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# Influence of climate change impacts and mitigation costs on inequality between countries

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1 **Influence of climate change impacts and mitigation**  
2 **costs on inequality between countries**

3 **Nicolas Taconet · Aurélie Méjean ·**  
4 **Céline Guivarch**

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7 Influence of climate change impacts and mitigation costs on inequality between countries.  
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9 **Abstract** Climate change affects inequalities between countries in two ways.  
10 On the one hand, rising temperatures from greenhouse gas accumulation cause  
11 impacts that fall more heavily on low-income countries. On the other hand,  
12 the costs of mitigating climate change through reduced emissions could slow  
13 down the economic catch-up of poor countries. Whether, and how much the  
14 recent decline in between-country inequalities will continue in the twenty-first  
15 century is uncertain, and the existing projections rarely account for climate  
16 factors. In this study, we build scenarios that account for the joint effects  
17 of mitigation costs and climate damages on inequality. We compute the evo-  
18 lution of country-by-country GDP, considering uncertainty in socioeconomic  
19 assumptions, emission pathways, mitigation costs, temperature response, and  
20 climate damages. We analyze the resulting 3408 scenarios using exploratory  
21 analysis tools. We show that the uncertainties associated with socioeconomic  
22 assumptions and damage estimates are the main drivers of future inequalities.  
23 We investigate under which conditions the cascading effects of these uncer-  
24 tainties can counterbalance the projected convergence of countries' incomes.  
25 We also compare inequality levels across emission pathways, and analyze when  
26 the effect of climate damages on inequality outweigh that of mitigation costs.  
27 We stress the divide between IAM- and econometrics-based damage functions  
28 in terms of their effect on inequality. If climate damages are as regressive as  
29 the latter suggest, climate mitigation policies are key to limit the rise of future  
30 inequalities between countries.

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<sup>32</sup> mitigation · Socioeconomic scenario · Climate change impact

## 1 Introduction

Income inequalities between countries have declined in recent decades notably as a result of rapid economic growth in China and India (Firebaugh, 2015; Milanovic, 2016). Most projections see inequalities continuing along this dwindling path throughout the twenty-first century (Hellebrandt and Mauro, 2015; Riahi et al., 2017; OECD, 2018; Rodrik, 2011; Hawksworth and Tiwari, 2011; Spence, 2011). However, they do not consider the impact of climate change on inequalities. Indeed, climate change will induce impacts that hit primarily the poorest countries (Oppenheimer et al., 2014; Burke et al., 2015; Nordhaus, 2014; Mendelsohn et al., 2006; Stern, 2007; Tol, 2018), which may slow or even reverse the expected convergence of per capita national incomes. Limiting these impacts through greenhouse gas reduction policies also bears consequences for inequalities, as mitigation policies could be a hurdle to development. How the distributional effects of reduced climate change damages compare with those of mitigation costs and how they weigh against other socioeconomic factors have not been analyzed. Our paper bridges this gap.

We analyze how climate change affects future inequalities between countries via joint impacts and mitigation costs. We build country-by-country GDP trajectories up to 2100, exploring the uncertainty around 6 dimensions: (1) socioeconomic assumptions, (2) emission pathways, (3) mitigation costs, (4) regressivity of mitigation costs, (5) temperature response, (6) climate change damages. The different combinations of uncertainties lead us to explore 3408 scenarios, for which we analyze between-country inequality as measured by the Gini coefficient, as well as the first income decile. We perform a statistical analysis of the outcomes to identify the main drivers of future inequality. We find that the burden of climate damages on poor countries is sufficiently large to lead to a reversal in the declining inequality trend in some combinations of socioeconomic pathways and damage estimates. We also analyze inequality levels of various emission pathways, showing that lower emissions are associated with a lower level of inequalities under the strongest damage estimates. If damage estimates are low, mitigation can still reduce inequalities in some combinations of assumptions regarding socioeconomic evolution, the level of mitigation cost and the distribution of these costs.

We discuss the drivers of future inequality in Section 2. We then present the methodology used to build scenarios in Section 3. We analyze the results of the projections in Section 4. We discuss limitations and conclude in Section 5.

## 2 Drivers of future inequality

We consider two types of factors affecting future economic growth: climate-related and socioeconomic factors. Climate change affects between-country inequality in two ways: through uneven climate damages and through differentiated mitigation costs.

75 First, climate change is expected to reduce future income, through direct  
76 production and capital losses and lower economic growth. It is also expected  
77 to increase investment needs for adaptation. These climate damages will be  
78 shared unevenly among countries, because physical impacts may differ, and be-  
79 cause the vulnerability to climate change and the ability to adapt vary widely  
80 across countries. For instance, some countries are more dependent than others  
81 on sectors that will be affected by climate change, such as the agricultural sec-  
82 tor. Damage evaluation is a perilous exercise: it is very difficult, if not impossi-  
83 ble, to predict how each country will be impacted by climate change. However,  
84 an extensive literature suggests that overall damages of climate change will be  
85 greater in poorer countries (Oppenheimer et al., 2014; Tol et al., 2004; Mendel-  
86 sohn et al., 2006; Burke et al., 2015; Nordhaus and Yang, 1996; Hallegatte and  
87 Rozenberg, 2017; Dell et al., 2012), and the Intergovernmental Panel on Cli-  
88 mate Change lists the distribution of impacts as one of the five “Reasons for  
89 Concern” about climate change.

90 Second, the cost of greenhouse gas emission reductions will affect coun-  
91 tries’ future income, with the costs depending on local contexts. For instance,  
92 current carbon intensities differ widely across countries, as do their potentials  
93 for the development of renewable energy. Mitigation policies can be more bur-  
94 densome for low-income countries than for rich countries, meaning that poor  
95 regions may lose a greater share of GDP than rich regions for the same amount  
96 of abated emissions (Krey, 2014; Edenhofer et al., 2014). Indeed, low-income  
97 economies are often characterized by higher energy and carbon intensities. By  
98 raising the price of energy, mitigation policies could thus hamper their ability  
99 to develop. Higher costs in low-income countries can also arise due to term of  
100 trade effects of climate policy (Leimbach et al., 2010). Some mitigation strate-  
101 gies, notably using biofuels, could also threaten food security in the poorest  
102 regions (Hasegawa et al., 2018; Fujimori et al., 2019). However, the actual re-  
103 gressivity of mitigation costs will depend on the way the burden of the emission  
104 reduction effort is shared among countries in the post-COP21 agenda (Aldy  
105 et al., 2017; Liu et al., 2016) and on the feasibility of international transfers  
106 (Fujimori et al., 2016).

