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Within-country inequality and the shaping of a just global climate policy

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Climate policy design must balance emissions mitigation with concerns for fairness, particularly as climate change disproportionately affects the poorest households within and across countries. Integrated Assessment Models used for global climate policy evaluation have so far typically not considered inequality effects within countries. To fill this gap, we develop a global Integrated Assessment Model representing national economies and subnational income, mitigation cost, and climate damage distribution and assess a range of climate policy schemes with varying levels of effort sharing across countries and households. The schemes are consistent with limiting temperature increases to 2 °C and account for the possibility to use carbon tax revenues to address distributional effects within and between countries. We find that carbon taxation with redistribution improves global welfare and reduces inequality, with the most substantial gains achieved under uniform taxation paired with global per capita transfers. A Loss and Damage mechanism offers significant welfare improvements in vulnerable countries while requiring only a modest share of global carbon revenues in the medium term. The poorest households within all countries may benefit from the transfer scheme, in particular when some redistribution is made at the country level. Our findings underscore the potential for climate policy to advance both environmental and social goals, provided revenue recycling mechanisms are effectively implemented. In particular, they demonstrate the feasibility of a welfare improving global climate policy involving limited international redistribution.

climate change | inequality | integrated assessment | climate policy

Significance

Effective climate policy must address equity both between and within countries. We develop a global integrated assessment model capturing subnational inequality in climate impacts and policy costs and show that carbon taxation paired with redistributive transfers can simultaneously reduce emissions, improve global welfare, and lower inequality. A Loss and Damage policy compensating low-income countries for climate damages requires only a modest share of global carbon revenues. Combined with redistribution of carbon tax revenues within countries, it ensures that the most vulnerable populations benefit from climate action, demonstrating that fairness and ambition can be jointly pursued through targeted revenue recycling.

Climate change is one of the most pressing issues that societies are facing. Research on climate policy often highlights the trade-off between taking action to efficiently address climate change and ensuring fairness. Poorer nations have contributed less to total emissions and are less able to afford mitigation and adaptation policies (1). Additionally, the burden of climate impacts tends to fall disproportionately on the poorest households within countries (2), and climate change impacts increase economic inequalities within and between countries (3). Ramping up mitigation policies to reach Paris agreement targets may also disproportionately affect the most vulnerable households, for example through its effects on prices (4).

Examining impacts beyond average regional effects can help inform decision-makers about the political feasibility of climate policies (5), and their interaction with other sustainable development goals. Subnational climate policy impacts depend on the international allocation of the climate burden, the relative vulnerability of populations within countries, and domestic policies. However, Integrated Assessment Models (IAMs) used for global climate policy evaluation have so far typically not considered inequality effects within countries.

Here, we develop a global climate policy model with income inequality, climate damages, and mitigation costs at the subnational level. Our approach examines how revenues from mitigation policy can be used to address distributional effects arising from mitigation costs and unavoidable climate impacts, both between and within countries. To this end, we focus on a scenario limiting the global temperature increase to 2 °C and analyze the global inequality and welfare impacts of a range of carbon taxation and transfer schemes, with varying levels of effort sharing across countries and households. Following the economic literature, we focus on measuring overall reductions in inequality and improvements in welfare, which are not limited to compensating for inequalities created by climate change (through damages) or climate policy (through mitigation costs). This aligns with the idea that, in a world with limited opportunities for redistribution, policies that do not directly aim to ensure distributional justice can still have distributional

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benefits (6). By extending our focus beyond efficiency, we also depart from the literature using Negishi weights in multiregion models (see *Materials and Methods*).

A number of studies have shown that recycling carbon tax revenues at the domestic or global level has the potential to generate poverty reductions and welfare gains (7–11), improve distributional outcomes (e.g., refs. 12 and 13) and foster political acceptance (14, 15). Closest to our approach, Emmerling et al. (16) studies carbon taxation and revenue recycling in a global climate policy model with subnational impacts, but covers only a subset of countries, thereby missing impacts on some of the world's most vulnerable populations.[*] In addition, we analyze a different set of policies, including differentiated taxes and international transfers. In the context of global discussions of policies targeting specifically low-income countries, it is important to assess precisely the net benefits of climate policy by country and income group. Our results show that even modest (international) transfers can lead to substantial improvements in global inequality and welfare, due to their impact on low-income countries and the most vulnerable households within countries, at a modest cost for developed countries provided a redistribution of the carbon tax is also implemented at the country level.

One proposal to improve fairness in facing the burden of climate change is to compensate the most vulnerable countries for the "Loss and Damage" they experience. The Warsaw International Mechanism for Loss and Damage, set up at COP19, proposes a fund financed by developed countries.[†] In this paper, we examine whether revenues from carbon taxation could be sufficient to compensate vulnerable low-income countries for the climate damages arising from a global temperature increase of 2 °C, and the resulting welfare and inequality effects. We contribute to the scarce literature providing quantitative estimates of Loss and Damage using IAMs (18, 19), and further account for within-country effects of transfers.

We consider different scenarios regarding the design of the global climate policy. First, scenarios involving international transfers, like Loss and Damage policies described above. However, given that international transfers may face feasibility constraints too, we also consider cases where redistribution is made only within countries. To make climate policy more equitable while upholding ambition, a possibility is to delay mitigation efforts in developing countries and compensate for that delay with stronger mitigation in developed countries. In the context of carbon taxation, this amounts to favoring carbon taxes that are differentiated across countries over a uniform tax—which is considered more cost-efficient but less fair. We thus study a scenario with differentiated carbon taxes, as well as a scenario with a uniform global carbon tax.

We first confirm that carbon taxation with redistribution increases global welfare (Section 2.1). We actually consider several such scenarios and show that scenarios with global redistribution perform best. Differentiated taxes are the best option only under neutral redistribution of carbon revenues. Second, we study in more detail a Loss and Damage scenario where revenues from a globally uniform carbon tax are (sometimes partially) redistributed to least developed countries (Section 2.2). We show that compensating least developed countries for their climate damages is feasible in the medium term, and strongly improves the welfare of these countries. Last, we highlight the mechanisms at play to explain the improvement in welfare in scenarios with global redistribution (Section 2.3). We show that global redistribution results in improvements in consumption per capita for the poor everywhere, mainly because they receive larger transfers than the carbon tax and mitigation costs they pay. An exception may be in richer or carbon-intensive countries when the revenues from the carbon tax are fully redistributed globally.

