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The Poverty Cost of Greenhouse Gas Emissions

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Abstract

Economic growth reduces current poverty but increases greenhouse gas emissions, which will increase poverty in the future. To quantify the combined effect of these two mechanisms, we introduce emissions-adjusted poverty, a new measure that sums a country's poverty today with the future global poverty that the country's emissions will create in the future. The key parameter of this measure is a human-centric analogue to the social cost of carbon, quantifying how current emissions increase future global poverty. We estimate that each kiloton of carbon dioxide emitted today adds two person-years of extreme poverty globally by 2100. Despite large uncertainties, we identify two robust insights. For poor countries, poverty reduction from economic growth outweighs future global poverty added from the emissions associated with this growth, even with historical carbon intensities. Conversely, for many rich countries, the climate-related poverty cost of growth outweighs the benefits unless the carbon intensity of growth falls.

Introduction

Reducing poverty and protecting human prosperity from climate change are two major global policy challenges. Deploying recent technologies and addressing market failures offer opportunities to make progress on both fronts. For example, renewable power creates new opportunities to connect poor people to electricity at lower cost than fossil fuels.[1–3] And better land management and climate-smart agriculture can increase yields while reducing greenhouse gas (GHG) emissions and increasing carbon storage in soils and vegetation.

But since economic growth is the largest driver of poverty reduction[4,5] and is still associated with higher GHG emissions, there is also a tension between these two challenges: economic growth reduces poverty over the short term while its greenhouse gas emissions increase temperatures and adversely affect future global poverty.[6,7] Such a tension appears even when policies allow for making progress on both fronts but one policy path is better at reducing poverty and another is better at mitigating emissions.[8,9]

Navigating the tension in a consistent way and monitoring the overall progress achieved requires an indicator that meaningfully reflects both challenges. One key desideratum for such an indicator is its ease of communication and simplicity. A black box indicator excludes non-specialists from the debates and cannot be used to inform the public.

We introduce emissions-adjusted poverty, which combines poverty and emissions. This indicator sums a country's current per capita poverty with the future global poverty that the country's current per capita emissions are expected to generate by 2100. This measure only reaches zero when a country has eliminated poverty within its borders and reached net-zero emissions.

Emissions-adjusted poverty

Emissions-adjusted poverty (EAP) in country j in year t is defined as

$$EAP_{jt} = \frac{P_{jt}}{N_{jt}} + \sum_{g \in \{CO_2, CH_4, N_2O\}} \gamma_t^g * \frac{E_{jt}^g}{N_{jt}} \qquad (1)$$

where N_{jt} is the number of people, P_{jt} is the number of poor people, and E_{jt}^g is the kiloton (kt) emissions from greenhouse gas g, of which we consider CO_2, methane (CH_4), and nitrous oxide (N_2O). Parameter γ_t^g captures the rate at which current emissions are expected to generate future poverty. It is defined as the global additional person-years in poverty resulting from the emission of one additional kt of greenhouse gas, g, in year t.

Emissions-adjusted poverty aggregates two undesirable outcomes observed in year t, namely the number of people who spend year t in poverty and the number of years that will be spent in poverty in the future due to the emissions of year t. The number of people who spend year t in poverty is also a number of person-years, and as a result, each of emissions-adjusted poverty's two terms have the same units. If we want to compare these outcomes across countries with different populations, we need to divide them by the population. When doing so, the first term is the country's current per capita poverty while the second term is the future global poverty generated by the country's current per capita emissions.

Parameter γ_t^g is related to the Social Cost of Carbon (SCC), which expresses the future economic damage caused by one ton of CO_2.[10] The key difference is that while the SCC attributes equal weight to a dollar lost to a wealthy person and a poor person, γ_t prioritizes damages to the poorest, acknowledging that a dollar lost for them has a larger impact on their livelihoods. In addition, γ_t makes the cost of emissions more human centric by expressing them in terms of years spent in poverty instead of dollars lost. γ_t plays the same role for emissions-adjusted poverty that the SCC plays for cost-benefit analysis of mitigation policies. Concretely, γ_t informs the reduction in current poverty that is needed to "compensate" for an increase in emissions. If a reform generates an additional kt of CO_2 while reducing the number of poor in year t by less than $\gamma_t^{\mathrm{CO}_2}$, then this reform has adverse consequences from the perspective of current and future global poverty.

Parameter γ_t is a special case of the equity-weighted SCC, SCC_t^{ew}, which uses distributional weights to adjust the SCC to give more importance to impacts on the poorest.[11–14] The SCC_t^{ew} expresses the cost in terms of a reference individual, meaning that emitting one additional ton of CO_2 causes a future global utility loss equivalent to the impact of losing SCC_t^{ew} of income for the reference person. While the equity-weighted SCC is conceptually solid, one key challenge is that communicating dollarized utility losses to non-experts is difficult. We see our proposal as a cruder but more communicable version of the equity-weighted SCC (for more details, see Materials and Methods).

Both the SCC_t^{ew} and emissions-adjusted poverty require selecting a normative parameter: The elasticity of marginal utility of consumption for SCC_t^{ew} and a poverty line for emissions-adjusted poverty. Only the latter can be easily communicated to non-specialists. We use poverty lines of \$3.00 or \$8.30 per person per day, corresponding to the median poverty line in low and upper-middle income countries, respectively. These lines are adopted by the World Bank and the former also by the Sustainable Development Goals for global poverty reporting.[15] The \$3.00 line approximately reflects the costs of covering basic minimal caloric needs and non-food consumption that households prioritize over satisfying basic caloric needs, such as simple cooking tools, clothing, school fees. We refer to the former as extreme

poverty and the latter as moderate poverty. As a robustness check, we use an approximation of country-specific national poverty lines.[16]

Both metrics also require selecting a discount rate and terminal year. We set the discount rate to zero under the argument that spending one year in poverty in the future counts the same as a year in poverty today (see Materials and Methods for details). As a robustness check, we use discount rates of 2% and 4%. For the terminal year, we choose 2100, such that γ_t^g is the number of years spent in poverty by the end of the century from a kt of greenhouse gas g emitted in year t. Impacts after 2100 are not large because, under our baseline growth assumptions, incomes are projected to increase, lowering the number of people who will be pushed below the poverty line due to climate change. As a robustness check, we explore a scenario with lower future growth rates.

To calculate emissions-adjusted poverty, we first need to estimate γ_t^g. We do so by relying on existing studies that link impulses of greenhouse gases to future temperature increases,[17] temperature increases to GDP and inequality shocks,[18–20] and GDP and inequality shocks to poverty shocks (see Fig. 1 for a visual overview).[5,21] As a robustness check, we use a study that links temperature increases to poverty directly. For more details, see Materials and Methods. To our knowledge, we are the first to estimate the poverty impacts of a marginal ton of emissions. If we apply our framework to estimate the extreme poor in 2030 caused by the emissions from 1990 to 2024, we get a figure of 103 million people, which is quite aligned with past approaches quantifying the poverty impact of climate change.[9]

The uncertainty from estimating γ_t^g is substantial, as is typical for studies quantifying the socioeconomic impacts of climate change. This uncertainty stems from primary data sources (such as poverty rates), projections of population and living standards up to 2100, and the estimated impacts of climate change on those standards. Because quantifying these joint uncertainties is nearly impossible, we adopt a second-best approach: we test the robustness of our results by assuming our main estimate could be incorrect by a factor of ten. While this factor is arbitrary, it serves as a generous sensitivity check. By comparison, an authoritative paper on the Social Cost of Carbon (SCC) finds the 5%–95% range spans from a factor of four below to a factor of two above the main estimate.[10]

The global poverty costs of emissions

For every $ktCO_2$ emitted in 2024, we estimate that an additional 2.2 years will be spent in extreme poverty somewhere around the world by 2100 ($\gamma_{2024}^{CO_2} = 2.2$), while 6.8 years will be spent in moderate poverty. To put these numbers into context, CO_2 emissions per capita in some of the highest emitting countries are around 40 tons. In these countries, the annual average emissions of 3-4 individuals (or roughly 1 household) cause one additional year to

be spent in moderate poverty. The annual emissions of the top 0.01% globally were 2.3 kilotons in 2019,[22] meaning that each person in this bracket causes about five future years to be spent in extreme poverty. Importantly, this quantifies the negative externality of income through higher emissions, ignoring other channels that can be negative (e.g., other forms of pollution) or positive (e.g., induced job creation, demand-led growth, and charity).