107 Climate damages and the economic impacts of mitigation policies are  
108 closely intertwined, as the greater the emission reductions through mitiga-  
109 tion policies, the smaller the damages. Thus, while greenhouse gas emission  
110 reduction may place a greater burden on poor countries, it also reduces future  
111 damages that fall disproportionately on them, so that the resulting effect of  
112 mitigation is ambiguous in terms of inequality: avoided climate change may  
113 reduce inequality only if mitigation costs do not fall too heavily on the poor-  
114 est countries. Yet, no study has brought both sides of the issue together to  
115 study future inequalities. Here, we analyze inequalities between countries for  
116 different emission pathways.

117 Climate-related factors are only one piece of the future inequality puzzle,  
118 as other socioeconomic factors affect the gap between rich and poor coun-  
119 tries, such as demographics, technological progress, education, and institu-  
120 tions (Barro and Sala-i Martin, 2004). A key question concerns the ability of

**Table 1** The Shared Socioeconomic Pathways (SSP)

SSP	Name
1	Sustainability
2	Middle of the Road
3	Regional Rivalry
4	Inequality
5	Fossil-fueled Development

low income countries to mimic China and India’s rapid economic catch-up. Whether convergence is just a question of time, occurs only regionally or is country-specific is the subject of intense debates in the development literature (Milanovic, 2006; Rodrik, 2011), and how fast the income of different countries can converge in the twenty-first century remains deeply uncertain.

### 3 Methodology

#### 3.1 Building the scenarios

We build scenarios to explore future inequalities between countries, accounting for socioeconomic and climate-related factors. We model 6 dimensions of uncertainties: (1) socioeconomic assumptions, (2) emission pathways, (3) mitigation cost estimates, (4) regressivity of mitigation costs, (5) temperature response, (6) climate change damages. A summary of the uncertainties and sources considered is provided in table 2.

##### 3.1.1 Socioeconomic assumptions

We use shared socioeconomic pathways (SSP) scenarios to explore possible evolutions of socioeconomic factors in the twenty-first century (Riahi et al., 2017). SSPs consist of five pathways (SSPs 1 to 5) that reflect combined and consistent hypotheses on demographics, technological progress, and socioeconomic evolutions (see table 1). SSPs project economic growth for all countries based on future population, technological progress, physical and human capital, as well as energy and fossil resources (Dellink et al., 2017). While SSPs 1 and 5 depict sustained growth and convergence of income levels by the end of the century, in SSPs 3 and 4 poor prospects for developing countries and lack of cooperation lead to much slower reduction of inequality. SSP 2 lies in between, with moderate growth and convergence. For each country, initial GDP per capita levels in 2015 are set using the latest World Development Indicators (WDI 2017, May), and economic growth is set based on SSP trajectories.<sup>1</sup>

<sup>1</sup> SSP trajectories are available at SSP Database (Version 2.0).

### 149 3.1.2 Emission pathways

150 The SSP growth projections for all countries assume there are no climate policy  
151 and no climate change impacts. We build on these projections to compute  
152 projections for different mitigation pathways with radiative forcing targets  
153 corresponding to representative concentration pathways (RCPs). The radiative  
154 forcing levels reached in the baseline case in 2100 differ across SSPs, with the  
155 highest — SSP 5 — being the only one above RCP 8.5, while the lowest —  
156 SSP 1 — is below RCP 6.0 (Riahi et al., 2017). Thus, we leave aside RCP  
157 8.5, and only keep RCPs 2.6, 4.5, and 6.0, to which we add the intermediary  
158 radiative forcing target of  $3.4 \text{ W/m}^2$  from the SSP database. Of these, only  
159 RCP 2.6 is likely to meet the target of limiting global mean temperature  
160 increase below  $2^\circ\text{C}$  compared with pre-industrial levels (Stocker et al., 2013).  
161 For all mitigation scenarios, we account for mitigation costs to meet the target  
162 and for the economic impacts from a changing climate.

### 163 3.1.3 Mitigation costs

164 We compute mitigation costs based on regional projections from the SSP  
165 database, which provides the results from six different integrated assessment  
166 models (IAMs) for scenarios spanning the SSP-RCP matrix. We use mitiga-  
167 tion costs calculated by the IAMs that include an endogenous growth module  
168 (AIM/GCE, MESSAGE-GLOBIUM, REMIND-M, and WITCH). Other IAMs  
169 in the SSP database (IMAGE and GCAM) assume exogenous GDP growth  
170 pathways that are not affected by mitigation policies and thus do not change  
171 according to the RCP. We exclude the results from these models, as they do  
172 not represent the effect of mitigation on growth. Of the four models, some have  
173 not run all SSPs, so we have between 2 and 4 estimates for each combination  
174 of SSP/RCP. A clear advantage of using the mitigation costs from the SSP  
175 database is that they are consistent with the storylines of the SSPs. Thus, the  
176 same target is more difficult to reach in a scenario where baseline emissions  
177 are large or technical progress is slow. However, the cost projections rely on a  
178 least-cost approach, which brings two caveats. First, the actual cost of reaching  
179 the target may in fact be higher due to real-world market imperfections, for  
180 instance if there is inertia or imperfect foresight (Waisman et al., 2012). Sec-  
181 ond, emission reductions are supposed to take place in the region where they  
182 are the cheapest, regardless of equity considerations. Given the limited coop-  
183 eration and policy harmonization across countries on climate change issues at  
184 present, the distribution of costs may differ from those assumed in the SSP  
185 database. To account for different effort-sharing schemes, we use two variants  
186 of mitigation cost distribution: first, we distribute the regional costs from the  
187 IAMs within each region proportionally to each country’s income. Second, we  
188 look at the more regressive case of equally-shared costs within a region. As we  
189 explain in section 5.1, more progressive distributions could be envisaged that  
190 would reflect different burden sharing approaches under international negoti-

191 ations. Such distribution would strengthen the impact of climate damages on  
192 inequality relative to mitigation cost.

### 193 *3.1.4 Temperature response*

194 There is great variability in the evolution of temperature at the country level  
195 for a given RCP as given by climate models (Stocker et al., 2013). Therefore,  
196 we consider values for temperature changes corresponding to the mean, and the  
197 10th and 90th percentile of outcomes. Temperature changes in 2100 are taken  
198 from the Climate Intercomparison Model Project CMIP5<sup>2</sup>. CMIP5 provides  
199 national mean annual temperature changes in 2100 for RCPs 2.6, 4.5, 6.0 and  
200 8.5. When the radiative forcing in 2100 of a scenario falls between two values  
201 provided by CIMP5, we perform a linear interpolation to calculate temperature  
202 change in 2100. Using the 2100 value, we assume that temperatures increase  
203 linearly over time.