1. Methodology

We develop a global climate policy model in the vein of the Nested Inequalities Climate Economy model (NICE, 20), which features within-region inequality for twelve world regions. We build on the latest version of the model, which allows for carbon tax revenue recycling (9). To investigate carbon tax and revenue recycling scenarios, including scenarios with international transfers and taxes differentiated by country, we augment the granularity of the model to the country level, with 179 countries.[‡] We downscale mitigation costs, carbon tax burdens, and climate damages to the country-level and distribute them across deciles within countries. Details can be found in *Materials and Methods*.

We start from a business-as-usual scenario (BAU) characterized by a peak in CO_2 emissions just before 2050 (*SI Appendix*, Fig. S2), an increase in global average temperature close to 3 °C by the end of the century (*SI Appendix*, Fig. S3), global consumption per capita rising at around 1.75% per year (*SI Appendix*, Fig. S4), and a decreasing global consumption inequality measured by the Gini inequality index.[§] Then we compare several policy scenarios (see *Materials and Methods* for a full description). We compare the effects of different policy designs consistent with a 2 °C temperature increase target: differentiated carbon taxes by country versus a globally uniform carbon tax. In the case of a global carbon price, we equalize the marginal cost of abatement in all countries, thus ensuring cost-effectiveness (21). In that case, revenues are either recycled in a neutral way to exactly offset tax payments across deciles (scenario U/N), via a Loss and Damage fund, where revenues are used to compensate low-income countries for the climate damage they incur (scenario U/L&D), or on an equal per capita basis, either globally (scenario U/G-epc) or within countries (scenario U/C-epc). In the case of differentiated carbon taxes across countries, the burden sharing is not based on efficiency but on fairness considerations. The sharing rule reflects the notion that an additional dollar is more valuable in a poorer country, by taking into account differences in the marginal welfare derived from consumption. To implement this approach, we find the set of carbon prices that maximizes the sum of utilities from consumption under the given global emission constraint (see details in *SI Appendix*, section C).[¶] Here, revenues are recycled either in a neutral way (scenario D/N) or on an equal per capita basis within countries (scenario D/C-epc), see Table 1 and *Materials and Methods*.

We evaluate climate policy scenarios based on average consumption, the Gini index for inequality, and a more comprehensive welfare measure. For the welfare comparison, we employ equally distributed equivalent consumption (EDEC), see refs. 23 and 24. This is an inequality-adjusted per capita consumption

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[*] In particular, ref. 16 includes Sub-Saharan African countries as a single region.

[†] The idea that more developed countries should help developing ones to ensure their transition and adaptation to climate change is widely accepted in international negotiations. Notably, the Paris Agreement envisions financial transfers in the form of assistance (Paris Agreement, Article 9, 17).

[‡] This set of countries corresponds to the set represented in the Shared Socioeconomic Pathways, with Somalia, Venezuela, New Caledonia, and Trinidad and Tobago removed due to data limitations.

[§] The global consumption Gini in the BAU scenario decreases from just below 60 in 2020 to about 42 in 2100 (*SI Appendix*, Fig. S4).

[¶] Our rule is different from that in ref. 22. They analyze uniform versus differentiated taxes with a global IAM but focus on a rule of tax differentiation that achieves "equitable effort sharing" (i.e. equal effort as share of GDP) across twelve regions, and does not include subregional inequality.

Table 1. Scenario description

Scenario name				Cum. emissions 2020–2100 $GtCO_2$	Emissions peak date	Global temp. 2100 °C
Short	Long	Carbon price	Revenue recycling			
BAU	Business-as-usual	n/a	n/a	3,206	2055	2.9
U/N	Uniform tax, distributionally neutral	Globally Uniform	Neutral*	853	2025	2
U/L&D	Uniform tax, loss and damage		Loss and damage fund**			
U/G-epc	Uniform tax, global per capita recycling		Equal per capita globally			
U/C-epc	Uniform tax, within-country recycling		Equal per capita within countries			
D/N	Differentiated taxes, distributionally neutral	Differentiated By country	Neutral*	858	2025	2
D/C-epc	Differentiated taxes, within-country recycling		Equal per capita within countries			

*carbon tax revenues are refunded to exactly offset tax payments across deciles.

**carbon tax revenues are used to compensate low-income countries for the climate damages they incur, exceeding revenue is recycled on an equal per capita basis within countries.

measure. The methodology is similar to the one used for the Inequality-adjusted Human Development index; see ref. 25: Average consumption is "discounted" according to the level of consumption inequality (for instance, global consumption per capita "discounted" according to global inequality). EDEC is equal to the average consumption value when there is no inequality, but falls below average consumption as inequality rises. The key parameter is inequality aversion η. For a given level of inequality, the larger η, the larger the loss (or "discount") applied to the average consumption (see *SI Appendix*, section E for details). We set inequality aversion to $\eta = 1.5$, in line both with expert surveys and meta-analyses on inequality aversion in the context of climate policy (26, 27), and with ref. 28.

2. Results

2.1. 2 °C Scenarios With Carbon Taxation and Revenue Recycling Improve Global Welfare. In all scenarios, global welfare increases compared to the BAU within the first decades (Fig. 1*A*). Welfare increases from the implementation of the policy in all scenarios which feature revenue recycling, and later on in scenarios with distributionally neutral recycling. Around 2085, global welfare converges across scenarios as global decarbonization is reached: Carbon tax revenues dry up, and welfare benefits stem from avoided climate damages, which are common to all 2 °C scenarios. The overall global welfare impact, as measured by the EDEC, reflects the impact of the policy schemes on average consumption and on inequality. In all scenarios, global consumption per capita decreases compared to the BAU until midcentury (Fig. 1*B*), but this is compensated by a reduction in global inequality (Fig. 1*C*).

