How many people will live in poverty because of climate change? A macro-level projection analysis to 2070

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Abstract

Fossil fuel-based economic development both causes climate change and contributes to poverty alleviation, creating tensions across societal efforts to maintain growth, limit climate damage, and improve human development. While many studies explore key aspects of this dilemma, few direct attention to the pathways from climate change through socioeconomic development to the future of poverty. We build on projections of global temperature change (representative concentration pathways) and country-specific economic development (economic growth and income distribution across the shared socioeconomic pathways) to model how climate change may affect future poverty with the International Futures (IFs) model, projecting poverty across income thresholds for 175 countries through 2070. Central tendency scenarios with climate effects compared with scenarios that do not model climate change show that climate change-attributable extreme poverty will grow to 25 million people by 2030 (range: 18 to 30), 40 million by 2050 (range: 9 to 78), and 32 million by 2070 (range: 4 to 130) though overall levels of global poverty decline. If climatic tipping points are passed, the climate-attributable extreme poverty grows to 57 million people by 2030 (range: 40–72), 78 million by 2050 (range: 18–193), and 56 million by 2070 (range: 7–306). To mitigate baseline effects of climate change on extreme poverty, an improvement of global income inequality of 10% is required (range: 5–15%).

Highlights

●This paper introduces scenarios that combine RCPs with economic growth and inequality series from the SSPs, creating alternative climate-informed socioeconomic projections.

●Forecasts of climate-driven poverty increases in this paper are lower than estimates made using bottom-up approaches, suggesting that macro-level approaches miss dynamics related to prices and consumption power, though these are difficult to project over very long-time horizons.

●Tipping points are a significant threat to future socioeconomic development and drive significant increases in poverty across scenarios.

●Productivity gains can directly reduce poverty but also increase climate change on a fossil fuel energy system.

●Long-term effects of climate change on poverty could be mitigated with a sustained effort to improve income distribution.

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1 Introduction

The adverse effects of anthropogenic climate change on human and social development are well documented (IPCC 2022), although the extent of these effects remains uncertain (Dickerson et al. 2021). This manuscript contributes to our understanding of the impacts and uncertainties of climate change and poverty across different income levels (Hallegatte et al. 2016; Moyer et al. 2022) by introducing alternative scenarios using the International Futures (IFs) modeling system (Hughes et al. 2019). These scenarios operationalize the relationship between temperature change, economic activity (Nordhaus 2014; Tol 2009), and inequality (Dasgupta et al. 2020; Paglialunga et al. 2022).

We focus on poverty because it is the first Sustainable Development Goal (SDG) and one indicator of human wellbeing which is itself a multidimensional concept (Moyer and Hedden 2020; Aguilar and Sumner 2020). The impact of climate change is operationalized using representative concentration pathways (RCPs) that rely on temperature change to drive outcomes. The general effect of climate change on economic growth is captured using the DICE model damage function (Nordhaus 2018), while the economic cost of tipping points is also represented, which could increase the social cost of carbon (SCC) by an additional 25% (Dietz et al. 2021)[1]. To model the effects of climate change on inequality, we use Paglialunga et al.'s (2022) analysis of changing temperature from 2003 to 2017 for 150 countries and its relationship to inequality. To model the future of socioeconomic development, we rely on both the IFs model's endogenous projections as well as the shared socioeconomic pathways (SSPs) (O'Neill et al. 2017). We adjust SSP scenarios modeling the future of economic growth (Dellink et al. 2017) and inequality (Rao et al. 2017) for expected changes based on the literature identified above.

Technology plays a cross-cutting role in both amplifying the magnitude of climate change through increased economic activity and potentially mitigating future greenhouse gas emissions (Moyer and Hughes 2012). As technology improves, it can increase productivity and accelerate the use of fossil fuels, further damaging climate systems. Economic growth can be a problem for the environment, but it also remains an important input into human development processes. On the other hand, technology can directly reduce reliance on fossil fuels for energy production, allowing for a relative decoupling of fossil fuel inputs into economic production processes. Balancing the role of technology as a driver of both socioeconomic development and climate change will be crucial as humans try to balance competing crises of climate change, pollution, and biodiversity loss with ongoing crises of poverty, undernutrition, and civil conflict.

The approach taken in this manuscript uses macro-level relationships that do not capture the full extent of climate-human interactions, and results should be interpreted as the product of the methodology and not point predictions about what will happen. By neglecting micro-level dynamics, we may be under-estimating the impact of climate change on poverty by not accounting for the direct relationship between food or energy prices and the consumption power of the poor, for example. We are also missing important pathways related to other environmental systems that are being impacted by human activity, such as dangerous loss in biodiversity and acute pollution in the air, land, and sea, further complicating our ability to comprehensively analyze this challenging puzzle.

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[1] The SCC is the economic price of damages caused by emitting one ton of carbon dioxide and is used to evaluate the benefits of mitigation (Rode et al. 2021), something we operationalize as an impact on GDP directly.

The results of this analysis show that climate change will remain a significant challenge for future patterns of socioeconomic development, with tens of millions pushed into poverty because of climate change even in more optimistic scenario combinations. While the results of this analysis do not show as rapid a rise in poverty in worst-case scenarios compared with other recent literature (Hallegatte et al. 2016; Jafino et al. 2020), the effects of climate change on poverty are very significant. However, when compared with other recent analysis that explores other drivers of poverty, such as COVID-19 or future patterns of intrastate conflict (Moyer et al. 2023; Moyer et al. 2022), the climate change model results suggest that a variety of global challenges must be simultaneously addressed to balance socioeconomic development needs, climate damages, and future wellbeing on a planet of finite resources.