### 204 *3.1.5 Climate change damages*

205 Given that future climate change damages are very uncertain, we use 8 esti-  
206 mates from different sources for damages associated with different temperature  
207 changes, from Integrated Assessment Models, and from the econometrics lit-  
208 erature.

209 Integrated assessment models are primarily used to analyze the interac-  
210 tion between climate and the economy (Nordhaus, 2008). In particular, they  
211 are used to derive optimal emissions pathways balancing the cost of mitiga-  
212 tion with the benefits of avoided damages. However, they typically provide  
213 global damage estimates – and the damage estimates they rely on are global,  
214 too. RICE and FUND are notable exceptions: we therefore use estimates from  
215 RICE2010 (Nordhaus, 2014).<sup>3</sup> We also draw upon estimates relying on the  
216 GTAP model (Global Trade Analysis Project). Roson and Sartori (2016) (RS  
217 hereafter) assess the economic changes associated with higher temperature in  
218 different sectors (agriculture, health, tourism...) for 140 regions. We use their  
219 aggregate estimates of the percentage change of GDP in a 3°C scenario com-  
220 pared with the associated baseline, for the different regions. This percentage  
221 GDP change may be positive or negative depending on the region. We assume  
222 that this effect on GDP grows proportionally with global temperature.

223 Finally, we use estimates from the econometrics literature, which shows ev-  
224 idence that temperature changes have impacted economic growth in the past,  
225 and more heavily so in poorer countries. This difference is attributed either to  
226 national development levels (Dell et al., 2012), or to mean temperature (Burke  
227 et al., 2015). Burke et al. (2015) (BHM hereafter) derive a damage function  
228 from historical GDP and temperature data. The authors econometrically es-  
229 timate the effect of higher than average annual temperature, controlling for

<sup>2</sup> [https://climexp.knmi.nl/plot\\_atlas\\_form.py](https://climexp.knmi.nl/plot_atlas_form.py)

<sup>3</sup> We are not aware of publicly available regional damage estimates from FUND.



other variables. They find a non-linear bell-shaped relationship between temperature and economic growth, showing a maximum for an annual average temperature of around 13°C.

Additionally, we consider econometric estimates from Dell et al. (2012) (DJO hereafter), who find a strong and significant effect of temperature on growth in poor countries, while the effect for rich countries is small. We account for the future divide between rich and poor countries in two ways: (1) a static version, where poor countries are defined as those currently below median income, a definition that is set over the whole horizon, (2) a dynamic version, with current median income defining the threshold between poor and rich countries, thus allowing countries to switch status over time. This second version accounts for some form of adaptation where income growth compensates (here almost fully) the negative impact of climate change.

For both damage functions, we use the regressions with 0 and 5-year lags. A distributed lag model with 5-lags adds up the effect of temperature in the current and 5 previous years. This allows capturing the cumulative effect of temperature on income rather than solely a short-run effect. We discuss the limitations of relying on econometric estimates to project future damages in section 5.1.

### 3.1.6 Computing economic growth

Using mitigation costs and climate damages for each country, GDP per capita  $Y$  at time  $t$  in a given RCP scenario is calculated as follows, for RICE and RS:

$$Y_{t,RCP} = X_{t,RCP} \Omega(GMT_t) Y_{t,baseline} \quad (1)$$

where  $X_{t,RCP}$  is the mitigation cost factor,  $\Omega(GMT_t)$  is the damage factor in the region for a global mean temperature change of  $GMT_t$ , and  $Y_{t,baseline}$  is the GDP per capita in the corresponding baseline scenario.

For econometrics-based damage functions (BHM and DJO), the equation writes:

$$Y_{t,RCP} = X_{t,RCP} (1 + g_{t,baseline} + \Delta g(T_t)) Y_{t-1,RCP} \quad (2)$$

where  $g_{t,baseline}$  is the growth projected in a baseline without climate impacts and  $\Delta g(T_t)$  is the loss of economic growth under national temperature  $T_t$  due to climate change.

In total, we are able to compute the projections for 161 countries, currently representing 96% of world population. We exclude countries for which we lack either initial GDP or future temperature projections.

The combination of different socioeconomic assumptions (5 SSPs), emissions pathways (baseline and between 2 and 4 RCPs, depending on the SSP), mitigation costs estimates (2 to 4 estimates depending on the SSP and RCP, with 2 variants of the distribution of costs within region for each estimate), temperature response to a given RCP (3 cases), and damage estimates (8

**Table 2** Uncertain factors considered in the study

Dimension	Levels	Source
Socioeconomic	5 growth pathways	SSP database
Emissions	baseline and lower pathways among RCPs 2.6, 3.4, 4.5, 6.0	SSP database
Mitigation costs	regional costs from 2 to 4 models	SSP database
Distribution of mitigation costs	Equal distribution or proportional to income within regions	
Temperature	Low (10th percentile), Medium (mean), and High (90th percentile)	CMIP5
Damages	8 damage functions (IAM- and econometrics-based)	RICE2010, Roson and Sartori (2016), Dell et al. (2012), Burke et al. (2015)

models) results in 3408 scenarios. Scenarios are consistent in the sense that for each combination, the mitigation costs are those estimated for the corresponding SSP/RCP, while climate damages are calculated according to the temperature change induced by the emission pathway against the temperature response. However, we ignore the fact that damages that damages for a given temperature change may also depend on the socioeconomic pathway. This limitation is discussed in section 5.1. Besides, some combinations of factors may be more plausible than others, but we nevertheless consider all of them without making *a priori* judgements about their likelihood.

### 3.2 Measuring income inequality

The literature distinguishes three types of income inequality (Milanovic, 2011): (1) unweighted international inequality compares countries' income regardless of their size, (2) population-weighted international inequality weighs countries' income according to their population (3) total inequality accounts for households' or individuals' revenue distributions within and across countries. We focus on the second type of inequality, which gives equal weight to all individuals across countries. This choice of international inequality is motivated as follows. First, between-nation inequality represents, as of today, the greatest source of inequality between individuals (Firebaugh, 2015; Bourguignon and Morrisson, 2002). Besides, future income distribution within a country is subject to policy choices that would be difficult to model.