Global consumption per capita decreases before increasing at the end of the century in all scenarios compared to the BAU (Fig. 1*B*). This is because abatement costs are borne from the moment mitigation begins, while benefits from avoiding climate change (keeping global average temperatures below 2 °C instead of reaching 3 °C) ramp up later on. Given that revenue recycling of carbon tax revenues does not affect average consumption at the global level, the impact on global consumption per capita is the same across scenarios with uniform taxes on the one hand, and differentiated taxes on the other hand. Consistent with environmental economics theory, our results show that differentiated carbon taxes are less cost-efficient and imply larger global abatement costs, indicated by a larger percentage reduction in consumption per capita compared to BAU than with a global uniform tax (Fig. 1*B*). The magnitude of the loss in global consumption per capita when comparing differentiated to uniform taxes is determined by countries' abatement costs and deviations in carbon tax levels from the uniform tax case.[#]

Global inequality, as measured by the global Gini index (based on the population-weighted decile per capita consumption level in all countries), decreases by up to around 1.75 percentage points in all scenarios compared to the BAU (Fig. 1*C*). Reductions in the global Gini reflect changes in inequality between and within countries. In all 2 °C scenarios, keeping mean temperature increases below 2 °C compared to 3 °C in the BAU benefits poorer and more vulnerable countries relatively more. Because poorer households bear a disproportionate cost of climate damages (following the evidence in ref. 29; see *Materials and Methods* for details), reduced climate impacts also improve inequality within countries. Inequality is further affected across different scenarios due to the distribution of abatement costs across countries and the impacts of carbon taxation and revenue recycling within and between countries. Section 2.3 decomposes these effects in more detail for the scenarios with global transfers.

Comparing different schemes in terms of their global welfare effects, we identify the two scenarios with global uniform taxation and international transfers as the most welfare-enhancing (U/G-epc and U/L&D, Fig. 1*A*). Under the global equal per capita recycling scheme (U/G-epc), global welfare increases up to 15% compared to the BAU. This scheme combines the cost-effectiveness of uniform taxation with the strongest decline in the global Gini compared to the BAU (up to 1.75 p.p., Fig. 1*C*), in part explained by the flows of international transfers that the scheme entails (up to 2.25% of global GDP, *SI Appendix*, Fig. S6). The Loss and Damage scheme (U/L&D) results in an increase in welfare of up to 5% compared to BAU (Fig. 1*A*) and is the second best policy in terms of Gini index reductions (Fig. 1*C*). A small number of countries receive Loss and Damage transfers. However, as these are low-income and relatively unequal countries, the scheme reduces between- and within-country inequality more than the uniform carbon taxation without international transfers scheme (U/C-epc).

In the absence of international transfers, scenarios with domestic equal per capita transfers result in most welfare improvements (U/C-epc and D/C-epc). The differentiated tax scheme (D/C-epc) results in larger reductions in the global Gini index (Fig. 1*C*) compared to the uniform tax scheme (U/C-epc), because abatement costs are shifted from poorer toward richer countries. However, differentiated taxes also lead to higher overall costs (Fig. 1 *B*). Under differentiated taxes, carbon taxes in

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[#] With differentiated carbon taxes, the level of differentiation depends on the inequality aversion parameter η. As can be seen in the sensitivity analysis in *SI Appendix*, Fig. S9, a higher level of inequality aversion produces a larger spread of differentiated taxes, as more weight is put on costs in relatively poorer countries.

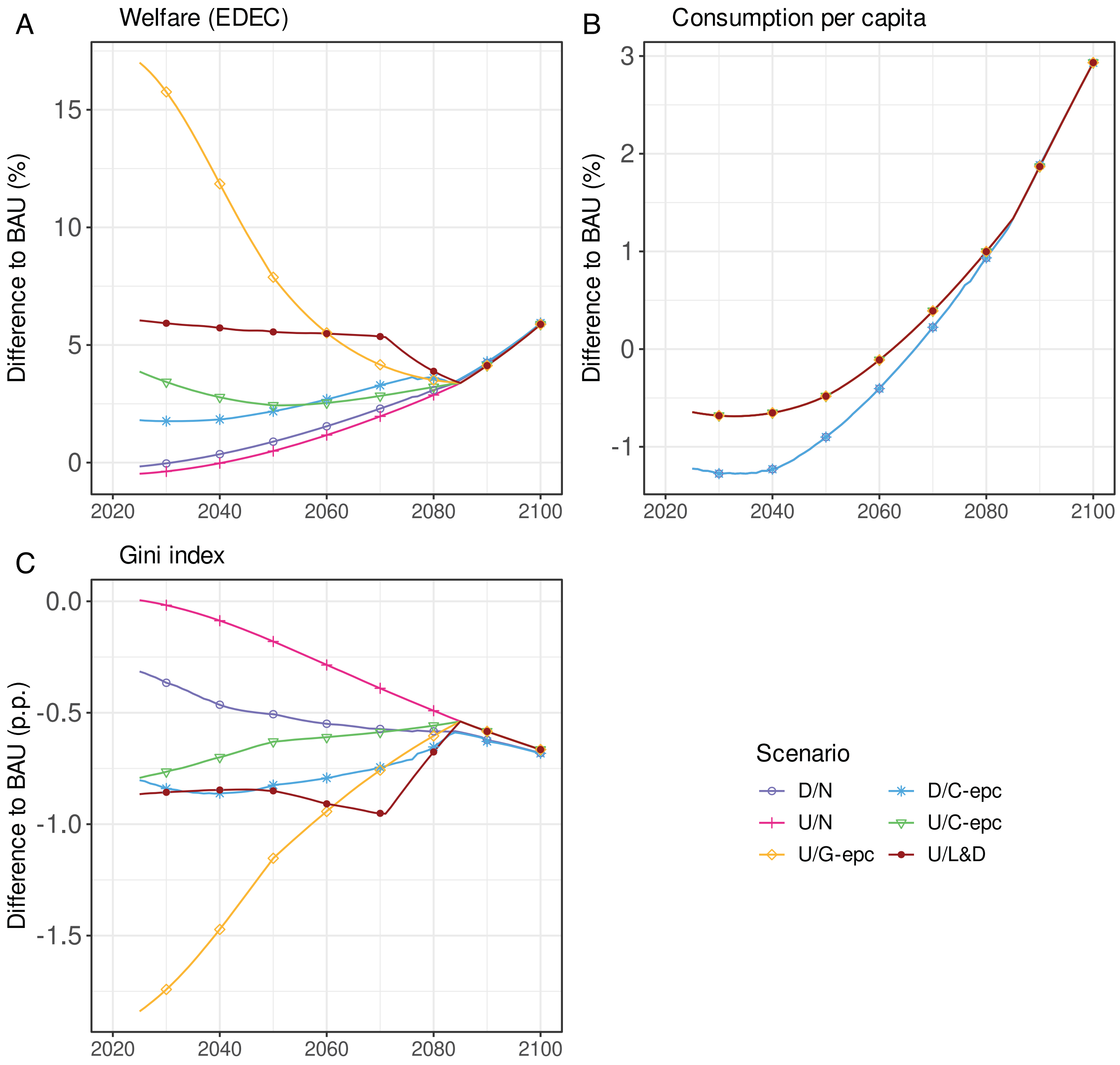

Fig. 1. Difference compared to the business-as-usual scenario (BAU) of (*A*) welfare (equally distributed equivalent consumption, %), (*B*) consumption per capita (%), and (*C*) Gini index (computed from the population-weighted decile per capita consumption level in all countries, p.p.), in the 2 °C scenario and for the six carbon tax and revenue recycling scheme alternatives.

