not represent the precise values that the modelled scenarios project, but it does provide a reliable reference value for these countries for the key variables of interest. Further, for countries that are the dominant economies of the region, the regional averages may be expected to provide an even closer approximation.

Methods

All global mitigation pathways are based on scenarios with some underlying regional classification. In particular, models and scenarios that have an underlying 10-region classification allow us to distinguish developed and developing regions, which in turn provide the basis for assessing equity in the projected outcomes.

We analyse 556 scenarios that have *both regional (for 10 regions) and global* projections from the "IPCC-AR6_ R10 Database". These 556 scenarios correspond with the 1.5℃ and 2 ℃ warming targets of the Paris Agreement. We focus on the scenario categories C1, C2, C3, and C4 as classified in the IPCC's 6th Assessment Report.

- Categories C1 includes model scenarios in which warming is projected to be limited to 1.5 ℃ , with a likelihood of 50% or greater (>50%) with “no or limited overshoot”
- Category C2 includes model scenarios in which warming is projected to be limited to 1.5 ℃ , with a likelihood of 50% or greater (>50%) with “overshoot of 0.1-0.3 ℃ for up to several decades".
- Category C3 includes model scenarios in which peak warming is projected to be limited to 2 ℃ with a likelihood of 67% or greater (>67%)
- Category C4 includes model scenarios in which peak warming is projected to be limited to 2 ℃ with a likelihood of 50% or greater (>50%).

These four scenario categories cover the range of temperature targets that are included in the Paris Agreement and are of particular relevance for policymaking. Our analysis covers 79% of the 700 total scenarios assessed in the AR6 that correspond to the 1.5℃ or 2°C targets. The remaining scenarios have either a 5 or 6-region classification. 94% of these 556 scenarios originate from institutions in Annex-I regions (See Figure 1).

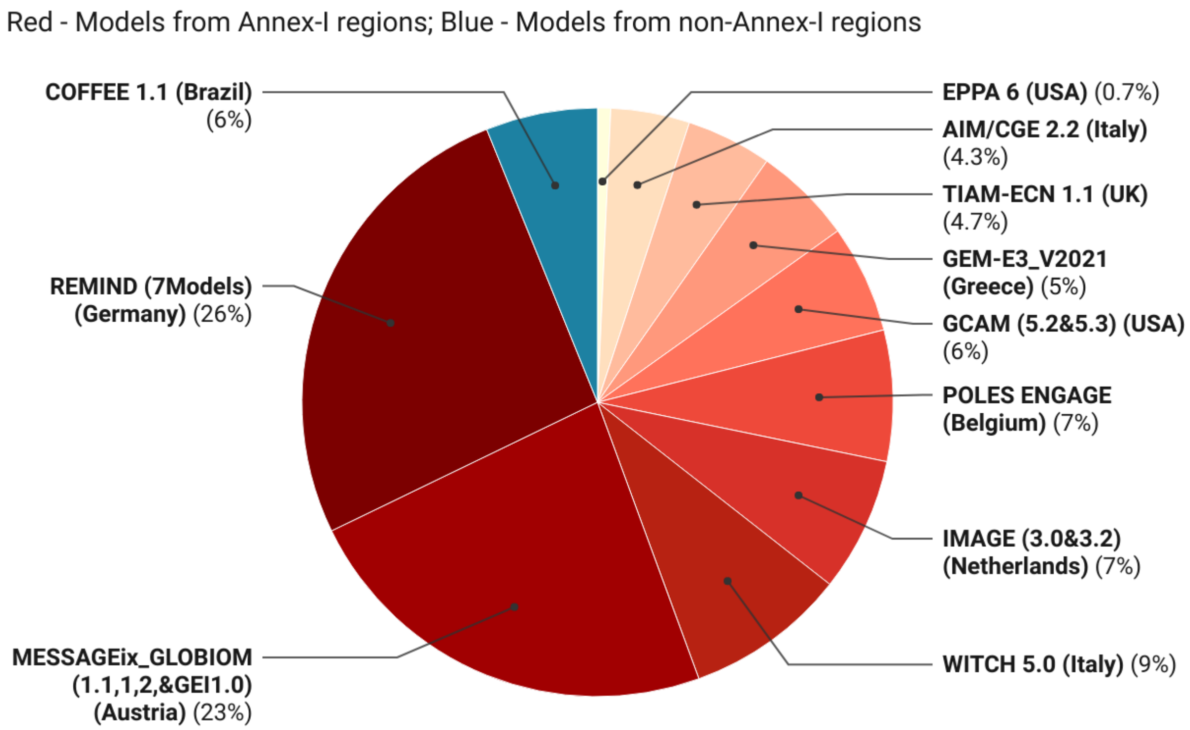


Figure 1. Model-wise distribution of the 556 scenarios analysed in this paper. Red wedges show models from Annex-I regions, blue wedges show models from Non-Annex-I regions. Figure Created with Datawrapper.

The regional classification differs across all the models. For example, while some models report variables for the category 'Sub-Saharan Africa' as defined by the UN, others include only some countries in this category and the rest of the countries in this region are classified under the category "Rest of the World". Similarly, some countries of North and East Africa are classified under the region termed "Middle East" in some models. In some models, the South Asian region contains all countries of the region and in others, it represents India alone with the rest of the countries in this region being placed under "Rest of the World". The population projections of the different regions reported in the models are therefore different. From the calculation of all values of variables reported in the models, we estimate per capita values based on the population projections from the respective model scenarios, as reported[7]. For the calculation of historical emissions, we use the classification of the MESSAGEix_GLOBIOM1.1 model since this model reports explicit results for Africa. We note, however, that the inequalities that we track down between the global North and South is replicated in all other model scenarios as well.

For each region and for each model, we calculate the weighted average of the projected values of all variables, typically at 2050. The scenarios in the database also provide values of variables at intermediate years but we describe the evolution of only select key variables. This weighted average is taken by categorizing the scenarios according to their cumulative emissions to net zero, grouping them in bins increasing progressively by 10 GtCO2, and weighting, by the number of scenarios in that bin, the average value of the variable for all scenarios in that bin. This bin distribution is kept the same for all variables. Therefore, the weighted average of a variable reported for a particular region, for a scenario category (say C1) is the weighted average value of all scenarios in that category, for that region in the given model. The per capita values of key variables, i.e., energy, emissions, and fossil fuel use, are reported as a weighted average across all models for each scenario category. For example, for the C1 category of scenarios, the weighted average across models that provide results for C1 scenarios is estimated and reported. For variables for which we report absolute values, the regional differences must be accounted for. In this case, we do model-wise calculations. Figures are reported for the REMIND_MAgPIE and/or MESSAGEix_GLOBIOM model which together provide 50% of the scenarios assessed in this paper. Again, we also provide model-wise results where relevant. For the sake of brevity, therefore, we report the result for scenarios from these models. However, the analysis has been done for all 21 models.

[7] In the calculation of per capita values, we exclude those models for which regional population data is not reported in the AR6 R10 database, i.e COFFEE 1.1 and TIAM ECN 1.1.

We adopt a per-capita approach to assess equity between regions in the model scenarios. We emphasize that while the allocation of a fair share of the total carbon budget (accounting for both historical emissions and the remaining carbon budget) to regions is a fundamental dimension of equity, there are other measures of equity as well, particularly for resource use, energy and electricity consumption and measures of economic well-being. The comparison of these values across regions and their ranges provides natural measures of equity though there need not be a corresponding concept of a fair share.

The fair share allocation of the carbon budget based on the region/country's share in the global population (the contemporary population) that we use in this paper has been strongly argued for, by authors from the global South (; Baer et.al, 2009; Jayaraman et.al, 2011; Jiahua, 2011; Kanitkar et.al, 2013;). Other claimed approaches to equity have been proposed in the literature, but as has been argued elsewhere the one used in this paper has some significant claims to being the appropriate one. We will not repeat these arguments here, but refer the reader to Sinden, (2010), Jayaraman et al, (2012), and Kanitkar and Jayaraman, (2019).