Many indicators can be used to measure this type of inequality (Charles-Coll, 2011). The most routinely used index is the Gini index, which computes the dispersion of income, ranging from 0 (perfect equality) to 1 (one individual or entity owns all the income). The Gini index is the ratio of the mean absolute difference between two individuals or entities to twice the mean level of income. If countries indexed by  $i$  are ranked based on their per capita income  $I_i$ , with  $p_i$  their population, we can define the cumulated proportion of income and population as follows:

$$p_{c,i} = \frac{\sum_{k=1}^i p_k}{\sum_{k=1}^N p_k} \quad (3)$$

$$I_{c,i} = \frac{\sum_{k=1}^i I_k}{\sum_{k=1}^N I_k} \quad (4)$$

298 The Gini index then writes:

$$Gini = 1 - \sum_{k=i}^N (p_{c,i} - p_{c,i-1})(I_{c,i} - I_{c,i-1}) \quad (5)$$

299 with  $I_{c,0} = 0$  and  $p_{c,0} = 0^4$ . Appealing for its simplicity, the Gini index  
 300 is also criticized, notably because it may be regarded as overly sensitive to  
 301 changes in the middle of the distribution, and because it measures relative  
 302 inequality (Cowell, 2000). Indeed, a world with more inequality may still be  
 303 better for the poorest in absolute terms. Thus, we also examine the absolute  
 304 situation of the bottom 10%, as measured by the first income decile (see section  
 305 4.4).

## 306 4 Results

307 We compute the Gini index in all scenarios, and analyze the drivers of its  
 308 evolution over the twenty-first century.

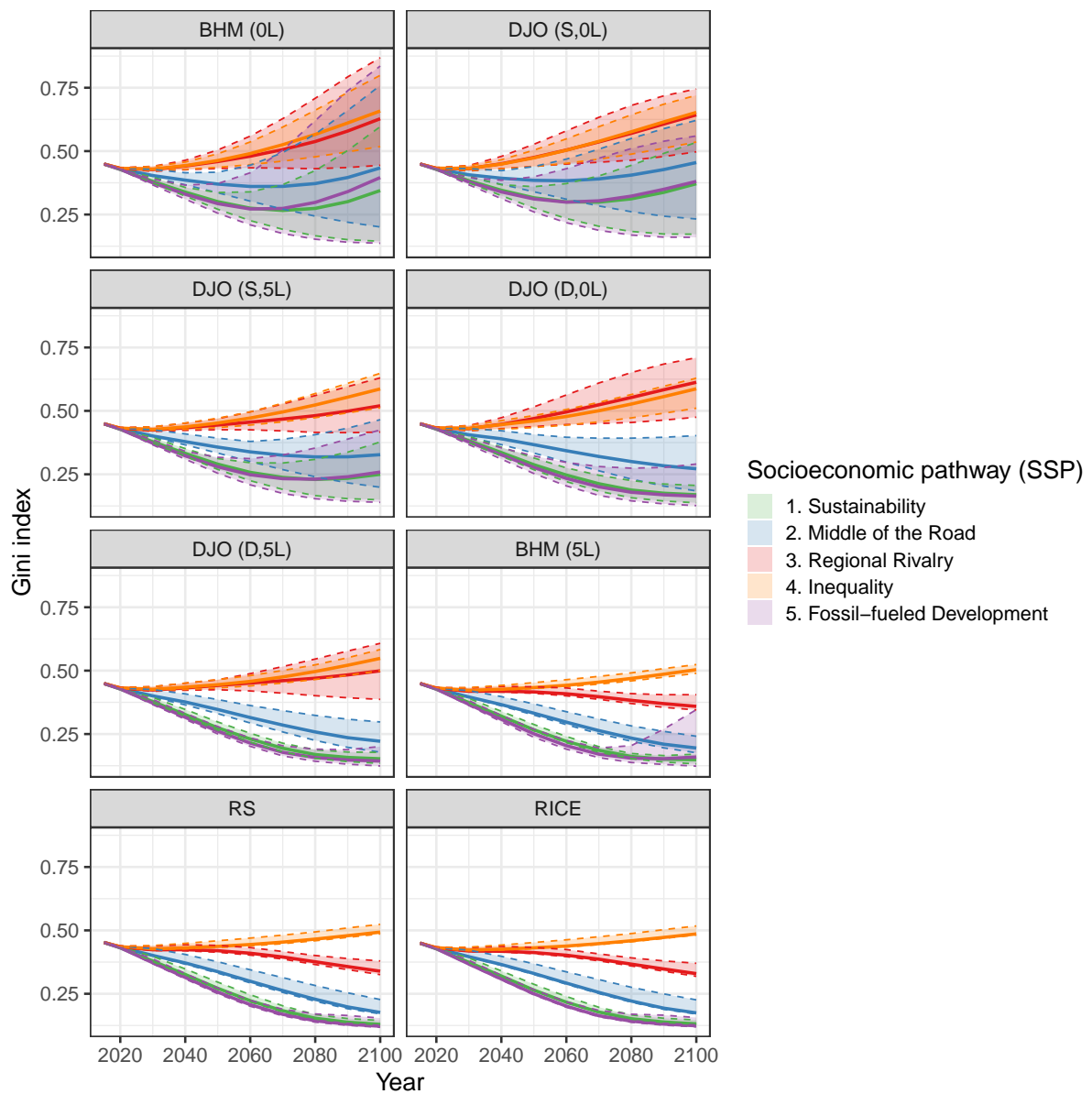
### 309 4.1 A trend reversal in inequalities

310 Both socioeconomic and climate-related uncertainties strongly influence the  
 311 evolution of future inequalities (figure 1). In many scenarios, inequalities con-  
 312 tinue to decline for a few years or decades, but as climate change impacts  
 313 gradually occur, they may outweigh the forecasted economic catch-up by low-  
 314 income countries, and inequalities may rise again as a result.

315 We perform a PRIM analysis to identify the combinations of uncertainties  
 316 that lead to this trend reversal, using the method described in Guivarch et al.  
 317 (2016)<sup>5</sup>. The results of this analysis show that there are cases of trend reversal  
 318 in all socioeconomic pathways, even in the most optimistic ones (see table 3).  
 319 Inequalities rise again systematically in SSP 4, a socioeconomic world depict-  
 320 ing a great divide between rich and poor countries. With the low prospect  
 321 for catch-up assumed in SSP 3, a trend reversal in inequality can also occur,  
 322 but only for high damage estimates (namely BHM (0 lag), and all DJO es-  
 323 timates). For other socioeconomic pathways, regressive damage specifications

<sup>4</sup> The pairs  $(p_{c,i}, I_{c,i})$  represent the Lorenz curve: a proportion  $p_{c,i}$  of the population earns a proportion  $I_{c,i}$  of global income. Graphically, the Gini coefficient is worth half the area between the Lorenz curve and the first bisector.