relatively poorer countries ramp up later in the century,[‖] which implies that transferrable carbon tax revenue is available later in these countries. As a result, the uniform scheme (U/C-epc) is more welfare-enhancing than the differentiated taxes scheme (D/C-epc) until midcentury. Finally, we find that if international transfers are excluded and recycling of revenue is distributionally neutral, then differentiated taxes are more welfare improving than a uniform tax (D/N and U/N, Fig. 1*A*). This result confirms that, in the absence of domestic and international transfers, a differentiated tax scheme that shifts abatement costs onto richer countries can lead to global welfare gains compared to a uniform tax (22).

Our results show that scenarios with recycling of carbon tax revenues improve global welfare and that scenarios with international transfers (U/G-epc and U/L&D) improve welfare the most. Differentiated taxes perform best only in the absence of international and equal per capita domestic transfers, or only later in the century with equal per capita domestic transfers (D/C-epc). These global welfare results depend on the value of the inequality aversion, set to $\eta = 1.5$. Increasing or decreasing η does not qualitatively affect the results, but shifts the level of welfare gains (*SI Appendix*, Fig. S10).

2.2. Funding Needs and Welfare Effects of Loss and Damage Policies.

Next, we focus on the impacts of the Loss and Damage scheme (U/L&D), in which revenues from uniform taxation are transferred to cover up to 100% of damages in low-income countries, and remaining carbon revenues are recycled within countries. This represents an intermediary scenario between recycling all carbon revenues on a global scale, which requires large international transfers, and recycling revenues only within countries. We evaluate the welfare effects of the U/L&D scenario

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[‖] See *SI Appendix*, Figs. S7 and S8 for illustration of the trajectories of uniform and differentiated taxes.

in low-income countries and in the rest of the world, in comparison with two other scenarios (Fig. 2*A*) and the magnitude of international transfers of carbon tax revenues (Fig. 2 *B* and *C*).

The U/L&D scenario results in larger welfare improvements (more than 10 percentage points) for low-income countries than the scenario with only recycling within countries (G/C-epc), with little effect on welfare in nontargeted countries (Fig. 2*A*). In 2050, the welfare gains for low-income countries in the U/L&D scenario are similar to those in the global equal per capita recycling scenario (U-G-epc), while requiring only a fraction of global revenues (Fig. 2*B*).

We find that compensating for all damages in low-income countries would require relatively small shares of global tax revenues in the first decades: 100 billion USD2017 in 2030 (5% of revenues) and 500 billion USD2017 in 2050 (15% of revenues) (Fig. 2*B*). Our estimates for Loss and Damage compensation in low-income countries are in the same order of magnitude as the (scarce) previous published estimates.[**] The differences can be explained by different damage functions, target countries, and definitions of unavoided losses and damages from climate change.[††] Later in the century, the Loss and Damage scheme requires using all carbon tax revenues, as decarbonization reduces tax revenues while climate damages ramp up.

In 2030, a majority of countries (excluding low-income countries) contribute below 100 USD2017 per capita to the Loss and Damage fund (Fig. 2*C*). The largest contributors in per capita[‡‡] terms are countries with high emissions per capita and fossil fuel producers, such as Qatar, Kuwait, or the United States (see *SI Appendix*, Table S1 for the list of the ten largest contributors). In 2030, targeted low-income countries receive upward of 50 USD2017 per capita (Fig. 2*C*), with Sudan the largest recipient in per capita and absolute terms (*SI Appendix*, Tables S1 and S2).

Our results show that, in the medium run, a fraction of global revenues from uniform carbon taxation could be sufficient to fund a Loss and Damage scheme compensating for damages in low-income countries. The scheme strongly improves welfare in low-income countries, while maintaining welfare gains relative to the BAU in the rest of the world. We also test an alternative Loss and Damage scenario, aiming to compensate for damages in both low- and low-middle income countries (*SI Appendix*, Fig. S11). In this case, global revenues from uniform carbon taxation become insufficient to compensate for all climate damages in the targeted countries within a few decades.

2.3. Global Redistribution Increases Consumption for the Poor (Almost) Everywhere. Finally, we assess the net benefits of climate policies with international transfers for different income and country groups. We decompose the costs and benefits of the policy (relative to the BAU) in 2030 for global uniform carbon taxation with global equal per capita transfers (U/G-epc) and with the Loss and Damage scheme (U/L&D) (Fig. 3). Costs for income deciles consist of carbon tax payments used for domestic redistribution or financing international transfers, and abatement costs due to the deployment of carbon-free alternatives. Benefits consist of received domestic or international transfers and avoided climate damages caused by reducing the global temperature increase from 3 °C to 2 °C. We group income deciles within countries into the poorest 50%, the middle 40%, and the richest 10%, and countries according to their level of income (low-income, lower-middle-income, upper-middle-income, and high-income country groups, following the World Bank classification).[§§]

The poorest 50% of households within countries generally benefit from the climate policies with international transfers in 2030 (Fig. 3). On average, the net gains for the bottom 50% in low-income countries amount to around 430 USD2017 per capita in the U/G-epc scenario (around +68% relative to consumption per capita in the BAU) and to around 190 USD2017 per capita in the U/L&D scenario (around +20%). The only exceptions are the bottom 50% in high-income countries who experience a small loss in the U/G-epc scenario. However, the bottom 50% is a fairly aggregated group. When looking only at the bottom 10%, the lowest decile is a net transfer recipient (lower carbon tax payments than received transfers) in almost all countries, with only a few exceptions in very rich or carbon-intensive countries (*SI Appendix*, Fig. S12). Higher income groups always experience a smaller net gain or a higher net loss with these two policies compared to lower income groups in the same country. The top 10% in high income countries lose around 1800 USD2017 per capita, on average, which is, however, less than 2% of consumption per capita in the BAU.

