

Global trade-offs between consumption, carbon prices and equity

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As the remaining carbon budget continues to dwindle, economic growth strains efforts to limit global warming to 1.5 °C. Reducing unnecessary production and consumption in high-income regions and among the wealthy, and organising production more around human needs and human well-being, may alleviate pressures on technology-driven decarbonisation strategies. We employ a modified integrated assessment model to explore the interaction between converging per-capita consumption, climate policy stringency and equity. Our pathways demonstrate that lower-consumption futures are associated with substantially lower warming, 0.3–1.1 °C across different carbon price trajectories, relative to high-consumption futures. Comparatively, global convergence of incomes between regions has a small influence on global temperature outcomes ($<\pm 0.1$ °C). These findings indicate that reducing high per-capita consumption in high-income regions is a primary lever for achieving futures with equitable and decent living standards while meeting global climate targets. While such transformations may face political challenges, our scenarios suggest that unconstrained growth futures make it considerably harder to remain within safe climate limits.

Keeping global surface temperatures below 1.5 °C is becoming increasingly difficult as remaining carbon budgets vanish^{1,2}. Emission pressures from economic growth have globally tended to outpace efficiency improvements and technological change, making rapid and deep emissions reductions difficult to achieve^{3–6}. Relying on technological innovation as the predominant lever for climate mitigation raises concerns, with demand reduction being a complementary strategy that may improve energy security⁷ and feasibility^{8–11}. Post-growth and degrowth have emerged as conceptual frameworks questioning the necessity of continued economic expansion for achieving high levels of human well-being. Post-growth refers broadly to socioeconomic pathways in which well-being is decoupled from continued GDP growth, while degrowth denotes a more specific transformational

perspective that goes beyond the current capitalist system and is centered on deliberate and egalitarian reductions in material production and consumption, particularly in high-income contexts, with strong principles rooted in international justice. These approaches envisage scaling down harmful production, expanding public provisioning systems, and focusing economic activity on well-being^{12–14}. Importantly, a globally effective post-/degrowth transition relies on international equity and justice for garnering sufficiently widespread acceptance and support¹⁵.

This approach, however, has only started to be incorporated in mainstream modelling frameworks^{13,16,17} that underpin climate mitigation scenarios typically reviewed by the Intergovernmental Panel on Climate Change (IPCC). Recent syntheses of degrowth and

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post-growth modelling studies^{18,19} show that a rapidly growing number 12 out of 75 – employ Integrated Assessment Models (IAMs) that link key societal and economic processes with conditions of the biosphere and atmosphere. Most of these IAM-based studies rely on newly developed frameworks¹⁹, such as International Futures²⁰, WoLim²¹, MEDEAS-Europe/World^{22,23}, and stock-flow-consistent IAMs^{24,25}, which relax the growth-dependent structure embedded in traditional IAMs. However, these models are generally limited in terms of the detailed, process-based representation of energy systems, land use, and multi-gas emissions that characterise the IAMs used in IPCC assessments. Only a few studies^{17,26,27} apply a process-based IAM that generates detailed and disaggregated projections across key greenhouse gases and other climatically relevant species (e.g., CO₂, CH₄, N₂O, and SO₂) and land-use change – an essential feature of the IAMs used by the IPCC to assess mitigation scenarios. Moreover, global analyses examining how alternative consumption levels, international income convergence and climate policy jointly affect climate and development outcomes remain limited. Previous IAM-based studies have typically focused either on demand reduction in energy services (for example, the Low Energy Demand scenario⁹) or on alternative macroeconomic trajectories, without systematically examining the interaction between global consumption levels, equity and climate policy. Kallis et al. (2025)²⁸ highlight the absence of global post-growth or degrowth scenarios within established IAM frameworks as an important research gap for future climate assessments.

One common element of post-growth and degrowth perspectives is the pursuit of improved equity, intra- as well as inter-nationally^{29,30}. Recent empirical work further shows that carbon footprints are highly unequal both internationally and within countries, and vary not only with income but also with household composition, urban form, and consumption patterns^{31–34}. Despite the importance of climate-equality-postgrowth interlinkages, equity considerations have been under-explored in climate mitigation analyses^{9,29,35}. Related work by Oswald and Millward-Hopkins³⁶ explores the emissions implications of global income convergence using a reduced complexity model that applies empirically derived, declining carbon-intensity rates. Very recent work from Chancel et al.³⁷ uses a multi-regional input-output framework coupled with a climate model and covering multiple greenhouse gases, identifying that convergence to €60,000 per capita (2025 PPP) is compatible with the 2 °C target only under deep structural transformation, including sectoral reallocation, working-time reductions and food-system changes. To date, however, limited post-growth modelling work has been undertaken using process-based integrated assessment models that quantify transitions that explicitly incorporate equity considerations at the level of detail required for climate change analysis, with a consistent description of not only energy and industrial systems but also land use change, covering all climatically relevant species.

Van Eynde et al. (2026)³⁸ surveyed modellers to identify what model elements are required to be able to analyse post-growth futures, while Slameršak et al. (2026)³⁹ synthesise the literature to distil a set of principles that scenarios reflecting a post-growth future should incorporate. These include well-being, sufficiency, reduced inequality, economic restructuring, and global convergence³⁹. Such frameworks highlight that post-growth pathways extend beyond reduced Gross Domestic Product (GDP) or consumption, and involve socio-institutional transformations that are largely unrepresented in current IAMs.

