ENVIRONMENTAL RESEARCH
LETTERS

PURPOSE-LED
PUBLISHING™

LETTER • OPEN ACCESS

Income and inequality pathways consistent with eradicating poverty

To cite this article: Jihoon Min *et al* 2024 *Environ. Res. Lett.* **19** 114041

View the article online for updates and enhancements.

You may also like

- Flammable futures—storylines of climatic impacts on wildfire events and palm oil plantations in Indonesia
Shelby N Corning, Esther Boere, Andrey Krasovskiy et al.
- Toward the quantification of the climate co-benefits of invasive mammal eradication on islands: a scalable framework for restoration monitoring
Miroslav Honzák, Geoffrey Roberts, Bradley J Cosentino et al.
- Multilevel actor networks in China's growing fossil-fuel based role in the global electricity sector
Jürgen Michael Thomas Sauer, Julian Kirchherr, Judith Plummer-Braeckman et al.

This content was downloaded from IP address 62.226.46.101 on 13/11/2024 at 06:08

ENVIRONMENTAL RESEARCH
LETTERS

OPEN ACCESS

RECEIVED
23 January 2024

REVISED
11 September 2024

ACCEPTED FOR PUBLICATION
16 September 2024

PUBLISHED
4 October 2024

Original content from this work may be used under the terms of the Creative Commons Attribution 4.0 licence.

Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

LETTER

Income and inequality pathways consistent with eradicating poverty

Jihoon Min[1,*], **Bjoern Soergel**[2], **Jarmo S Kikstra**[1,3,4], **Johannes Koch**[2] and **Bas van Ruijven**[1]

[1] International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria
[2] Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany
[3] Grantham Institute for Climate Change and the Environment, Imperial College London, London, United Kingdom
[4] Centre for Environmental Policy, Imperial College London, London, United Kingdom
[*] Author to whom any correspondence should be addressed.

E-mail: min@iiasa.ac.at

Keywords: poverty eradication, poverty–growth–inequality triangle, gini pathways, GDP pathways, sustainable development goals

Supplementary material for this article is available online

Abstract

To investigate concurrent climate action and poverty eradication, we present combined income growth (GDP/capita) and domestic income inequality (measured as Gini coefficients) pathways that pursue (absolute and relative) poverty eradication reflecting the three narratives of Sustainable Development Pathway. The GDP/capita pathways are modifications of the Shared Socioeconomic Pathway SSP1 scenario, including one post-growth future for high-income countries and higher growth for all currently lower-income countries. Current inequality levels, together with the total national income from the GDP pathways, determine the inequality reductions required to eradicate poverty in individual countries; they are based on a methodology that specifies the relationship between poverty, inequality, and growth. Our pathways show rapid and sustained reductions in within-country inequality (Gini), even with high economic growth. The speed of redistribution is limited to the highest historically observed changes in inequality. We identify which countries face the greatest difficulties in meeting their poverty eradication targets and estimate the level of international transfers needed to fill the gap for those countries. Our findings reconfirm the importance of reducing within-country inequality in eradicating global poverty.

1. Introduction

Future income growth, inequality, and the prevalence of poverty are key socioeconomic indicators of the future state of a society and have important links to broader multidimensional metrics of well-being (Alkire and Santos 2010, Rao and Min 2017). Despite its importance, distributional analysis has long been a blind spot in the global energy–land–climate scenarios that underpin the analysis of long-term climate change mitigation pathway analyses (Rao *et al* 2017). Improved modeling of income inequality and poverty is particularly important in scenarios that aim to assess progress toward, and interactions between, different Sustainable Development Goals (SDGs).

There was a decline in the number of people living in poverty worldwide until 2020 (albeit at too slow a pace to achieve SDG target 1.1 by 2030). Since 2020, however, the number of people living in poverty has not fallen and has even increased due to the effects of the COVID-19 pandemic and the repercussions of the Russia–Ukraine war (Nature 2023). Achieving the SDG target 1.1 ('eradicate extreme poverty for all people') looks increasingly unlikely from today's perspective. According to model-based projections, even for optimistic socioeconomic assumptions (Shared Socioeconomic Pathways SSP1 and SSP5 (Riahi *et al* 2017)) poverty eradication targets are not being met (Crespo Cuaresma *et al* 2018, Soergel *et al* 2021a)[5], and the same applies to many other SDGs (Soergel *et al* 2021b).

This calls for a new perspective of 'target-seeking' scenarios that identify the changes required to achieve

[5] The inequality pathways for the SSPs were derived ex-post from a regression relationship between the Gini coefficient as a measure of inequality and total factor productivity (TFP), educational attainment, and social public spending (Rao *et al* 2019).

© 2024 The Author(s). Published by IOP Publishing Ltd

the poverty eradication target in conjunction with a broader set of SDGs. To this end, we develop three different Sustainable Development Pathway (SDP) scenarios that aim to make as much progress as possible toward achieving the SDGs and reflect three different sustainable development narratives (table S1 in the supplementary information (SI), details in Kriegler *et al* this issue). The present paper focuses on developing the socioeconomic scenarios of future income growth (GDP/capita) for the three different SDPs and derives the levels of income inequality (Gini coefficients) consistent with meeting poverty eradication targets, acknowledging different national contexts. This sheds light on potential pathways to zero poverty and their respective challenges. It also provides the necessary foundation for model-based scenario analysis of target-seeking scenarios in a broader SDG context (Kikstra *et al* n.d. , Soergel *et al* n.d.).

SDG1 deals with various indicators of poverty and well-being, including multi-dimensional poverty, access to services/resources, resilience, assistance, or government funding. The work explained in this paper focuses on single-dimensional income poverty: having an income that is less than a certain minimum level. In this view, income poverty directly relates to the mean income (growth) and its distribution (inequality). This three-way relationship is commonly referred to as the 'poverty–growth–inequality (PGI) triangle' (Bourguignon 2004).

Previous studies have focused empirically on the bilateral links within the triangle (e.g. the trickle-down effect (Arndt 1983, Škare and Družeta 2016)). Hence, many studies have focused heavily on the growth or inequality elasticity of poverty[6], and have considered poverty as an outcome variable of a growth- or equity-oriented scenario (Ravallion 1997, 2001, 2013, Ferreira and Ravallion 2008, Amini and Dal Bianco 2016, Bergstrom 2020, Lakner *et al* 2022), a perspective that is also reflected in tools such as growth incidence curves (Ravallion and Chen 2003).

Here we introduce a simple and flexible framework that solves the PGI triangle backwards and generates inequality pathways consistent with eradicating poverty. To reflect different national contexts between countries, and between now and the future, we let national poverty lines (NPLs) increase as a function of per capita income projections. We compare the resulting pathways for the three SDP narratives ranging from 'Economy-driven Innovation' (**EI**; focusing on innovation-driven economic growth) and 'Managing the Global Commons' (**MC**; moderately growing economy oriented toward human services) to 'Resilient Communities' (**RC**; post-growth economy in high-income countries) (Kriegler *et al* this issue). Our methodology highlights how differences in economic growth or in inequality reduction rates matter for poverty reduction. The questions we ask are:

- What future GDP/capita and Gini pathways are required to achieve global income poverty eradication?
- How differently will countries fare under the SDP narratives with different growth and inequality settings?
- Will domestic efforts alone be sufficient to reach the global poverty eradication goal?

In section 2 below, we explain the methodology for developing the GDP pathways and the target-seeking Gini pathways for the SDPs at the country level. Section 3 presents the patterns of these pathways and discusses their global and national implications.