Tax payments and received transfers are the main driver of the changes in consumption per capita in all country and income groups, with stark differences between the U/G-epc and the U/L&D scenarios. The U/G-epc scenario entails large international transfers that benefit all individuals equally (light blue bars) but are predominantly financed by individuals from high-income countries (brown bars). This international redistribution makes all income groups better off in low-income countries, and the bottom 90% in lower-middle income countries. The policy comes with the caveat, however, that on average the bottom half in high-income countries loses. In contrast, the U/L&D scenario leads to net gains for the bottom half in high-income countries through large domestic transfers (green bars) because a significant portion of carbon tax revenues is recycled within contributor countries (red bars). At the same time, it still generates strong net gains for low-income countries through international transfers (light blue bars). Since the U/L&D scenario makes, on average, a majority of households in all countries better off (the bottom 50%), it is more likely that it may garner public support (30–32).

Abatement costs (yellow bars) and avoided damages (dark blue bars) affect consumption less strongly than tax payments and transfers and have within-country distributional impacts according to the calibration based on ref. 9 for abatement costs and ref. 29 for damages. The pattern of net-winners and net-losers is similar in 2050, but with a larger contribution of avoided damages and abatement costs in both scenarios, and larger international transfers in the U/L&D scenario, leading to higher net gains in low-income countries (*SI Appendix*, Fig. S13).

3. Discussion

We build a global climate policy model that captures the distribution of income, mitigation costs, and climate damages at the subnational level, and we examine the global inequality and welfare impacts of both country-level and global climate policies, including transfers. We find that climate policy scenarios with

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[**] Ref. 18 estimate needs of 20 to 80 billion USD2005 in 2030 and 1.1 to 1.7 trillion USD2005 in 2050. In a commentary, Tavoni et al. (19) estimate total Loss and Damage funding needs to be between 128 and 937 billion USD for the year 2025.

[††] Here, we take the extreme position that all damages in poor countries are unavoided losses and damages.

[‡‡] Largest contributors in absolute terms in 2030 are large economies, such as China, India, and the United States (*SI Appendix*, Table S2).

[§§] Additionally, *SI Appendix*, Figs. S14 and S15 display the decomposition for a selection of countries belonging to the different income groups.

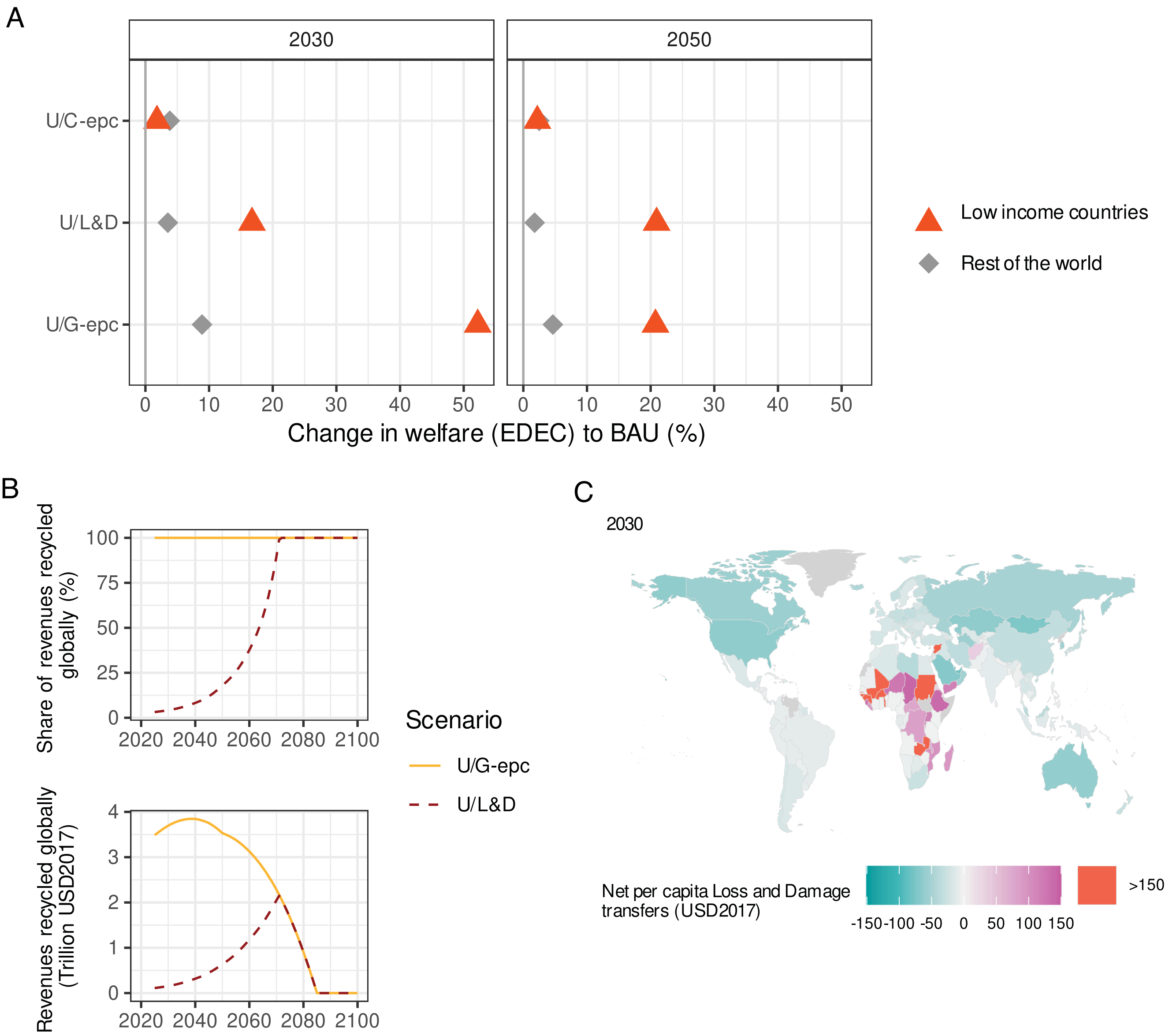

Fig. 2. (*A*) Difference (%) compared to the business-as-usual scenario in welfare (equally distributed equivalent consumption, %); (*B*) share (%) and amount (trillion USD2017) of carbon tax revenues recycled globally; (*C*) Net per capita international transfers (USD2017) in the Loss and Damage scenario. Low-income countries as defined by the World Bank; see *SI Appendix*, section D.

redistribution increase global welfare, and we identify a uniform global carbon tax with global per capita recycling as the most inequality-reducing policy. However, this climate policy would entail collecting and redistributing globally up to 2.25% of global GDP and may harm the bottom 50% of the population in richer countries, at least in the near term.