We calculate the ranges for a region's fair share of the global carbon budget using two approaches, with and without historical responsibility. The approach "without historical responsibility" does not consider the historical emissions of countries and divides the remaining carbon budget (2020 to net-zero) in a particular scenario, on a per capita basis between regions.

The approach "with historical responsibility" calculates a region's per capita share of the total carbon budget. The total carbon budget is the sum of the cumulative historical CO2 emissions (1850-2019) excluding LULUCF[8], and the remaining carbon budget available to meet the temperature target in each scenario. The actual historical CO_2 emissions of each region (1850-2019) are then deducted from this share to obtain the remaining fair share for a region in each scenario. We calculate the fair share of the carbon budget for each scenario category using equations 1 and 2.

$$F_{ij} = R_j * (p_i / \sum_i p_i) \qquad \ldots \textit{ Without historical responsibility} \qquad (1)$$

[8] We exclude historical LULUCF emissions since these are excluded in the PRIMAP database and due to the uncertainties and methodological issues involved in assigning regional LULUCF emissions in global book-keeping models.

$$F_{ij} = [(R_j + \sum_i E_i) * (p_i / \sum_i p_i)] - E_i \qquad \text{... With historical responsibility} \qquad (2)$$

where,

F_{ij} is the fair share of region i for a given scenario j,

E_i is the aggregated CO_2 emissions from countries in the region for the period 1850-2019, excluding LULUCF,

R_j is the remaining global carbon budget to meet the temperature target of the scenario,

p_i is the aggregated population of the region for 2020

E_i is calculated by regional aggregation of country-wise historical emissions from the PRIMAP database (Gutschow et al 2021). R_j is obtained by adding the area under the CO_2 emissions trajectory from 2020 to net-zero for all regions in a particular scenario. We get R_j for each scenario by obtaining the area under the emissions curve from 2020 till the year of net-zero, by applying the trapezoidal rule for integration, using the *pracma* package in R. p_i is the population projection used in each model for region i.

The year of attaining net-zero CO_2 emissions for a region is calculated using the intercept of that region's projected CO_2 emissions trajectory with the time (x) axis. As scenarios report CO_2 emissions in 5-year or 10-year intervals, we compute the year of net-zero attainment by linear interpolation between the two points where emissions change from positive to negative values. We examine the range of years (earliest to most delayed) in which different regions attain net-zero CO_2 in each scenario category in each model. For regional labelling, we broadly follow the regional classification of the MESSAGEix_GLOBIOM1.1 model.

Results

The WGI Report of the IPCC to AR6, notes that the value of the remaining carbon budget for a 50% probability of limiting warming to 1.5 ℃ is only 500 GtCO2 (C1 and C2 category scenarios). For a 67% and 50% probability of limiting warming to 2℃ the remaining carbon budget is 1150 and 1350 respectively. Rapid emissions reductions are required to limit warming to the targets of the Paris Agreement. Scenarios used in the AR6 explore the potential and/or required changes in socio-economic factors including population, economic growth, education, urbanization, and the related technological development to meet these targets (O'Neill et.al, 2014).

The modelled scenarios used in AR6 are largely drawn from the Shared Socio-Economic Pathways (SSP) framework. The reports of all three working groups of the IPCC depend significantly on this framework that couples the RCPs (Representative Concentration Pathways) to the SSPs. The RCP-SSP framework uses a modelling process in which radiative forcing is used as a starting point to encourage modelling studies that will focus on evaluating adaptation needs and strategies, exploring mitigation options, and improving understanding of potentially large feedbacks for a particular radiative forcing (O'Neill et.al, 2011). Central to this process is the concept that radiative forcing pathways can be achieved by a diverse range of socioeconomic and technological development scenarios. Among other issues, this process is supposed to facilitate exploration of the question 'What are the ways in which the world could develop in order to reach a particular radiative forcing pathway? (Moss et. al, 2010). The modelled scenarios assessed in this paper showcase the perspectives of the modelers and by extension, that of the IPCC, in answering this question, focusing especially on the question of equity between regions/countries.

GDP and Consumption of Goods and Services

Economic and emissions outcomes are based on process variables such as GDP and rates of urbanization, consumption of goods and services, and a range of assumptions for costs and potential scales of mitigation technologies projected into the future. Figure 2 shows the GDP and consumption outcomes for 2050 across model scenarios for Categories C1 (1.5 ℃ without overshoot) and C3 (2 ℃ with 67% probability).

The GDP increases across all regions at different rates. The developed countries, have higher GDP in 2020 to begin with, i.e., in 2020, the per capita GDP of the North American region is ~17 times more than that of Sub-Saharan Africa, and ~10 times more than that of the South Asian region. In 2050, the difference between the regions reduces slightly but remains significant. Moreover, except for China, the per capita GDP, in the rest of the developing world in 2050 is restricted to USD 9,000 – USD 28,000 at the most and for South Asia and Sub-Saharan Africa at even lower levels of ~USD 18,000 and ~USD 9,000 respectively. It is important to note that this is lower than the current per capita GDP levels of developed countries as a whole and much lower if compared to the current per capita GDP of OECD countries.