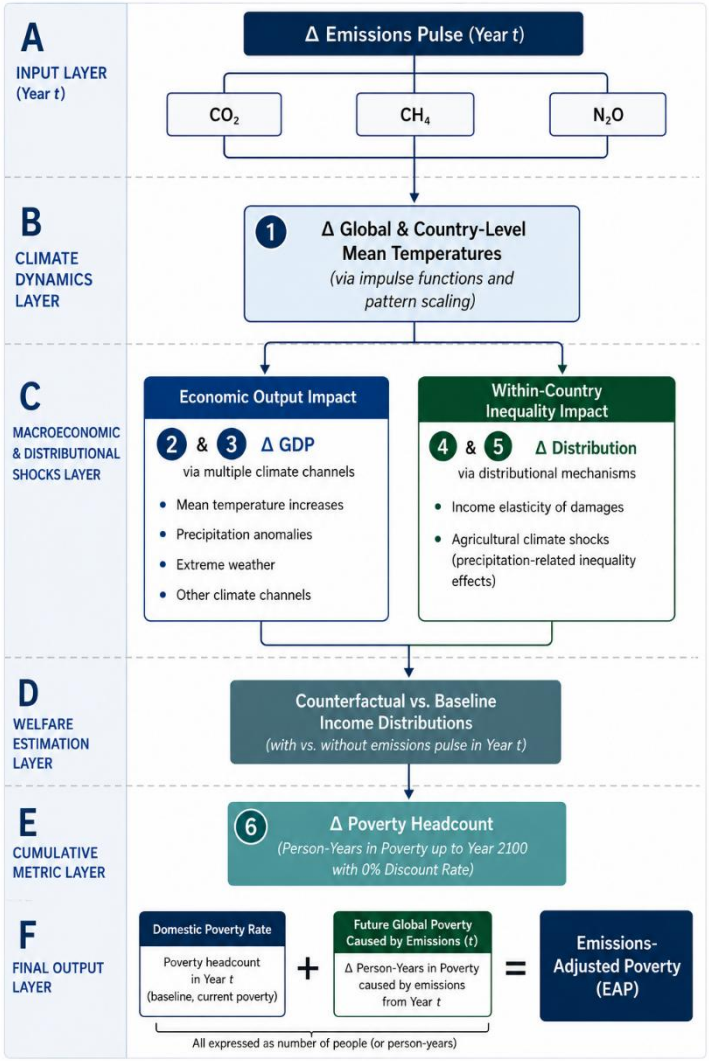

Fig. 1. Visual depiction of steps to estimate γ_t^g starting from a pulse of emissions in time t. The numbered circles indicate the methodical steps as described in Materials and Methods.

If we tally up the total future poverty impact of global emissions from CO_2, CH_4, and N_2O in 2024, we estimate they will cause 141 million more years of extreme poverty by 2100. For context, we estimate that in 2024, 894 million people lived in extreme poverty. Of the 141 million years, 109 are caused by the emissions of upper-middle and high-income countries, yet they will only experience 13 million years of the poverty caused (Fig. 2a). All geographical regions contribute to future poverty, with East Asia & Pacific being responsible for the largest

share. The consequences of the emissions are far from equal, with Sub-Saharan Africa estimated to experience 109 million of the 141 years of future poverty (Fig. 2b). 93 million years of poverty are expected to occur due to growth shocks to average incomes and 48 million due to the distribution of these shocks.

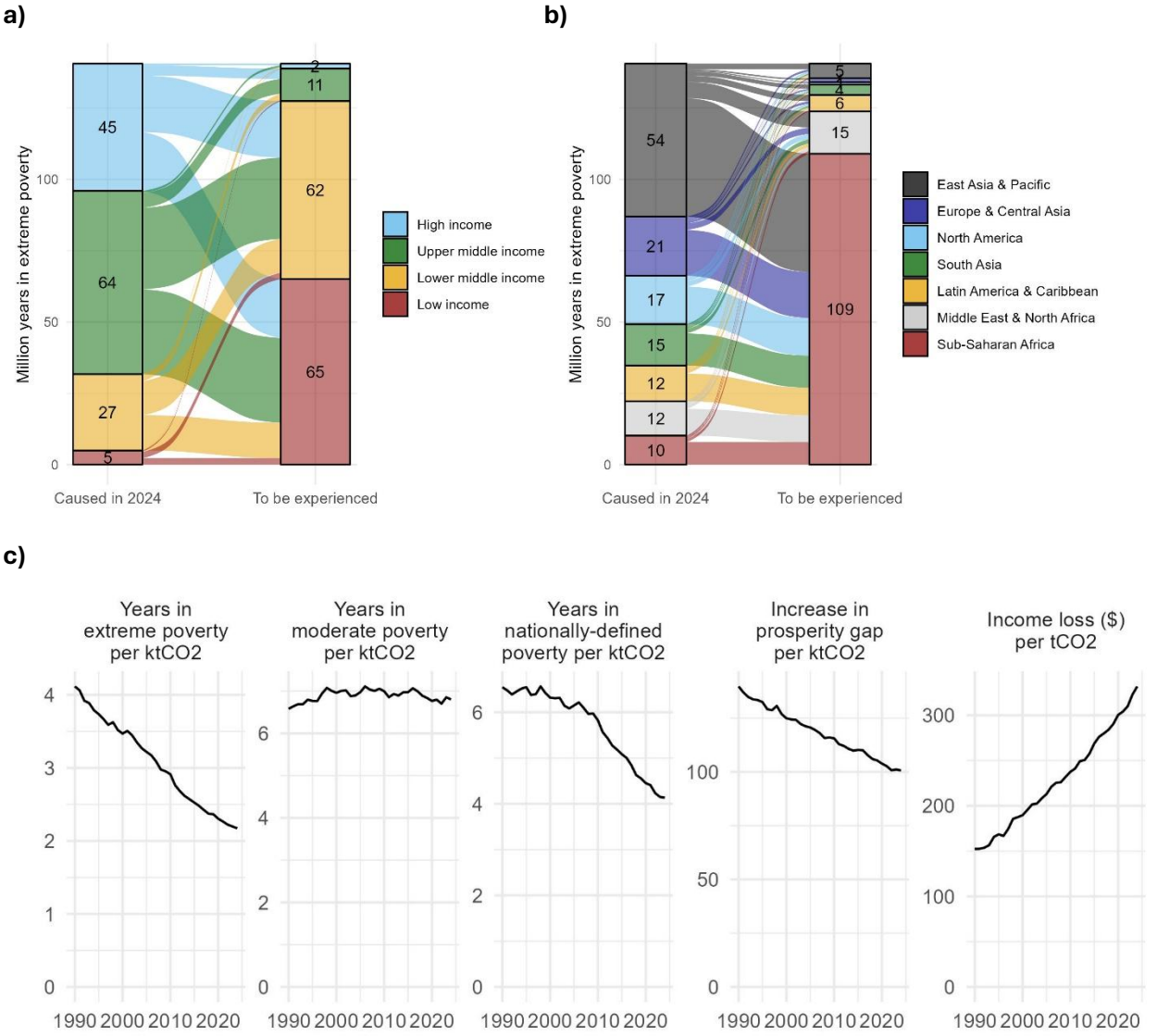

Fig 2. Years in poverty caused by emissions. (a) Years in extreme poverty caused and to be experienced by global emissions in 2024, by income group. (b) Same as panel (a) by region. (c) Future welfare costs caused by each $ktCO_2$ emitted, 1990-2024, for extreme poverty, moderate poverty, nationally defined poverty lines, the prosperity gap, and future annual income loss ($) per tCO_2.

The attribution and experience of poverty damages yield a different view than those from using the SCC. When working with the total dollar loss, high-income countries are responsible for the same share of damages caused (32%) but are expected to experience an even larger share of the damages (43%). This is in line with recent evidence which finds that

with the SCC, the US and the EU are experiencing more climate damages they are causing while the reverse applies to countries like Indonesia and Chad.*[25]

We estimate the poverty cost of each $ktCO_2$ has been decreasing since 1990, from around 4 years to 2 years today (Fig. 2c), using the fixed poverty line of $3.00. Since climate shocks hit a gradually richer world and higher incomes reduce the poverty implications of negative growth shocks, emissions today result in fewer people being pushed below the extreme poverty line than emissions of the past. Essentially, economic growth allows households to build a buffer against the negative consequences of climate change. The poverty costs at the moderate poverty line have stayed flat since 1990 because a large proportion of the world's population still finds itself much below this line (Fig 2c).

Using national-specific poverty lines or the prosperity gap (a measure which accounts for all damages, not just those leading to poverty-line crossings, while still giving the largest weight to the poorest) likewise gives rise to a declining γ^{CO_2}. This provides consistent evidence for a declining vulnerability to climate change over time (and thus for declining welfare costs of emissions). It is also consistent with a related paper which finds that the fraction of people at highest risk from climate hazards has halved in the last ten years, a result from development progress over this period.[26] The poverty cost of emissions is declining for all gases, though the decline is slower for CH_4 (Fig. S1), as the short atmospheric lifetime of the gas implies that short-term consequences dominate.

The decline in the poverty cost of carbon is in sharp contrast to the distribution-neutral SCC, which increases over time (Fig 2c). Even though economic growth lowers sensitivity to adverse effects of climate change, and hence the share of income lost to emissions, the absolute loss, which matters to the distribution-neutral SCC, still increases with income.[27] If countries continue to grow their economies in the coming decades, this pattern will continue, with the SCC increasing and the poverty cost of carbon declining. A more pessimistic scenario for baseline economic growth – for instance due to a slowdown in productivity growth or increased impacts of conflicts – would increase the estimated poverty cost of GHG emissions by 24% and decrease the SCC by 22% (Fig. S5).

* These findings change depending on how the economic damages of temperature increases are modeled. Some studies find that the coldest countries (which tend to be high-income countries) will see their GDP grow from further warming.[23] Others find that cold countries have negative damages because warmer weather reduces winter mortality rates and the need for heating expenses.[24] In either case, this would mean that they do not experience damages from climate change, even with a distribution-neutral SCC. In addition, richer countries are more able to finance costly adaptive investments, which lower the costs of climate change. Separately, our SCC differs from those commonly used because we measure income from household surveys rather than national accounts, apply no pure preference for the present (i.e., we do not discount utility or social welfare), stop our analysis in 2100, and rely on purchasing-power-parity exchange rates.