2 Background

According to the IPCC (2022), climate change will have broad impacts on future patterns of human development. However, despite a significant volume of climate impact literature produced between 1999 and 2021, only 28 studies have projected future climate impacts on food insecurity, water stress, and disease, all crucial aspects of human development in Sub-Saharan Africa, a region particularly vulnerable to climate impacts (Dickerson et al. 2021). This research highlights significant uncertainty about the effects of climate change on human development patterns, with estimates for hunger ranging from −500,000 to +55 million cases (Hasegawa et al. 2018; Janssens et al. 2020; Tesfaye et al. 2015), net change in water stress exposure from −240 million to +150 million cases (Kiguchi et al. 2015; Shen et al. 2014; Wiltshire et al. 2013), and malaria exposure from 30.1 million to 58.5 million cases (Ebi 2008; Kibret et al. 2016).

Hallegatte et al. (2016) focus on four pathways through which climate change impacts poverty: prices, assets, opportunities, and productivity. This research concludes that climate change has an indirect impact on poverty by increasing the price of food, housing, and healthcare, which decreases real income and reduces the ability of poor households to invest in their future through building assets or gaining education years (Ebi et al. 2017; Hallegatte et al. 2014; Hallegatte et al. 2018; Islam et al. 2014). Climate change can also increase poverty by reducing labor productivity and work hours predominately in the agricultural and industrial sectors via increased temperature and health risks, with the greatest reductions found in agricultural workers without air-conditioning (Dasgupta et al. 2021; Deryugina and Hsiang 2014; Heal and Park 2013; Kjellstrom et al. 2009). Park et al. (2015) find that years with more hot days relative to average temperature are associated with lower local income and payroll per capita. Another study by Deryugina and Hsiang (2014) found that one day with temperatures above 29 degrees Celsius reduces average annual income by approximately .065%.

Climate change also has direct impacts on poverty via agricultural losses, reductions in yields, and destruction of assets from climate-related disasters and shocks, all of which contribute to the loss of income (Connolly-Boutin and Smit 2016; Hallegatte et al. 2016). Lost agricultural income is one of the principal drivers by which climate change disproportionately impacts poor households (Hallegatte et al. 2016; S. N. Islam and Winkel 2017), with damage to livelihood assets forcing low-income groups into persistent poverty traps and transient poverty (Cinner et al. 2018; Kihara et al. 2020; Ward 2016). In addition, the real and perceived risk associated with climate-related disasters may lead poor households

to seek low-risk activities, limiting their opportunities for income growth (Hallegatte et al. 2016). The World Bank study shows that a *poverty* scenario (SSP4-RCP 8.5) will lead to an increase in the number of people living in extreme poverty of 122 million by 2030 (with a base year of 2014) relative to a world without climate change.[2] The methodology uses a micro-simulation which focuses on these pathways of change.

Climate change has been shown to have both within-country and between-country inequality impacts. Research by Burke et al. (2015) reveals that climate change and weather volatility have uneven impacts across countries, with economic growth responding non-linearly to temperature, even on the local level. A strong negative correlation exists between baseline income and temperature, implying that poor, hot countries will experience the largest reductions in growth, amplifying interstate inequality. In Burke et al.'s (2015) benchmark estimate, relative to a world without climate change, average income in the poorest 40% of countries declines 75%, whereas the richest 20% experience slight gains by 2100. Sedova et al. (2020) demonstrate that climate variation increases within-country inequalities in rural India because adverse weather variations reduce consumption of poor farming households at a greater sensitivity and higher rate than non-poor households. While almost all climatic effects can contribute to rising inequality, precipitation anomalies and rising temperatures lead to the most statistically significant increases in income inequality within countries (Sedova et al. 2020).

Climate tipping points are "critical thresholds" within natural systems that, once surpassed, will cause irreversible damage characterized by feedback which is uncertain and non-linear (IPCC 2022). Permafrost melt, ice sheet disintegration, and Amazon dieback represent a few of the tipping points that threaten biodiversity and human wellbeing through the collapse of ecosystem services. Although tipping points have been widely identified and studied by climate scientists, literature examining their impact on the economy has emerged at a slower pace. A study by Dietz et al. (2021) models the impact of tipping points on the social cost of carbon (SCC) for 180 countries, finding that if all tipping points are surpassed, the SCC will increase by about 25% by 2100.

We capture the impact of climate change on productivity via a damage function, which is a simplified approach to gauge the economic losses from worsening climate conditions, such as a rise in mean temperature (Wang and Teng 2022). The most commonly known damage functions are DICE, FUND, and PAGE, which calculate the SCC by percentage losses of GDP globally, regionally, and by sector relative to climate input variables (Barrage and Nordhaus 2023; Diaz and Moore 2017; Kahn et al. 2019; Nordhaus 2019; Tol 2009). Climate damages equate to the sum of residual changes in economic and human welfare after these adjustments and the assumed or measured costs of adaptation, represented in percentage changes in GDP (Diaz and Moore 2017). Damage functions are critiqued from various perspectives, including for being both too optimistic and pessimistic (Auffhammer 2018; Pindyck 2017). We also use the findings from Dietz et al. (2021) to operationalize the impact of tipping points in our analysis across all the alternative socioeconomic development and temperature change combinations.