2. Method

2.1. Developing GDP pathways for three SDPs

We first construct country-level GDP pathways designed to reflect the economic dimension of the SDP narratives (Kriegler *et al* this issue). The widely used SSP1 sustainability scenario (O'Neill *et al* 2017) is interpreted as a 'green growth' future in the SSP GDP pathways (Dellink *et al* 2017); it features sustained economic growth above historical trends in all countries and a gradually closing gap between high- and low-income countries due to higher growth rates in low-income countries. Here, we expand the scenario space by designing three variants representing a high-, moderate- and low-to-no-growth sustainable future, with the main differentiation in the GDP pathways being for higher-income countries. This picks up earlier proposals, such as a low-growth SSP1 variant scenario (O'Neill *et al* 2017) or a beyond-growth 'SSP0' (Otero *et al* 2020), and creates a foundation for addressing the current lack of post-growth climate change mitigation scenarios (Hickel *et al* 2021). All three SDP narratives feature a convergence of income levels between low- and high-income countries, albeit at a different pace. We thus differentiate the scenario assumptions on future economic growth between low-, middle- and high-income countries, reflecting that achieving progress on human development and satisfying decent living standards is tightly coupled to increasing GDP/capita at low national income levels, but not at high national income levels.

The GDP quantification starts from an updated version (Koch and Leimbach 2023) of the GDP/capita marker pathways for the original SSP1 scenario (Dellink *et al* 2017). The updates include more recent historical years and near-term forecasts capturing the effect of the COVID-19 pandemic, as well as updates to national accounting conventions and purchasing power parity (PPP) conversions (Koch and

[6] The inequality elasticity of poverty is the responsiveness of poverty rate to a change in inequality index.

Table 1. Economic narrative dimension of the SDP scenarios and its implementation for the quantitative GDP pathways. Note: we construct the GDP scenarios in the $\$_{PPP2005}$ unit of the original SSP scenarios, as converting the PPP base year to more recent years (2011 or 2017) would result in changes of GDP/cap ranking and convergence across countries due to variation of GDP deflators across countries.

Scenario	**Economic dimension of SDP narrative** (Kriegler *et al* this issue)	**Quantitative scenario assumption** (Modification of GDP/capita growth rates of SSP1 scenario; see the supplementary data (table S2) for detailed equation and parameter choices. Modifications to growth rates are not kept constant but evaluated dynamically based on the GDP/cap values).
SDP-EI	**Innovation-driven economy:** High GDP growth in all regions	Growth rates enhanced for low- and middle-income countries: growth rates increased by up to 15% (relative increase) for low-income levels; enhancement decreases as logistic function of log (GDP/cap) with midpoint at 15 000 $\$_{PPP2005}$. No modification at high income levels.
SDP-MC	**Service-driven economy:** Moderate GDP growth in developed countries and high GDP growth in other regions	Growth rate reduced for high-income countries: Countries at or above U.S. GDP/cap have growth rates reductions of 50%; for countries below U.S. GDP/cap the reduction is lower and depends on GDP/cap relative to the U.S. value (logistic function with midpoint at 80% of U.S. GDP/cap). Reductions phased in gradually until 2030. No modification at low-income levels.
SDP-RC	**Society-driven economy:** Post-growth future in developed countries; continued growth in developing countries	Gradual transition to post-growth for high-income countries: logistic transition from no modification to zero growth at highest income levels (midpoint at 30 000 $\$_{PPP2005}$). Reductions phased in gradually until 2030. No modification at low-income levels.

Leimbach 2023). Next, we apply stylized modifications to the GDP/capita growth rates that implement the features of the respective SDP scenario narratives (table 1). All modifications are phased in or out as GDP/capita-dependent logistic functions over time to ensure smooth pathways without jumps in growth rates. Finally, the recent SSP1 population projections (Lutz *et al* 2018), which are assumed to be the same in all three SDPs, are used to construct the final GDP pathways.

2.2. Projecting NPLs

Given our focus on the development of domestic poverty, we define how we set up NPLs as national income grows, with the given GDP pathways outlined above. Historical NPLs were estimated 'implicitly' by the World Bank in the course of setting up the international poverty lines (Jolliffe and Prydz 2016). Based on these NPL data and borrowing ideas from Ravallion and Chen (2013) and Jolliffe and Prydz (2021) on global poverty measures, we fit a relative poverty line (figure 1) with the minimum NPL set at the $2.15 per day international poverty line (World Bank 2022). This setup thereby captures that poverty lines in countries with greater national incomes are higher, while never going below extreme absolute poverty income values.

Our NPLs increase as national income grows, following a log–log linear trend line between the Gross National Income (GNI) per capita and the NPL. In contrast to existing poverty lines set out in Ravallion and Chen (2013) and Jolliffe and Prydz (2021), our formulation is directly workable with future GDP/GNI projections. Translating between GDP and GNI pathways is done based on the assumption that the GDP to GNI ratio observed at the base year applies to future years for each country. In sum, a future GNI trajectory is projected based on the GDP growth projections (section 2.1) and is then mapped to a future NPL trajectory through the fitted trend in figure 1 (also see 'National poverty lines' in the SI).

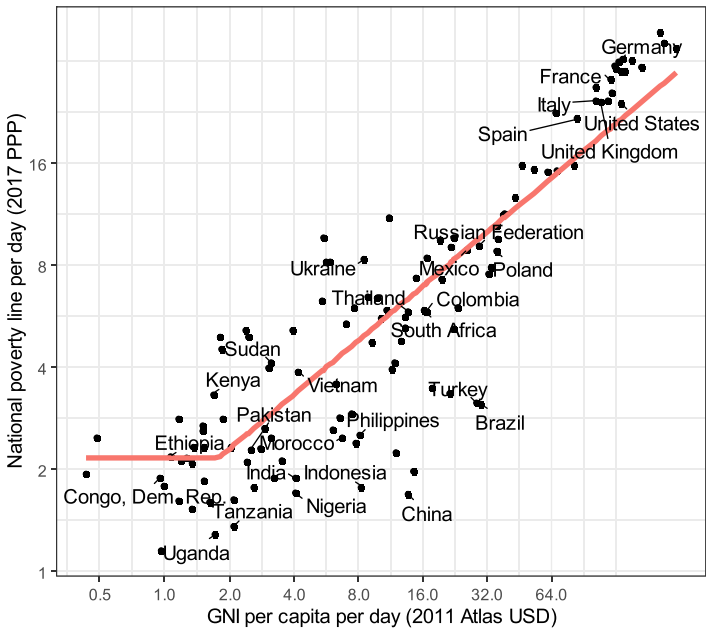

Figure 1. The relationship used for projecting national poverty lines. Each dot is an estimate for a country in one year, retrieved from appendix 2 of Jolliffe and Prydz (2016). The y-axis is converted to 2017 PPP to reflect the $2.15/day threshold defined on 2017 PPP.

2.3. Gini estimation

We estimate how low the Gini would have to be, at the given mean income, to bring everyone above the NPL. We use the method developed by Min and Rao (2023), which is an extension of earlier studies (Kakwani 1993, Ferreira and Leite 2003). The method does not rely on a specific assumption on the income distribution shape.[7] It can be formulated as:

$$G_{X_y} = \frac{\mu_{X_y} - d_y}{\mu_{X_y}} G_{X_0}. \quad (1)$$

X_y is per capita income in year y, and μ_{X_y} is its mean, derived from the SDP GDP/capita pathways. d_y is the NPL (Section 0), and G_{X_0} is the Gini index at the base year. For calculations in this study, the base year is set at 2020[8].

With these inputs, we derive the normative target Gini G_{X_y} for achieving poverty eradication by year y. The main assumption of this method is that the future income distribution is an affine transformation of the base year income distribution (Min and Rao 2023)[9]. This is a type of progressive redistribution in that everyone's income goes through inequality-invariant transformation (e.g. fixed-rate tax) and then receives an equal payment.