When we add the future poverty caused by current emissions to a country's poverty rate and calculate emissions-adjusted poverty rates, the effects vary. Globally, poverty has fallen drastically since 1990 while CO_2 emissions have risen by 70% since 1990. The sharp decline in poverty has had a much stronger effect on emissions-adjusted poverty than the rise in CO_2 emissions, causing the overall indicator to fall (Fig 3a).

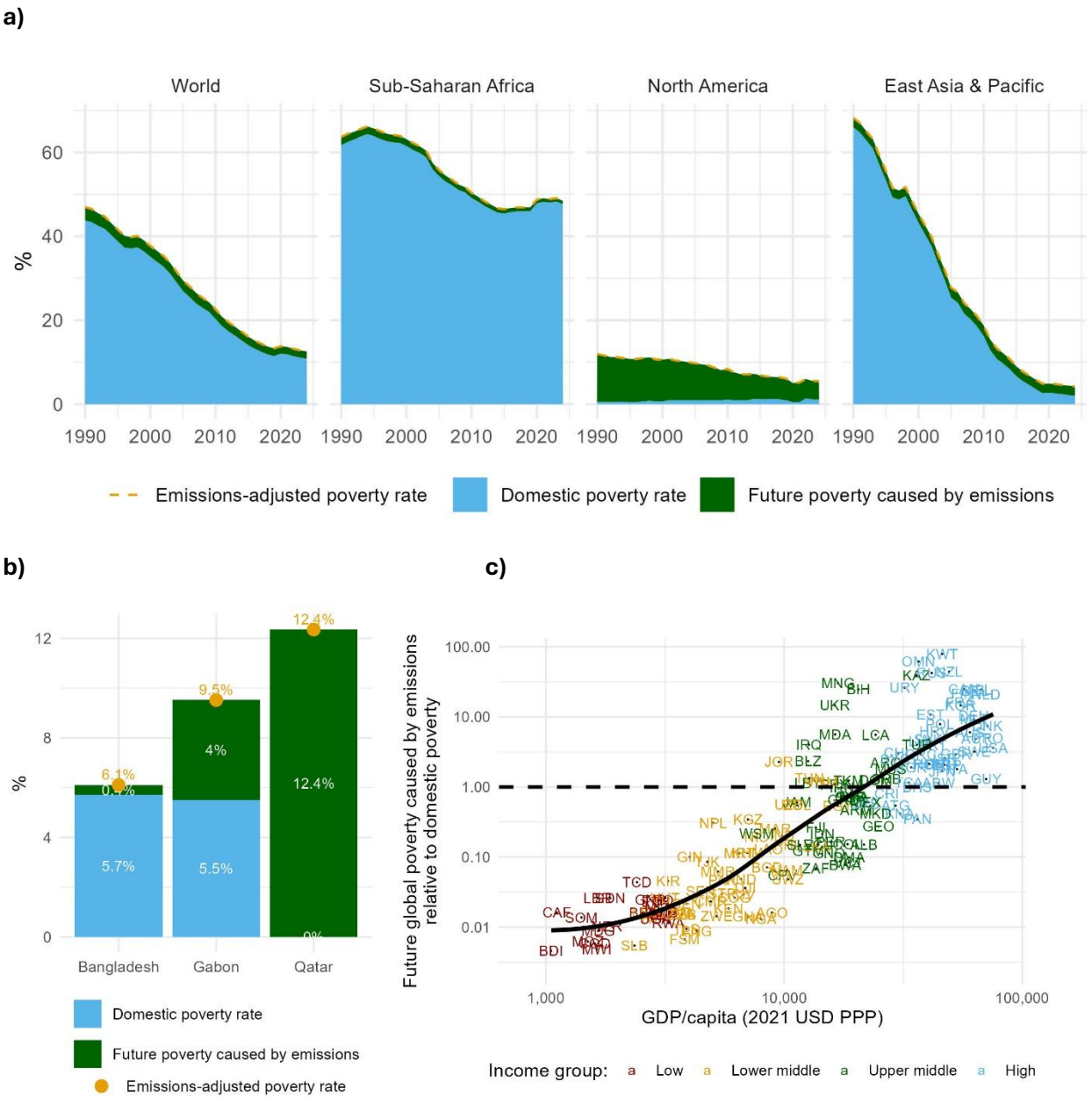

Fig 3. Emissions-adjusted extreme poverty globally, by region, country, and component. a) Emissions-adjusted extreme poverty from 1990-2024 for the world and three regions, b) Emissions-adjusted poverty for 2024 for three countries, c) the two components of emissions-adjusted poverty relative to each other, by GDP/capita in 2024.

In Sub-Saharan Africa, both poverty and emissions-adjusted poverty are around 50%, reflecting the low per capita emissions from the continent, and the limited future global poverty caused by these emissions. In North America, the story is the reverse, with close to zero extreme poverty in the region, but a sizable number of future global poor created through emissions. The future poverty created has decreased over time because of falling γ (Fig 2c) and because CO_2 emissions per capita have fallen for the region. East Asia & Pacific displayed a pattern like Sub-Saharan Africa in the 1990s but today has virtually ended extreme poverty within its borders and contributes to future global poverty through its emissions, similar to North America.

The addition of poverty caused by emissions to regular poverty rates can change how a country ranks compared to other countries. For example, Bangladesh has more extreme poverty than Gabon, which in turn has more poverty than Qatar. However, the countries differ in their reliance on fossil fuels, and when adding the future global poverty caused by the three countries' emissions, the ranking reverses: Qatar has higher emission-adjusted poverty than Gabon or Bangladesh (Fig 3b).

For all low-income countries, domestic poverty is more than 10 times greater than future global poverty caused by their emissions, while for most high-income countries, global poverty caused by emissions is larger than domestic poverty (Fig 3c). This is partly driven by high-income countries having virtually zero extreme poverty. However, the result is the same when using the prosperity gap: most high-income countries are generating more deprivations in the future with their emissions than they experience today within their borders (Fig. S3). Again, this is in sharp contrast to estimates using a distribution-neutral SCC, which suggests that the total damages caused in rich countries is a smaller share of their own income than in poor countries (Fig. S2).

When growth is good for the poor

It is widely understood that growth in real GDP per capita in a country is good for the poor of that country.[4] Yet this ignores that growth in GDP is associated with growth in emissions which cause future economic damages that create more poverty around the world.[28] The change in emissions-adjusted poverty arising from growth in real GDP per capita accounts for this and is a function of five elements. Growth will cause emissions-adjusted poverty to fall if

$$p_{jt} * |\varepsilon_{jt}^{p}| > \sum_{g \in \{CO_2, CH_4, N_2O\}} \gamma_t^g * e_{jt}^g * \varepsilon_{jt}^g \qquad (2)$$

The left side reflects the *benefits* of growth for domestic poverty reduction. The benefits are a function of the poverty rate, p_{jt}, and poverty-growth elasticity, ε_{jt}^{p}, which reflects how much 1% growth changes domestic poverty. The more inclusive growth is, the more it will lower poverty. The right side reflects the *costs* of growth. They depend on the emission-growth elasticity (ε_{jt}^{g}), that is, the increase in emissions arising from 1% growth, emissions per capita (e_{jt}^{g}), and the extent to which emissions generate future global poverty (γ_{t}^{g}).

Emissions-growth elasticities are not fixed: they depend on development pathways, energy mix and efficiency, or land-use patterns. Future elasticities are expected to be smaller than historical ones, thanks to progress in low-carbon technologies and the implementation of climate policies. To minimize our reliance on historical elasticities, we compute each country's break-even emissions-growth elasticity, $\tilde{\varepsilon}_{jt}$, (fixed to be identical across gases) that would leave the country's emissions-adjusted poverty unchanged:

$$\tilde{\varepsilon}_{jt} = \frac{p_{jt} * |\varepsilon_{jt}^{p}|}{\sum_{g\in\{CO_2,CH_4,N_2O\}} \gamma_{t}^{g} * e_{jt}^{g}} \qquad (3)$$

We apply these elasticities to analyze the impact of 1% growth in the present year. A country improves its emissions-adjusted poverty if it grows with an emissions-intensity lower than this value (i.e., if $\varepsilon_{jt}^{g} < \tilde{\varepsilon}_{jt}$ for all g).

Plotting $\tilde{\varepsilon}_{jt}$ across countries for 2024 using the prosperity gap reveals that it exceeded 10 in all low-income countries (Fig 4a). This means that even if low-income countries increase emissions by 10% whenever they grow 1%, the domestic benefits will outweigh future global costs. By comparison, our best estimate of historical emission-growth elasticities yields a median of 0.52 for CO_2 (interquartile range 0.46-0.59), 0.14 (0.05-0.24) for CH_4, and 0.17 (0.14-0.19) for N_2O (see Material and Methods) – or in other words an order of magnitude lower than 10. Hence, for low-income countries, it never makes sense to reduce growth to reduce emissions, even though lower-carbon growth is preferable. In short, in low-income countries and from a poverty perspective, lower carbon-intensity growth is better than historical growth, which in turn is better than slower growth.

For high-income countries, the break-even elasticity is typically in the range 0.1-4, which still exceeds estimated historical elasticities for about 40% of high-income countries. In other words, in around 40% of high-income countries we find that the costs of growth outweigh the benefits (Fig. S4a). If our point estimate is off by a factor of 10, we can no longer be certain that growth contributes to more domestic benefits than future global costs in any high-income country save for two small island nations. These results mean that, in high-income

countries and from a poverty perspective, lower carbon-intensity growth is better than historical growth, which in turn may be better or worse than slower growth.