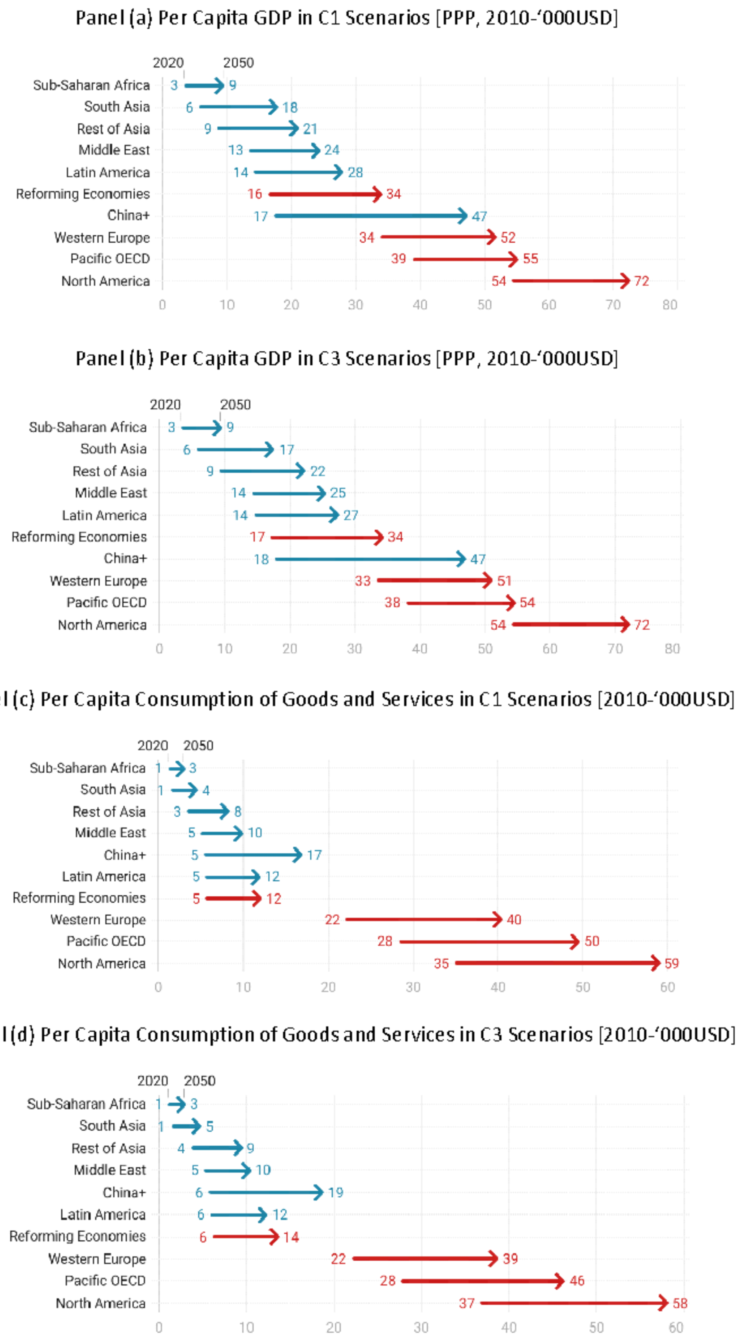


Figure 2. Projected Per capita GDP and Consumption in C1 and C3 scenarios (2020 to 2050); Panel (a) shows the weighted average per capita GDP across models for scenario category C1. Panel (b) shows the weighted average per capita GDP across models for scenario category C3. Panel (c) shows the weighted average per capita consumption of goods and services across models for scenario category C1. Panel (d) shows the weighted average per capita consumption of goods and services across models for scenario category C3. Values reported are in units used in the models, i.e. Constant 2010 values in '000 USD at purchasing power parity for GDP and constant 2010 values'000 USD for consumption. Reddish arrows show Annex-I parties to the UNFCCC and blueish arrows are used for non-Annex-I regions. Both Figures Created with Datawrapper.

There is a very strong and significant correlation between GDP, often used as a proxy for income, and human development indicators such as, inter alia, infant mortality, female life expectancy, and mean years of schooling. The positive feedback and interlinkage between human development and GDP growth is explored extensively in the literature (Suri et. al, 2011; Ramirez et.al., 1997; Strauss and Thomas, 1995). Far from allowing for aspirations of universal well-being, the model scenarios deny incomes that would ensure even basic development, even as late as 2050, to non-Annex-I regions, most notably to Sub-Saharan Africa, and South Asia. These two regions are currently home to more than one-third of the global population.

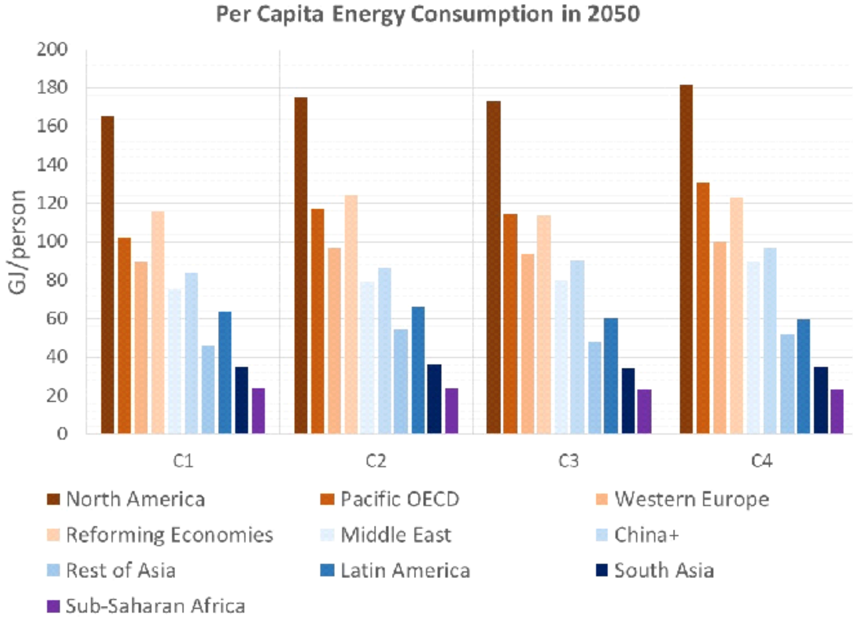
The non-Annex-I regions are projected to grow (in terms of both GDP and consumption) at a faster rate (4% on average) as compared to Annex-I countries (1-2% on average). However, given the large inequalities that exist currently between these regions, these rates imply that there will be no convergence in per capita GDP across regions till well beyond 2100.

GDP is one of the main drivers of emissions across models, even with its relative decoupling from energy and emissions over time that is assumed in the models. The results indicate therefore that restricting GDP growth in developing countries is assumed to be a significant route to limiting emissions and hence temperature rise. Across model scenarios, the inequality in consumption outcomes between regions is even starker than that seen for GDP.

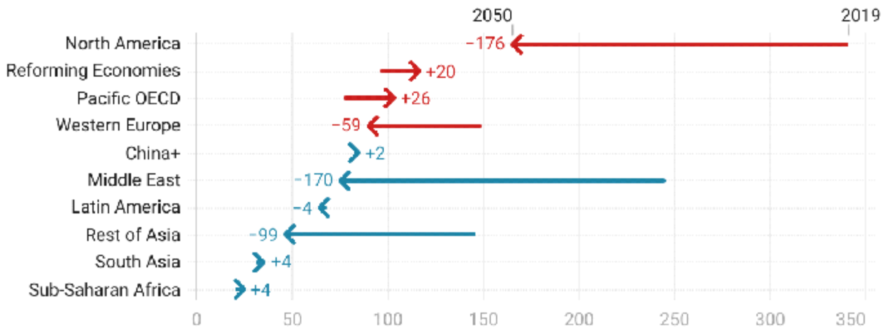
Energy Consumption

The GDP and consumption trends have a direct impact on energy use, even though models also assume some amount of decoupling between energy use and GDP. The extent of this decoupling varies across models and regions. Across scenarios and scenario categories, per capita energy consumption in Annex-I regions, remains well above that of non-Annex-I regions, even in 2050 (Figure 3).

Panel (a) Projected Per Capita Energy Consumption in 2050 in Scenario Categories C1 to C4



Panel (b) Per Capita Energy Consumption in 2019 and Model Projections for 2050 – C1 Scenarios



Panel (c) Per Capita Energy Consumption in 2019 and Model Projections for 2050 – C3 Scenarios

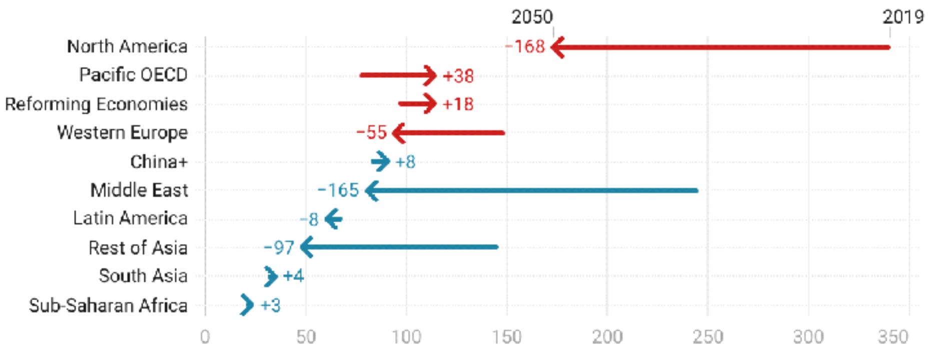


Figure 3. Per capita energy consumption across C1 to C4 category scenarios. All values are in Giga joules/person/year. Reddish bars/arrows show Annex-I parties to the UNFCCC and blueish bars/arrows are used for non-Annex-I regions. Panel (a) shows the projected average per capita energy consumption across regions in each category. In Panel (a) the values are weighted averages across the models. Panel (b) shows the actual per capita energy consumption in 2019 vs. the projected value for 2050 in C1 category scenarios. Panel (c) shows the actual per capita energy consumption in 2019 vs. the projected value for 2050 in C3 category scenarios. Panel (b) and (c) figures Created with Datawrapper.

The North American region is projected to have the highest per capita energy consumption in 2050, across scenarios. It is projected to consume about 6-8 times more energy than Sub-Saharan Africa and ~5 times more energy than South Asia in 2050. Therefore, the current inequality in energy consumption between these regions is projected to remain, or even increase by 2050. This is also pointed out in other literature since the publication of the AR6 (Hickel et.al, 2022).