Once G_{X_y} is identified, we consider how we transition from G_{X_0} to G_{X_y}. We aim for the 'lowest and fastest possible' Gini transitions which historical observations show to be the universal normative target for all countries in seeking 'to ensure a life of dignity for all' (United Nations n.d.). With this in mind, Gini indices observed between 1979 and 2019 give the realistic ranges of Gini levels and the rates of Gini improvement (World Bank n.d.). We acknowledge that outliers may have been caused by measurement challenges or exceptional domestic situations. Instead, we assign the 1st (SDP-RC), 2nd (SDP-MC), and 5th (SDP-EI) percentile values of historical Gini indices, finding the most equal national income distributions during the last four decades at Gini values of around 24–26.

For the speed of inequality reduction (the Gini decrease rates), we look at domestic Gini change observations over periods longer than 10 years and find that at the 99th percentile of historical observations, Gini values declined by 2.5% (note, % not in p.p.) per year. At the 98th and the 95th percentiles, these rates are 2.1% and 1.8% per year, respectively. We find these empirical observations to be consistent with a similar exercise in Lakner *et al* (2022) and we use them as a rule-of-thumb for Gini reduction rates, which—although drastic—are not without historical precedent; the goal is to enable a rapid reduction in the number of people suffering from poverty. We

[7] Earlier studies dealing with future income distribution following certain Gini projections typically assumed log-normal income distribution because of its computational simplicity. Narayan *et al* (2023), however, find that the use of log-normal distribution considerably underestimates the level of inequality.

[8] For the base Gini G_{X_0}, considering the World Bank has no Gini observations for the year 2020 for all countries, we take an average of all available Gini observations between 2015 and 2020. If there are no observations for that period for a country, we borrow the 2020 value from existing SSP1 Gini projections (Rao *et al* 2019).

[9] Also referred to as 'Lorenz-convex transformation' (Ferreira and Leite 2003)

Table 2. Historical observations of the Gini decrease rates and the lower bounds.

Percentile among all observations	5% (SDP-EI)	2% (SDP-MC)	1% (SDP-RC)
Gini decrease rate	−1.8%/year	−2.2%/year	−2.5%/year
Gini lower bound	26.2	24.8	24.0

assign observations at a certain percentile to each SDP scenario, as shown in table 2, reflecting the respective narratives (see table S1).

The year in which national poverty eradication targets are reached when the national Gini has decreased to the required Gini value for eradicating poverty—following equation (1). When national incomes grow, the Gini reduction requirement becomes less strong, even while NPLs increase at the same time. Figure 2 illustrates the case for India, finding the year that national poverty is eradicated at different times for different scenarios. It is worth stressing that this methodology suggests normative pathways toward poverty eradication: it does not consider other concerns regarding the political and social feasibility of Gini reduction or other country-specific factors that could impede Gini improvements and delay poverty eradication, beyond what is captured implicitly in the historical precedents from which we derive our maximum inequality reduction rates. We note that our analysis excludes two exceptional countries (Azerbaijan, Ukraine) where the base year Gini is found to be lower than the assumed lower bounds.

2.3.1. Considering the relative inequality target

Beyond absolute poverty, relative poverty is also known to affect well-being. While rich countries may be able to meet national poverty targets even though they have strong levels of inequality, such circumstances cannot be deemed to be sustainable development. This relative poverty is captured in SDG10 ('Reduced inequalities'). There is no quantitative target connected to SDG10, but in its spirit we adopt an upper bound on within-country equality reflected by a Gini value of 30. Looking at historical Gini observations, a Gini of 30 roughly corresponds to the 30th percentile in our data (World Bank n.d.). This upper bound can be considered ambitious but achievable. This means that we allow the Gini trajectories of countries able to achieve their poverty target at Gini > 30 to continue to fall to 30[10]. In our pathways, therefore, where the reduction of relative poverty is pursued as a goal in itself, the Gini level never increases over time.

2.3.2. Total necessary international transfer to achieve the goal universally

For a sizable number of countries, the projected growth rates and inequality reduction, even if fast, are not fast enough to reach poverty eradication targets in the near term. One way to fill such economic gaps is via international transfers of money. We can use the formulation in equation (1) to calculate the required additional monetary transfers that need to flow into countries with remaining poverty gaps in a given year in order for there to be zero poverty.

Along our pathways, the poorest person in the country's population reaches an income level $d_{y,\text{lowest}}$ in year y,

$$d_{y,\text{lowest}} = \mu_{X_y} \cdot \left(1 - \frac{G_{y,\text{ lb}}}{G_{X_0}}\right), \tag{2}$$

where $G_{y,\text{ lb}}$ is the Gini value on the empirical lower bound in year y, G_{X_0} is the Gini at the base year, and μ_{X_y} is the average per capita income (per year). In year y, if $d_{y,\text{lowest}}$ is still lower than the NPL d_y, we estimate the necessary transfer to the country as the amount needed to fill the gap $(d_y - d_{y,\text{lowest}})$ for everyone below the poverty line.

We assume that the share of population below the NPL ($r_{y,\text{povhc}}$) in year y decreases linearly from the initially observed rates to zero until the poverty goal is achieved[11]. The base year poverty rate used here is the mean of the three most recent observations for the base year (World Bank n.d.). A summary plot of historical poverty rates is provided in the SI (figure S2).

Then, the final formulation for deriving the total necessary transfer for a country is:

$$\begin{aligned}&(\text{Total external transfer})\\ &= \text{Pop}_y \cdot r_{y,\text{povhc}} \cdot \left(d_y - \mu_{X_y} \cdot \left(1 - \frac{G_{y,\text{ lb}}}{G_0}\right)\right),\end{aligned} \tag{3}$$

where Pop_y is the total population in year y. Note that in this calculation regarding the need for international transfers to eradicate poverty in a certain year, we assume that the monetary transfer in year $y+1$

[10] The aim of the UNSDGs is the full implementation of the agenda by 2030. We acknowledge, however, that the actual achievement of individual goals is likely to come later than 2030, so when we mention 'to achieve SDGs,' we mean the achievement of the goals by any point in time, not necessarily by 2030.

[11] Poverty headcount ratio at national poverty lines (% of population) is taken from the World Bank data page. Without knowing the base income distribution for each country, projecting the poverty headcount ratio to the future is not straightforward. Hence, we here adopt the stylized linear phase-out of poverty. For a small number of countries with missing ratio information, we assume a ratio of 30% in the base year, which is around the mean of the ratios for non-HIC countries. (More details in SI)