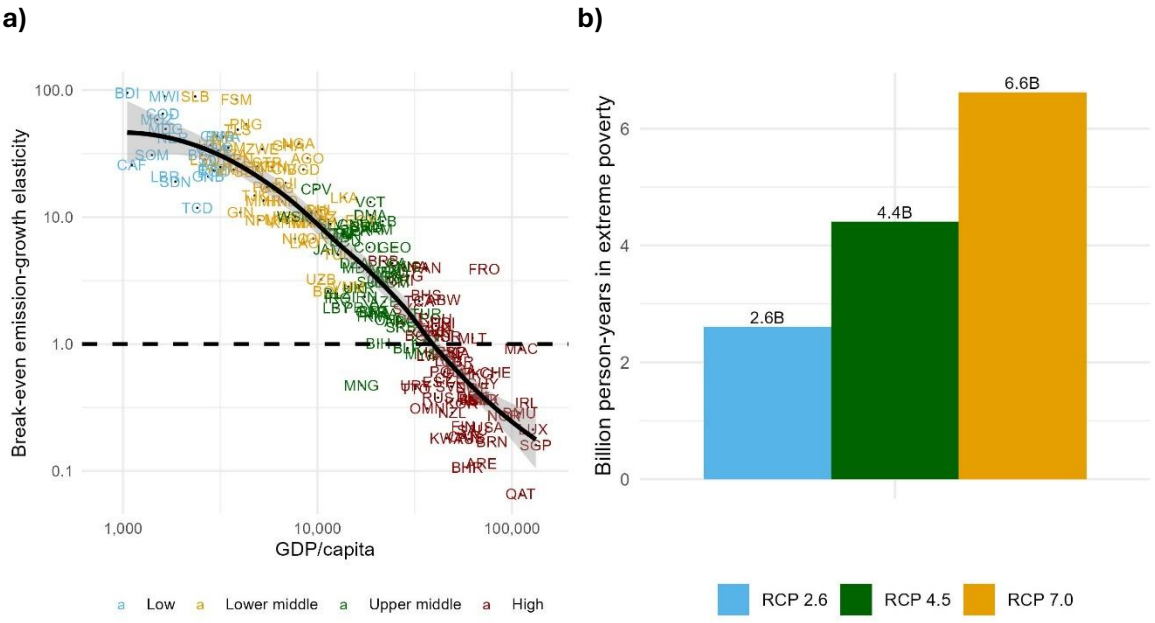

Fig. 4: Relationship between economic growth, emission-growth elasticities, and emissions-adjusted poverty. a) Maximum emission-growth elasticity for growth to be beneficial for emissions-adjusted poverty by GDP/capita. b) Billion years in extreme poverty from present to 2100 caused by emissions from present to 2100, by representative concentration pathway (RCP).

The findings change dramatically when we move to a distribution-neutral SCC, whereby growth with historical emission intensity is worthwhile in all countries with our central estimate (Fig. S4b). However, if we are off by a factor of 10, costs outweigh benefits in nearly all low-income countries yet in less than 20% of high-income countries (Fig. S4c).

Lower emission-growth elasticities can have vast implications for the future poverty costs of emissions. If countries grow according to our projections and underpin this growth with emissions in line with Representative Concentration Pathway (RCP) 7.0, 6.6 billion years of extreme poverty will be caused by 2100 (Fig. 4b). If countries manage to reduce emissions in line with RCP 2.6, while maintaining the same growth rates, then 4 billion years of extreme poverty by 2100 will be spared. RCP 4.5, which necessitates large drops in emissions over the next 10 years, falls in between with 4.4 billion years of poverty caused by 2100.

Discussion

These findings can inform debates at the intersection of economic development and climate change. We find that, in low-income countries, the local, immediate poverty-reduction

benefits of growth vastly outweigh its future global climate costs, even with historical carbon intensities. Without removing the value of favoring development paths with lower carbon intensities, this result emphasizes the need to ensure that climate policies contribute to economic growth in these countries. For high-income countries, in contrast, economic growth may only yield net poverty gains if carbon intensities are lower than historical ones, emphasizing the need for increasingly ambitious climate policies.

To reduce global poverty, both growth and carbon intensity matter, but the ranking of considerations differs across income groups: in low-income countries, policies should achieve the minimum possible carbon intensity among the highest-growth pathways; in high-income countries, policies should achieve the maximum possible economic growth among low-carbon development pathways.

There are multiple caveats to these conclusions. First, they only consider the climate impact of emissions, and not other planetary boundaries that may create additional constraints on economic growth.[29] And our assessment is based on the marginal effect of emissions, without considering compounding effects over time and the increased risks of tipping points at the global scale. It does not capture the dynamic nature of development pathways that can imply trade-offs between short-term and longer-term growth rates.

Second, we do not account for spillover effects of growth in high-income countries on growth in poorer countries. For example, if 1% growth in Germany causes 0.05% growth elsewhere in the world, the benefit/cost ratio for Germany of 1% growth increases from 0.8 to 9.2. We also ignore distributional effects: an action that takes two people out of poverty in one country but brings one person in poverty in another country is considered equivalent to an action that takes one person out of poverty in one country. And we have focused on low poverty lines, ignoring impacts on people with incomes above these lines but still well below common standards of living in high-income countries.

And finally, our approach is based on historical carbon intensities when new technologies and policies can reduce emission-growth elasticities without slowing down growth.[1] Lower carbon intensity magnifies the poverty benefit of economic growth at all income levels: if high-income countries grow with an emission-growth elasticity equal to the 10th percentile lowest elasticities observed between 2015 and 2024, then poverty costs outweigh poverty benefits in 20% of countries only (instead of 40%) (Fig. S4c). The combination of positive economic growth with declining GHG emissions in most high-income countries — and an increasing number of low- and middle-income countries — illustrates the potential for decoupling economic output and emissions, thereby accelerating progress toward a world free of poverty.

Materials and methods

Definition of γ_t^g

Suppose a decision maker is interested in minimizing the global, intertemporal number of people living in poverty. This could be done using the following social welfare function (W):

$$W_t = \sum_{\tau=t}^{T} \sum_{j \in J} \sum_{i=1}^{N_{j\tau}} p(y_{ij\tau}, z) \times \frac{1}{(1+\rho)^{\tau-t}} \qquad (4)$$

The term $p(y_{ij\tau}, z)$ reflects the poverty status of individual i with respect to poverty line, z, and income level, y. That is, $p(y_{ij\tau}, z) = 1$ when $y_{ij\tau} < z$ (i.e., i is poor) and $p(y_{ij\tau}, z) = 0$ otherwise. The number of poor in country j in time τ is $P_{j\tau} = \sum_{i=1}^{N_{j\tau}} p(y_{ij\tau}, z)$. Parameter ρ is the discount rate, year T sets the time horizon during which future poverty is accounted for, and J is the set of all countries.

This social welfare function is directly connected to our key parameter, γ_t^g. Concretely, parameter γ_t^g is defined as the change in W_t arising from an additional kt of greenhouse gas, g, emitted in year t (ΔW_t^g). In other words, it reflects the discounted number of additional person-years caused by this pulse of emissions. Formally,

$$\gamma_t^g = \Delta W_t^g = \sum_{\tau=t}^{T} \frac{1}{(1+\rho)^{\tau-t}} \sum_{j \in J} \Delta P_{j\tau}^g \qquad (5)$$

where $\Delta P_{j\tau}^g = P(y_{j\tau}) - P(y_{j\tau}^g)$, $y_{j\tau}$ is the distribution of income in country j in year τ under a baseline scenario for countries' development and $y_{j\tau}^g$ is the distribution of income under a modified scenario with a kt less g emitted in year t. $\Delta P_{j\tau}^g$ is the estimated additional number of poor in country j in year τ caused by a kt of g emitted in year t.

Relationship with the social cost of carbon

The SCC has the same conceptual foundation as our estimate of the poverty cost of carbon, $\gamma_t^{CO_2}$. Both $\gamma_t^{CO_2}$ and SCC reflect estimated changes in W_t arising from either a ton or kiloton of CO_2 emitted in time t. The difference pertains to the definition of social welfare used. To see this, consider a more generic social welfare function, which for expositional purposes could be defined as

$$W_t = \sum_{\tau=t}^{T} \sum_{j \in J} \sum_{i=1}^{N_{j\tau}} u(y_{jti}) \times \frac{1}{(1+\rho)^{\tau-t}} \qquad (6)$$

where u is the utility function, which defines how much an additional unit of income to an individual i in country j generates additional welfare to i.