A Loss and Damage policy, where revenues from global carbon taxation are used to compensate vulnerable countries for climate damages, could improve global welfare while requiring limited international transfers. By 2050, only around 15% of global carbon tax revenues would be needed to compensate low-income countries. This compensation could bring strong inequality reduction and significant welfare increases in low-income countries, while also improving welfare in the rest of the world if the revenues that are not transferred are recycled domestically. Those domestic transfers can improve consumption per capita of the poorest 50% everywhere in the Loss and Damage scheme compared to the business-as-usual. This is not the case with global per capita recycling, where the bottom 50% in high-income countries are net losers. However, governments may be hesitant to participate in revenue sharing on such a large scale. If international transfers are limited, our results suggest that a good alternative policy could be to implement differentiated taxes with domestic revenue recycling.

Our results remain conditional on a number of assumptions and could be extended. We assume that revenues can be redistributed effectively and at a negligible cost, either at the domestic or global levels. While this assumption might be a good approximation at the country level in developed countries because states already operate fiscal and distributive systems, distributing revenues to the poorest households in the least developed countries might be more challenging (33). Collecting and distributing funds at a global level would lead to additional bureaucratic costs. Taking those into account could reduce the magnitude of the benefits of implementing the climate policies we consider. We also abstract from modeling negative emissions.

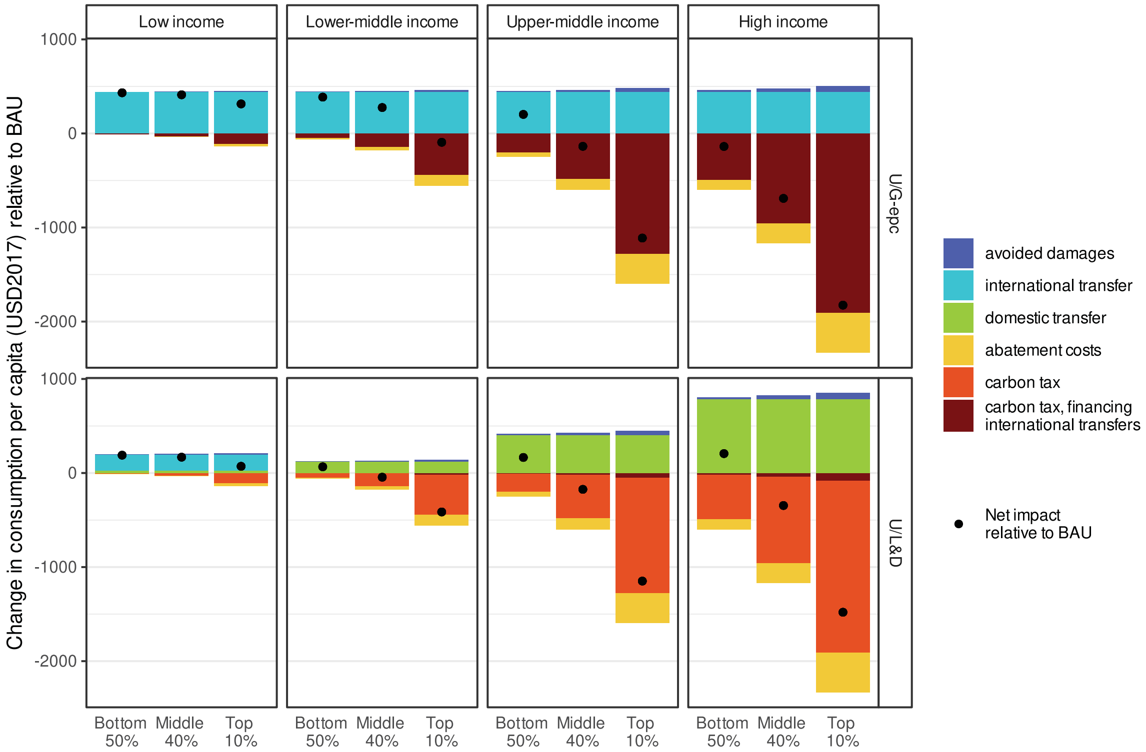

Fig. 3. Net and decomposed difference (%) of consumption per capita compared to the business-as-usual scenario (BAU) for a uniform tax with global equal per capita recycling (U/G-epc) or with Loss and Damage fund (U/L&D) in 2030. Average difference of income deciles pertaining to an income and country group. Changes in predamage preabatement output are omitted. Country groups as defined by the World Bank; see *SI Appendix*, section D.

Using a substantial share of tax revenues to finance negative emissions could reduce the magnitude of our welfare results but would likely not qualitatively change them. Including negative emissions could also dampen the inequality improvements from mitigation if the returns from net emissions technologies accrue disproportionately to rich investors (34). Last, our analysis does not feature trade and economic feedback effects of transfers.

4. Materials and Methods

4.1. Within-Country Inequality and Distributional Impacts. While the previous versions of the NICE model featured consumption quintiles (9, 20), we introduce consumption deciles. We calibrate baseline deciles using country income gini projections until 2100 in the SSP2 scenario, as provided by Rao et al. (35). SSP2 is the "Middle of the road" Shared Socio-economic Pathway (SSP) and corresponds to a scenario where socio-economic and technical projections continue historical trends. Importantly, SSPs do not account for the likelihood of different socioeconomic and emissions futures, and thus neglect an important source of model uncertainty. We note, however, that the results from prior work using NICE remain largely unchanged when using alternative SSP scenarios that assume either low (SSP1) or high (SSP3) levels of global inequality (9).

We assume that for each country i, income is distributed across deciles according to a lognormal distribution $LN(\mu_i, \sigma_i)$. We can deduce SDs σ_i from country Gini indices.[¶¶] From the SDs σ_i, we can deduce a Lorenz curve for each country and each time step, from which we obtain country income deciles over time. We use a transformation vector to derive consumption deciles from income deciles, following the approach proposed by Pinkovskiy and Sala-i Martin (37).