In this work, our aim is to use the process-based MESSAGEix-GLOBIOM⁴⁰ IAM to explore a set of global scenarios focusing on a subset of these dimensions – consumption, equity, and convergence – and to further couple them with varying climate policy stringency. Particularly, our modelling framework spans futures from growth-oriented pathways through to pathways that radically reduce the size of the economy, particularly in the Global North. Importantly,

we do not model socio-political transition dynamics, institutional change, or provisioning-system transformations. Rather, we systematically examine ‘what-if’ futures within a process-based IAM, comparing prevailing growth-based with convergence-based pathways, while maintaining methodological continuity with established climate assessment practices. Our contribution lies particularly in bridging post-growth research with a process-based IAM framework commonly used in IPCC assessments, enabling systematic comparison of consumption and equity dynamics within a detailed representation of energy, land, and emissions systems. We explore a set of global scenarios with economy-wide detail to examine radical convergence between regions and to describe the interaction of such radical convergence with climate action and outcomes, while also analysing within-region inequality, all while maintaining the capability to report emissions at the high granularity required for climate models. Under the assumptions explored here, we show that high consumption in high-income economies (referring to North America, Western Europe, and Pacific Organisation for Economic Co-operation and Development (OECD), following the MESSAGE-GLOBIOM regional aggregation⁴⁰) strongly influences warming outcomes, whereas international income convergence has only a small influence on temperature but plays an important role in determining whether low-consumption futures avoid energy poverty in parts of the Global South. These findings highlight the joint constraints between climate mitigation, global consumption and equitable development.

Results

Modelling consumption, carbon price and equity futures

Using the MESSAGEix IAM⁴⁰, we explore a set of $4 \times 3 \times 3 = 36$ different future scenarios that span alternative assumptions about consumption levels, global income distribution, and climate policy. The scenarios vary along three dimensions: i) the global economy experiences (4) various increases or decreases of average per-capita income; ii) global consumption inequality either follows a Shared Socioeconomic Pathways 2 (SSP2) trajectory, markedly improves beyond SSP2, or is eliminated entirely; iii) a global carbon price is either zero, follows trajectories consistent with IPCC Sixth Assessment Report (AR6) C4⁴¹ scenarios (limit global warming to 2 °C above pre-industrial levels by 2100 with at least a 50% probability), or trajectories consistent with and C6⁴¹ scenarios (limit global warming to 3 °C above pre-industrial levels by 2100 with at least a 50% probability) (Supplementary Fig. 1).

Long-term affluence is represented by four alternative global average per-capita consumption levels in 2100: $\bar{c} = \{5, 10, 20, 50\}$ 2005 US\$ k cap⁻¹ (thousand US dollars per capita in 2005 prices). These values span a wide range of possible future consumption levels discussed in the literature, from low-consumption (5–10 2005 US\$ k cap⁻¹) to growth-oriented futures approximating the global consumption level projected under SSP2⁴² (50k). For reference, the current global average consumption level is approximately 7 2005 US\$ k cap⁻¹ in 2020⁴². Equity is represented by three global interregional Gini indices $\gamma = \{0.5, 0.25, 0\}$ of consumption, representing current, improved and perfect global equality, respectively. Notably, 0.5 and 0.25 correspond to the 2020 and 2100 interregional Gini indices across the 11 MESSAGEix regions under SSP2⁴³.

Combining these dimensions yields five distinct future archetypes along the affluence-equity axes (Fig. 1a). Two archetypes represent two extreme futures: low consumption with strong international convergence (Archetype I) and high consumption with persistent inequality (Archetype IV). Three intermediate archetypes combine elements of these extremes: high consumption with convergence (Archetype II), low consumption with persistent inequality (Archetype III), and an intermediate pathway broadly consistent with SSP2⁴³ (Archetype V). These archetypes provide a schematic representation of the scenario space explored in the model experiments: Archetype I has some elements of degrowth⁴⁴ such as significantly reduced

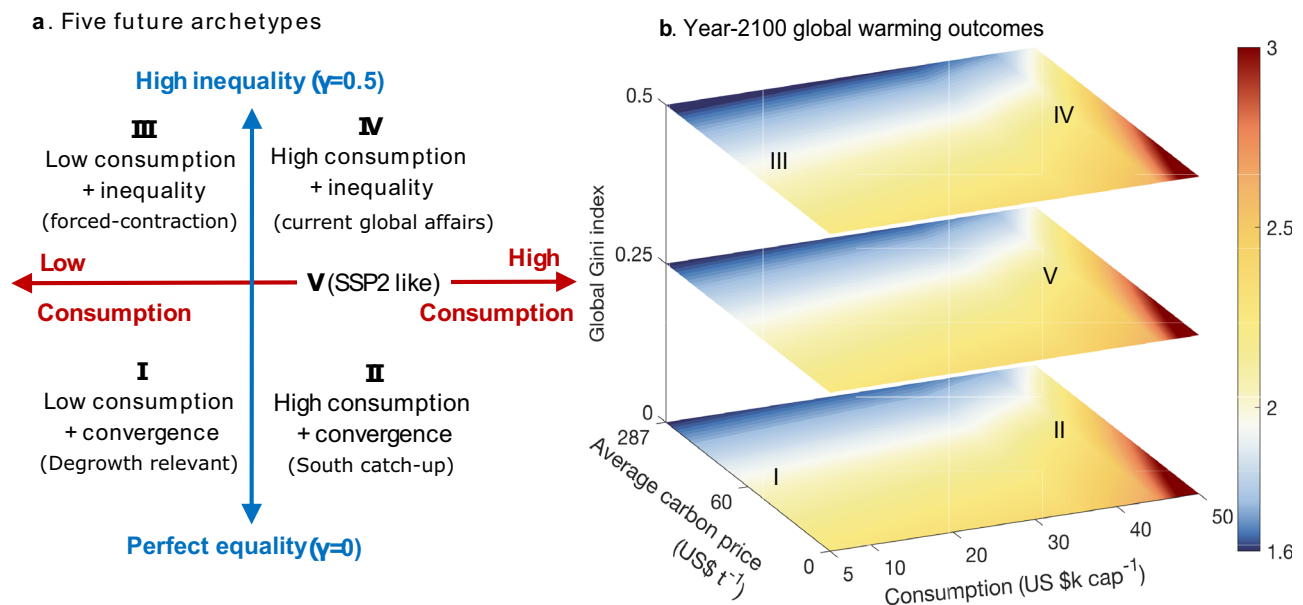


Fig. 1 | Year-2100 temperature anomalies (warming) ΔT ($^{\circ}\text{C}$) of the growth/equity futures. **a Five distinct future archetypes emerge from the 36 modelled futures, where lines represent income per capita for each region across the study years. **b** Year-2100 temperature anomaly outcomes. Values refer to a 1-in-2 chance of not being transgressed by average global temperature anomalies. Roman numerals refer to the five future archetypes (I degrowth relevant, II Global South**

catch-up, III unequal post-growth, IV current affairs, V SSP2 narrative). Carbon prices shown are the population-weighted averages for the three carbon price scenarios: 0 (no carbon price), 60 ($\text{US\$ t}^{-1}$ CO_2 ; C6-consistent carbon price, 3 $^{\circ}\text{C}$, >50%); 287 ($\text{US\$ t}^{-1}$ CO_2 ; C4-consistent carbon price, 2 $^{\circ}\text{C}$, >50%); Carbon price trajectories are in Supplementary Fig. 1. Data for Fig. 1b are in Supplementary Table 1.