Most uses of the SCC are underpinned by a distribution-neutral social welfare function, which relies on defining $u(y_{jti}) = y_{jti}$. This social welfare function assumes that an additional unit of income has the same impact on social welfare when it is given to a rich or poor individual. It is thus blind to the living standards of those most affected by the future damage of the emissions. In this case, the SCC can be interpreted as the discounted future monetary losses from one unit of emissions:

$$SCC = \sum_{\tau=t}^{T} \frac{1}{(1+\rho)^{\tau-t}} \sum_{j \in J} \sum_{i=1}^{N_{j\tau}} \left(\Delta y_{j\tau}^{g}\right) \qquad (7)$$

Studies have proposed distribution-sensitive social welfare functions that rely on concave utility functions, and through that provide an SCC that gives more weight to losses from poor individuals.[11–14] This requires selecting the value for a parameter tuning the concavity of u, which defines the social welfare function's sensitivity to inequality. The larger this sensitivity, the more damages to the poorest are prioritized. Prima facie, this equity-weighted SCC, SCC^{ew}, is expressed in current utils. Since such units are hard to grasp, the equity-weighted SCC re-expresses these costs as the reduction in the current total income of a reference individual $\hat{\imath}$ that yields the same reduction in social welfare as those generated by the unit of emissions. The SCC is thus implicitly defined by

$$W(y_{\hat{\imath}t}) - W\left(\left(1 - \frac{SCC_{\hat{\imath}t}}{Y_{\hat{\imath}t}}\right) \times y_{\hat{\imath}t}\right) = SCC_t^{ew} \qquad (8)$$

Poverty rates can be understood as a crude distribution-sensitive social welfare function. In contrast to the social welfare function underpinning the equity-weighted SCC, which reflects changes in income in a continuous fashion, poverty rates only account for changes in income that push people in or out of poverty. While the equity-weighted SCC is more comprehensive, using poverty rates to quantify the social welfare costs of emissions has distinct advantages.

First, expressing the damages in terms of their impact on the number of people living in poverty, rather than using monetary units, is more human centric. Second, poverty rates are simpler to communicate and understand than distribution-sensitive social welfare functions.[30] This is reflected by the fact that poverty is regularly discussed in the media while social welfare functions are never mentioned outside specialized circles. In this, we mimic the use of the "extreme poverty" concept by the World Bank Group and other global institutions, which has increased attention and accountability on progress on poverty

reduction in a way that more complex distribution-sensitive welfare functions have not.[30] Search tools reveal that the equity-weighted SCC is hardly used and that the regular SCC is used about 1000 times as much (Table S1).

Using poverty rates allows constructing emissions-adjusted poverty, an easy-to-communicate indicator that aggregates current poverty with current emissions. The values for this summary indicator are directly comparable across countries and across time and thus allow monitoring the progress made on poverty reduction and emissions reduction together.

It would also be possible to construct a summary indicator based on a generic distribution-sensitive SWF as follows

$$EAW_{jt} = \frac{W_{jt}}{N_{jt}} + \sum_{g \in \{CO_2, CH_4, N_2O\}} \gamma_t^{g,W} \frac{E_{jt}^g}{N_{jt}} \qquad (9)$$

As a robustness check, we construct such an indicator based on a distributional social welfare function called the Prosperity Gap (PG).[30] The Prosperity Gap is defined as the average factor by which incomes must be multiplied to get to a reference prosperity standard of $28 per person per day, denoted by s,

$$PG_{jt} = \frac{W^{PG}(y_{jt})}{N_{jt}} = \frac{1}{N_{jt}} \sum_{i=1}^{N_{jt}} \frac{s}{y_{jti}} \qquad (10)$$

We define the emissions-adjusted prosperity gap by replacing W by W^{PG} in Equation (10).

Other papers have calculated the non-economic impacts of marginal emissions using other metrics than poverty, that highlight other non-dollarized damages of climate change. Past papers have calculated the mortality costs of one unit of carbon,[31] the loss of crop protection per degree of warming,[32] and the marginal effects of a ton of CO_2 on glacial sea ice, life expectancy, and more.[33]

Data

The poverty data comes from the World Bank's Poverty and Inequality Platform (PIP).[34] PIP contains more than 2,500 income and consumption distributions from household surveys spanning 172 countries and is used for reporting on poverty and inequality for the United Nations' Sustainable Development Goals. Household surveys are available irregularly in many countries, so PIP interpolates and extrapolates distributions such that there is a distribution for every country and every year from 1981-2025, collapsed to 1,000 points per country-year.[35] We use a version of PIP that adjusts for within-country comparability breaks

over time.[36] All welfare distributions are denominated in purchasing power parity adjusted 2021 U.S. dollars in daily terms.

For some countries, mostly high-income countries and countries in Latin America, the distributions reflect measures of disposable income. For the remainder of countries, they reflect consumption. Income and consumption distributions are not comparable and evolve differently over time. To increase cross-country comparability and make the results more aligned with studies on the SCC (which use income), we convert all consumption aggregates to income aggregates following a method trained on data for 50+ countries that explains more than 90% of the variability out-of-sample.[37] The method converts the 1,000 consumption points to income using the following formula: $inc = \left(\frac{con - 0.42}{0.96}\right)^{1/0.94}$.

Beyond 2025, we extrapolate the income vectors forward using projections of real GDP per capita. Concretely, if GDP per capita in a country is projected to grow by 1%, we increase everyone's income by 1%. This is consistent with how PIP extrapolates income vectors for old data. Until 2030, we use GDP forecasts from the October 2025 version of the International Monetary Fund's World Economic Outlook. Beyond 2030, we use the median growth forecast from a Bayesian latent factor model for long-horizon forecasting.[38] Whenever a country lacks a growth forecast in either of these two sources, we assign it the median growth forecast of countries belonging to the same income group and World Bank region. As a robustness check, we use the 25th percentile and 75th percentile of the growth forecast (Fig. S5).

Our temperature data comes from the Weighted Climate Dataset, based on ERA5, using concurrent population weights to aggregate the country-level average temperatures.[39,40] Our data on emissions come from the Emissions Database for Global Atmospheric Research.[41] The CO_2 data we use include land use and land-use change. Our population data comes from the United Nations' World Population Prospects.[42]

Estimating γ_t^g

To estimate γ_t^g, we proceed in six steps. A visual depiction of these six steps is given in Fig. 1.

Step 1: Impact of emissions on mean temperatures. Our first step is to quantify how the CO_2, CH_4, and N_2O emitted into the atmosphere in year t impact global mean surface temperature in year t and onwards to 2100. Given the different atmospheric lifetimes of these gases, converting them to CO_2-equivalents does not properly account for their year-by-year global warming potential, and as a consequence, their year-by-year adverse impacts on future poverty. For that reason, we consider the gases separately and use impulse functions

developed with the different atmospheric lifetimes in mind.[17] We remove all emissions from one year at a time (rather than a smaller unit of emissions) to create a larger temperature impulse, which will have a larger GDP impact. A smaller impulse of emissions results in more erratic impacts on whether any of the 1,000 bins in our distributions get pushed above or below a given poverty line. An example showing the impact of emissions in 2024 on global temperatures is given in Fig. S6. Next, we compute how much these global temperature increases are likely to impact temperatures in any given country using pattern scaling estimates from the U.S. Environmental Protection Agency.[43]

Step 2: Impact of temperature increases on GDP. Our next step is to estimate the impact of these temperature increases from the emissions in year t on economic output in every country from year t onwards. Numerous studies exist on the topic.[44–47] Crucial assumptions in these studies include how long a temperature increase influences growth rates and the spatial granularity of the input data. We rely on Waidelich et al. (2024),[20] which uses subnational data and assumes the growth shock from temperature changes lasts for two years. Other studies find no evidence against the shocks lasting in perpetuity.[44] Hence, in this regard, our estimates may yield conservative GDP shocks, which is one of the reasons why we use as a sensitivity test a 10-fold increase in damages.

Step 3: Impact of other climate channels on GDP. Economic output is impacted by climate in many other ways than through mean temperature increases. To estimate the impact of other climate channels, we again rely on Waidelich et al. (2024), which also analyzes how growth is impacted by annual precipitation, temperature variability, monthly precipitation deviation, number of wet days, and extreme precipitation. We scale the growth shocks from the mean-temperature-increase channel, such that they make up the same proportion of the total growth shock. For example, if the impact on growth from mean temperature increases is 50% of the total impact on growth of the channels, we will multiply our growth impacts by two. This is equivalent to assuming that impact through non-temperature channels responds linearly with the change in temperature. The impact of these other channels is relatively small.

Step 4: Impact of temperature increases on inequality. The growth shocks of climate change are unlikely to hit all within a country equally.[48,49] To model how the growth shocks from temperature increases will be distributed, we use an estimate of the within-country income elasticity of damages.[13,18] Estimates find this elasticity to be 0.64 for countries that experience damages in incomes due to temperature increase and indistinguishable from 1 for countries that experience gains in incomes from temperature increases.[18] An elasticity of 0.64 means that for every 1% income increase, damages increase by 0.64%. We apply this elasticity to change the distribution of the growth shock coming from temperature increases while keeping the total damages for the country fixed. With our data, this roughly means that

the poorest 10% in each country experiences 2.6 times the relative loss as the richest 10% (interquartile range: 2.3-2.8), which is consistent with other approaches.[9]

Step 5: Impact of other climate channels on inequality. To model how the growth shocks from other climate channels are distributed, we rely on a study which finds that the impact of precipitation anomalies on inequality depends on the agricultural intensity and yearly precipitation.[19] This study finds that countries with high agricultural intensity and high annual precipitation see large declines in the income share held by the bottom 50%. For countries with high agricultural intensity but low yearly precipitation, more rainfall increases the income share of the bottom 50%. For countries with low agricultural intensity, the impact of changes to precipitation on inequality is modest. A change in the income share of the bottom 50% can materialize in many ways. To model how the change in the share of the bottom 50% materializes across the income distribution, we apply a convex growth incidence curve,[21] which means that the largest proportional losses are felt at the very bottom. This, we think, is consistent with the findings of the study, which are stronger for inequality measures very sensitive to the income of the bottom.[19]

Step 6: Derivation of γ_t^g. We now have an income distribution for each country from year t and onwards to 2100, and a counterfactual welfare distribution for each country over the same years. The latter reflects our estimates of the income distribution had the emissions of year t not entered the atmosphere. The final step involves calculating poverty rates (and other welfare metrics) for each country-year, and the difference in poverty between the baseline and counterfactual distributions. Examples of the future poverty impacts of the emissions of 2024 are shown in Fig. S7.