In most non-Annex-I regions, the average per capita energy consumption is projected to reduce by 2050, with the highest reduction in energy consumption projected to be in the Middle East and Rest of Asia (excluding China+ and South Asia). For Sub-Saharan Africa and South Asia, a minor increase is projected despite currently very low levels of primary energy consumption. As a result, all Annex-I regions (including Western Europe and North America, despite the projected reduction between 2019 and 2050), have a higher per capita energy consumption in 2050 as compared to any of the non-Annex-I regions (including the Middle East and China+). It must be emphasized here that these values are for total primary energy consumption, not just the consumption of fossil fuels. The implication is therefore a severe restriction of energy consumption, even from renewable energy sources, for non-Annex-I regions. This is evident when we assess the projections for fossil fuel consumption for 2050.

Fossil Fuel Consumption

In the scenarios, higher energy consumption in Annex-I regions is supported by the continued use of fossil fuels even in 2050, notwithstanding their declared net-zero targets. Fossil fuel consumption is in fact restricted much more severely in most of the non-Annex-I regions (See Figure 4). An additional feature of the scenarios is that as the quantum of the remaining carbon budget increases from scenario category C1, which has the most stringent temperature target of 1.5 ℃ (<50%) with no or limited overshoot, to scenario category C4 which corresponds to a 50% probability of limiting warming to 2 ℃, the per capita fossil fuel use in Annex-I countries increases with little to no difference across scenario categories for the lowest energy-consuming non-Annex-I regions. The higher carbon space afforded by a less stringent temperature target is disproportionately allocated to the Annex-I countries.

Across scenario categories, by 2050, Pacific OECD and North America, continue to use more coal per capita compared to other regions except China. Sub-Saharan Africa and Latin America are projected to use no coal by this time. Across all scenarios, per capita consumption of oil and gas in North America and Europe also continues to remain high while it is lower in Africa, South Asia, and Latin America compared to all other regions. The continued use of gas and oil across the global North also holds true for C1 category scenarios that project warming to remain at 1.5 ℃ with no or limited overshoot (Figure 4, Panel (b)), in which global emissions reach net zero around 2050. This implies that the scenarios assume that continued fossil fuel emissions from the global North are offset by terrestrial sinks in the global South, or by the deployment of (as yet speculative) CCS technologies. We will explore this in detail in the next section.

Even if we examine absolute fossil fuel consumption values, we find that the relative share of Annex-I countries in global fossil fuel use, increases compared to 2019 across all scenario categories. The reductions in fossil fuel use in 2050 as compared to 2019 levels are highest in non-Annex-I regions, even when the values in 2019 are low. The highest reduction in fossil fuel use, across all the three fuels is in Sub-Saharan Africa. For example, in C1 scenarios, Sub-Saharan Africa is projected to reduce its coal consumption by 100%, oil consumption by 95%, and gas consumption by 80%. In contrast, in the same scenarios, the reduction in fossil fuel use in North America, which uses much more in 2019 as compared to Sub-Saharan Africa is less, i.e., 88% reduction in coal, 75% reduction in oil, and 91% reduction in gas. In Western Europe, natural gas consumption is projected to reduce by only 32% in C1 category scenarios in the MESSAGEix_GLOBIOM1.1 model.

Across scenarios, Latin America, Sub-Saharan Africa, and South Asia, are projected to have a higher share of non-fossil energy in their total primary energy mix compared to Annex-I regions in 2050. It must be noted here that this is in addition to a much lower value of per capita energy consumption in these non-Annex-I regions.

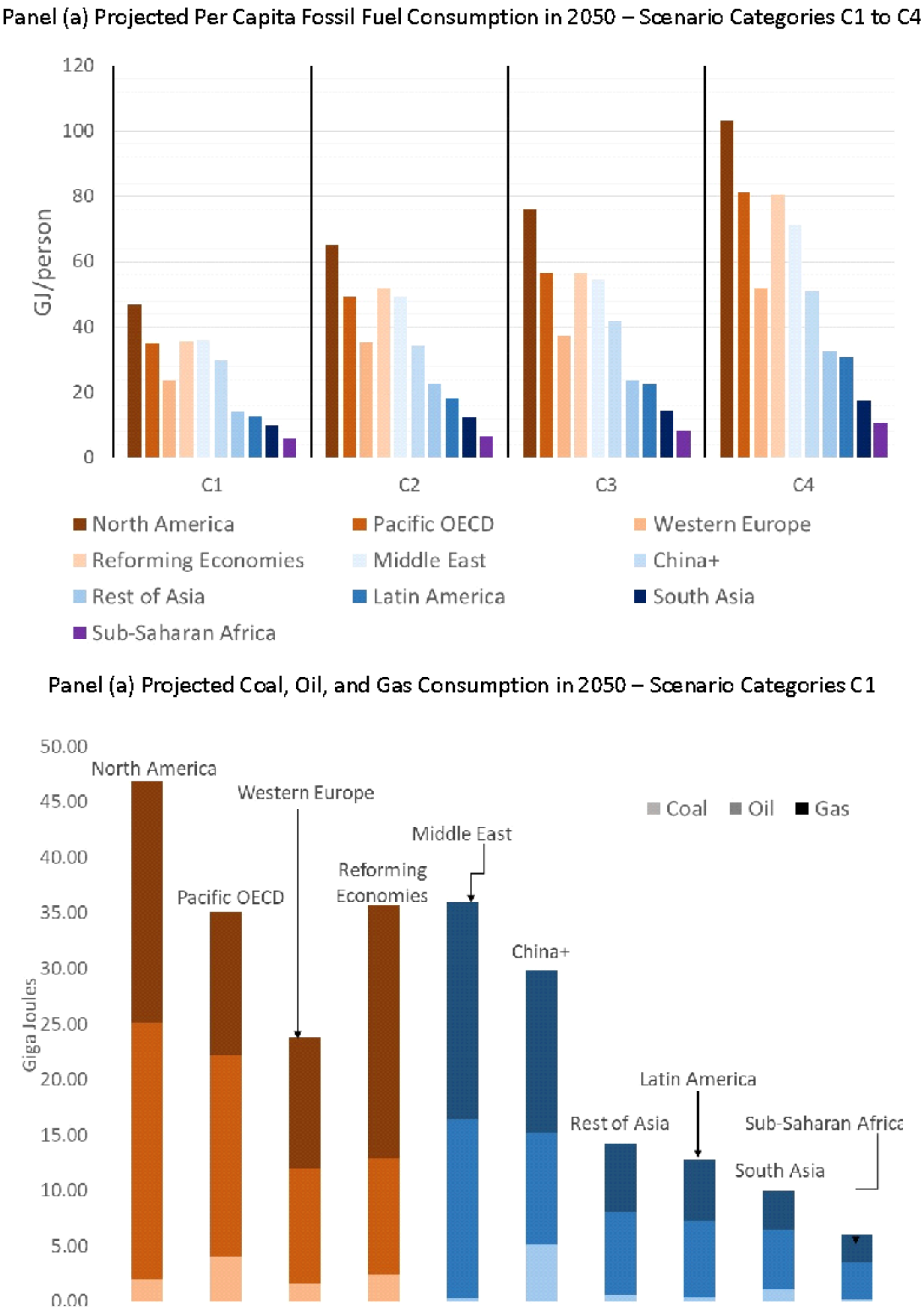


Figure 4. Projected per capita fossil fuel consumption in 2050. All values are in Giga joules/person/year. Reddish bars show Annex-I parties to the UNFCCC and blueish bars are used for non-Annex-I regions. Panel (a) shows the projected average per capita fossil fuel consumption across regions in each category. In Panel (a) the values are weighted averages across the models. Panel (b) shows the distribution of coal, oil, and gas in 2050 projected in C1 category scenarios, i.e. scenarios that are projected to limit warming to 1.5 deg. C with no or limited overshoot with a 50% probability.