Inequality is the second driver of poverty explored in this paper. Some studies show that climate change will increase inequalities between and within countries (Diffenbaugh and Burke 2019), with regional studies finding increased inequalities between countries

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[2] This study was recently updated to show that climate change could lead to an additional 132 million people in poverty by 2030 (Jafino et al. 2020).
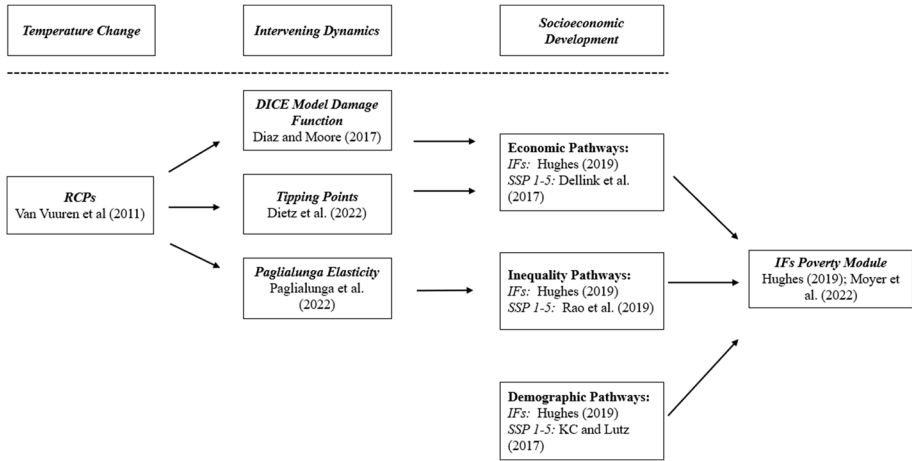
Fig. 1 Temperature, intervening dynamics, and socioeconomic development pathways used in this analysis

(Deryugina and Hsiang 2017) and within countries and communities (Dasgupta et al. 2020; Hsiang et al. 2019; Paglialunga et al. 2022; Sedova et al. 2020). We use a study by Paglialunga et al. (2022), which examines over 150 countries between 2003 and 2017 to assess the extent to which temperature and precipitation variation affected income disparities, identifying agricultural activity as one of the most important channels through which climate change exacerbates inequality, directly and indirectly. While depressed agricultural yields directly affect rural income, they likely affect poor urban populations indirectly by jeopardizing their real income and consumption patterns via increased food prices (Paglialunga et al. 2022). The study finds that a 1% increase in temperature raises the Gini coefficient for income inequality by 0.5 points on a 0–100-point scale.

3 Methodology

We use several tools, including SSPs (O'Neill et al. 2017), RCPs (van Vuuren et al. 2011), and IFs (Hughes et al. 2019), to model economic production, income distribution, and population change for 175 countries from 2017 to 2070, a process outlined in Fig. 1. We begin by using RCP temperature trajectories to measure median temperature change relative to pre-industrial levels on a country basis using a 10-year moving average. We then introduce damage functions (Diaz and Moore 2017; Nordhaus 2018; Tol 2009) and tipping points (Dietz et al. 2021) to capture the impacts of climate change on overall economic activity. Replication results can be found online[3].

We draw upon the SSPs for forecasts of GDP (Dellink et al. 2017), population (Samir and Lutz 2017), and inequality (Rao et al. 2017). We create alternative versions of these scenarios (see Table 1) that reflect the economic and inequality effect represented in the intervening dynamics in Fig. 1. This produces alternative socioeconomic development pathways for GDP and inequality that include or exclude climate effects. We use scenarios

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[3] https://ifs02.du.edu/Replication%20Files/Manuscript%20Replication.zip

Table 1 The components of each scenario

Scenario name	Demographic forecast	Economic forecast	Inequality forecast	Temperature-economy assumption	Temperature-inequality assumption	Poverty module
IFs No Climate	IFs (Hughes et al. 2019)	IFs (Hughes et al. 2019)	IFs (Hughes et al. 2019)			IFs (Hughes et al. 2019)
SSP1-5 No Climate	SSP1-5 Samir and Lutz (2017)	SSP1-5 Dellink et al. (2017)	SSP1-5 Rao et al. (2019)			IFs (Hughes et al. 2019)
IFs-RCP 6.0	IFs (Hughes et al. 2019)	IFs (Hughes et al. 2019)	IFs (Hughes et al. 2019)	DICE model (with and without tipping points)	Paglialunga et al. (2022)	IFs (Hughes et al. 2019)
SSP1-RCP 2.6	SSP1 Samir and Lutz (2017)	SSP1 Dellink et al. (2017)	SSP1 Rao et al. (2019)	DICE model (with and without tipping points)	Paglialunga et al. (2022)	IFs (Hughes et al. 2019)
SSP2-RCP 4.5	SSP2 Samir and Lutz (2017)	SSP2 Dellink et al. (2017)	SSP2 Rao et al. (2019)	DICE model (with and without tipping points)	Paglialunga et al. (2022)	IFs (Hughes et al. 2019)
SSP3-RCP 6.0	SSP3 Samir and Lutz (2017)	SSP3 Dellink et al. (2017)	SSP3 Rao et al. (2019)	DICE model (with and without tipping points)	Paglialunga et al. (2022)	IFs (Hughes et al. 2019)
SSP4-RCP 6.0	SSP4 Samir and Lutz (2017)	SSP4 Dellink et al. (2017)	SSP4 Rao et al. (2019)	DICE model (with and without tipping points)	Paglialunga et al. (2022)	IFs (Hughes et al. 2019)
SSP5-RCP 8.5	SSP5 Samir and Lutz (2017)	SSP5 Dellink et al. (2017)	SSP5 Rao et al. (2019)	DICE model (with and without tipping points)	Paglialunga et al. (2022)	IFs (Hughes et al. 2019)

without climate effects to serve as a baseline that allows us to capture the climate-attributable impact of each SSP-RCP and IFs-RCP scenario.