To calculate the total intertemporal poverty loss, we aggregate all losses through 2100. We assume a pure rate of time preference of 0%, meaning that a year spent in poverty is equally bad regardless of when it occurs. In standard SCC calculations, positive discount rates are applied partly to reflect diminishing marginal utility, as a one-dollar loss has less impact on a future, richer individual. Under an absolute poverty standard, this rationale is not applicable. However, a positive discount rate could still be justified by a pure rate of time preference due to the risk of non-existence. One study on poverty discounting uses a rate of 3%.[50] As a robustness check, we apply a discount rate of 2% and 4% (Fig. S8).

To ensure that the γ_t^g of later years are not "penalized" by there being fewer future years in our dataset (which stops in 2100) and hence less future damage to discount, we only use 76 future years of discounted damage regardless of which year we are calculating gamma for. This prevents the estimates for later years from being artificially lower simply because there are fewer future years left to analyze in the dataset. γ_t^g is then simply calculated as the total damage divided by the kilotons of emissions in a particular year. We repeat these six steps for each t from 1990 to 2024.

Direct approach

As a robustness check, we estimate γ_t^g using a more direct approach that replaces Step 2-Step 6 with one step. Concretely, we rely on a recent study that relates temperatures to extreme poverty rates directly.[51] The paper finds that each Celsius increase in temperatures increases extreme poverty for poor countries by about 2 or 5 percentage points, depending on the model, while having no effect on rich countries. Applying these estimates suggests a γ_{2024}^{CO2} equal to 2.4 or 4.1, depending on the model. These estimates are 11% and 87% higher than our baseline estimate.

An advantage of using this direct approach is skipping many of the intermediate steps and the uncertainty involved in each of them. A disadvantage is that poverty data is much sparser than GDP data, preventing using the most robust empirical methods to linking temperatures and poverty, which require balanced, panel data. This is particularly the case for poorer countries, which matter the most in this exercise. Whereas there are only 49 country-year estimates of poverty changes across all current low-income countries, there are 1,353 country-year estimates of GDP growth rates in such countries.

Emission-growth and poverty-growth elasticities

To estimate emission-growth elasticities, ε_{jt}^g, we regress growth in per capita emissions, $\Delta e_{jt}^g = \ln(e_{jt}^g) - \ln(e_{jt-1}^g)$, on growth in real GDP per capita, $\Delta y_{jt}^g = \ln(y_{jt}^g) - \ln(y_{jt-1}^g)$, allowing for country-specific random intercepts, β_{0j}, and country-specific random slopes, β_{1j}:

$$\Delta e_{jt}^g = (\beta_0 + \beta_{0j}) + (\beta_1 + \beta_{1j})\, \Delta y_{jt}^g + \epsilon_{c,t} \qquad (9)$$

We only use data from the past 10 years given the recent changes in the costs and availability of zero- or low-carbon technologies like solar and wind power, or electric mobility. These technologies have become least-cost options in many contexts, which has likely changed the impact of growth on emissions compared with earlier years when renewable energies were more expensive. We allow for random intercepts and random effects by country as a way of getting country-specific elasticities. If we use country fixed effects, we would heavily overfit the model due to the large noise in the data for many countries. Still, the largest estimated elasticities are likely influenced by data anomalies, so we winsorize them at the 10th and 90th percentiles, which is 0.39 and 0.68 for CO_2, -0.02 and 0.53 for CH_4, and 0.10 and 0.23 for N_2O. Density plots of the estimated elasticities (prior to winsorizing) are available in Fig. S3, while the regression output is available in Table S2.

The positive estimated elasticities do not contradict that many countries have decoupled emission and GDP levels. It is possible to delink *levels* of emissions and GDP without

delinking *growth* in emissions and GDP. This can happen because countries reduce their per capita emissions independently of economic growth—for instance, by replacing old infrastructure with less carbon-intensive capital.[26] In our model, this would imply a negative intercept. For CO_2, the median intercept is about -0.01, meaning a country with zero GDP growth reduces its emissions by 1% annually. If a country has an intercept of -0.02, a growth rate in GDP of 2% per year, and a growth elasticity of 0.5, each year CO_2 would fall by 1%.

We do not estimate growth-poverty elasticities directly because they are known to be mechanically a product of the level of poverty.[52] Concretely, growth-poverty elasticities mechanically become larger in absolute value as poverty rates fall due to the shape that income distributions take. Hence applying any elasticity estimated on past data (where poverty rates on average were higher) to future development would underestimate the impact of growth on poverty. To circumvent this issue, we infer growth-poverty elasticities from the scenario where growth in real GDP per capita affects all incomes equally.

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Supplementary Information

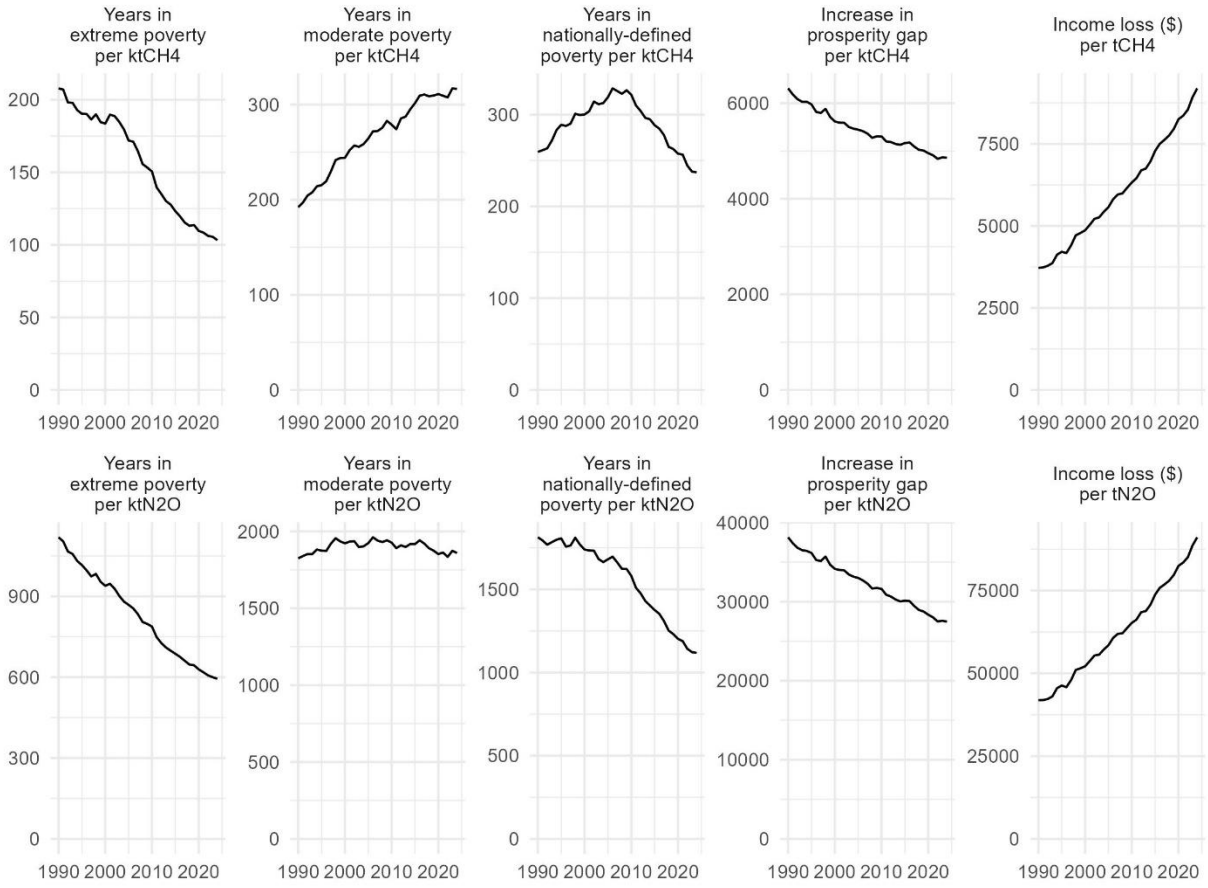

Fig. S1. Future years in poverty caused by a $ktCH_4$ or $ktN2_O$ emitted, 1990-2024, for extreme poverty ($3.00/day poverty line), moderate poverty ($8.30/day poverty line), a nationally-defined poverty line, the prosperity gap, and future annual income loss ($) per tCH_4 or $tN2_O$.