<sup>5</sup> Results from the PRIM analysis are provided in the Appendix.



**Fig. 1** Evolution of the Gini index over time. A panel corresponds to a damage function. For each socioeconomic pathway, the dotted lines represent the minimum and maximum values of the Gini index, while the plain line is the mean. 'DJO': Dell et al. (2012), 'BHM': Burke et al. (2015), 'RS': Roson and Sartori (2016). For DJO, 'S' and 'D' stand respectively for static and dynamic poor/rich distinction. For DJO and BHM, '0L' and '5L' refer to 0-year lag or 5-year lag regression.

**Table 3** Each line is a combination where a trend reversal in the Gini occurs, of factors leading to a trend reversal in inequality, as revealed by PRIM analysis. The trend reversal can occur in all SSPs, but in some SSPs only for high damages, a high RCP or a high temperature response.

SSP	Damage	RCP	Temperature response
SSP 1	BHM (0L)	$\geq$ RCP 3.4	All
	DJO (S,5L)	All	Medium, High
	DJO (S,0L)	$\geq$ RCP 3.4	All
SSP 2	BHM (0L)	$\geq$ RCP 3.4	Medium, High
	DJO (S,5L)	$\geq$ RCP 3.4	Medium, High
	DJO (S,0L)	$\geq$ RCP 3.4	All
SSP 3	BHM (0L)	All	All
	DJO (S,5L)		
	DJO (S,0L)		
	DJO (D,0L)		
	DJO (D,5L)		
SSP 4	All	All	All
SSP 5	BHM (0L)	$\geq$ RCP 3.4	All
	DJO (S,5L)	$\geq$ RCP 3.4	
	DJO (S,0L)	$\geq$ RCP 3.4	

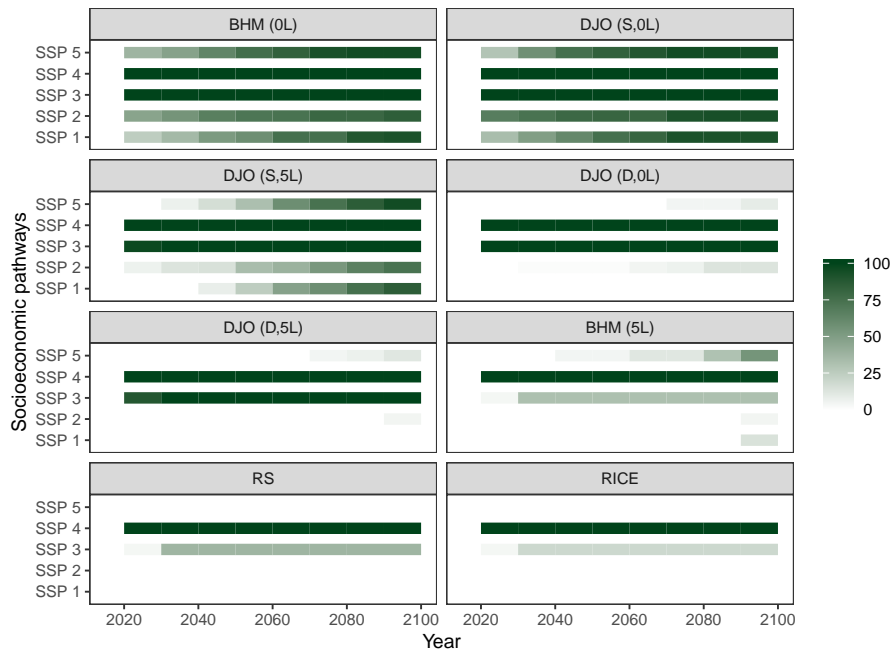
324 (i.e. econometrics-based) slow down the convergence, and make inequalities  
 325 rise again under strong temperature change (either because of high emission  
 326 or high temperature response).

327 In the cases where inequalities rise again, the timing of the trend reversal  
 328 also varies depending on the uncertainties, in particular the combination of  
 329 socioeconomic assumptions and damage function (see figure 2). The reversal  
 330 occurs systematically as early as in the 2020s in SSP 4. In SSP 3, the occur-  
 331 ring decade is determined by the damage estimates, but varies between lowest  
 332 and highest damage estimates. For the more 'optimistic' socioeconomic path-  
 333 ways (SSPs 1, 2 and 5), there is great variability in the date at which the  
 334 trend reversal occurs for high damage estimates. In such cases, lower emission  
 335 scenarios or low temperature response scenarios delay the reversal.

## 336 4.2 Analyzing the Gini index using regression trees

337 We analyze how the different uncertainties affect the Gini index, and we com-  
 338 pute a regression tree to identify the main drivers of its value in 2100. We use  
 339 recursive partitioning to select the factors in order to reduce the heterogeneity  
 340 of the output value.<sup>6</sup> The regression tree identifies socioeconomic assumptions  
 341 (SSPs) and the damage function as the first two nodes of the decision tree,  
 342 suggesting that these dimensions are the most influential on inequalities in  
 343 2100 (figure 3). The first node splits the scenarios into two groups, the first  
 344 one composed of scenarios with 'optimistic' socioeconomic assumptions (SSPs  
 345 1,2 and 5) in terms of convergence between poor and rich countries, and the

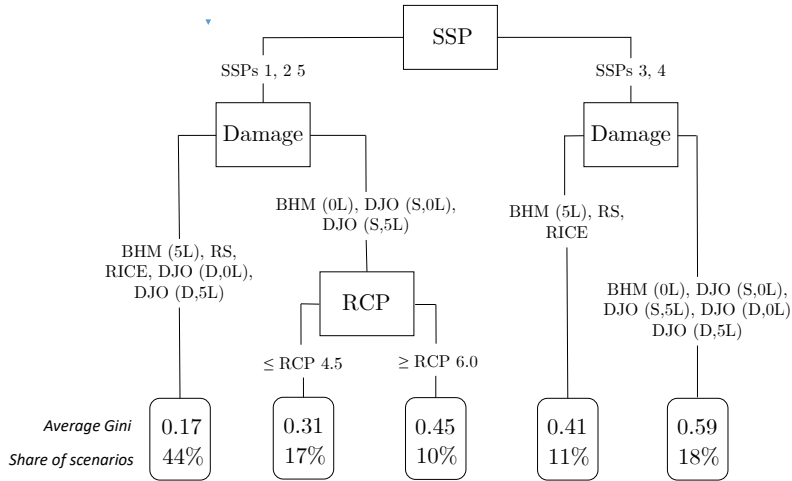
<sup>6</sup> We used rpart function of R (complexity parameter of rpart function is set at 0.02, meaning that a split is retained if it increases the fit by a factor 0.02)



**Fig. 2** Cumulated percentage of scenarios where a trend reversal has occurred, for a given combination of damage function and socioeconomic assumptions.