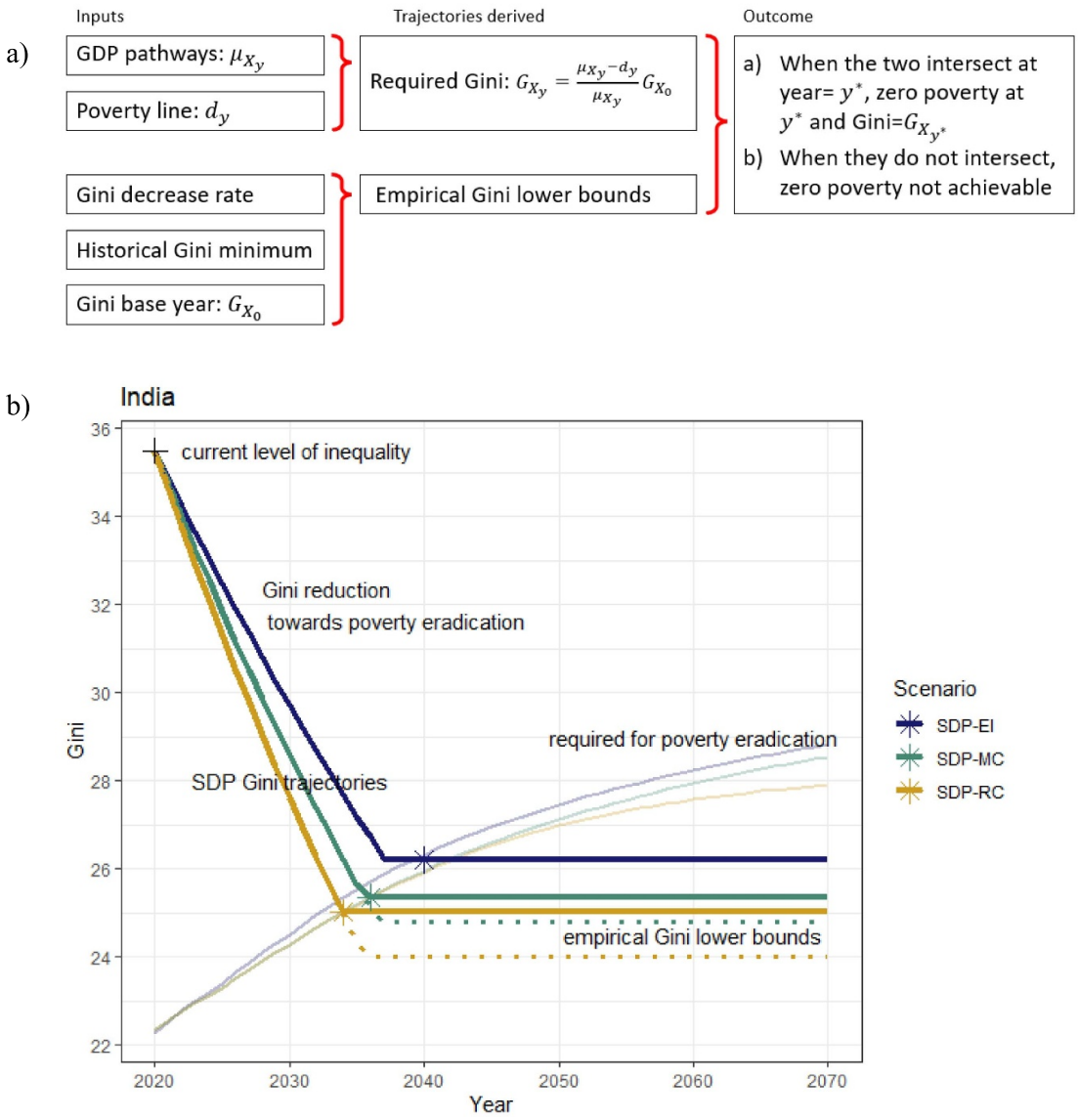

Figure 2. How a Gini trajectory is derived: (a) Schematic of the derivation process; (b) illustration of the derived Gini curves for India. Asterisks represent the points at which each scenario achieves poverty eradication.

is not impacted by any potential previous international transfers in year y or earlier. Such knock-on effects would depend on how the transfer is used to maintain the flow of national income through, for example, investment in social and physical infrastructure, which could in turn increase growth rates. We therefore expect cumulative transfer estimates to be at the higher end of the range, as our annual estimates do not account for potentially positive persistent effects. We note that this paper only discusses the global need for international transfers and does not discuss who should supply the funds. This discussion will be a necessary next step in poverty research and can also be meaningfully linked to existing mitigation burden-sharing discussions (Höhne *et al* 2014, Robiou du Pont *et al* 2017, Leimbach and Giannousakis 2019, Pachauri *et al* 2022).

3. Result and discussion

3.1. GDP pathways

We show the resulting GDP/capita pathways in figure 3, comparing the three new SDP scenarios to the original SSP1 GDP pathway and to the SSP2 scenario, where historical patterns of economic growth are assumed to continue. The SDP scenarios for high-income countries (e.g. Canada, Germany, Japan, USA (figure 3)) are designed to span the range between a continued high-growth pathway in SDP-EI and a stabilization of GDP/capita close to current levels in SDP-RC (figure 3). On the other hand, for countries starting at low income levels (e.g. India, Indonesia, Nigeria) all SDP scenarios feature initially faster economic growth than SSP2. In SDP-EI and to a lesser extent in SDP-MC, this rapid economic

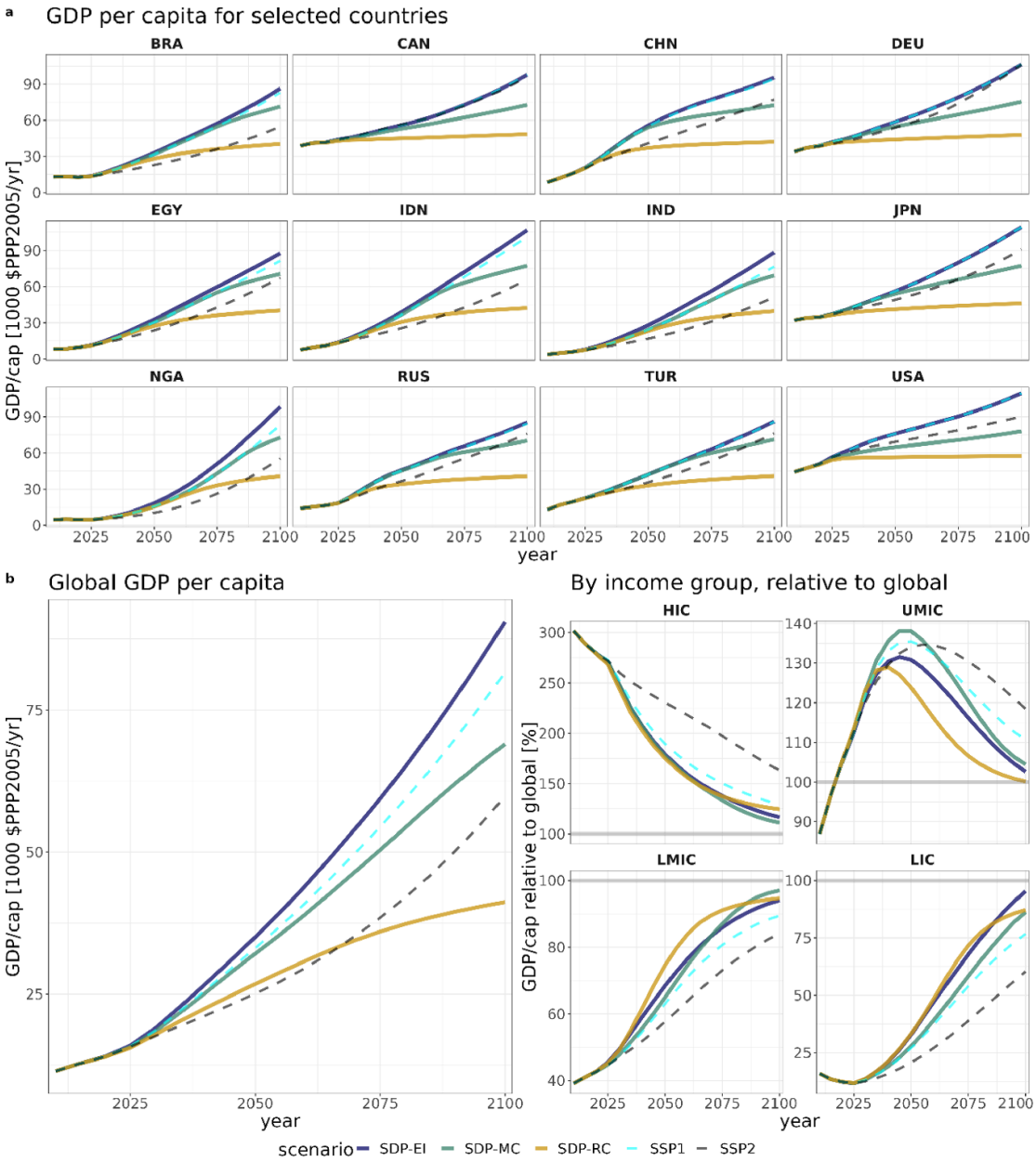

Figure 3. GDP/capita pathways for the new SDPs (solid lines), compared to the SSP1 and SSP2 scenarios (dashed lines). (a) GDP/capita for twelve representative countries; (b) global GDP per capita (bottom left) and GDP/capita of current high (HIC), upper-middle (UMIC), lower middle (LMIC) and low-income (LIC) countries relative to the global average (bottom right. Income group classification is kept fixed to current 2023/2024 World Bank classification to illustrate convergence).