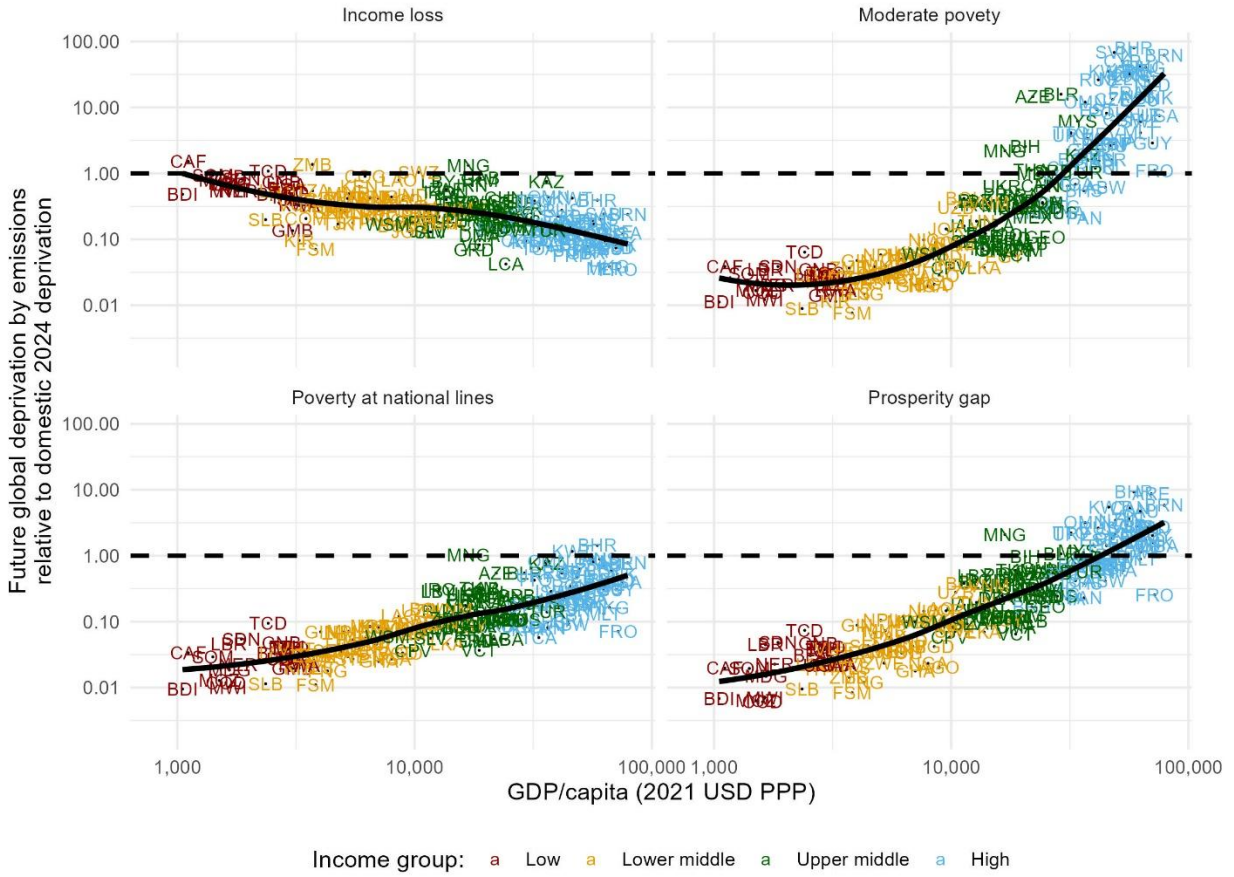

Fig. S2. The two components of emissions-adjusted poverty relative to each other, by GDP/capita in 2024, using alternative poverty lines and welfare metrics.

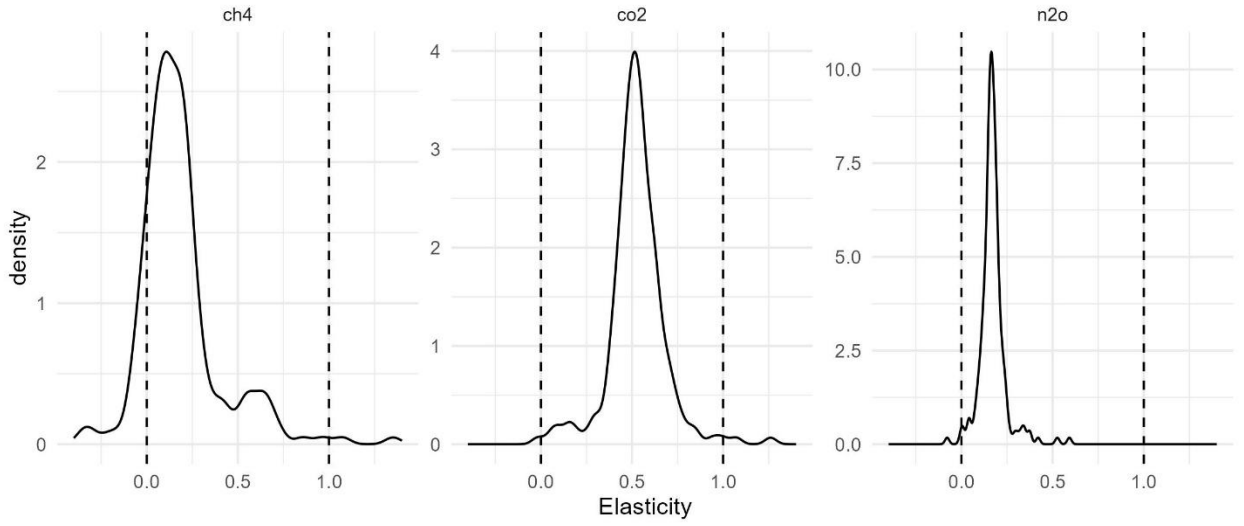

Fig. S3. Distribution of estimated country-level growth-emission elasticities by greenhouse gas.

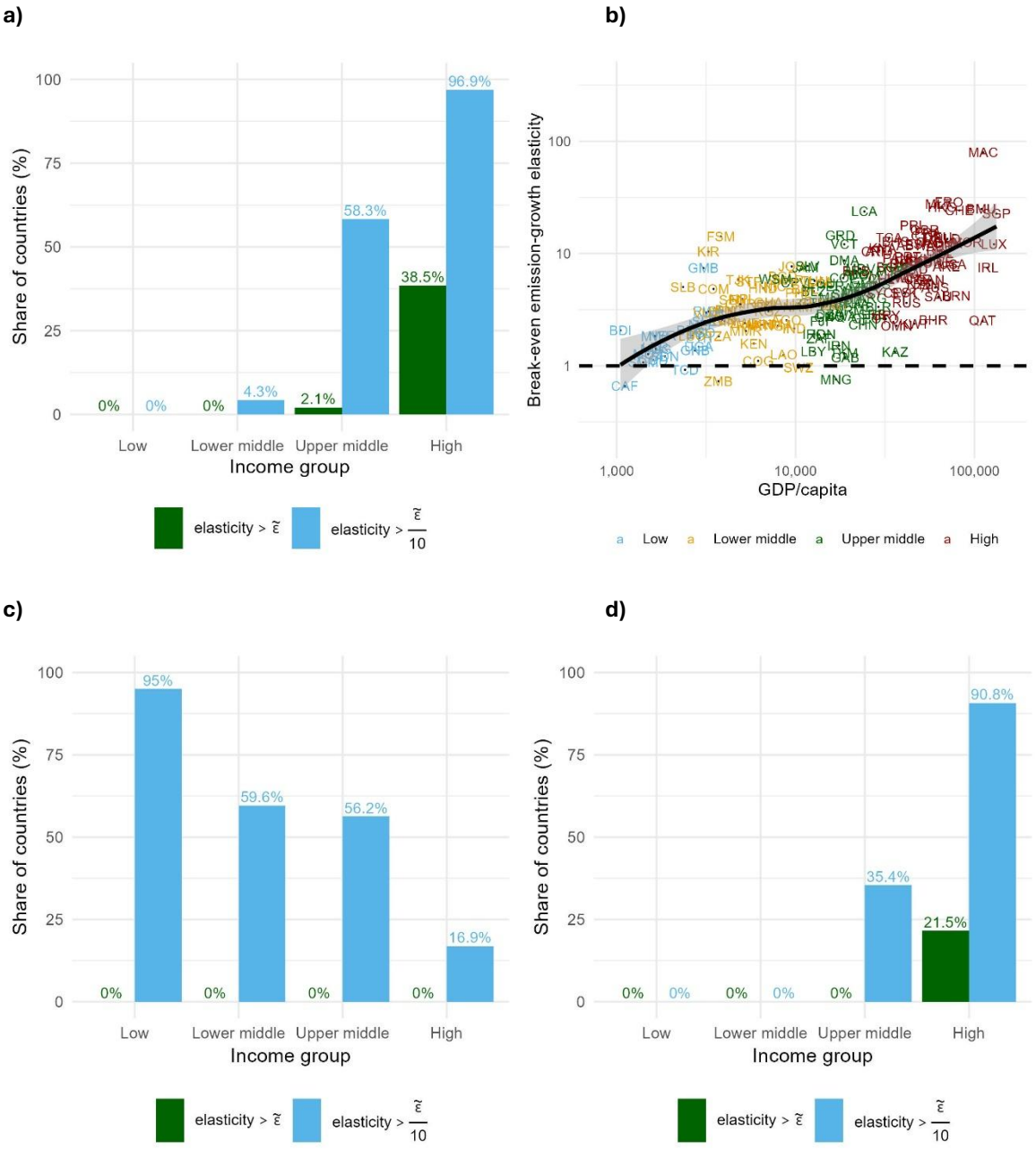

Fig. S4: Relationship between economic growth, growth-emission elasticities, and emissions-adjusted poverty. A) Share of countries with estimated historical elasticities from 2015-2024 larger than the break-even elasticity (maximum elasticity for growth to be beneficial for emissions-adjusted poverty) or one-tenth of the break-even elasticity. b) break-even emission-growth elasticity by GDP/capita when using a distribution-neutral SCC. c) Share of countries with estimated historical elasticities from 2015-2024 larger than the break-even elasticity (or a 10th of the break-even elasticity), by income group, with a distribution-neutral SCC. d) Share of countries with elasticities larger than the break-even elasticity (or a 10th of the break-even elasticity) if they achieve a 10th percentile best performer growth-emission elasticity, by income group.