Combining all the variations of socioeconomic development pathways, climate pathways, economic relationships, and inequality relationships leads to a large number of scenarios. To simplify our presentation, we focus on the SSP-RCP combinations that are more coherent, such as a high fossil fuel socioeconomic pathway with a high emission pathway (SSP5-RCP 8.5). For the IFs model results, we compare the socioeconomic development assumptions with the SSPs and RCPs and find that it most closely reflects an RCP 6.0 world. We present full results in the Supplementary Information as well as replication instructions.

3.1 International Futures

The IFs model includes a six-sector general equilibrium model of the economy (Burgess et al. 2023; Hughes et al. 2019; Hughes et al. 2021; Hughes and Narayan 2021), which simulates production in each sector using Cobb-Douglas type production functions that incorporate sector-specific labor (LABS), capital (KS), total factor productivity (TEFF), and utilization factor (CAPUT). The model initializes inter-sectoral flows with GTAP sectoral-flow data and uses a set of input-output tables grouped by per capita income ranges to establish sector-flow pathways as economies become more developed. Final consumption demand for each sector is initialized with data and changes with income levels.

Agents in the IFs model (households, firms, and the government) optimize each annual time step on the path to equilibrium, which is simulated through stabilization of stock levels, though full equilibrium is never reached at any given point in time. The model incorporates both domestic flows among households, firms, and the government, as well as international trade, to represent the flows that go into sectoral stocks. Household income is determined by labor earnings and business income, after adjustments for taxes paid and transfers received, and this income can be used for consumption or savings. Consumption levels for the six different sectors vary with income levels, and propensity to save varies with income and age.

The poverty calculation in IFs is based on the assumption of a log-normal income distribution (Hughes et al. 2009; Moyer et al. 2022). This distribution is updated annually based on changes in projected consumption and the Gini index of inequality. Poverty rates are computed by determining the cumulative density at the threshold consumption level (the threshold varies depending on the level of poverty analyzed), and the poverty headcount is obtained by multiplying the poverty rate by the population. To initialize the poverty model, poverty data from the World Bank is used. To reconcile the poverty rates generated by the model with historical data, country-specific adjustment factors are computed in the initial time step (see Moyer et al. (2022) for a detailed overview of the IFs poverty module).

4 Results

We begin by introducing the baseline behavior of scenarios across key indicators in Fig. 2 both with (dashed lines) and without forward linkages from temperature change to inequality or economic production (solid lines). RCP 2.6 has an increase of average global temperature to 20.6 degrees centigrade by 2070. RCP 4.5 reaches a temperature of 21.4 degrees by 2070, while RCP 6.0 reaches a temperature of 21.3 degrees by 2070. RCP 8.5 has a steady increase of average global temperature which reaches 22.4 by 2070.
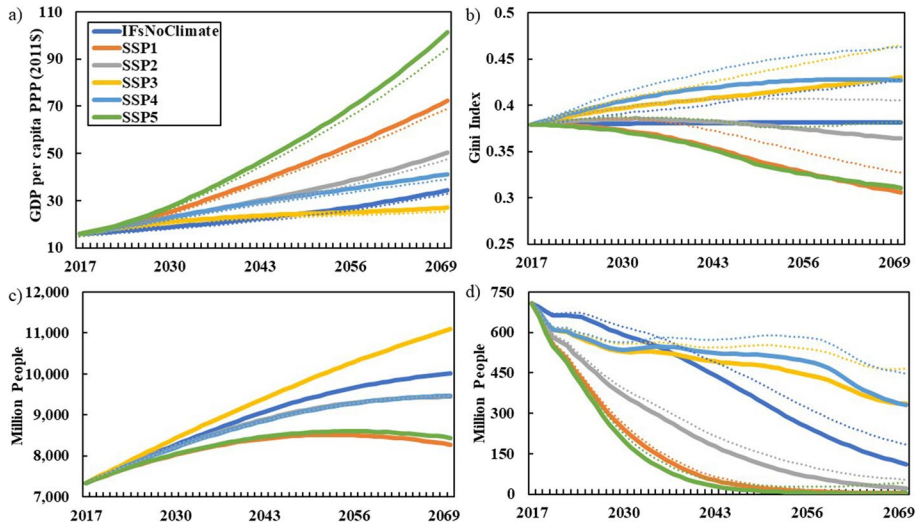
Fig. 2 Each graph shows global forecasts for all *No Climate* scenarios in solid lines for **a** GDP per capita at PPP measured in 2011 USD, **b** Gini index for income inequality measured on a 0–1 scale, **c** population measured in millions, and **d** extreme poverty (less than $1.90 per day) measured in millions. Dotted lines represent the same socioeconomic development scenario with the impact from the most likely RCP combination, as reported below in more detail

Future levels of average per capita GDP increase most rapidly in SSP5, a world of high growth and investment and high challenges to mitigation (Dellink et al. 2017). By 2070, per capita GDP grows to $97.4 thousand USD, up from a 2017 value of $15.3 thousand. Economic production in this scenario is followed by SSP1, a world of sustainable development and few challenges to mitigation and adaptation, with average income increasing to $69.7 thousand USD by 2070. The *middle-of-the road* scenario—SSP2—shows GDP per capita increasing to $48.8 thousand by the end of our time horizon. Scenarios with greater challenges to adaptation show lower long-term growth in per person economic production and consumption, with SSP4 growing to $39.6 thousand USD and SSP3 growing to $25.8 thousand USD by 2070. The IFs scenario is most closely aligned with SSP3 and is the most pessimistic across the time horizon, growing to $33.5 thousand USD by 2070. Income distribution in the *No Climate* scenarios are the most unequal in worlds of high challenges to adaptation, such as SSP3 and SSP4 (Rao et al. 2019). Scenarios with fewer challenges to adaptation, such as SSP1 and SSP5, show much more equal distributions of resources, with the Gini values falling by nearly 20% by the end of the time horizon. The values for SSP2 show slightly improving patterns of income distribution between scenarios with high and low challenges to adaptation. The IFs *No Climate* scenario keeps the Gini coefficient for income flat across time at a country level.