consumption in high-income regions, archetype II envisions a future where a strongly growing Global South catches up with the Global North, archetype III describes a forced-contraction or collapse future, in which global GDP contracts whilst incomes remain unequal², and archetype IV reflects the current state of global affairs concerning future consumption and equity levels.

Low-consumption scenarios are not necessarily degrowth or post-growth pathways. In this study, we consider three elements that are relevant to a degrowth or post-growth future: (i) consumption declines in high-income regions, (ii) global inequality improves, and (iii) Decent-Living Energy⁴⁵ levels are accessible for all. Population and technology trajectories in the IAM follow the SSP2 middle-of-the-road shared socio-economic pathway in all our futures, whilst consumption levels follow a peaking utility function (see *Methods - IAM modifications for degrowth analysis*).

Affluence, carbon pricing, equity and warming

In a world growing to an average consumption level of $\bar{c} = 50 \text{ US\$k cap}^{-1}$ by 2100 (archetypes II, IV and V, Fig. 1a), mitigation challenges remain substantial. Even under optimistic assumptions about emission-GDP decoupling (3.7–5% during 2030–2050, historically 1.3–2.2%), rapid renewable energy deployment (2 EJ yr^{-1} – 5 EJ yr^{-1} during 2030–2050, historical rates of -2 EJ yr^{-1} over the past decade) and CO_2 removal ($0.3 \text{ GtCO}_2 \text{ yr}^{-1}$, historically $\leq 50 \text{ MtCO}_2 \text{ yr}^{-1}$), global warming reaches 2.7°C – 3.4°C (Fig. 1b, average carbon prices of 0–60 $\text{US\$ t}^{-1}$ CO_2) above pre-industrial levels. Limiting warming to around 2°C in these high-consumption futures requires a stringent carbon price rising from 95 $\text{US\$ t}^{-1}$ in 2050 to more than 800 $\text{US\$ t}^{-1}$ by 2100.

Lower global consumption levels substantially reduce warming outcomes. Under identical technology assumptions and assuming a C6-consistent (3 $^{\circ}\text{C}$, >50%) carbon pricing scheme (Supplementary Fig. 1), we find that converging to world-average consumption levels of $\bar{c} = 5 - 10 \text{ US\$k cap}^{-1}$ could limit warming to around 2°C whilst allowing for equity to be improved concurrently (Fig. 1b, centre slice). A stringent C4-consistent (2 $^{\circ}\text{C}$, >50%) carbon price further limits warming further to around 1.6°C . If no carbon price were levied

(>3 $^{\circ}\text{C}$), warming would reach 2.3°C even under degrowth to world-average consumption levels of $\bar{c} = 5 - 10 \text{ US\$k cap}^{-1}$. Note that these convergence thresholds should be understood as modelling heuristics. They should not be interpreted as necessary limits to meet a climate target. Sector-specific transformations – such as those explored by Chancel et al.³⁷ – may enable higher convergence levels while remaining within Paris-compatible budgets.

International income convergence has a generally small influence on global temperature outcomes. Under C6-consistent (3 $^{\circ}\text{C}$, >50%) carbon pricing, moving from current inequality ($\gamma \approx 0.5$) to perfect equality ($\gamma = 0$) increases warming up to 0.07°C (Supplementary Table 1). These changes arise primarily from the redistribution of consumption (Supplementary Fig. 2–3) across regions with different emissions intensities, which slightly shifts the global emissions profile (Supplementary Fig. 5–7). Greater international convergence shifts consumption from currently high-income regions such as North America (NAM) and Western Europe (WEU) towards lower-income regions, including South Asia (SAS) and Sub-Saharan Africa (AFR). In the MESSAGEix framework, energy intensity and technological change follow the default SSP2 assumptions. Rapidly growing regions initially exhibit higher energy intensity, reflecting slower capital turnover and delayed technology adoption, but converge over time as technology diffusion accelerates. As a result, increased consumption in emerging regions partly offsets emissions reductions in high-income economies. To isolate the effect of inequality, all scenarios share identical global income trajectories at each time step, with redistribution affecting only the regional allocation of income (see Methods). In our model, convergence primarily affects the distribution of energy demand and the ability of low-consumption pathways to avoid energy poverty, while total consumption levels dominate temperature outcomes. This result of only neutral or small additional impacts of global equality is in line with concurrent work by Oswald & Millward-Hopkins³⁶ who use a deterministic data-driven model.