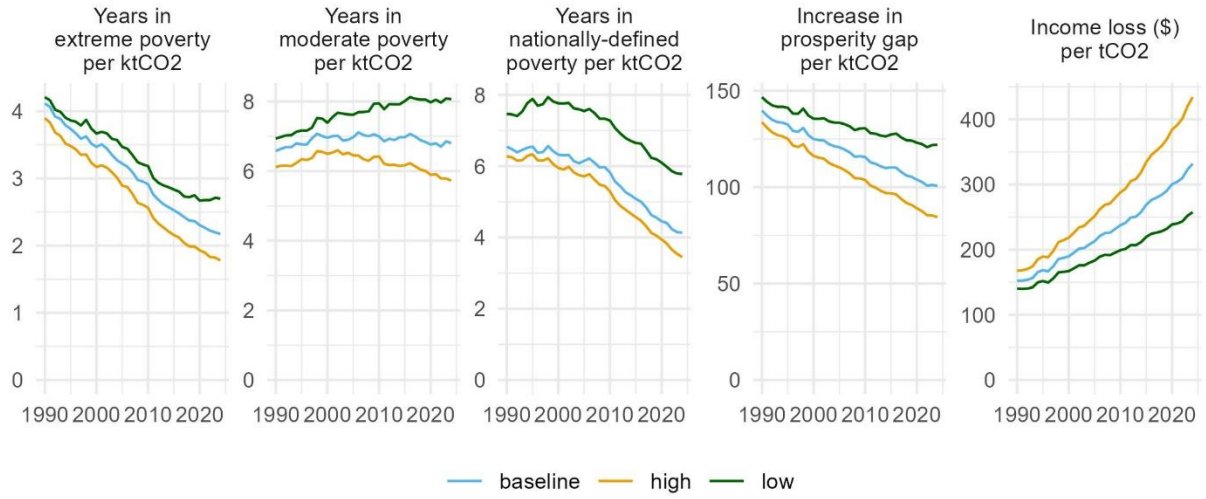

Fig. S5. The costs of emissions over time, by welfare metric, and growth scenario. *Baseline* uses the growth scenarios from the main body of the paper, which is the 50th percentile growth from a range of scenarios. *High* uses the 75th percentile and *low* the 25th percentile.

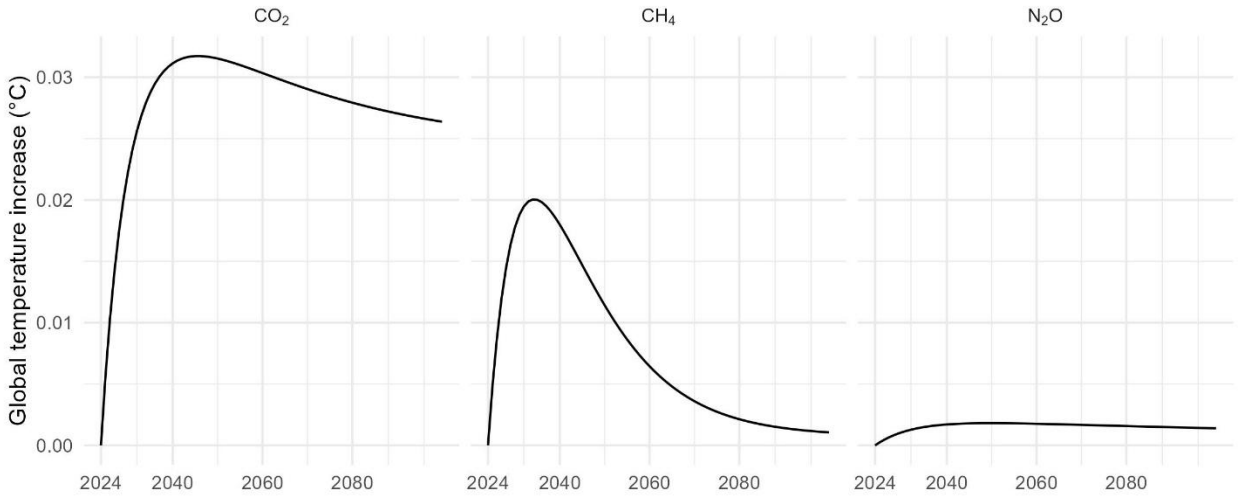

Fig. S6. Increase in global temperature from global emissions of 2024, by gas.

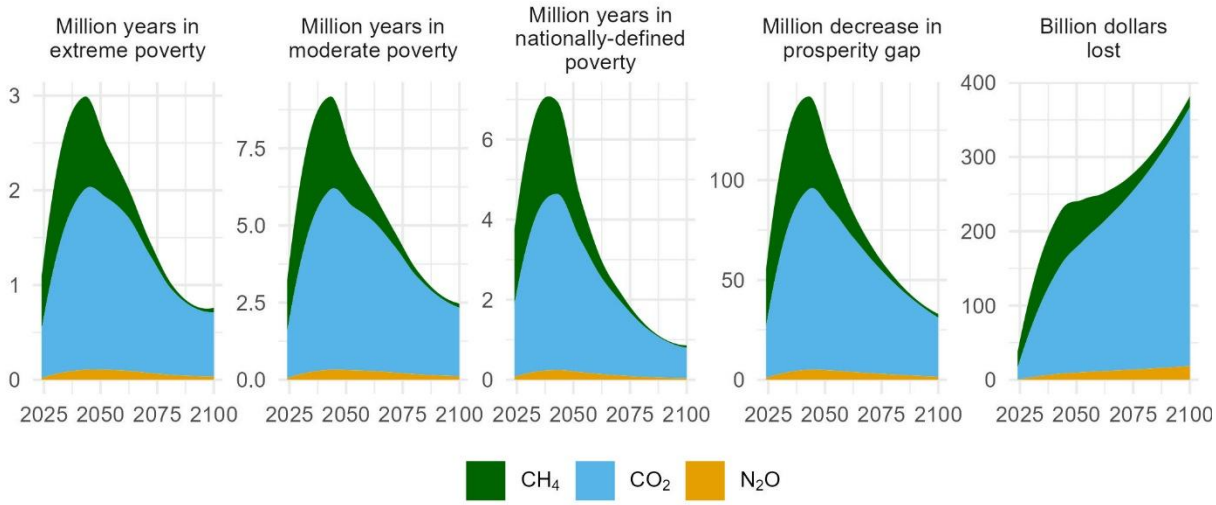

Fig. S7. Future damages caused by the global emissions of 2024.

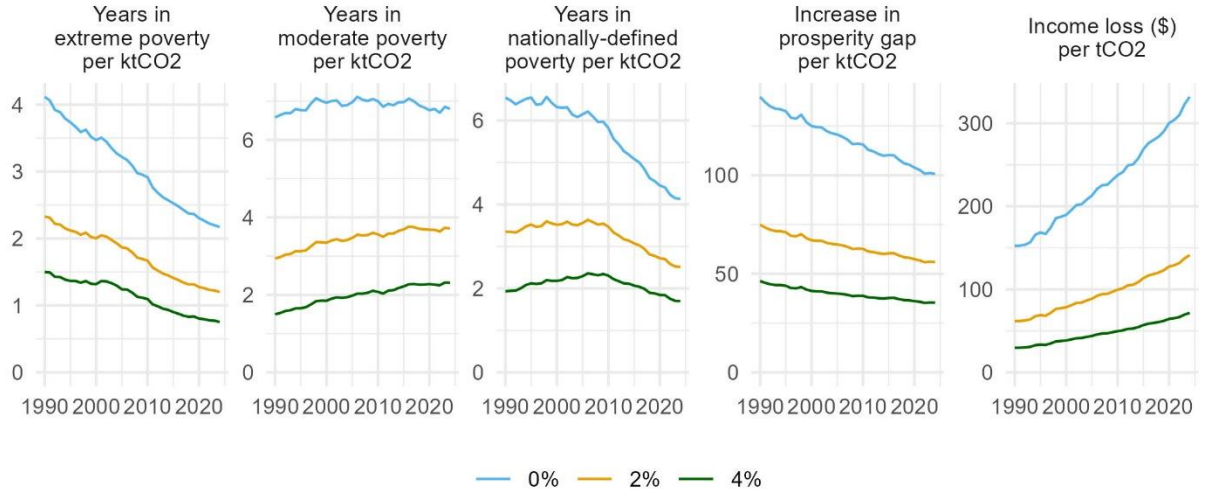

Fig. S8. The costs of emissions over time, by welfare metric, and discount rate. The main body of the paper uses a 0% discount rate.

	Academic use Google scholar	**Policy use** nlp4dev.org	**Public use** Google
Social cost of carbon	26,100	573	264,000
Equity weighted social cost of carbon	257	0	257

Table S1. Use of social cost of carbon and equity weighted social cost of carbon. The search results are from 2026.05.15.

	Growth in per capita		
	CO_2	CH_4	N_2O
Intercept (β_0)	-0.009	-0.007	-0.005
Growth in GDP per capita (β_1)	0.527	0.192	0.171
Std. dev. of random effects			
Intercept (β_{0j})	0.006	0.015	0.012
Growth in GDP per capita (β_{1j})	0.295	0.363	0.194
Observations	1888	1908	1908
Number of countries	190	192	192

Table S2. Regression output from estimation of elasticities