Carbon Sequestration from Land Use and Carbon Capture and Sequestration (CCS)

Models report values for carbon sequestration by region, from 'Land Use Change', and from negative emissions technologies such as 'Carbon Capture and Sequestration (CCS)'. The category for 'Land Use' reports values of carbon sequestration from afforestation, and the category of 'CCS' includes carbon sequestration, in the following sectors: i) Biomass (use of biomass as a direct energy source), ii) Biomass Energy Supply (Bioenergy with Carbon Capture and Storage and other Biomass energy uses), iii) Fossil, iv) Fossil Energy Demand Industry, v) Fossil Energy Supply, and iv) Industrial Processes.

For this variable , we report values by model in cumulative terms by region. Since the regional classification is different across models, we do not calculate weighted averages for variables when reporting absolute (as opposed to per capita) values. Across models, the total sequestration from land use and CCS, before the time of net-zero, for C1 category scenarios ranges from 107.58 $GtCO_2$ (REMIND-Transport 2.1) to 533 $GtCO_2$ (IMAGE_3.2). About 65-84% of this sequestration happens in developing countries. Even in C3 scenarios, about 60-85% of the sequestration happens in developing countries (See Figures 5 and 6). The EPPA model is the only exception, but it has only 3 scenarios in the C3 category.

It is important to note that the values we report for carbon sequestration here are for sequestration *before* net-zero CO_2 emissions are reached. While the report of WG-III of the IPCC provides the ranges for negative emissions across scenario categories *after* net-zero emissions are reached, they do not discuss negative emissions in the near future, i.e., before the time of net-zero CO_2 emissions. While not all carbon sequestration translates to net negative emissions (for example sequestration of fossil fuel emissions does not lead to negative emissions), a part of the sequestration numbers discussed here will be net-negative.

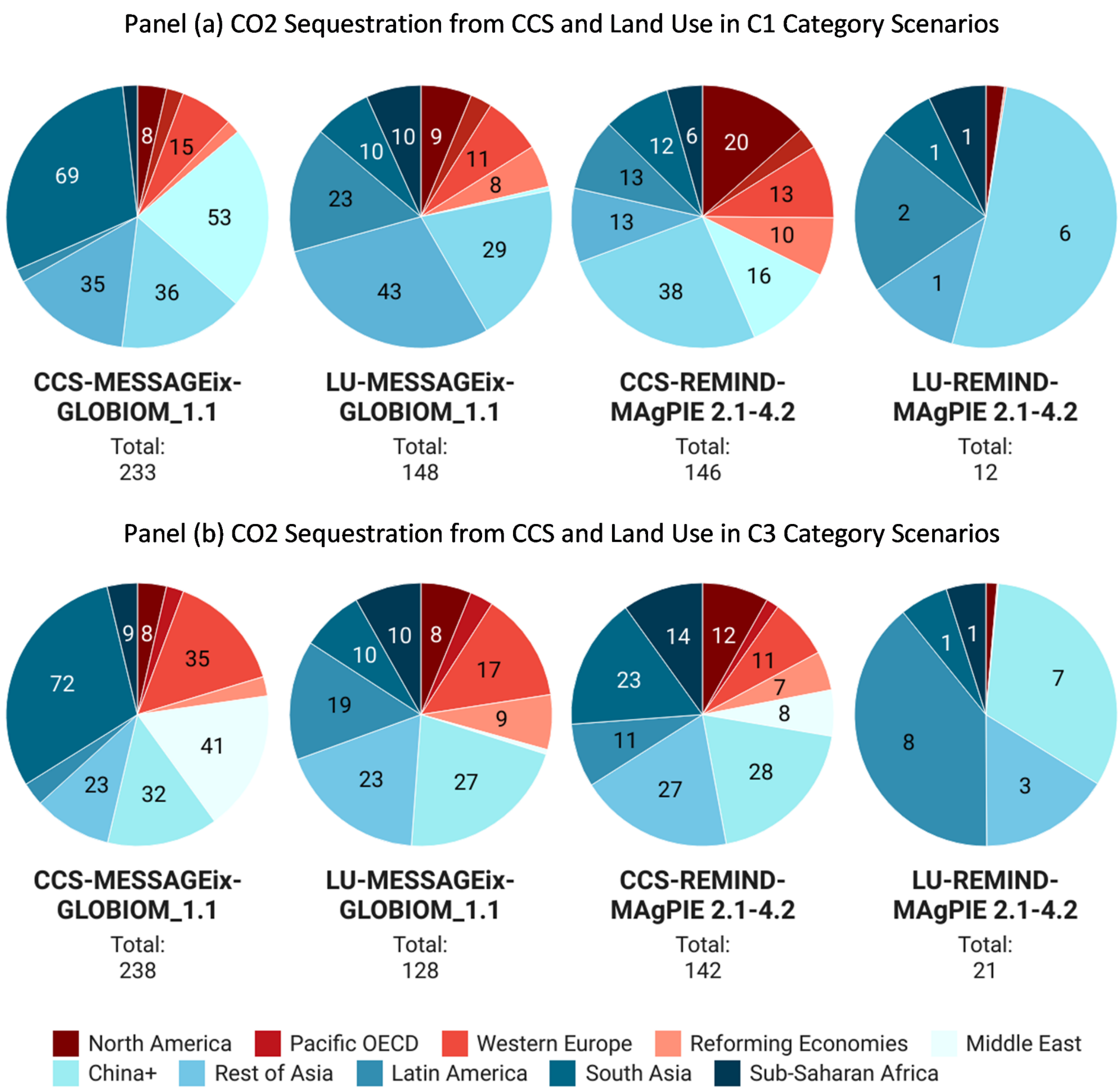


Figure 5. Projected carbon sequestration between 2020 and the time of net-zero CO2 emissions (or till 2100 if the region does not reach net zero CO2) by region in the MESSAGEix_GLOBIOM_1.1 and REMIND-MAgPIE_2.1-4.2 model scenarios. All values are in $GtCO_2$. Reddish bars/wedges show Annex-I parties to the UNFCCC and blueish bars/wedges are used for non-Annex-I regions. Panel (a) shows the projected carbon sequestration from land use and CCS separately in scenario categories C1. Panel (b) shows the projected carbon sequestration from land use and CCS separately in scenario categories C3. Figures Created with Datawrapper.