Climate damages, mitigation costs, and carbon tax burdens are distributed across deciles using consumption elasticities (see ref. 20, for the use of elasticities in the modeling of distributional impacts in NICE). The initial burden of a carbon tax is the distribution of mitigation costs and carbon tax payments before tax revenues are recycled and redistributed. Within each country, mitigation costs and carbon tax payments are assumed to be distributed across deciles using the same consumption elasticity of the initial burden for a given country at a given time. The consumption elasticity of the initial burden is calibrated using the estimation provided in ref. 9, which they derive from a review of the literature on the initial burden of carbon taxation across countries before the redistribution of tax revenues. The consumption elasticity of the initial burden $w_{i,t}$ of country i at time t is thus given by $w_{i,t} = \hat{\alpha} + \hat{\beta} \cdot \log y_{i,t}$, with y the GDP per capita. This elasticity is thus endogenous, as it depends on GDP per capita computed by the model at each time step. We use the values estimated in ref. 9, which are $\hat{\alpha} = 3.22$ and $\hat{\beta} = -0.22$.

The distribution of climate damages across deciles in a given country could range from being inversely proportional to consumption (damage elasticity of consumption $\xi = -1$), to being proportional to consumption ($\xi = 1$) or more than proportional to consumption ($\xi > 1$). (29) are the first to provide an estimate of the global within-country income-elasticity of damages.[##] We use the mean of their estimates for the SSP2-based projections, resulting in an income-elasticity of 0.6. Given this elasticity value, richer deciles suffer more from climate change than poorer deciles in absolute terms (because $\xi > 0$). However, poorer deciles face higher damages relative to their income or consumption level than richer deciles, as the distribution is less than proportional to income or consumption, i.e., $\xi < 1$.

To assess welfare, we follow the literature and use EDEC. This measure puts an equal weight on the welfare of all individuals at a given time period, and gives more value to increasing consumption of poorer people through inequality aversion, in the spirit of "equity weights," that have received attention in the context of climate policy for a long time (see ref. 38).

[¶¶] Ref. 36 shows that, in the case of a lognormal distribution, we have the following relation:

$$\sigma_i = \sqrt{2} \cdot \Phi^{-1}\left(\frac{Gini_i + 1}{2}\right),$$

where Φ^{-1} is the inverse of the cumulative distribution function of a standard normal distribution.

[##] The authors estimate several damage functions using within-country inequality data, and compute an elasticity for projected distributional impacts, based either on SSP2 or SSP3.

This is in contrast with approaches using Negishi weights, which have been widely used in the literature on regionally disaggregated IAMs (39–41). Negishi weights assign welfare values that are inversely proportional to marginal utility and ensure a globally uniform carbon price. The rationale behind their usage is that climate policy should prioritize efficiency gains and prevent international transfers. This paper evaluates the inequality and welfare consequences of climate policy, not the efficiency of climate policy without international transfers. Therefore, we do not use Negishi weights because they render distributional concerns across regions irrelevant. They would make the geographical incidence of climate damages and mitigation costs irrelevant to welfare evaluation (42). Negishi weights have also faced substantial ethical objections because they imply that individuals in wealthier regions are more valuable than those in poorer regions (43).

In this paper, we address the issue of international transfers directly. We either prevent them altogether (Scenarios U/N, U/C-epc, D/N, and D/C-epc) or describe the precise channels through which they occur, such as the redistribution of revenues from a globally uniform carbon tax to the least developed countries, either in full or in part. While the welfare-maximizing differentiated carbon prices may reflect an international redistribution of the climate action burden, our main scenarios focus on a globally uniform carbon tax.

4.2. Country Level Output, Emissions, and Abatement. Future output (GDP) levels for each country are calibrated with initial data from the Penn World Tables 10.0 (PPP values in 2017USD) and the GDP per capita growth rates from the SSP2 scenario (44) (see section above for a description of the SSP2 scenario). Following ref. 20, we assume national saving rates start at their empirical value from the Penn World Tables 10.0 (taking the average from 2010 to 2020) and converge to a fixed long term saving rate of 27% at a rate of 3% per year.

Country level emissions intensities of output are computed until 2100 from projected GDP streams based on the SSP2 trajectory, and from emission trajectories based on the ReMIND model in a business-as-usual scenario. The initial country-level emission intensity of output is computed by dividing observed emissions (from the Global Carbon Project database) by observed GDP (from the Penn World Tables). To project emission intensity in the BAU scenario, we use SSP2 data on BAU emissions, provided by the ReMIND model. Only regional level data are available for projected emissions (twelve world regions). We derive regional growth rates of the emission intensity of output based on GDP and emissions growth rates from the SSP2 BAU scenario. Then, we estimate a linear, region-specific OLS model of emission intensity growth over time. The growth rates of emission intensity are negative in all regions and become more negative over time in most regions. In the few regions where growth rates of emission intensity increase, we bound the growth rate of the emission intensity to zero. Finally, we use the estimated time- and region-specific growth rates of emission intensity of output to project the country-level emission intensities of output, starting from the initial values estimated for each country.

Next, we model country level mitigation trajectories. We use the same abatement cost function as in ref. 28, but differentiate the multiplicative parameter by country. As a result, the cost of abatement as a share of gross output in country *i* for a mitigation rate of μ_i is

$$\Lambda_{it}(\mu_{it}) = \theta_{1,it}\mu_{it}^{\theta_2},$$

with $\theta_2 = 2.6$ (taken from ref. 28). We calibrate the multiplicative parameter $\theta_{1,it}$ using the global backstop price from ref. 28 and the assumption that the marginal cost of abatement at a 100% mitigation rate per unit of emission (in USD per unit of emissions) is equal to the global backstop price in every country.

As a result, the mitigation rate μ_{it} is a function of θ_2 and the ratio between the carbon tax and the backstop price. Because the backstop price and θ_2 are set at the global level, a given level of carbon tax in *t* results in the same mitigation rate in every country. However, the abatement cost in terms of share of gross output is heterogeneous across countries for a same level of mitigation, due to the heterogeneity in θ_1. Details can be found in *SI Appendix*, section A.

Finally, we follow ref. 9 and rule out negative emissions, because the distributional effect of revenues would still be pronounced even if a large share of revenues was used for negative emission technologies. The Loss and Damage scenario targeting low-income countries shows that the welfare-enhancing effect of redistributing revenues holds for these countries even though only a small share of global revenues is redistributed in the first decades.