346 second one composed of scenarios with pessimistic such assumptions (SSPs  
 347 3 and 4). Within each branch, the tree further splits scenarios according to  
 348 the magnitude of climate change damages. Interestingly, the grouping of the  
 349 damage functions differs across the two branches of the tree. Indeed, when the  
 350 vulnerability of countries depends on their income (in the 'dynamic' versions of  
 351 DJO), climate damages strongly depend on the socioeconomic pathway: con-  
 352 vergence assumptions limit the effect of climate change on inequalities, because  
 353 poor countries can shield themselves from climate damages through develop-  
 354 ment. The contrary holds if poor countries are assumed to slowly catch-up  
 355 with rich countries. Finally, if optimistic SSPs are combined with high dam-  
 356 ages, the next node splits the remaining scenarios according to the level of  
 357 emissions. All the other dimensions of uncertainties, that is mitigation costs,  
 358 their distribution within regions, as well as temperature response uncertainty,  
 359 contribute to a lesser extent to the Gini index in 2100.

360 For the highest damage estimates (i.e. mostly econometric estimates), the  
 361 cascading effect of emission pathway and temperature response uncertainty  
 362 translate into great variability in the benefits of avoided damages for the poor-  
 363 est, and thus a greater variability of the Gini index in 2100 (figure 4). With  
 364 the most regressive specifications, damages are such that they may completely  
 365 cancel out expected convergence in some scenarios, and lead to a higher Gini



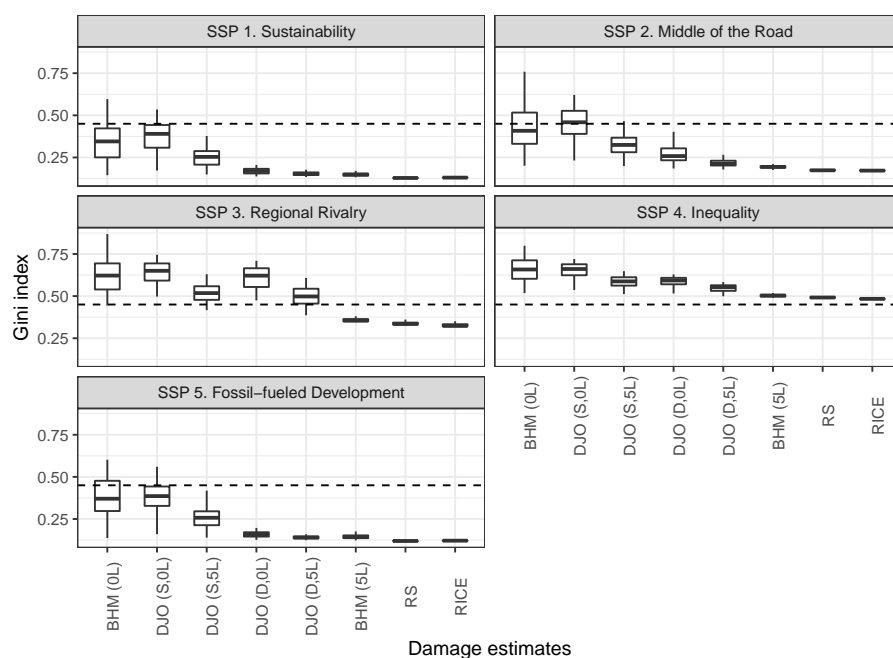
**Fig. 3** Regression tree on the value of Gini in 2100. The algorithm splits scenarios to best predict the value of the output, thus generating groups with minimal heterogeneity. In each leaf of the tree, the upper number is the mean of Gini for the scenarios in the box, while the lower number is the percentage of scenarios it represents.

366 index in 2100 than today. In particular in SSP3, most scenarios with econo-  
 367 metric damage estimates show Gini levels higher than today, while it is not  
 368 the case under low damage functions. Gini index can be higher than today  
 369 in other socioeconomic pathways, but only when combining the most regres-  
 370 sive damage functions (BHM (0L) and DJO (S,0L)) with the highest emission  
 371 pathways. However, in the short run (the Gini index in 2050 is shown in figure  
 372 5), socioeconomic assumptions appear as the main drivers of inequalities, with  
 373 limited variability across other dimensions.

#### 374 4.3 Does mitigation reduce inequalities?

375 We compare inequality levels in 2100 across emissions pathways to analyze  
 376 how the regressive impacts of climate damages compare to those of mitigation  
 377 costs. We analyze which emission pathway, all else being equal, has the lowest  
 378 inequality level (figure 6). Unsurprisingly, lower emission pathways are pre-  
 379 ferred when assuming regressive damages. We look specifically for the cases in  
 380 which RCP 2.6 is the preferred emission pathway, because it is the only RCP  
 381 likely to achieve the 2°C target.<sup>7</sup> Whether RCP 2.6 performs best in terms of  
 382 inequality depends primarily on the damage function. With the most regres-  
 383 sive damage estimates (BHM, 0L), inequalities are always lowest under RCP

<sup>7</sup> Note that models have not produced this emission pathway under the most pessimistic socioeconomic pathway (SSP 3), where low growth is combined with high challenge to mitigation

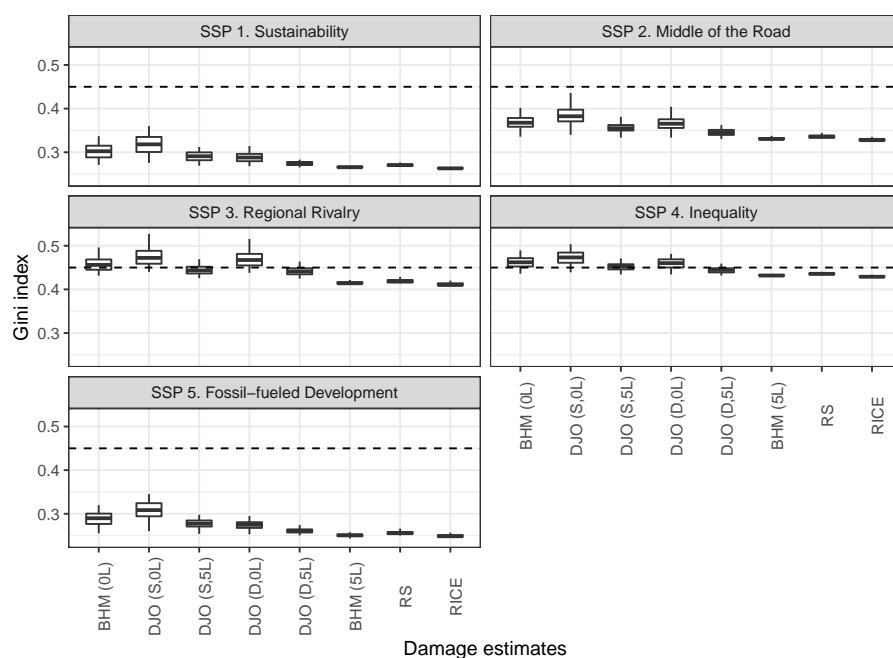


**Fig. 4** Boxplot of the Gini index in 2100, for combinations of socioeconomic assumptions (panel) and damage functions (x-axis)