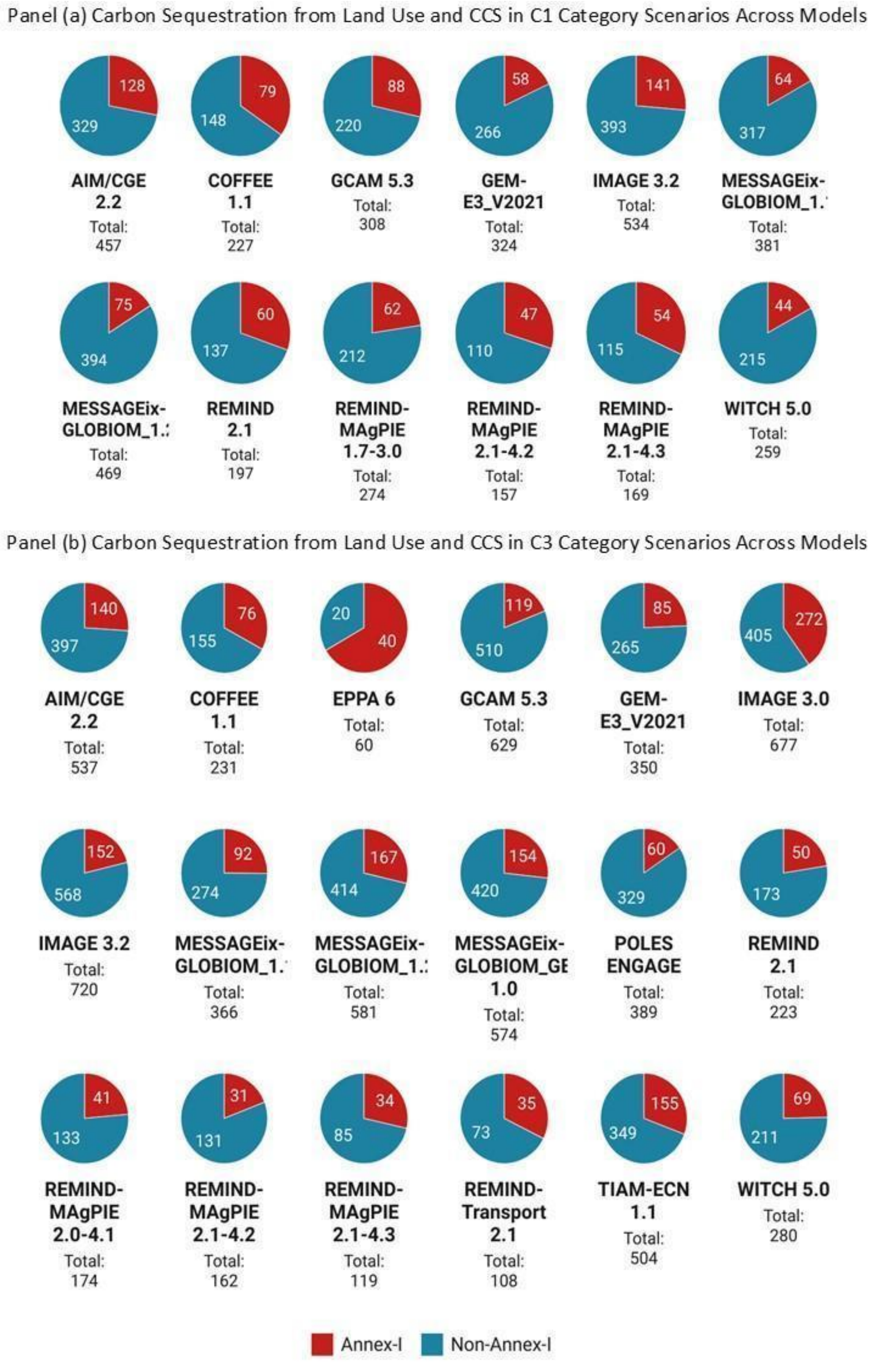


Figure 6. Projected carbon sequestration between 2020 and the time of net-zero CO2 emissions or till 2100 if the region does not reach net-zero CO2. All values are in $GtCO_2$. Reddish bars/wedges show Annex-I parties to the UNFCCC and blueish bars/wedges are used for non-Annex-I regions. Panel (a) shows the combined carbon sequestration from land use and CCS in Annex-I and non-Annex-I regions in C1 scenarios. Panel (b) shows the combined carbon sequestration from land use and CCS in Annex-I and non-Annex-I regions in C3 scenarios. Figures Created with Datawrapper.

CO_2 Emissions and the Global Carbon Budget

The series of projected outcomes for GDP, consumption, energy, fossil fuel use, and carbon sequestration lead directly to high inequity in per capita emissions (See Figure 7) and the highly inequitable distribution of the global carbon budget. Between scenario categories C1 and C3, as a higher global carbon budget becomes available, the constraint on emissions eases for developed country regions.

Per capita emissions in Latin America, South Asia, and Sub-Saharan Africa remain the lowest, with net negative emissions in the Latin American region in 2050 in scenario categories C1 and C2. This results in earlier net zero years for Latin America compared to any other region. For example, in C1 category scenarios, the latest net-zero years across models for Latin America are still much earlier than the earliest net-zero years for Europe.

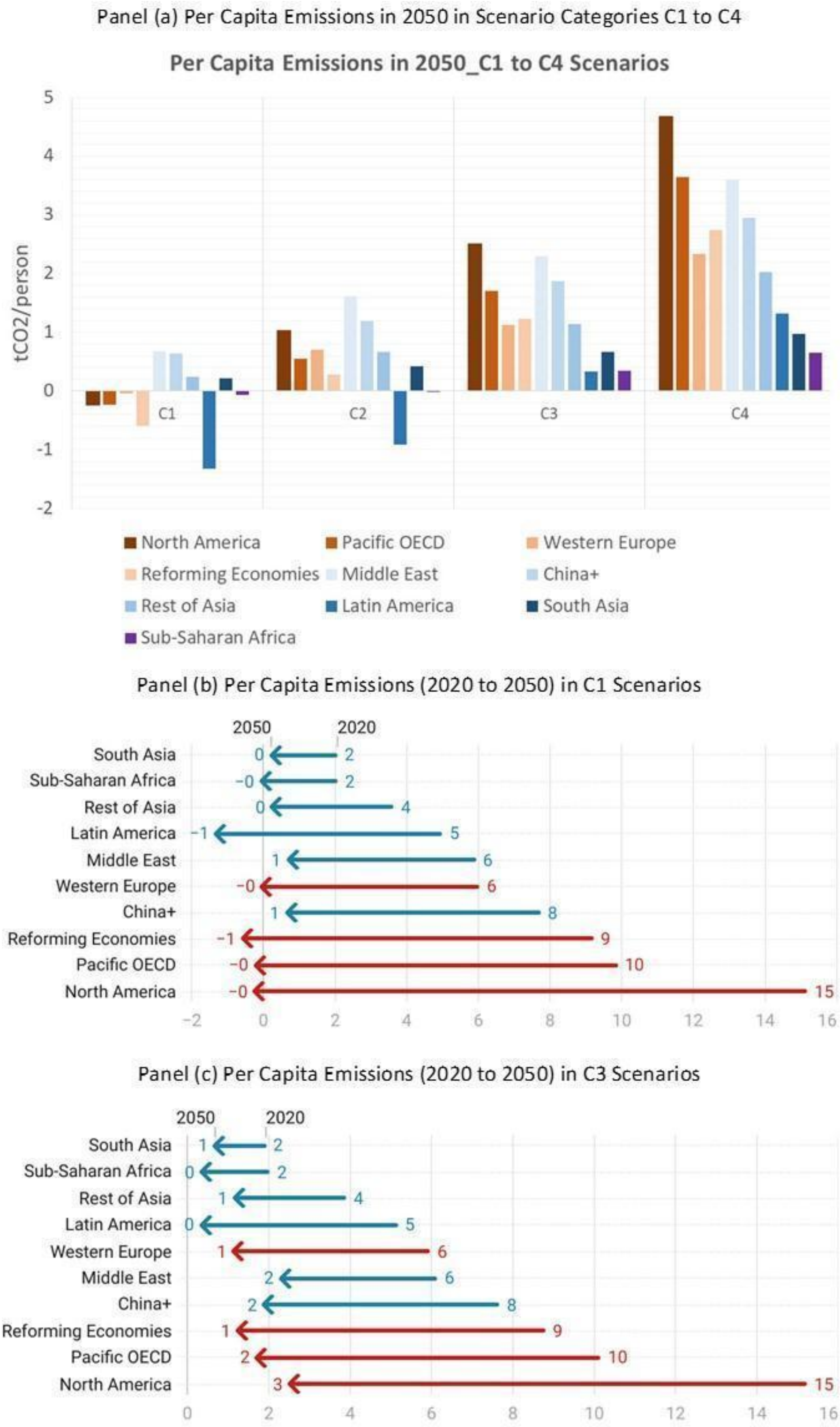


Figure 7. Per Capita Emissions. All values in tCO2/person. Reddish bars/arrows show Annex-I parties to the UNFCCC and blueish bars/arrows are used for non-Annex-I regions. Panel (a) Projected per capita emissions in 2050 in scenario categories C1 to C4. Panel (b) Change in per capita emissions between 2020 and 2050 in C1 Scenarios. Panel (c) Change in per capita emissions between 2020 and 2050 in C3 Scenarios. Panel (b) and Panel (c) figures Created with Datawrapper.