To illustrate the underlying dynamics, we focus in more detail on the scenario of a low consumption world economy ($\bar{c} = 10 \text{ US\$k cap}^{-1}$) under C6-consistent (3 $^{\circ}\text{C}$, >50%) carbon prices⁴⁶, for perfect ($\gamma = 0$,

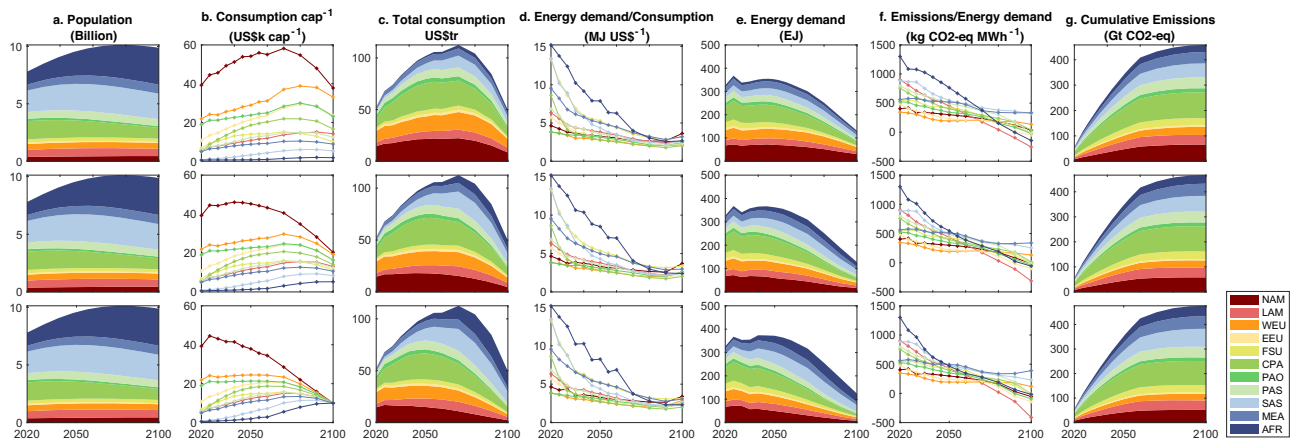


Fig. 2 | Global trajectories of socioeconomic, energy, and emissions indicators for a low-consumption world economy under different equality scenarios. **a–g** show 2020–2100 trajectories of population (**a**), consumption per capita (**b**), total consumption (**c**), useful energy intensity (**d**), useful energy (**e**), emission intensity (**f**), and cumulative emissions (**g**) for 11 MESSAGEix regions (colours in legend). Consumption is at $\bar{c} = 10\text{US\$k cap}^{-1}$ with C6-consistent (3°C , $>50\%$) carbon prices. Rows correspond to three global equality levels: unchanged (top row, gini = 0.5,

archetype III unequal post-growth), improved (centre row, gini = 0.25), and perfect (bottom row, gini = 0, archetype I degrowth relevant) global equality. Region acronyms: NAM North America, LAM Latin America & the Caribbean, WEU Western Europe, EEU Central & Eastern Europe, FSU Former Soviet Union, CPA Centrally Planned Asia & China, PAO Pacific OECD, PAS Other Pacific Asia, SAS South Asia, MEA Middle East & North Africa, AFR Sub-Saharan Africa. Data are provided in Source Data.

archetype I), improved ($\gamma = 0.25$) or unchanged ($\gamma \approx 0.5$, archetype III) global equality (Fig. 2). In the MESSAGEix IAM's SSP2 default setting^{47–49}, population (Fig. 2a) increases significantly in Sub-Saharan Africa (AFR), slightly in South Asia (SAS), stagnates or reduces in other regions except for Centrally Planned Asia (CPA, mainly China), where it strongly reduces because of low birth rates. Combined with the different income distributions assumed in our scenarios (Fig. 2b), the world's consumption (Fig. 2c) increases to about 100 US\$tr (2005 US\$) by the end of the century. However, whereas in an unequal world this economic growth is driven by North America (NAM) and Western Europe (WEU), in an equal world it is driven by South Asia (SAS) and Sub-Saharan Africa (AFR). In the MESSAGEix SSP2 baseline configuration, rapidly growing regions initially exhibit higher energy intensity due to faster demand growth and slower technology turnover. Consequently, AFR and SAS display higher energy intensity than NAM and WEU until around 2070, after which technology diffusion and investment gradually reduce these differences. As consumption shifts toward emerging regions under greater international convergence, global energy demand increasingly reflects growth in AFR and SAS rather than NAM and WEU. Similar dynamics apply to emissions intensity, which reflects the evolving energy carrier mix. Under stronger convergence, technology diffusion eventually reduces fossil-fuel shares in AFR and SAS, whereas under persistent inequality, slower structural change maintains higher fossil fuel dependence.

Overall emissions, therefore, reflect the combined effects of declining consumption in high-income regions and rising consumption in rapidly developing regions. These dynamics illustrate that the climate impact of international income convergence depends on the balance between these opposing trends and remains small relative to the influence of global consumption levels.

Equity and energy needs

We further examine how energy consumption levels change under different equity and economic growth scenarios. Grubler et al.⁹ describe a Low-Energy Demand scenario of 25 GJ cap^{-1} of final energy use (51 GJ cap^{-1} for the Global North and 19 GJ cap^{-1} for the Global South), describing the level of potentially reducible energy consumption due to rapid social and institutional changes. Millward-Hopkins et al.⁴⁵ further estimate the minimum required final energy use to provide a set of decent living standards⁴⁵. Our IAM results are

expressed in terms of useful energy, which differs from final energy by excluding loss of energy in the end-use stage, such as the heat generated in a light bulb. Converting final into useful energy using a year-2020 global ratio yields Low Useful Energy measures of 15 and 41 GJ cap^{-1} for the Global South and North, and Decent-Living Useful Energy measures of 10 and 14 GJ cap^{-1} for the Global South and the North, respectively. Most of the literature defines decent living energy at the final energy level. Here, we translate this internally in MESSAGEix to useful energy as it is more directly related to energy services and therefore provides a more stable basis for long-term comparison. This method reduces dependency on the final-to-useful (or final-to-service) conversion, which changes strongly over time, dependent on the²⁷ as processes and technologies in use change⁵⁰. Under global carbon prices, improving equity leads to the South Asia (SAS) and Sub-Saharan Africa (AFR) regions experiencing shorter periods of sub-decent living conditions in all scenarios. Under our scenarios for equitable low consumption futures characterised by significantly declining consumption in high-income regions, improved global equity, and Decent-Living energy levels⁴⁵ accessible for all - the low consumption world ($\bar{c} = 5 - 10\text{US\$k cap}^{-1}$) with perfect equality ($\gamma = 0$; Fig. 3i, j) satisfies these conditions. With Western Europe at around 50 GJ cap^{-1} for 2060, energy use in this scenario is at a similar level as a study for the UK¹⁰ concluding with a final energy consumption of about 40 GJ cap^{-1} . The Global South averages around $20\text{ GJ cap}^{-1}\text{ yr}^{-1}$, remaining above the Decent-Living threshold for the Global South⁴⁵.