Population projections are also an important driver of poverty headcounts, and the SSP scenarios with high challenges to adaptation show increases in global populations through 2070 (Samir and Lutz 2017). SSP3 is the scenario with the greatest population growth, increasing to 11.3 billion by 2070. Both SSP2 and SSP4 models increased population that peaks by 2070 at 9.4 and 9.5 billion people, respectively. Scenarios with much lower population growth—SSP1 and SSP5—reflect global populations that are declining by 2070, to

Table 2 The effect of climate change on global economic growth measured in cumulative trillions of 2011 US$ at market exchange rates and in percent terms in parenthesis for 2030, 2050, and 2070

Scenario	2030	2050	2070
IFs-RCP 6.0	−$1.1 (−0.2%)	−$17.0 (−0.9%)	−$78.8 (−1.7%)
SSP1-RCP 2.6	−$6.0 (−0.5%)	−$37.4 (−0.8%)	−$103.0 (−0.8%)
SSP2-RCP 4.5	−$5.7 (−0.5%)	−$39.2 (−1.1%)	−$132.9 (−1.6%)
SSP3-RCP 6.0	−$5.0 (−0.5%)	−$27.3 (−0.9%)	−$83.0 (−1.6%)
SSP4-RCP 6.0	−$5.1 (−0.5%)	−$31.0 (−0.9%)	−$100.8 (−1.5%)
SSP5-RCP 8.5	−$6.9 (−0.6%)	−$65.7 (−1.5%)	−$344.1 (−3.2%)

Table 3 The effect of climate on global Gini measured on a 0–1 scale in absolute terms and in percent change in parenthesis for 2030, 2050, and 2070

Scenario	2030	2050	2070
IFs-RCP 6.0	0.010 (2.7%)	0.028 (7.2%)	0.046 (12.0%)
SSP1-RCP 2.6	0.012 (3.2%)	0.022 (6.6%)	0.023 (7.5%)
SSP2-RCP 4.5	0.012 (3.1%)	0.029 (7.7%)	0.042 (11.6%)
SSP3-RCP 6.0	0.010 (2.4%)	0.023 (5.5%)	0.035 (8.2%)
SSP4-RCP 6.0	0.010 (2.4%)	0.023 (5.5%)	0.036 (8.5%)
SSP5-RCP 8.5	0.016 (4.3%)	0.042 (12.7%)	0.074 (23.9%)

8.3 and 8.4 billion people, respectively. The IFs scenario projects a more rapid population growth than most SSP scenarios, showing growth to 10.3 billion by 2070. This is generally in line with the UNPD medium variant population projection.

Global poverty in *No Climate* scenarios decreases, though to different levels and at different rates. In scenarios with few challenges to adaptation—SSP1 and SSP5—global poverty declines rapidly from 706.7 million people in 2017 to fewer than 25 million people by 2050 and fewer than 5 million by 2070. In SSP2, poverty declines more slowly, reducing below 110 million people by 2035 and to fewer than 25 million people by 2070. In scenarios of greater challenges to adaptation, the number of people in poverty remains high. SSP3 and SSP4 maintain global poverty levels above 500 million through the 2040s, only declining to below 350 million by 2070. The IFs *No Climate* scenario shows that poverty levels rose during the COVID-19 global pandemic (Moyer et al. 2022) and then projects them to fall to under 500 million by the 2040s and to under 150 million by 2070.

4.1 Climate effects on economic growth and inequality

According to the DICE model damage function, the impact of climate change on global economic production is projected to reduce GDP across all scenarios. By 2030, the GDP reduction ranges from −0.2 to −0.6%, while by 2050, it ranges from −0.8 to −1.5% and by 2070, the GDP reduction ranges from −0.8 to −3.2% (Table 2). In total, this represents a significant reduction in overall cumulative economic activity, with the range of negative impact estimated at $1.1–6.9 trillion by 2030, $17–65.7 trillion by 2050, and $78.8–344.1 trillion by 2070.

Table 3 presents the impact of changing temperature on future levels of inequality. The increase in global inequality driven by temperature is projected to range from 0.01 to 0.016
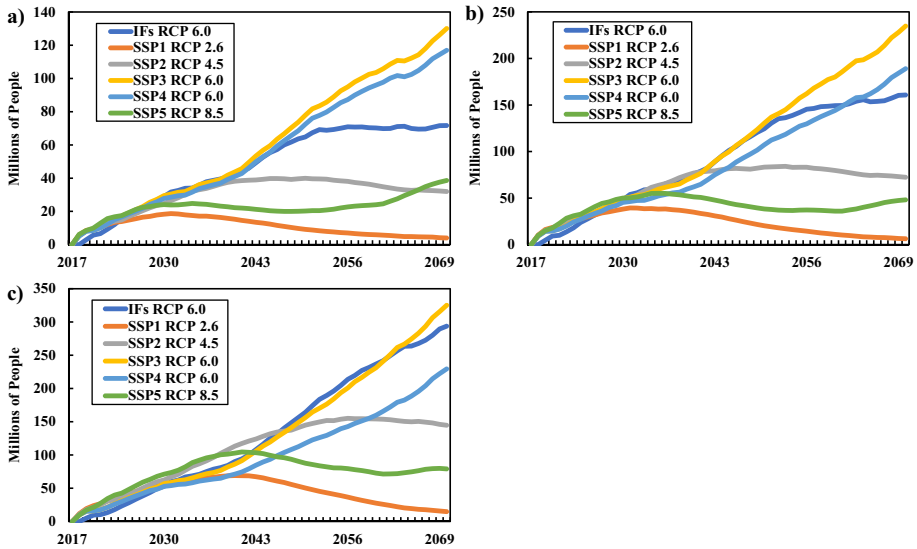
Fig. 3 Each graph shows the effect of climate on global poverty measured in millions: **a** extreme poverty (less than $1.90 per day—top left), **b** poverty (less than $3.20 per day—top right), and **c** moderate poverty (less than $5.50 per day—bottom left)