384 2.6 unless the high baseline emissions of SSP 5 is combined with the highest  
 385 mitigation costs estimates (WITCH). Under the other econometric damage  
 386 estimates, RCP 2.6 is the less unequal emission pathway either for optimistic  
 387 SSPs with low challenges to mitigation (1, 2, 4), or when mitigation costs are  
 388 low (all except WITCH). RCP 2.6 is less often the scenario with the lowest  
 389 inequality levels IAM-based damage functions, i.e. RICE and RS. Netherless,  
 390 even under low damage estimates, RCP 2.6 may still be the emission pathway  
 391 with the lowest inequality level in some specific combinations, in particular for  
 392 optimistic SSPs, provided that mitigation costs are not shared evenly within  
 393 regions.

394 Likewise, looking at SSP 3, the damage estimate also primarily drives the  
 395 comparison across emission pathways, and the same pattern can be observed.  
 396 For high damages, avoided damages outweigh the cost to keep emissions com-  
 397 patible with RCP 3.4, while the contrary holds in the case of lower damages.  
 398 Given that SSP 3 depicts a low-growth, low-technical progress world, mitiga-  
 399 tion is particularly costly, so that the lowest inequality levels do not always  
 400 coincide with the lowest emission pathway.





**Fig. 5** Boxplot of the Gini index in 2050, for combinations of socioeconomic assumptions (panel) and damage functions (x-axis)

#### 401 4.4 Does mitigation improve the situation of the poorest?

402 The Gini index only provides a relative measure of inequality, and thus does not  
 403 give information about the absolute situation of the poorest. Here, we compute  
 404 the first income decile in 2100, which reflects the situation of the poorest 10%  
 405 (figure 7). Socioeconomic assumptions appear as the first driver of the situation  
 406 of the poorest 10%, as it is the case with the Gini index, with differences larger  
 407 than one order of magnitude across SSPs. There are also strong discrepancies  
 408 between damage functions, and the most regressive results in terms of Gini  
 409 are not necessarily the ones for which the situation of the poorest is the worst.  
 410 However, the first income decile is almost systematically larger under RICE  
 411 and RS damages than for econometrics-based damage functions.

412 We also compare the first income decile across emissions pathways (see  
 413 figure 8). The distribution of the preferred emission pathway based on the value  
 414 of the first income decile is generally close to that based on the Gini index.  
 415 As it was the case for inequality, the situation of the poorest 10% tends to be  
 416 better in lower emission pathways for econometrics-based damage functions.  
 417 However, for the dynamic specification of DJO (0-lag) in high-growth SSP 5,  
 418 rapid convergence allows the poorest 10% to become less vulnerable to climate  
 419 change, so that mitigation does not improve their situation. Even under RICE



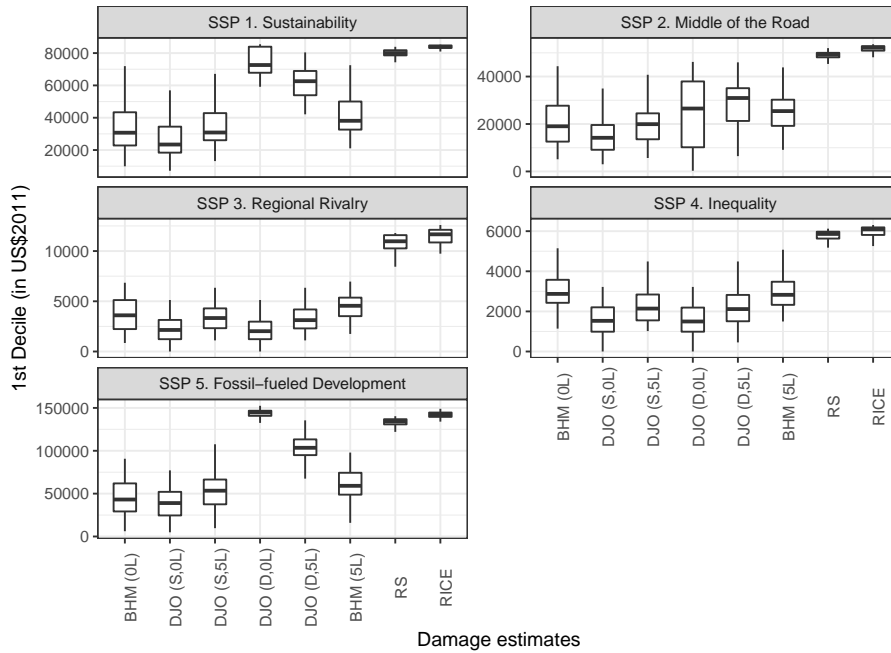
**Fig. 6** Which emission pathway has the lowest inequality level? We compare inequality levels across emission pathways, all else being equal. The graph shows the percentage of scenarios in which each emission pathway has the lowest inequality level. We group scenarios based on SSP (panel) and damage estimates (x-axis). For instance, in SSP 1 and under BHM (0L) damages, RCP 2.6 always has the lowest Gini.

420 damages, the first income decile can be higher for higher emission pathways.  
 421 It is the case for SSPs where a significant number of countries stay behind  
 422 (SSPs 3 and 4); and in SSPs 2 and 5, although only under low or moderate  
 423 temperature response. Finally, with RS damages function, the poorest 10%  
 424 are better off without mitigation if we assume low growth (SSP 3) or high  
 425 mitigation costs (WITCH).