growth continues, leveling off at roughly the current GDP/capita of high-income countries in SDP-RC.

For global GDP/capita (figure 3(b), left panel), SDP-EI and SDP-MC are broadly comparable to SSP1 until mid-century, but subsequently deviate to reach higher (SDP-EI: around 90 000 $\$_{PPP2005}$/cap in 2100) or lower (SDP-MC: around 69 000 $\$_{PPP2005}$/cap) values by 2100. The post-growth SDP-RC scenario breaks with the SSP1 trend much earlier. It maintains a global GDP/capita above SSP2 until 2065 due to strong income growth in low- and middle-income countries. However, by the end of the century, its global GDP/capita of around 41 000 $\$_{PPP2005}$/cap is well below the SSP2 value and around half that of SSP1, reflecting that the leveling-off of economic growth is assumed eventually to take place in the current low-income countries when they reach high income levels.

Comparing the average GDP/capita of country income groups (as per the current [2023/2024] World Bank classification) to the global average (figure 3(b), right panels), we find that all SDP scenarios show faster convergence between initially low- and high-income countries than a continuation of historical trends (SSP2) and SSP1. Under the SDPs the average GDP/capita of high-income countries would be 1.11–1.25 times the global average in 2100 (down from 2.7 times in 2020), compared to 0.86–0.95 the global

average for current low-income countries (up from just 0.12 in 2020). Under these GDP/capita pathways developed for the SDP scenarios, the income disparity between current high- and low-income countries (HIC and LIC) would therefore decrease from a factor of around 23 in 2020 to a factor of 1.2–1.4 in 2100, while especially in SSP2 a substantial gap factor of 2.7 in SSP2 would remain (SSP1: 1.7). The regional developments underlying this convergence differ between the SDPs. While in SDP-EI the economies of low-income countries grow fastest and eventually catch up with the still-growing current high-income countries, in SDP-RC convergence is mainly driven by the leveling-off of GDP/capita in current high-income countries. SDP-RC also features the fastest convergence for lower-middle- and upper-middle- income countries.

3.2. Gini trajectories by country

Figure 4 shows the overall shapes of Gini pathways derived for each scenario and for individual countries, grouped into four income groups. Given the large number of countries, we select—for visualization purposes—seven countries with the largest populations in each income group. Because of the assumptions in table 2, the SDP-EI pathway follows the slowest downward slope, and SDP-RC the steepest, until they hit the scenario-specific minimum Gini values.

Countries generally fall into four typical patterns, which can be found in figure 4(a).

I. Pattern #1: A country hits the Gini minimum before it achieves the no-poverty target, but then later in time with proper economic growth, it can achieve the target at that minimum Gini level.
II. Pattern #2: A country achieves the target in the middle of the downward slope (>minimum Gini), and then continues to come down to the inequality target (=30). (see 2.3.1)
III. Pattern #3: The target is achieved at a Gini between 30 and the minimum, where from then on it stops decreasing
IV. Pattern #4: A country cannot achieve the target within the given time horizon even at the minimum Gini level (i.e. no asterisk marked in figure 4(a))

When making comparisons among scenarios, we see that the poverty target will be met earlier in SDP-RC or SDP-MC than in SDP-EI (figure 4(b)), mainly thanks to faster Gini decreases being allowed for in the first two scenarios. We find the existing Gini projections for the SSPs (without considering the impact of climate change; dotted curves in figure 4(a)) mainly stay higher than the normative Gini pathways. When the climate impact on inequality is also taken into account, the Gini can likely go up further depending on national contexts (Dasgupta *et al* 2023). This suggests that the projected pace of inequality reduction in the SSPs will fall well short of poverty eradication under the given SSP growth rates.

It is important to note that, by focusing on one year in the time horizon, we can identify which countries do not achieve zero poverty by then, even ones with ambitious Gini improvements (hereafter referred to as 'countries with remaining poverty gaps'). Figure 4 shows that many high-income countries (such as France and Japan) do not achieve the zero-poverty goal even by 2100; this is because, given their relatively high poverty lines (around $16 and $18 for France and Japan respectively in 2020) combined with low Gini at the base year, there is little 'wiggle room' for Gini improvements under the assumed redistribution scheme. However, given the high wealth concentration observed in the top income population in high income countries (HICs; Alvaredo *et al* 2013), we assume that these countries have abundant domestic resources for poverty eradication (Bolch *et al* 2022), such that more targeted redistribution (i.e. 'top-to-bottom') can achieve poverty eradication with smaller Gini changes, as shown in Min and Rao (2023). We do not, however, consider this case in the design of this pathway, as it is a much more specific assumption on redistribution, which is also historically unobserved. For this reason, we keep the HICs outside the scope of poverty eradication in this study.

Other non-HICs with remaining poverty gaps by 2030 are listed below (table 3), and similar tables for 2030 and 2100 are in the SI. All LICs can achieve the target as late as 2100, as their poverty lines are also very low, while the GDP growth rates are set high enough (see section 3.1). In 2030 there are clearly many more countries with remaining poverty gaps than in later years. The main reasons for failing to meet the targets are a mixture of: (a) a mean income being too close to the poverty line, so that these countries would need to be extremely equal to bring everyone above the poverty line; or (b) the base year Gini already being close to the historical minimum, so in this case countries needing to rely mainly on the growth lever for poverty eradication (see examples, figure S4).

3.3. International transfers for closing remaining poverty gaps in the SDPs

Even strong national growth rates and within-country inequality reductions are not sufficient for all countries to meet their poverty eradication target in the near term. Figure 5 shows the yearly estimates for the additional external transfer required to close remaining poverty gaps (based on section 2.3.2) for each of the SDP scenarios. In the base year 2020, reflecting the current national income distributions, international transfers of the order of $\$_{PPP2011}$ 2300 billion per year would be required to