The results presented so far have focussed on projections for the year 2050. However, if we look at emissions reduction rates in the near term, say between 2020 and 2030, we find that these are even more egregiously in violation of the principles of equity and CBDR&RC, and the principle of developing countries taking the lead in climate action. In the C1 category scenarios, not only do all regions start emissions reductions immediately, in 2020, but the rates of emissions reduction are also higher for some developing countries compared to developed countries (See Table 1).

Table 1. Emissions reductions between 2020 and 2030 in the REMIND and MESSAGE Models, covering 50% of all assessessed scenarios consistent with 1.5 ℃ and 2℃ warming

Emissions growth between 2020 and 2030 -C1 scenarios - REMIND			Emissions growth between 2020 and 2030 -C1 scenarios - MESSAGE		
	Mean	Median		Mean	Median
Sub-Saharan Africa	-10%	-11%	Sub-Saharan Africa	-16%	-16%
China+	-7%	-7%	China+	-11%	-11%
Western Europe	-6%	-7%	Western Europe	-7%	-7%
South Asia	-3%	-3%	South Asia	-8%	-8%
Latin America	-8%	-7%	Latin America	-12%	-11%
Middle East	-2%	-2%	Middle East	-4%	-3%
North America	-7%	-7%	North America	-7%	-7%
Pacific OECD	-7%	-8%	Pacific OECD	-10%	-10%
Reforming Economies	-6%	-6%	Reforming Economies	-9%	-9%
Rest of Asia	-5%	-5%	Rest of Asia	-6%	-6%

In other scenarios, the peaking year is slightly delayed, progressively from C2 to C4, over a decade. (See Table 2).

Table 2: Peaking years for developing regions across scenario categories (years are weighted averages across models)

	C1	C2	C3	C4
Sub-Saharan Africa	2022	2023	2028	2032
China+	2020	2021	2022	2023
Western Europe	2020	2021	2021	2023
South Asia	2022	2024	2027	2027
Latin America	2020	2021	2022	2021
Middle East	2020	2024	2026	2028
North America	2020	2020	2020	2021
Pacific OECD	2020	2020	2020	2021
Reforming Economies	2020	2021	2022	2023
Rest of Asia	2020	2022	2021	2022

The IAMs do not consider past emissions, but we know from global emissions databases that the total historical cumulative emissions between 1850 and 2019 are ~ 2390 GtCO2 (±240 GtCO2). These emissions are responsible for global warming of ~1.07 deg. C in this period (IPCC, 2021). The estimate of 2390 GtCO2 includes emissions from the Land Use and Land Use Change and Forestry (LULUCF) sector. However, the uncertainties associated with LULUCF emissions are very high (IPCC, 2022). Regional attribution of LULUCF emissions further increases the uncertainties as the use of global book-keeping models versus the use of national inventories for this purpose is still contested and there is a significant difference (both quantitative and qualitative) in the regional LULUCF emissions from these sources (Grassi et.al, 2021; Grassi et. al, 2018). Therefore, we focus on non-LULUCF emissions in this report while discussing historical emissions between 1850 and 2019.

The cumulative non-LULUCF CO_2 emissions between 1850 and 2019 are ~1698 GtCO2 (Gütschow et al, 2021). Despite being party to the UNFCCC which clearly states that developed countries must take a lead in emissions reductions, their efforts since 1990 have fallen far short of what is required, and these countries have continued to consume a disproportionate share of the global carbon budget. Between 1990 and 2019, Annex-I parties have been responsible for 44% of the cumulative non-LULUCF CO_2 emissions. Model scenarios perpetuate this inequity into the future by projecting a disproportionate allocation of even the remaining carbon budget to developed countries (See Figure 8).

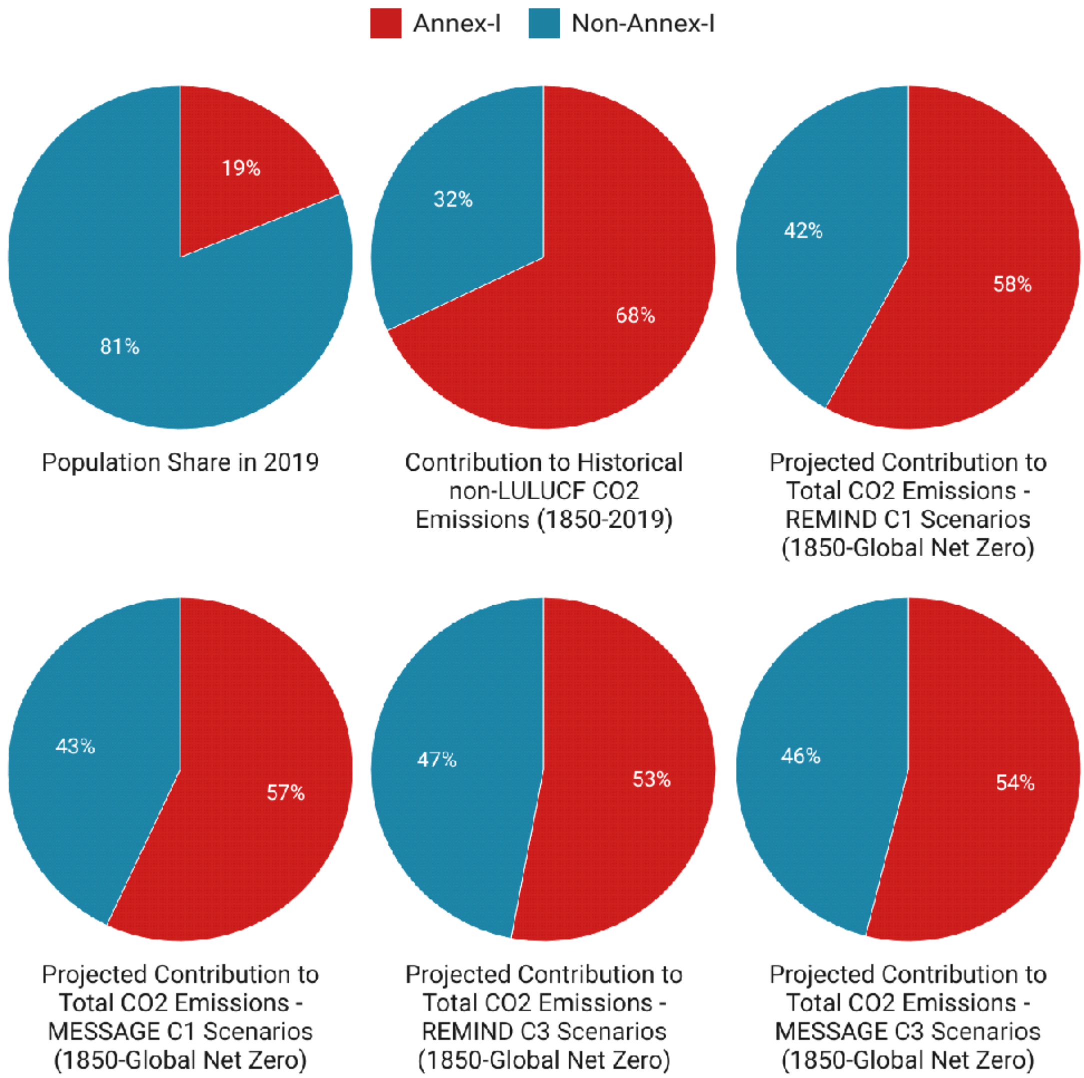


Figure 8. Fair Share, Contribution to Historical Emissions between 1850 and 2019, and Contribution to Projected Total Emissions between 1850 and Global Net-Zero for Scenarios Categories C1 and C3. Cumulative emissions projections for 2020-Net-Zero are from the REMIND_MAgPIE model scenarios and MESSAGEix_GLOBIOM model scenarios. The projected contribution to total emissions is the sum of past non-LULUCF CO2 emissions (1850-2019) and the modelled share of the remaining carbon budget for the respective scenario category. Population shares are calculated based on regional population estimates in the MESSAGEix_GLOBIOM1.1 model. Figures Created with Datawrapper.