by 2030, 0.022 to 0.042 by 2050, and 0.023 to 0.074 by 2070, measured on a scale of 0 to 1. This represents a percentage increase in inequality of 2.4 to 4.3% in 2030, 5.5 to 12.7% by 2050, and 7.5 to 23.9% by 2070.

Figure 3 displays the number of people who are expected to fall into extreme poverty due to climate change in each scenario. By 2030, the projected number of people pushed into extreme poverty[4] ranges from an additional 18–30 million. In 2050, the range of uncertainty[5] widens considerably, and the *SSP1-RCP 2.6* scenario, which assumes improved socioeconomic development and low emissions, shows an increase of 9 million people in poverty, a reduction from the level forecast for 2030. This scenario suggests that if socioeconomic development and climate change mitigation efforts are effectively balanced, the number of people pushed into poverty by climate change could be as low as 4 million by 2070.

On the other hand, the more pessimistic *SSP3-RCP 6.0* scenario, which models slow socioeconomic development and moderately high levels of emissions, leads to an increase in the number of people in poverty by 30 million by 2030, 78 million by 2050, and 130 million by 2070. The *SSP5-RCP 8.5* scenario, which assumes high socioeconomic development and high emissions, also results in an increase in the number of people in poverty, albeit at much lower levels than the scenarios with lower socioeconomic development. Specifically, the *SSP5-RCP 8.5* scenario pushes an additional 24 million people into poverty by 2030, 20 million into poverty by 2050, and 39 million into poverty by 2070.

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[4] The phrase "pushed into extreme poverty" is used to highlight the marginal difference between the various climate scenarios and a scenario where the climate impacts are not included. This phrasing does not suggest that poverty rates overall are increasing or decreasing.

[5] The uncertainty treatment here does not use longitudinal error bands and instead considers the broad assumptions made across SSP and RCP scenarios to reflect a broad treatment of future uncertainty.

Table 4 The effect of climate on poverty across thresholds measured in millions in 2030, 2050, and 2070

	$1.90			$3.20			$5.50		
	2030	2050	2070	2030	2050	2070	2030	2050	2070
IFs-RCP 6.0	29.1	65.1	72.0	48.2	125.1	161.7	53.0	164.6	295.1
SSP1-RCP 2.6	18.3	9.2	4.0	38.2	20.3	6.3	55.7	50.4	15.0
SSP2-RCP 4.5	24.7	39.9	32.0	46.9	83.3	72.5	62.7	144.9	144.9
SSP3-RCP 6.0	29.5	77.9	130.1	49.6	130.6	234.9	56.9	156.4	325.5
SSP4-RCP 6.0	27.8	72.5	116.9	45.4	107.3	189.1	53.0	117.8	229.7
SSP5-RCP 8.5	24.1	20.2	38.6	50.1	38.3	48.2	71.3	87.7	79.2

Fig. 4 Climate-attributable percent of the impoverished population in the IFs-RCP 6.0 scenario across poverty thresholds ($1.90, $3.20, $5.50)
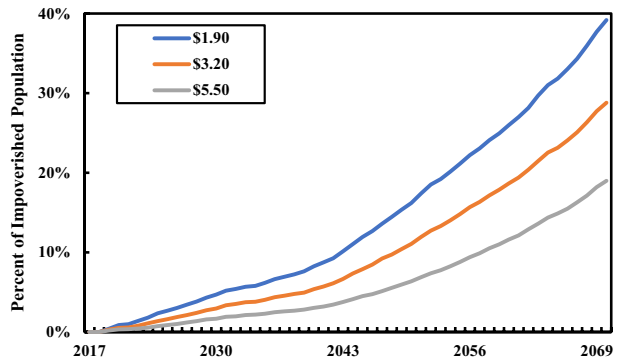
The full range of results for the population pushed into poverty under different income thresholds is provided in Fig. 3 and Table 4. These model results are lower than results from Hallegatte et al. (2016), which produces a *poverty* scenario using SSP4 and RCP 8.5 showing 122 million pushed into poverty because of climate change from 2014 to 2030. Using the same period of time and scenario assumptions, our SSP4-RCP 8.5 scenario without tipping points increases the number of people in poverty by 48 million, and including tipping points increases that number to 99 million.

Future patterns of climate change will also increase the share of the population living on lower income thresholds more than higher income thresholds, as demonstrated in Fig. 4. By 2070, nearly 40% of the population living on less than $1.90 per day will be attributable to climate change in an IFs-RCP 6.0 scenario. As we climb the income ladder, nearly 30% of the future population living on less than $3.20 per day will be there due to climate change. At the $5.50 threshold, nearly 20% will be climate change attributable.

Previous analyses in this manuscript did not consider the potential impact of tipping points, which could have catastrophic effects on socioeconomic development. To address this, we incorporated additional shocks to simulate a worst-case scenario aligned with estimates from recent literature (Dietz et al. 2021). Table 5 presents the effect of exceeding tipping points on GDP levels over time. These tipping points are estimated to increase the number of people living in poverty across various income thresholds, as shown in Fig. 5.