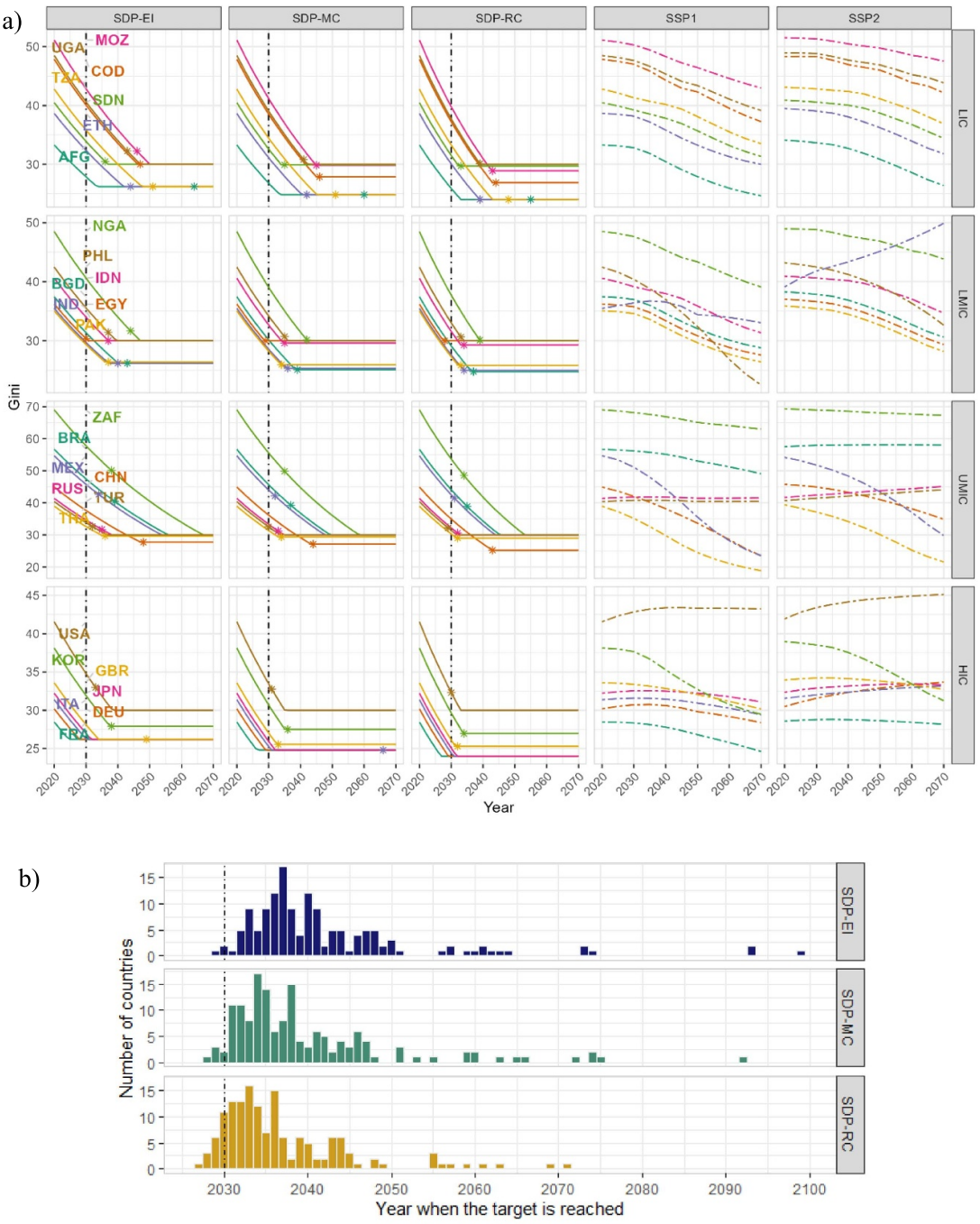

Figure 4. (a) Gini pathways for selected countries. The dotted curves in SSP1/SSP2 panels show the pathways for SSPs based on historical relationships (Rao *et al* 2019). Asterisks mark the points at which each country achieves the zero-poverty goal, as described in figure 2. The vertical line at 2030 is to point out the SDG timeline. (b) Distribution of years when the target is reached. SDP-EI shows later achievement, while SDP-RC is earlier.

meet the poverty eradication target. Yearly estimates for the required external transfer decrease quickly over time for all scenarios, thanks to both rapid GDP/capita growth especially in low- and middle-income countries and reductions in inequality in the SDPs. In 2030 they range between around $370 billion (SDP-RC, 0.24% of total global GDP) and $760 billion (SDP-EI, 0.47% of total global GDP), illustrating how fast the external financial needs decrease along the GDP and Gini pathways of the SDPs.

Table 3 provides a list of countries which do not eradicate poverty by 2030, as well as a breakdown of the global transfer requirements into country income groups. The number of countries not meeting the target by 2030, and therefore the need for international monetary transfers is highest in SDP-EI. This further illustrates that poverty phases out more slowly in SDP-EI due to the slower reduction in inequality (see assumptions in table 2), despite its faster economic growth in low-income countries. The

Table 3. Countries with a remaining poverty gap and international transfer requirements to fill the gap in 2030, by income group. The corresponding results for 2050 are in supplementary table S3. The monetary unit is $\$_{PPP2011}$. The numbers at the end of the country list indicate the total number of countries in the cell.

Scenario	Income group	Countries with remaining poverty gaps by 2030	Annual transfer ($ bil.)	Scenario total ($ bil.)
SDP-EI	LIC	Afghanistan; Burkina Faso; Burundi; Central African Republic; Chad; Congo, Dem. Rep.; Ethiopia; Gambia, The; Guinea; Guinea-Bissau; Liberia; Madagascar; Malawi; Mali; Mozambique; Niger; Rwanda; Sierra Leone; Sudan; Tajikistan; Tanzania; Togo; Uganda (23)	133	762
	LMIC	Algeria; Angola; Bangladesh; Benin; Bhutan; Bolivia; Cabo Verde; Cambodia; Cameroon; Comoros; Congo, Rep.; Cote d'Ivoire; El Salvador; Eswatini; Ghana; Haiti; Honduras; India; Indonesia; Iran, Islamic Rep.; Jordan; Kenya; Kiribati; Kyrgyzstan; Lao PDR; Lesotho; Mauritania; Micronesia, Fed. Sts.; Mongolia; Morocco; Myanmar; Nepal; Nicaragua; Nigeria; Pakistan; Papua New Guinea; Philippines; Samoa; Sao Tome and Principe; Senegal; Solomon Islands; Sri Lanka; Timor-Leste; Tunisia; Ukraine; Uzbekistan; Vanuatu; West Bank and Gaza; Zambia; Zimbabwe (49)	430	
	UMIC	Albania; Argentina; Armenia; Belarus; Belize; Bosnia and Herzegovina; Botswana; Brazil; Bulgaria; China; Colombia; Costa Rica; Dominica; Dominican Republic; Ecuador; Equatorial Guinea; Fiji; Gabon; Georgia; Grenada; Guatemala; Guyana; Iraq; Jamaica; Kazakhstan; Libya; Malaysia; Maldives; Marshall Islands; Mauritius; Mexico; Moldova; Montenegro; Namibia; North Macedonia; Paraguay; Peru; Russian Federation; Serbia; South Africa; St. Lucia; St. Vincent and the Grenadines; Suriname; Thailand; Tonga; Türkiye; Turkmenistan; Tuvalu (48)	199	
SDP-MC	LIC	Same as SDP-EI (23)	115	526
	LMIC	Same as SDP-EI (49)	279	
	UMIC	Same as SDP-EI, minus Georgia and Türkiye (46)	132	
SDP-RC	LIC	Same as SDP-EI (23)	98	374
	LMIC	Same as SDP-EI, minus Tunisia (48)	184	
	UMIC	Same as SDP-EI, minus Armenia, Georgia, Maldives, Mauritius, Mexico, Moldova, Montenegro, North Macedonia, and Türkiye (38)	93	