Discussion

Our study contributes to the growing field exploring demand reduction and international and intranational inequality reduction. It also carries some insights for post-growth and degrowth modelling by integrating these dimensions into a process-based IAM framework. Whereas most existing IAMs in the field of post-growth modelling have been developed relatively recently, with simplified representations of energy and land systems^{18,19}, our work shows what can be learned from a simple adaptation of established IAMs such as MESSAGEix-GLOBIOM, adding energy-system-level detail to previous analyses³⁶. Contractionary and convergence-oriented pathways can be explored besides growth futures, while maintaining the detailed representation of energy systems, land use and multi-gas emissions used in IPCC assessments.

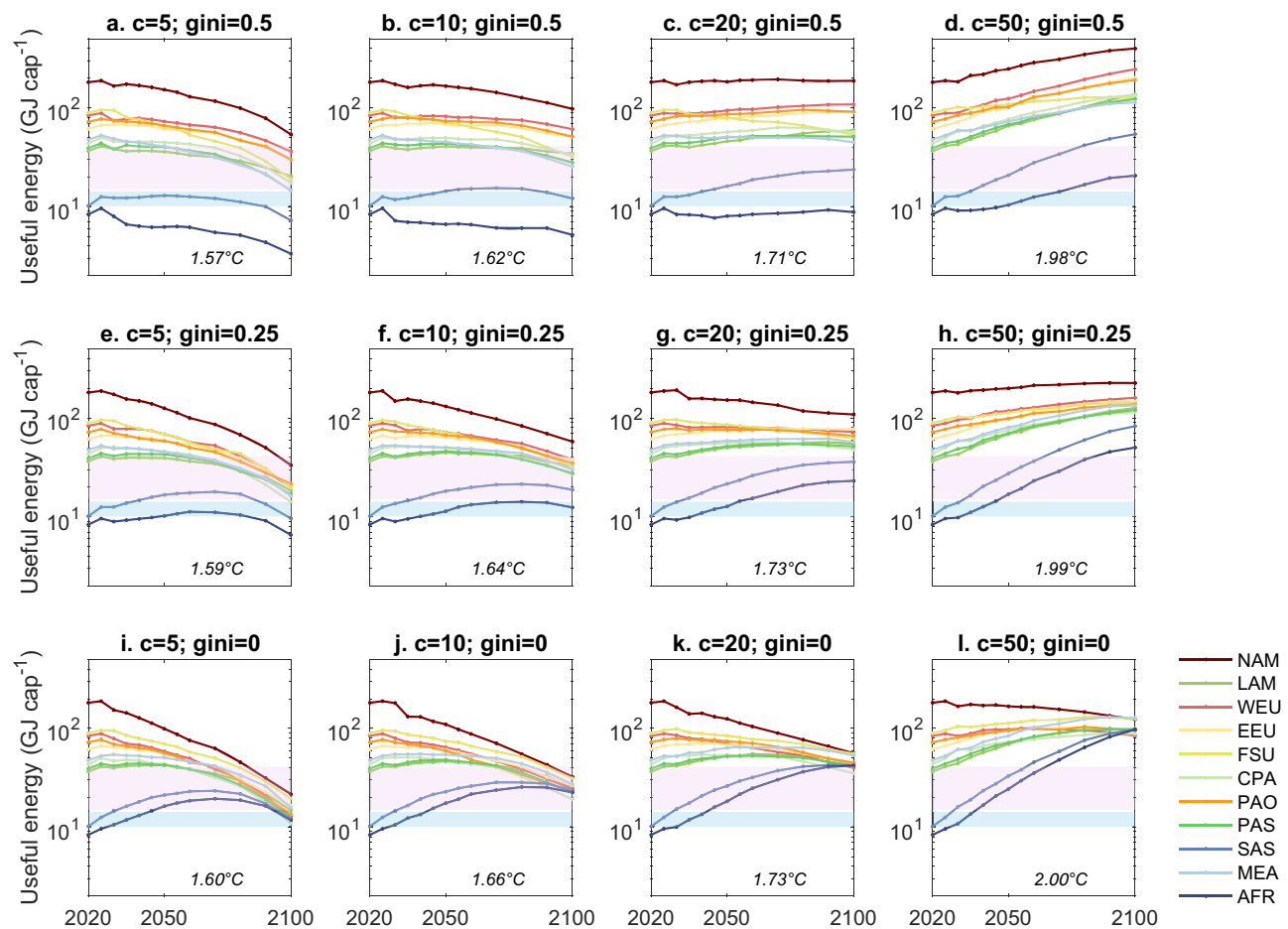


Fig. 3 | Per-capita useful energy trajectories for all combinations of average consumption levels and interregional Gini indices. a–l show 2020–2100 trajectories of useful energy per capita (GJ cap^{-1}) for the 11 MESSAGEix regions (colours in legend), across 12 combinations of global average consumption ($\bar{c} = 5, 10, 20, 50 \text{ k US\$ cap}^{-1}$) and interregional Gini index (0, 0.25, 0.5). Results are for C4-consistent (2°C , >50%) carbon prices (for no and C6-consistent (3°C , >50%) carbon price settings in Supplementary Fig. 8 & 9). Comparison is against the Low-Useful-

Energy⁹ value of $15\text{--}41 \text{ GJ cap}^{-1}$ (purple band) and the Decent-Living Useful Energy⁴⁵ range of $10\text{--}14 \text{ GJ cap}^{-1}$ (blue band). Region acronyms: NAM North America, LAM Latin America & the Caribbean, WEU Western Europe, EEU Central & Eastern Europe, FSU Former Soviet Union, CPA Centrally Planned Asia & China, PAO Pacific OECD, PAS Other Pacific Asia, SAS South Asia, MEA Middle East & North Africa, AFR Sub-Saharan Africa. Data are provided in Source Data.