Scenario	2030	2050	2070
IFs-RCP 6.0	−$36.8	−$326.1	−$1,112.0
SSP1-RCP 2.6	−$41.5	−$431.5	−$1,644.0
SSP2-RCP 4.5	−$40.6	−$389.8	−$1,422.0
SSP3-RCP 6.0	−$38.9	−$326.3	−$1,033.0
SSP4-RCP 6.0	−$40.0	−$371.5	−$1,261.0
SSP5-RCP 8.5	−$44.0	−$529.3	−$2,340.0

Table 5 The cumulative effect of tipping points on global GDP measured in trillions of 2011 US$ at market exchange rates
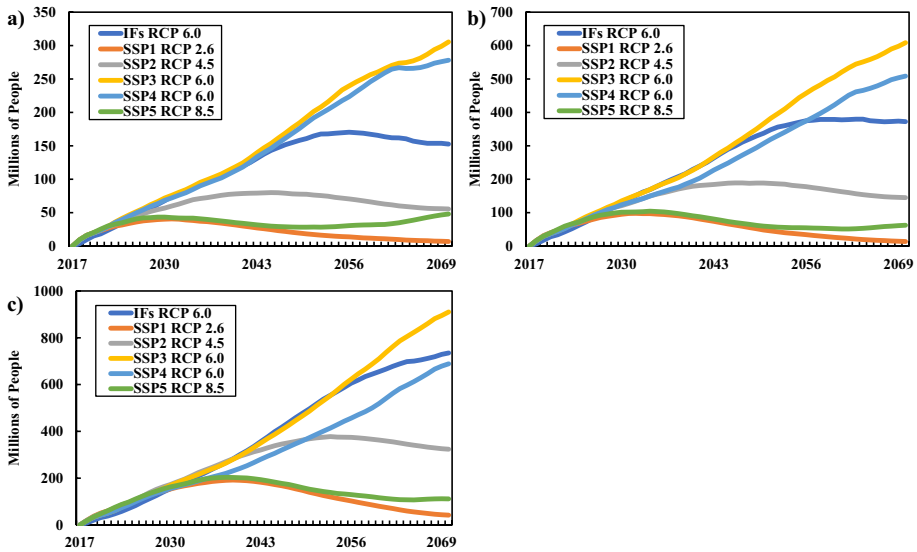

Fig. 5 The climate-attributable effect of RCP scenarios plus surpassing tipping points (a loss in GDP of 25% achieved relative to a *No Climate* economic future by 2100) across global poverty thresholds measured in millions: **a** extreme poverty (less than $1.90 per day—top left), **b** poverty (less than $3.20 per day—top right), and **c** moderate poverty (less than $5.50 per day—bottom left)

The sensitivity of the IFs-RCP model results to scenarios that exogenously changed the Gini coefficient for income inequality was tested to establish a policy-relevant relationship between inequality and climate-induced poverty. The results of this analysis are shown in Fig. 6, which presents the climate-attributable poverty for each IFs-RCP combination alongside five alternative scenarios that exogenously reduce income inequality by different rates to determine the magnitude of change in income inequality required to offset the climate-attributable poverty increases in different RCP scenarios. In addition, we tested two additional relationships between temperature change and income inequality, one being an implicit elasticity in the work of Hallegatte et al. (2016) and a second from Dasgupta et al. (2020) (see Supplemental Information for more on this).

In an RCP 2.6 world, global income inequality would need to be improved by five percent through 2070 to eliminate climate-attributable poverty. In RCP 4.5 and 6.0, the additional improvement in income inequality required to eliminate climate-attributable
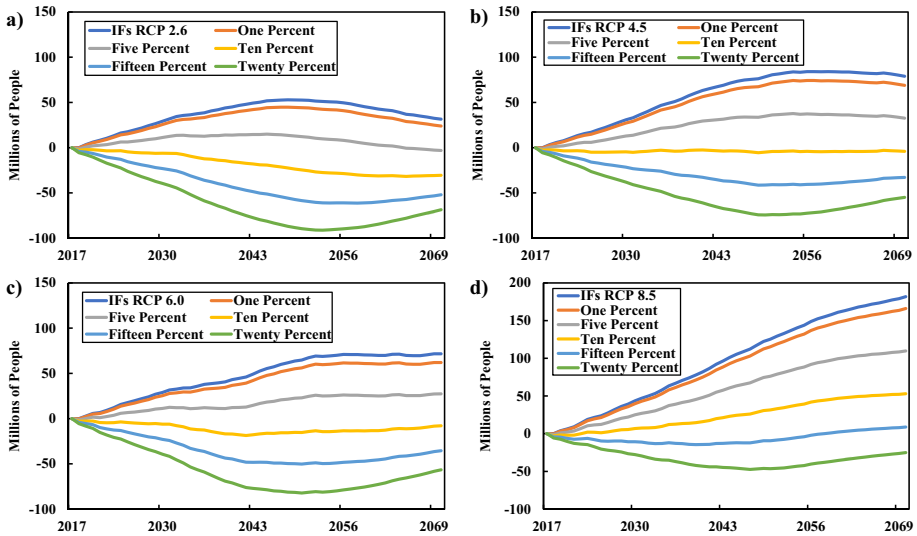
Fig. 6 Global climate-attributable poverty (under $1.90 per day) for *IFs-RCP* scenario combinations minus *IFs No Climate* scenario with alternative scenarios that exogenously reduce global income inequality by one, five, ten, fifteen, and twenty percent interpolated through 2070

extreme poverty would be approximately ten percent globally. In the more extreme climate scenario of RCP 8.5, a fifteen percent reduction in income inequality would be necessary. For context, reducing the Gini coefficient by fifteen percent is equivalent to moving from the average level of income inequality in Latin America and the Caribbean (0.47) to Sub-Saharan Africa (0.41). A reduction of ten percent is equivalent to moving from the Caribbean (0.41) to East Asia (0.37), while a reduction of five percent is equivalent to moving from the average income inequality in Southern Europe (0.345) to Northern Europe (0.33).