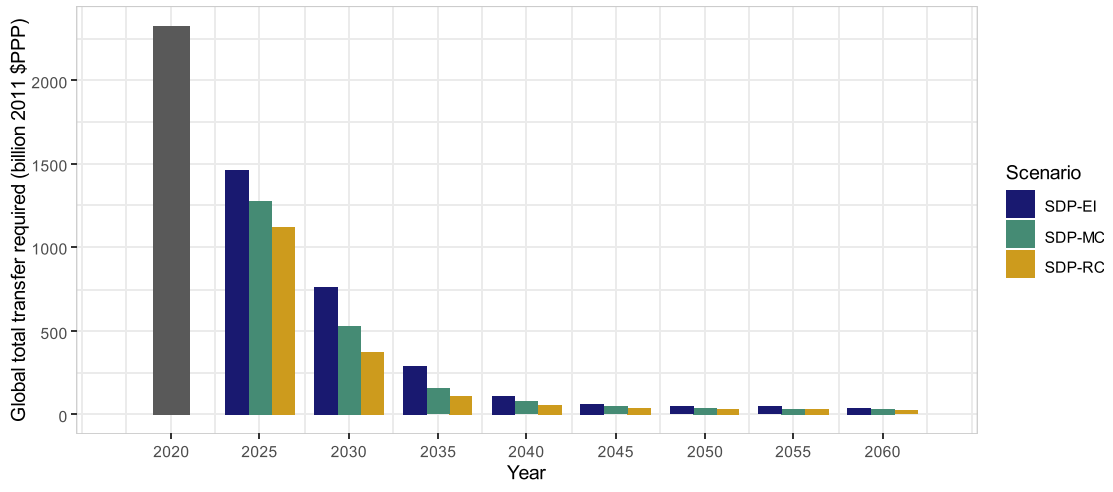

Figure 5. Total required transfer estimates each year by scenario. This assumes that the transfer in one year does not affect the national GDP the following year, as described in section 2.3.2. The base value for 2020 is common for all scenarios.

remaining poverty gap is smallest for SDP-RC, which allows for the strongest domestic inequality reductions, followed by SDP-MC. Beyond 2030, continued economic growth and inequality reductions further decrease the need for international transfers, with a range between $33 billion (SDP-RC) and $50 billion (SDP-EI) for closing the remaining poverty gap in 2050 (table S3).

These numbers allow the cost of poverty eradication to be compared to other contemporary international development funding. Total official development assistance by the Development Assistance Committee countries in 2022 was $204 billion (OECD 2023), which falls short of the committed aid target of 0.7% of the GNI (CONCORD 2023). The Sharm-El-Sheikh Adaptation Agenda estimates that, in total, $140 to $300 billion for developing countries will be required by 2030 for financing climate adaptation and resilience alone (UNFCCC 2022), while developed countries failed to meet a $100 billion/year climate fund target for multiple subsequent years (Timperley 2021). Crucially, if countries fail to reduce domestic inequality, future international transfers for poverty eradication will be much higher than have been shown here.

We note that our estimates shown above assume unconditional cash transfers to households. Non-cash aid will also be passed through households, ultimately contributing to poverty eradication. However, we cannot easily quantify the necessary cash transfer size based on such non-cash aid schemes, as their effectiveness in income poverty eradication is greatly heterogeneous depending on the nature of funding projects or beneficiaries (Sachs *et al* 2001, Juselius *et al* 2014, Rose and Glassman 2018).

4. Conclusion

In this paper we present GDP and Gini pathways that pursue poverty eradication around the world as a useful basis for target-seeking scenario design. These economic pathways underpin the SDPs discussed in other publications of this special issue and will be a useful contribution to further scenario modeling efforts. The resulting set of Gini and GDP pathways illustrates a range of challenges faced by countries in different economic situations. The narratives of SDP-MC and SDP-RC, with a higher emphasis on equality, enable earlier achievements of poverty targets than the growth-oriented SDP-EI and highlight the importance of reducing inequality for poverty eradication.

We find 16–24 countries cannot eradicate poverty through domestic redistribution by 2050 even along the SDP's GDP and Gini pathways; this stresses the need for international contributions. The amount of cross-country financial transfers necessary to achieve global zero poverty is substantial, and much higher in the absence of domestic inequality reduction. SDP-EI has the largest global transfer requirements, due to its slower achievement of targets. We also confirm previous findings that the conventional SSP variants do not meet poverty targets without additional inequality reduction and large international transfers.

We acknowledge that not all the repercussions of recent and current crises, most notably the COVID-19 pandemic and the Russia–Ukraine war, are fully captured in our scenarios. While construction of the GDP scenarios takes recent historical data and near-term outlooks into account (Koch and Leimbach 2023), inequality data are more challenging to work with due to their infrequent and patchy availability for recent historical years. We therefore take 2020 as a base year, for which, at the time of writing, historical inequality data for most countries are available. Consequently, our scenarios might underestimate the challenge for countries that have seen substantial increases in inequality in the past few years. This, however, only reinforces our point that rapid and sustained reductions in inequality are needed to meet the poverty eradication target. Furthermore, our methodology straightforwardly allows for updates to the target-seeking inequality scenarios from a new historical starting point. The pathways presented are not the only imaginable paths to achieving zero poverty but they can serve as a meaningful benchmark for future scenario designs.

Our methodology does not assume a specific shape of the distribution in the base year, which is an excellent characteristic for our no poverty target pathway design. It does, however, come with the drawback that it cannot easily estimate poverty headcounts during the transition periods. A meaningful extension would be to project the development of poverty headcounts along these scenarios using additional information on national income distributions.

Finally, while our inequality scenarios illustrate the pace of inequality reduction required to meet zero poverty, they do not assess how to best implement them in different country contexts. Implementation of such pathways, for example through adjustments to national tax, subsidy, and transfer schemes, would improve well-being for a large majority of the population. Nonetheless, implementing them can also be expected to be politically challenging, not least because of the lack of political will and the barriers raised by vested interests. Research into the enablers, barriers, and feasibility frontiers of rapid and sustained rates of inequality reduction for different country contexts is thus much needed.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files). The result pathways provided in the supplementary data is also available in a public repository (https://doi.org/10.5281/zenodo.13753583).

Acknowledgments

This work has been funded through the project SHAPE. SHAPE is part of AXIS, an ERA-NET initiated by JPI Climate, and funded by FORMAS (SE), FFG/BMWFW (AT), DLR/BMBF (DE, Grant No. 01LS1907A), NWO (NL) and RCN (NO) with co-funding by the European Union (Grant No. 776608).

ORCID iDs

Jihoon Min https://orcid.org/0000-0002-0020-1174
Bjoern Soergel https://orcid.org/0000-0002-2630-7081
Jarmo S Kikstra https://orcid.org/0000-0001-9405-1228
Johannes Koch https://orcid.org/0000-0003-2920-8086
Bas van Ruijven https://orcid.org/0000-0003-1232-5892