Limitations

Several qualifications of our modelling framework should be noted. First, the assumptions underlying our 36 scenarios are expressed in terms of the monetary value of aggregate consumption. Critics of post-growth modelling have argued that, because of the focus of post-growth on wellbeing, societal engagement and decommodification of economic activity, monetary measures of consumption are inadequate at least for affluent societies, and that therefore the neoclassical monetary optimisation in IAMs is misdirected⁸. In this work, to partly address this critique, we have therefore removed a key element of neoclassical thinking—consumption maximisation, in which utility increases with consumption—and instead use non-monotonic, peaking utility functions that embody declining wellbeing towards higher levels of consumption (see Methods²⁶). While this allows exploration of futures in which consumption stabilises or declines in high-income regions, monetary consumption remains an imperfect proxy for broader structural changes in provisioning systems emphasised in the post-growth literature. Moreover, our work remains rooted in neoclassical modelling principles of cost minimisation and general equilibrium, which have been criticised as unrealistic⁵¹ and which remain within a competitive, monetary market economy framework. The latter point contrasts with the degrowth focus on a social transformation

beyond market economies and capitalism, instead emphasising a shift towards care work, decommodification of economic activity, job guarantee, democratic planning, sharing, gifting and commons. This leaves room for future research. Second, the model represents aggregate consumption rather than detailed end-use services or sector-specific demand categories. As a result, it does not operate with detailed transformations in provisioning systems such as mobility, housing or food systems that are frequently discussed in degrowth and post-growth research. Our analysis, therefore, focuses on macro-economic consumption levels and energy outcomes rather than the detailed service-level transformations that would likely accompany such transitions. This approach was chosen to enable a methodological link with process-based IAM practice, but it does not capture sector-specific transformations. Sectoral change may enable faster GDP-emissions decoupling and could thus allow higher GDP convergence within Paris-compatible budgets³⁷. For a comparison with the convergence scenarios of Chancel et al.³⁷, please see Supplementary Discussion in this study and Li et al.⁵². The convergence thresholds we identify, therefore, should be understood as modelling heuristics rather than a normative benchmark or necessary limits. Further, our focus remains the same as in Kikstra et al.²⁷, with the exception of their national approach that is here expanded to a global one. Third,

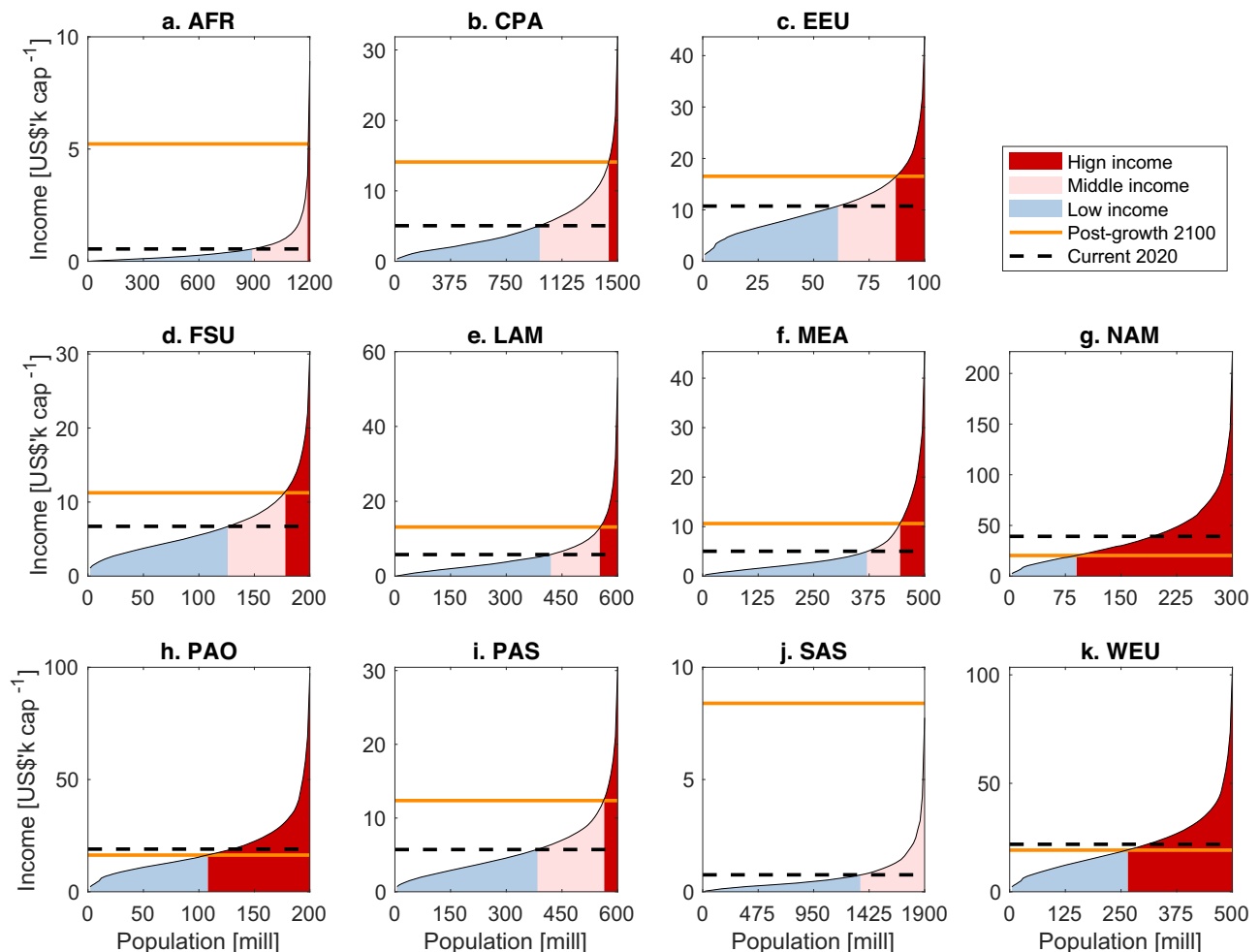


Fig. 4 | Within-region inequalities, gains and losses, in a more but not perfectly equal world economy ($\gamma = 0.25$, C6-consistent (3°C , $>50\%$) carbon prices⁴⁶). a–k show domestic income distributions for 11 MESSAGEix regions. Black solid line: Regional income distribution⁷³; black dashed line: Current mean regional income; orange horizontal solid line: 2100 income levels for $\gamma = 0.25$ and $\bar{c} = 10\text{US\$k cap}^{-1}$; blue areas: population segments that can grow significantly; light red areas:

population segments that experience limited growth opportunities; dark red areas: population segments that need to reduce their consumption. Acronyms: mill millions, NAM North America, LAM Latin America & the Caribbean, WEU Western Europe, EEU Central & Eastern Europe, FSU Former Soviet Union, CPA Centrally Planned Asia & China, PAO Pacific OECD, PAS Other Pacific Asia, SAS South Asia, MEA Middle East & North Africa, AFR Sub-Saharan Africa.

population and technology trajectories follow the SSP2 baseline across all scenarios, again to ensure comparability with established IAM assessments. It should also be noted that MESSAGEix-GLOBIOM does not capture economy-wide rebound effects⁵³.

Equity, societal acceptance and political feasibility

Because of their particular equity and consumption features, certain scenarios could be environmentally and/or societally unacceptable and/or politically infeasible in certain regions. For example, recent or projected (eg by International Monetary Fund or SSP2) economic growth rates in Sub-Saharan Africa (AFR), CPA (notably China), other Pacific Asia (PAS) and South Asia (SAS) are significantly above the growth rates implied by our low consumption world ($\bar{c} = 5 - 10\text{US\$k cap}^{-1}$) scenarios. Given these regions' need for economic development, downgraded growth targets could be politically unpalatable. This seems to be especially the case as long as 1) the Global North continues its economic growth based on material appropriation from the global South^{54,55} and 2) there is no significant material support, e.g. in terms of technological transfers and reparations, coming from Global North countries^{56,57}. The perfectly equal scenarios are also precisely those in which the affluent North America

(NAM), Western Europe (WEU), and Pacific OECD (PAO) regions would face negative growth rates of around -0.5 yr^{-1} to -4 yr^{-1} towards the end of the century, representing a stark departure from their current positive growth rates of between $+1\text{ yr}^{-1}$ and $+3\text{ yr}^{-1}$. In these regions, significant parts of the respective populations would be affected by income reductions. In our low consumption scenario ($\bar{c} = 10\text{US\$k cap}^{-1}$), these parts represent more than half of the regional population in NAM, WEU and PAO (see Fig. 4g, h, k intersection of S-shaped within-region income distribution with the orange horizontal line at $\bar{c} = 10\text{US\$k cap}^{-1}$). This finding is largely consistent with distributional analyses where 50% of general resource use and environmental impact is covered by the richest 15–30%, and 80% by the richest 40–60%^{58,59}. Some selected commodities, such as air travel are more concentrated on wealthy population segments (80% by the richest 10%)⁵⁹, but on the whole, achieving $\Delta T \leq 2^\circ\text{C}$ through equitable degrowth requires not just the superrich and affluent⁶⁰, but major parts of NAM, WEU and PAO populations to drastically change their lifestyles and their governments to support these transitions. Any of the alternatives is undesirable: degrowth during which current inequalities ($\gamma \approx 0.5$) persist and the global poor remain poor leads to energy poverty (archetype III); growth in which

the entire world assumes Western affluence leads to dangerous climate change with ΔT of well above 2 °C (archetype II)⁶¹.

Implications for climate mitigation and global equity

In many influential policy-relevant reports, including IPCC reports, scenarios have played an important role, serving as a vehicle for integrating scientific insights across academic communities studying climate physics, climate impacts, and climate solutions. Such scenarios are meant to be plausible scenarios, with internally consistent quantifications of storylines' dynamics. The scenarios presented in this manuscript serve a slightly different purpose, and are 'what-if' scenarios, where the plausibility of projected changes in the scenario design inputs (population and GDP per capita) is not stated. For instance, real-world GDP projections are constrained by education levels, and a dynamic model could take account of this effect. Additionally, increased female education in turn would be expected to lower fertility rates, which would affect demographic trajectories—moving further away from the SSP2 quantification used here. Similarly, the drivers of change in our scenarios (income and consumption) and their links to energy demand are not easily translatable into desirable policies that increase well-being, because such policies and detailed demand-side representations of energy use and needs are not available here. These 'what-if' scenarios, therefore, primarily serve to explore the consistency of (potentially implausible) socio-economic trends with climate policies and outcomes.

Our analysis underscores a critical interplay between the economic structure of the Global North and the aspirations of the Global South. The prevailing trajectory, characterised by the North's embrace of growth, accumulation, consumerism and elite affluence, means that Global South nations must have their development curtailed and their consumption suppressed if the world is to meet its climate targets. This is not an acceptable future.

Addressing this issue necessitates a fundamental re-evaluation of prevailing paradigms within the Global North. Rather than perpetuating models based on the assumption of perpetual growth, there is a pressing need to explore alternative pathways that prioritise sustainability, equity, and well-being. One such approach gaining traction is degrowth, which advocates a deliberate, democratic reduction in unnecessary consumption and production to achieve ecological sustainability and social justice. While invoking principles of equity and justice in climate mitigation efforts is imperative for fostering cooperation and ensuring fairness⁶², the practical implications of such endeavours present formidable hurdles, particularly for the Global North, where the scale of emission reductions required to meet equitable targets is staggering. Still, a majority in European countries is already in favour of prioritising environmental protection over economic growth^{30,63}. This support increases with education as well as post-materialist, pro-environmental and altruistic values, while it declines with values of individualism, hierarchy and meritocracy³⁰. Additionally, increased levels of social trust can enhance peoples' willingness to make individual sacrifices⁶⁴. Nevertheless, substantial obstacles and doubts remain, not least due to degrowth being in stark conflict with the interests of powerful social groups⁶¹.