Even with an increased value of the remaining carbon budget between scenario categories C1 and C3, its distribution across regions does not change significantly, i.e., shares of the developed countries remain disproportionately high and, much higher than their fair share. The comparison of modelled share and fair share is shown in Tables 3 and 4.

Table 3. Fair Share vs. Modelled Share of the Remaining Carbon Budget between 2020 and Net-Zero for C1 scenarios (All values in $GtCO_2$)

	REMIND			MESSAGE		
	Share of the Remaining Carbon Budget (1850-Net-Zero) - With Historical Responsibility	Share of the Remaining Carbon Budget (2020-Net-Zero) - Without Historical Responsibility	Modeled Share of the Remaining Carbon Budget for C1 Category Scenarios from the REMIND Models	Share of the Remaining Carbon Budget (1850-Net-Zero) - With Historical Responsibility	Share of the Remaining Carbon Budget (2020-Net-Zero) - Without Historical Responsibility	Modeled Share of the Remaining Carbon Budget for C1 Category Scenarios from the MESSAGE Models
Sub-Saharan Africa	265	69	27	278	82	15
China+	200	102	144	219	122	116
Western Europe	-217	43	39	-209	51	44
South Asia	479	126	69	503	150	104
Latin America	115	44	30	124	52	31
Middle East	74	34	52	81	41	117
North America	-356	26	58	-352	30	72
Pacific OECD	-41	11	13	-40	13	16
Reforming Economies	-113	19	28	-110	23	26
Rest of Asia	110	42	56	118	50	71
Total	**516**	**516**	**516**	**614**	**614**	**614**

Table 4. Fair Share vs. Modelled Share of the Remaining Carbon Budget between 2020 and Net-Zero for C3 scenarios (All Values in $GtCO_2$)

	REMIND			MESSAGE		
	Share of the Remaining Carbon Budget (1850-Net-Zero) - With Historical Responsibility	Share of the Remaining Carbon Budget (2020-Net-Zero) - Without Historical Responsibility	Modeled Share of the Remaining Carbon Budget for C3 Category Scenarios from the REMIND Models	Share of the Remaining Carbon Budget (1850-Net-Zero) - With Historical Responsibility	Share of the Remaining Carbon Budget (2020-Net-Zero) - Without Historical Responsibility	Modeled Share of the Remaining Carbon Budget for C3 Category Scenarios from the MESSAGE Models
Sub-Saharan Africa	308	112	77	331	135	41
China+	263	165	210	297	200	206
Western Europe	-190	70	48	-176	84	95
South Asia	557	204	129	600	247	137
Latin America	142	70	47	157	85	66
Middle East	95	56	85	107	67	157
North America	-341	41	81	-332	50	130
Pacific OECD	-35	17	17	-31	21	31
Reforming Economies	-101	31	46	-95	37	51
Rest of Asia	136	68	95	150	82	95
Total	**834**	**834**	**834**	**1008**	**1008**	**1008**

When historical cumulative emissions are also taken into account, the fair share of the developed countries in the future is negative. This implies that these regions need to accelerate towards net negative emissions and make the remaining carbon budget available to other less developed regions. However, the scenario projections are precisely the opposite. The global North exceeds its fair share of the carbon budget, even when historical emissions are not considered. In contrast, the allocations from the carbon budget for Sub-Saharan

Africa, South Asia, and Latin America are significantly lower than their fair shares, continuing without any compensation for their loss in the past, and persisting with a low share of the carbon budget even in the future.

Discussion

Our analysis of the regional trends underlying the global modelled scenarios in the IPCC's 6th Assessment Report indicates that not only do the scenarios not "make explicit assumptions about global equity", but they in fact project existing global inequities far into the future. The scenarios do not consider the differential energy needs of countries in the future based on their levels of development. Per capita GDP, consumption, and energy use remain significantly high in developed countries, even as most developing regions are projected to stay at very low levels of income, consumption of goods and services, and energy.

Additionally, higher levels of energy consumption in the developed countries are facilitated by higher per capita fossil fuel consumption in these regions even as late as 2050. The scenarios appear to signal that developed countries can continue to use coal, oil, and gas, as long as energy consumption in the poorest regions of Africa and Southern Asia continue to remain low and the regions of Latin America and Asia providing the necessary sinks for their fossil fuel emissions. Uniformly across scenarios, developed countries which have already exhausted their fair share of the carbon budget are projected to use higher shares of even the remaining carbon budget.

The IPCC AR6 scenarios disregard both the historical responsibility of the global North for carbon emissions as well as the future energy needs of the global South required to meet developmental goals. The burden of climate change mitigation is placed squarely on less developed countries, while developed countries continue to increase their energy consumption unhindered by constraints on the use of fossil fuels. The inequities between regions inherent in the scenarios are most striking when emissions and energy trends projected for North America are contrasted with those for Sub-Saharan Africa. Our results show that Africa, despite its very low contribution to historic emissions, is projected to bear a disproportionately high burden of climate change mitigation. Sub-Saharan Africa is projected to use zero coal by 2050, even as North America continues to rely on coal-based energy.

The remarkably uniform lack of equity in the scenarios needs to be explored in greater depth. The analysis of this paper together with relevant information on the models from the WGIII Report suggest the following directions for further investigation:

1. Effectively only a small number of models, amounting to only 21, are underlying the large number of scenarios, with possible overlapping inter-relationships and frameworks that effectively reduce even this number, and that this is responsible for the strong uniformity and robust nature of the inequitable outcomes.
2. The uniform assumption of emissions reduction simultaneously across all regions beginning virtually at the same time, and the outcomes in terms of emission reduction pathways suggest that this is the key driver and that details of modelling frameworks and scenarios are not very influential in determining the outcomes.
3. The results are driven by fairly uniform inputs and assumptions made sector-wise, which then result in fairly uniform outcomes. The systematic analysis of the sectoral model assumptions is the logical corollary to this paper and would assist in explaining the uniformity of the outputs.
4. Summary assessments, taking all models and scenarios into account, are not the way to conduct the assessment, but the focus needs to be on the differences between models and the particular consideration of outliers, that could represent new and innovative solutions to the problem of determining future mitigation pathways.

There is no doubt that an alternative, equity-based framework, for modelling just climate and developmental futures is needed. Approaches that attempt to operationalize equity are available in the literature (Kanitkar et al 2013; Holz et.al., 2019; Baer et al 2022). These however do not make it to the IPCC report. The process of calling for scenarios that fit a predetermined framework appears flawed when viewed from the perspective of its overall outcomes, even though it is presented as transparent and democratic. A large majority of scenarios that finally make it to the report are constructed by modelling teams based in the global North. While this may not itself be reason enough for the scenarios to be devoid of any considerations of equity, the uniform lack of equity in the conclusions raises serious questions. The IPCC must thoroughly examine the process by which literature is accessed, assessed, reviewed, and included in its reports and must take serious cognizance of not only a complete lack of equity in its global modelled scenarios, but also a perpetuation of existing inequities in the future.

The WGIII Report states clearly that "…achieving climate stabilization in the context of sustainable development also requires a focus on equity considerations to avoid climate-induced harm, as well as unfairness that can result from urgent actions to cut emissions. This is ever more important as the diminishing carbon budget has intensified debates on which countries should have the greatest claim to the 'remaining space' for emissions…" (IPCC, 2022a). However, when it comes to operationalizing this understanding in its scenarios, the Report falls woefully short. Scenario construction should effectively be the imagination of possible futures, and an equitable world must be central to this imagination. Our analysis clearly underlines the need for new frameworks for emissions modelling, scenario building, and constructing ideas of a future that makes the planet "liveable" for all and not just some sections of the global population.

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