References

Alkire S and Santos M E 2010 *Acute Multidimensional Poverty a New Index for Developing Countries* (University of Oxford, Poverty and Human Development Initiative)
Alvaredo F, Atkinson A B, Piketty T and Saez E 2013 The top 1% in international and historical perspective *J. Econ. Perspect.* **27** 3–20
Amini C and Dal Bianco S 2016 Poverty elasticity to growth and inequality: new evidence from macro data *J. Dev. Areas* **50** 231–54
Arndt H W 1983 The "Trickle-down" Myth *Econ. Dev. Cult. Change* **32** 1–10
Bergstrom K 2020 The role of inequality for poverty reduction *Working Paper* (World Bank (https://doi.org/10.1596/1813-9450-9409)
Bolch K B, Ceriani L and López-Calva L F 2022 The arithmetics and politics of domestic resource mobilization for poverty eradication *World Dev.* **149** 105691
Bourguignon F 2004 The poverty-growth-inequality triangle *Indian Council for Research on International Economic Relations, New Delhi Working Papers* (*New Delhi, India*) (available at: https://EconPapers.repec.org/RePEc:ind:icrier:125)
CONCORD 2023 Bursting the ODA inflation bubble—AidWatch 2023 (available at: https://aidwatch.concordeurope.org/2023-report/)
Crespo Cuaresma J, Fengler W, Kharas H, Bekhtiar K, Brottrager M and Hofer M 2018 Will the sustainable development goals be fulfilled? Assessing present and future global poverty *Palgrave Commun.* **4** 1–8
Dasgupta S, Emmerling J and Shayegh S 2023 Inequality and growth impacts of climate change—insights from South Africa *Environ. Res. Lett.* **18** 124005
Dellink R, Chateau J, Lanzi E and Magné B 2017 Long-term economic growth projections in the shared socioeconomic pathways *Glob. Environ. Change* **42** 200–14
Ferreira F H G and Leite P G 2003 *Policy Options for Meeting the Millennium Development Goals in Brazil: Can Micro-Simulations Help?* (World Bank) (https://doi.org/10.1596/1813-9450-2975)
Ferreira F H G and Ravallion M 2008 Global poverty and inequality: a review of the evidence *SSRN Scholarly Paper No. ID 1149126* (Social Science Research Network)
Hickel J, Brockway P, Kallis G, Keyßer L, Lenzen M, Slameršak A, Steinberger J and Ürge-Vorsatz D 2021 Urgent need for post-growth climate mitigation scenarios *Nat. Energy* **6** 766–8
Höhne N, den Elzen M and Escalante D 2014 Regional GHG reduction targets based on effort sharing: a comparison of studies *Clim. Policy* **14** 122–47
Jolliffe D and Prydz E B 2016 Estimating international poverty lines from comparable national thresholds *J. Econ. Inequal* **14** 185–98
Jolliffe D and Prydz E B 2021 Societal poverty: a relative and relevant measure *World Bank Econ. Rev.* **35** 180–206
Juselius K, Møller N F and Tarp F 2014 The long-run impact of foreign aid in 36 african countries: insights from multivariate time series analysis* *Oxford Bull. Econ. Stat.* **76** 153–84
Kakwani N 1993 Poverty and economic growth with application to Côte D'ivoire *Rev. Income Wealth* **39** 121–39
Kikstra J *et al* n.d. (in preparation) Closing decent living gaps in energy and emissions scenarios: introducing DESIRE (https://doi.org/10.13140/RG.2.2.27951.14241)
Koch J and Leimbach M 2023 SSP economic growth projections: major changes of key drivers in integrated assessment modelling *Ecol. Econ.* **206** 107751
Kriegler E, Daioglou V, van Vuuren D, Keppler D, Weindl I, Popp A, Mastrucci A, Dombrowsky I, Soergel B and van Ruijven B this issue New narratives for sustainable development pathways preparation
Lakner C, Mahler D G, Negre M and Prydz E B 2022 How much does reducing inequality matter for global poverty? *J. Econ. Inequal* **20** 559–85
Leimbach M and Giannousakis A 2019 Burden sharing of climate change mitigation: global and regional challenges under shared socio-economic pathways *Clim. Change* **155** 273–91
Lutz W, Stilianakis N, Stonawski M, Goujon A and Samir K 2018 *Demographic and Human Capital Scenarios for the 21st Century—2018 Assessment for 201 Countries* (Publications Office) (https://doi.org/10.2760/835878)
Min J and Rao N D 2023 Growth and inequality trade-offs to eradicate absolute poverty *Heliyon* **9** e21441
Narayan K B, O'Neill B C, Waldhoff S T and Tebaldi C 2023 Non-parametric projections of national income distribution consistent with the Shared Socioeconomic Pathways *Environ. Res. Lett.* **18** 044013
Nature 2023 A decades-long decline in extreme poverty has gone into reverse—here's how to fix things *Nature* **618** 886
O'Neill B C *et al* 2017 The roads ahead: narratives for shared socioeconomic pathways describing world futures in the 21st century *Glob. Environ. Change* **42** 169–80
OECD 2023 Official development assistance (ODA) (available at: www.oecd.org/dac/financing-sustainable-development/development-finance-standards/official-development-assistance.htm) (Accessed 10 October 2023)
Otero I *et al* 2020 Biodiversity policy beyond economic growth *Conserv. Lett.* **13** e12713
Pachauri S, Pelz S, Bertram C, Kreibiehl S, Rao N D, Sokona Y and Riahi K 2022 Fairness considerations in global mitigation investments *Science* **378** 1057–9

Rao N D and Min J 2017 Decent living standards: material prerequisites for human wellbeing *Soc. Indic. Res.* **138** 225–44

Rao N D, Sauer P, Gidden M and Riahi K 2019 Income inequality projections for the shared socioeconomic pathways (SSPs) *Futures* **105** 27–39

Rao N D, van Ruijven B J, Riahi K and Bosetti V 2017 Improving poverty and inequality modelling in climate research *Nat. Clim. Change* **7** 857–62

Ravallion M 1997 Can high-inequality developing countries escape absolute poverty? *Econ. Lett.* **56** 51–57

Ravallion M 2001 Growth, inequality and poverty: looking beyond averages *World Dev.* **29** 1803–15

Ravallion M 2013 How long will it take to lift one billion people out of poverty? *World Bank Res. Obs.* **28** 139–58

Ravallion M and Chen S 2003 Measuring pro-poor growth *Econ. Lett.* **78** 93–99

Ravallion M and Chen S 2013 A proposal for truly global poverty measures *Glob. Policy* **4** 258–65

Riahi K *et al* 2017 The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: an overview *Glob. Environ. Change* **42** 153–68

Robiou du Pont Y, Jeffery M L, Gütschow J, Rogelj J, Christoff P and Meinshausen M 2017 Equitable mitigation to achieve the Paris Agreement goals *Nat. Clim. Change* **7** 38–43

Rose S and Glassman A 2018 *Committing to Cost-Effectiveness: USAID's New Effort to Benchmark for Greater Impact* (Center for Global Development) CGD Notes

Sachs J, Mellinger A and Gallup J 2001 The geography of poverty and wealth *Sci. Am.* **284** 70–75

Škare M and Družeta R P 2016 Poverty and economic growth: a review *Technol. Econ. Dev. Econ.* **22** 156–75

Soergel B *et al* 2021b A sustainable development pathway for climate action within the UN 2030 agenda *Nat. Clim. Change* **11** 656–64

Soergel B, Kriegler E, Bodirsky B L, Bauer N, Leimbach M and Popp A 2021a Combining ambitious climate policies with efforts to eradicate poverty *Nat. Commun.* **12** 2342

Soergel B *et al* n.d. (in preparation) Multiple pathways towards sustainable development goals and climate targets: a multi-scenario and multi-model analysis

Timperley J 2021 The broken $100-billion promise of climate finance—and how to fix it *Nature* **598** 400–2

UNFCCC 2022 COP27 presidency launches adaptation agenda to build climate resilience for 4 billion by 2030 (Climate Champions) (available at: https://climatechampions.unfccc.int/cop27-presidency-announces-ambitous-climate-resilience-agenda/) (Accessed 27 November 2023)

United Nations n.d. Reduce inequality within and among countries (United Nations Sustainable Development) (available at: www.un.org/sustainabledevelopment/inequality/) (Accessed 20 December 2023)

World Bank 2022 Fact sheet: an adjustment to global poverty lines (available at: www.worldbank.org/en/news/factsheet/2022/05/02/fact-sheet-an-adjustment-to-global-poverty-lines) (Accessed 11 June 2024)

World Bank n.d. PovcalNet: an online analysis tool for global poverty monitoring (available at: http://iresearch.worldbank.org/PovcalNet/) (Accessed 2 December 2019)