4.3. Country Level Climate Damages. The global temperature change caused by greenhouse gas emissions is modeled using mimiFaIRv2 (45), a Julia implementation of the Finite Amplitude Impulse Response model (FaIR). FaIR is a climate model designed to reproduce the response of the global climate system to emissions of carbon and other greenhouse gases, such as methane, fluorinated gases, nitrogen dioxide, inter alia, with good accuracy, and to capture nonlinearities in the carbon cycle, while keeping complexity level and run-time low (46). In our model, carbon emissions are endogenous to the carbon tax and output, whereas all other greenhouse gas emissions are exogenous. These gases are set to follow an "SSP2-4.5" forcing scenario as given in ref. 45, a scenario that together with untaxed carbon emissions would lead to a similar temperature increase as in our BAU. The global temperature anomaly is downscaled to a country level temperature anomaly with pattern scale coefficients taken from the Coupled Model Intercomparison Project Phase 6 (CMIP6, 47).

Following the usual practice in the literature, we assume that climate damages as a share of GDP are a function of the temperature anomaly. But contrary to most existing approaches (in particular models derived from the RICE model by 39), the country damage function depends on the local temperature anomaly that we obtain through our downscaling methodology. More specifically, the country-level damage function has the generic form:

$$\delta_i(\Delta_i T) = \beta_{i1} \cdot \Delta_i T + \beta_{i2} \cdot (\Delta_i T)^2,$$

where $\Delta_i T$ is the local temperature anomaly and $\delta_i(\Delta_i T)$ is the damage loss measured as a share of GDP lost for a given temperature anomaly. Parameters β_{i1} and β_{i2} are country-specific parameters that are calibrated to represent a general relationship between temperature increase and climate damages, as predicted in the econometric analysis by Kalkuhl and Wenz (48). More details, as well as plots of the damage function calibration process, can be found in *SI Appendix*, section B.

4.4. Globally Uniform and Nationally Differentiated Carbon Tax Trajectories, and Resulting Emissions. We implement 2 °C scenarios with either a global uniform tax or differentiated taxes by country. For the global uniform tax, we assume an exponentially increasing carbon tax pathway, and select the welfare optimizing carbon tax trajectory that keeps temperature under 2 °C until 2100. An exponentially increasing carbon tax path is in line with the optimal global carbon tax pathways in ref. 49 and the 2 °C compatible pathway in the second half of this century in ref. 28. For the differentiated taxes by country, we use a rule that gives the optimal ratio of carbon taxes between each country and a chosen reference country. The rule is derived from maximization of the sum of utilities from consumption for each country, under an emission budget constraint (the detailed method is presented in *SI Appendix*, section E). We choose the United States as the reference country. We find the tax trajectory for the United States (implying a tax trajectory for every other country through the rule) that enables the same global emissions reductions in each period until 2100 compared to the global uniform tax.

SI Appendix, Fig. S8 presents a few examples of implemented tax trajectories in the differentiated and uniform tax alternatives of the 2 °C scenario for countries with a variety of income levels and geographical locations. By construction, the global uniform carbon tax is always lower than the differentiated taxes in high income countries (e.g., USA, Germany, or the Republic of Korea).

The resulting emissions are presented in *SI Appendix*, Fig. S2. The emission trajectories of the differentiated and uniform tax scenarios are very close. Total carbon budgets over the 2020–2100 period are approximately 850 $GtCO_2$ and differ only by 5 $GtCO_2$ (less than 1%). This results in a likelihood of keeping the global temperature increase below 2 °C of over 83% (50). With the 2 °C scenario with a uniform carbon tax, CO_2 emissions fall to zero in 2080, while some CO_2 emissions persist until 2090 under the differentiated taxes 2 °C scenario.

4.5. Alternative Revenue Recycling Options. Our two carbon tax scenarios compatible with 2 °C result in global tax revenues of up to 4 trillion dollars (up to 2% of global GDP) for the uniform global tax, and up to 2.5 trillion dollars (up to 1.7% of global GDP) for the differentiated taxes (*SI Appendix*, Fig. S6) (The finding that differentiated carbon taxes yield a lower total revenue (*SI Appendix*, Fig. S6) implies that higher taxes in wealthy countries fail to compensate for the lost revenue from low-income countries). We consider six alternatives regarding the distribution of carbon tax revenues.

In the case of differentiated taxes by country, we explore two options: one where the recycling of revenues is neutral, i.e., carbon tax revenues are refunded within each country to exactly offset the carbon tax payment; the other where carbon tax revenues are redistributed as equal per capita payments within countries.

In the case of a global uniform carbon tax, we consider four alternatives. The first two options mirror the previously described scenarios for differentiated taxes: The first one assumes a redistribution of the revenues of the global carbon tax that neutralizes the distributional effect of the carbon tax within countries, the second assumes that the revenues of the global tax are redistributed on an equal per capita basis within each country.

Two additional alternatives are considered. The first one assumes that all tax revenues are collected globally and redistributed equally per capita at the global level. This scheme thus induces international transfers between countries, i.e., revenues raised in a given country are not necessarily redistributed within that country.

The last option represents a Loss and Damage policy. It assumes that the revenue from a uniform global carbon tax is used to compensate low-income countries for the climate damages they face. To do this, we create a climate fund, to which countries contribute with their carbon tax revenues. We consider two categories for the poor recipient countries. In the main text, we analyze the case where only low-income countries (World Bank classification; see *SI Appendix*, section D for the list) are targeted. The case where both low-income and low-middle income countries receive compensation is analyzed in *SI Appendix*, Fig. S11.

If there is enough carbon tax revenue to cover all the climate damages of low-income countries, each country contributes a share (the same for all countries) of its carbon tax revenue so that the total amount in the fund equals the total amount of climate damages of low-income countries. The revenue in the fund is then distributed to each low-income country to cover its national damages and redistributed equally per capita within the country. The remaining portion of carbon tax revenues is kept in each country and redistributed equally per capita within the country.

If there are not enough carbon tax revenues to cover the climate damages of low-income countries, the total amount of carbon tax revenues is transferred to the climate fund. Revenues in the fund are distributed to low-income countries in proportion to their national damages and redistributed equally per capita within the country.

Data, Materials, and Software Availability. Data and code have been deposited in GitHub (https://github.com/myoungbrun/replication_Young-Brun_et_al_2025) (51) and Zenodo (https://doi.org/10.5281/zenodo.16894909) (52).

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