## 426 5 Discussion

### 427 5.1 Limitations of the study

428 Our results are conditional on the relative magnitude of the mitigation and  
 429 damage cost estimates we use, as well as on their distribution across countries.  
 430 We highlight that many outcomes regarding future inequality will depend on  
 431 the level of damages. Although we have tried to include as many estimates  
 432 as possible in the analysis, IAM-based and econometrics damages all have  
 433 limitations (Diaz and Moore, 2017). Econometrics-based damage functions



**Fig. 7** Boxplot of the 1st income decile in 2100, for combinations of socioeconomic assumptions (panel) and damage functions (x-axis). Note that the scale of the y-axis differs across panels.

434 represent a large share of the estimates used here. Although they allow for an  
 435 empirically-grounded country-by-country treatment of damages, the validity  
 436 of extrapolating into the future the short-term effects of weather on economic  
 437 growth to assess the economic impact of climate change is subject to debate  
 438 (Schlenker and Auffhammer, 2018). On the one hand, long-term adaptation  
 439 may occur and reduce negative impacts. On the other hand, impacts could  
 440 be exacerbated by non-linear effects outside of historical experience and by  
 441 other potential sources of economic loss associated with climate change but  
 442 not linked to temperature change, such as sea-level rise. Which of these two  
 443 effects will prevail remains uncertain.

444 Another, related, limitation is the difficulty to account for the vulnerability  
 445 of countries, as well as their ability to adapt to climate change in different  
 446 socioeconomic pathways. Depending on the socioeconomic pathway, it may be  
 447 more or less challenging – and thus costly – to adapt to a given temperature  
 448 change. We account for some form of adaptation in the dynamic version of  
 449 DJO damages, where damages depend on the level of income of the country.  
 450 However, we do not proceed likewise for the other damage cases. Exploring  
 451 in a more sophisticated manner the ability of future societies to cope with  
 452 temperature changes would greatly improve the study, and strengthen the



**Fig. 8** What is the most favorable emission pathway in terms of the situation of the poorest 10%? We compare first income decile levels across emission pathways, all else being equal. The graph shows the percentage of scenarios in which each emission pathway has the greater first income decile. We group scenarios based on SSP (panel) and damage estimates (x-axis). For instance, in SSP 1 and with BHM (0L) damages, RCP 2.6 is always the emission pathway in which the situation of the poorest 10% is the best.

453 role of the socioeconomic pathway, as it does in the dynamic setting of DJO  
 454 damages, but it would also increase its complexity.

455 The magnitude of the actual macroeconomic mitigation costs may also  
 456 exceed the evaluations given by IAMs that quantified the SSPs, in particu-  
 457 lar considering real-world frictions and second-best mechanisms which were  
 458 not accounted for by those models (Guivarch et al., 2011). In addition, the  
 459 distribution of mitigation costs among countries will ultimately result from  
 460 the relative ambition for emissions reduction as defined by their nationally  
 461 determined contribution to the Paris Agreement, the stringency of policies  
 462 implemented to reach those, and international climate finance and technology  
 463 transfer mechanisms (Aldy et al., 2016). The distribution of costs may there-  
 464 fore be more or less regressive than the distribution implied by the mitigation  
 465 policies represented by the IAMs in the SSP database. Many effort-sharing  
 466 approaches, for instance accounting for historical responsibility, lead to more  
 467 stringent targets for developed countries, suggesting that international nego-  
 468 tiations may lead to distributions that are less regressive than cost-optimal  
 469 approaches (van den Berg et al., 2019). Considering such cases would reduce

470 the burden of mitigation on poor countries, and thus reinforce the result that  
471 mitigation can reduce inequalities.

472 Considering inequalities among individuals (Dennig et al., 2015; Alvaredo  
473 et al., 2018) and not only between countries, and accounting for dimensions of  
474 inequality beyond income, such as health inequalities, would complement our  
475 analysis of the inequality implications of climate change damages and mitiga-  
476 tion. Such extensions would bring further complexity, but have the potential  
477 to amplify the results because poor households are particularly vulnerable to  
478 climate change impacts (Hallegatte and Rozenberg, 2017). Health inequalities  
479 would probably worsen under severe climate change, since health impacts due  
480 to climate change disproportionately affect the poor (Patz et al., 2005; Haines  
481 et al., 2006), and mitigation generally results in health co-benefits (Smith  
482 et al., 2014).

## 483 5.2 Conclusion

484 We study how greenhouse gas reduction may affect inequality through miti-  
485 gation costs and avoided climate damages, with effects going in opposing  
486 directions. We build scenarios to account for their influence on future inequal-  
487 ities, and explore uncertainties along different dimensions: socioeconomic as-  
488 sumptions, emission pathways, mitigation costs, the regressivity of mitigation  
489 costs, temperature response, and climate change damages. We show that so-  
490 cioeconomic assumptions and climate change damages are the main drivers of  
491 the outcomes in the long term. The emission pathway also influences future  
492 inequalities, while the temperature response, the mitigation costs and their  
493 distribution play a lesser role. In most scenarios, inequalities among countries  
494 decline in the short to medium run, but can start rising again as climate change  
495 impacts gradually outweigh the expected economic convergence between low-  
496 and high-income countries. We show this occurs systematically in scenarios as-  
497 suming low socioeconomic convergence between rich and poor countries (SSP  
498 4). It can occur in all other socioeconomic pathways when considering high  
499 (i.e. econometrics-based) damage, but only under the most pessimistic temper-  
500 ature responses or the highest emission pathways. Whether mitigation reduces  
501 inequalities depends primarily on damage estimates. Under the highest dam-  
502 age estimates, it is very likely that inequalities may rise again, in particular  
503 in socioeconomic pathways with rather low challenge to mitigation, and when  
504 mitigation costs estimates are low. Mitigation can also reduce inequalities un-  
505 der less regressive damage functions, though under more specific assumptions  
506 regarding socioeconomic evolution and mitigation costs. In such scenarios, the  
507 benefits of avoided damages dominate the regressive effect of climate poli-  
508 cies. The same drivers play a crucial role when looking at the situation of the  
509 poorest 10%, and the benefits of avoided damages on the first income decile  
510 outweigh those of mitigation costs in the same scenarios.

511 Our results are subject to several caveats and should be interpreted with  
512 caution. Nonetheless, they indicate that the cascading uncertainties in emis-

513 sion pathways, temperature and damage estimates can lead the distributional  
514 impacts of future climate change to counterbalance the projected conver-  
515 gence of countries' incomes. We further stress the divide between IAM- and  
516 econometrics-based damage functions, showing that they do not only differ  
517 in terms of the aggregate level of damage, but also in terms of their effect  
518 on inequality. If climate change is as regressive as econometrics-based damage  
519 functions suggest, climate mitigation policies are key to limit the rise of future  
520 inequalities between countries.

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