5 Discussion

This manuscript presents an analysis of the impact of climate change on poverty across different countries and income thresholds using established macro-level relationships. Unlike previous work in this field, this study looks further into the future, shows results at the country level and across income thresholds, and presents a comprehensive range of SSP-RCP combinations helping to inform thinking about the relationship between economic development, climate change, and poverty. We show that the future impact of climate change on human development is characterized by significant uncertainty and that human choices related to mitigation can significantly reduce the climate-induced burden on poverty. We also demonstrate that sustained efforts to improve income distribution can mitigate the long-term effects of climate change on poverty.

The core relationships analyzed in this manuscript are illustrated in Fig. 7, with a special focus on the role of technology in changing the development dynamics. Economic production and fossil fuel use are the primary drivers of climate change, with increased growth
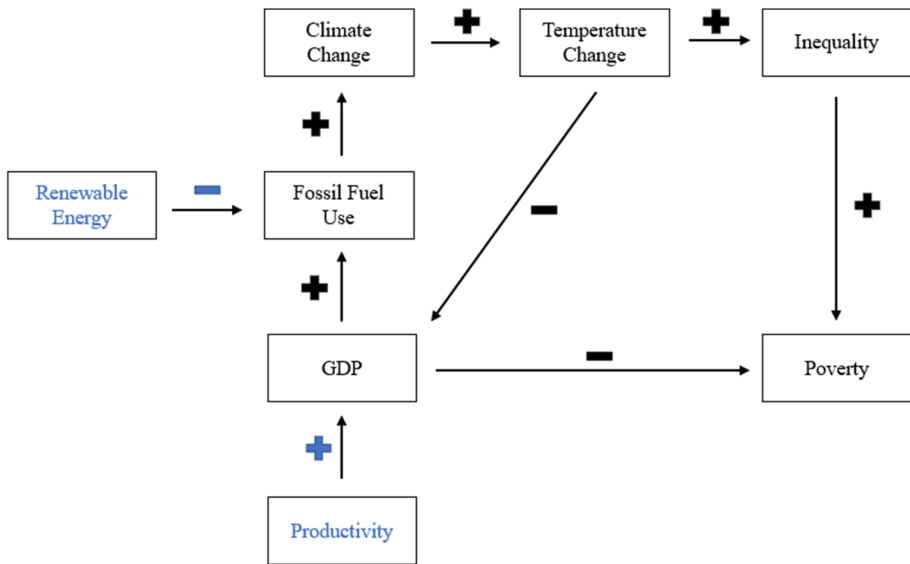
Fig. 7 Relationships explored in this manuscript highlighting the role of technology

and carbon energy systems driving greenhouse gas emissions and temperature increases. Temperature change, in turn, reduces economic growth and increases inequality, which are drivers of poverty. The role of technology in changing these dynamics is twofold, with productivity improvements exacerbating fossil fuel emissions and renewable energy improvements mitigating them (Moyer and Hughes 2012).

The limitations of the modeling exercise pursued in this manuscript are quite broad and include (a) the use of damage functions, which may be so broad that they are not useful (Pindyck 2017); (b) reliance on historical data on the relationship between temperature change and inequality during a period of limited climate change; (c) a lack of explicitly sectoral analysis, including dynamics associated with the agriculture sector (Hallegatte et al. 2016); (d) an omitted relationship between changing energy and food prices and the purchasing power of the poor; (e) representation of climate change via temperature and not precipitation; (f) a measure of human development that is consumption based and is adjusted for purchasing power in ways that may misrepresent actual consumption (Moatsos and Lazopoulos 2021); and (g) an inability to model shocks driven by exceeding planetary boundaries.

While there are significant limitations and gaps in our understanding of the future impact of climate change on socioeconomic development, we hope this research can push forward analysis that helps us better understand how to find a balance between future socioeconomic development, technological development, and climate change. Finding the best strategies for pursuing human development while also mitigating the effects of climate change will require policy solutions that (a) pursue technological solutions to reducing the carbon intensity of economic activity, (b) find opportunities to reduce human consumption where possible (Hickel et al. 2022), and (c) further invest in research to better understand how climate adaptation will likely unfold across various scenarios.

6 Conclusion

The "middle-of-the-road" scenario (SSP2-RCP 4.5) leads to an additional 40 million people in extreme poverty by 2050 relative to a world without climate change. This is lower than other model estimates of the number of people pushed into poverty due to COVID-19 (Moyer et al. 2022) and intrastate conflict (Moyer et al. 2023). This suggests that policymakers need to wrestle with a range of disruptive events that can make it more difficult to achieve SDG1 and that prioritizing across policy concerns will be increasingly difficult. Because the future effects of climate change on human development are characterized by such great uncertainty, mitigation and adaptation must remain a significant policy priority. Human development requires energy and damages the environment. While this damage can be mitigated, it cannot be eliminated, and policy strategies will increasingly require a dual focus on socioeconomic development and its environmental consequences. Finding a balance will be crucial for the wellbeing of future generations.

Declarations

Competing interests The authors have no completing interests to declare.

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