Moreover, pursuing equity in emission-reduction efforts will lead to increases in emissions in currently low-income regions of the Global South (Fig. 2). This phenomenon arises because regions with lower income levels often rely on outdated and inefficient technologies, resulting in higher energy and emissions intensity per unit of output. Addressing these complexities requires a nuanced approach that balances the imperatives of climate mitigation, social justice, and equitable development. Crucially, our results make clear that strategies must prioritise transfers and investments in sustainable technologies, capacity-building initiatives, as well as equitable distribution of resources to enable low-income regions to leapfrog to cleaner and

more efficient development pathways. The degrowth literature highlights this process as part of compensations, reparations, as well as transformations in mining, trade, financial systems and global governance to enable global justice^{56,57}. However, the 15th Conference of the Parties (COP15) climate finance pledge including its commitment to provide US\$ 100bn annually by 2020 to support climate mitigation and adaptation efforts in developing countries has only been realised in 2022 raising doubts about the international community's current commitment (the New Collective Quantified Goal (NCQG), adopted at COP29 tripled to US\$ 300bn annually⁶⁵) to addressing climate change and supporting vulnerable nations.

Methods

Recent synthesis of degrowth and post-growth modelling studies^{18,19} highlight that most existing post- and degrowth modelling studies rely on newly developed, often conceptual IAMs, such as *WoLim*, *MEDEAS*, and various stock-flow-consistent or system-dynamics frameworks, that relax growth assumptions but with limited detailed energy, land, and emissions representation. In contrast, our approach extends the established MESSAGEix-GLOBIOM process-based IAM, which is one of the IAMs selected to represent the Shared Socioeconomic Pathways (SSPs) that underpin scenario assessments by the IPCC⁶⁶. This allows us to compare prevailing growth-based pathways with convergence-based pathways within a detailed physical-economic system while maintaining methodological comparability with mainstream mitigation scenario studies.

Specifically, we use the MESSAGEix-GLOBIOM Integrated Assessment Model (IAM) in its global specification of 11 regions and 13-time steps (5-year periods between 2020 and 2060 and 10-year periods between 2060 and 2100) to explore 36 growth and contraction scenarios and their economic and environmental implications⁴². MESSAGEix-GLOBIOM IAM aims to provide policy-relevant insights into future environmental and energy system change by integrating energy, land-use, socio-economic and biophysical processes into one framework. Specifically, we base the socio-economic assumptions of MESSAGEix-GLOBIOM on the SSP2 as our starting point because it is tailored to extend historical trends⁶⁷.

The MESSAGEix-GLOBIOM tandem is a linear mixed integer optimisation model searching for future system configurations that satisfy exogenous demand at the lowest cost. MESSAGEix-GLOBIOM is linked to a macroeconomic model—MACRO⁶⁸—that incorporates economic feedback, including optimal savings, investment, and consumption decisions through maximising the intertemporal utility in each world region. MESSAGEix-GLOBIOM solves for cost-optimal energy and land system configurations that satisfy demand, while MACRO determines optimal savings, investment, and consumption decisions by maximising intertemporal utility in each region. In this framework, consumption is the argument of the utility function and represents aggregate economic welfare, following the original MESSAGE-MACRO formulation.

To translate emissions into climate outcomes, we utilise the climate model FaIR version 1.6.2, with the 'climate-assessment' setup^{69–71}, to convert emissions of greenhouse gases generated by different scenarios from the MESSAGEix-GLOBIOM to global mean temperature projections. Emissions from the MESSAGEix-GLOBIOM in 2020 are harmonised using the IPCC's Special Report on Global Warming of 1.5 °C-based reference dataset included in the climate-assessment setup (sr15.csv)⁷¹. Emissions in 2025 are calibrated against the latest available historical emissions data, using the observed change relative to 2020, so that near-term emissions remain consistent with both the harmonised 2020 baseline and recent historical trends. Emissions in subsequent years are then derived by applying the model-implied emissions ratios relative to 2025, ensuring comparability across scenarios while preserving each model's internal dynamics.

IAM modifications for degrowth analysis

In its standard formulation, MESSAGE-MACRO assumes exogenous growth trajectories and a monotonic utility function, implying that higher consumption always increases welfare. These assumptions limit its ability to represent futures in which consumption stabilises or declines. To enable exploration of such pathways, we introduce two targeted modifications to the model structure²⁶.

We make two modifications to the original MESSAGEix setup.

First, we relax the stringent scaling equality into an upper bound. Instead of enforcing equality with externally specified GDP paths, we implement these trajectories as upper bounds. After this modification, GDP is no longer scaled to exogenously defined values but is determined endogenously through utility maximisation, while remaining bounded by externally specified socio-economic trajectories. This allows GDP to be determined endogenously through utility maximisation while remaining consistent with externally defined socio-economic envelopes.

Second, we replace MESSAGEix's original monotonic utility function $U(C) = \log(C)$, where C is consumption, with a non-monotonic function $U(C, \alpha, \eta_0, \xi) = \alpha C^{\eta(C)} = \alpha C^{\eta_0 + \xi C}$, where $\eta = \frac{\partial U / \partial C}{U/C}$ is the consumption-elasticity of utility (Supplementary Fig. 10–11, Supplementary Method). For $\eta(C) = \eta_0 + \xi C$ with $\xi < 0$, utility will first increase with increasing consumption, then plateau, and finally decline. When expressed for more than one good, $U(C, \eta_0, \xi)$ it resembles the well-known Constant-Elasticity-of-Substitution (CES) function (see Supplementary Method)²⁶. In this framework, consumption enters directly as the argument of the utility function and represents aggregate economic welfare. Changes in consumption, therefore, influence energy demand and emissions indirectly through their effects on economic activity and energy service requirements. While this representation enables exploration of consumption-constrained futures within a process-based IAM, it remains an aggregate formulation and does not capture sectoral transformations, provisioning systems, or non-market dimensions of well-being emphasised in post-growth and degrowth literature.

Using the modified MESSAGE variant, we undertake 36 scenario runs in which the peak of the non-monotonic utility function shifts from its SSP2 initial value (2020) to 5–50 US\$ cap⁻¹, assuming global between-regions Gini indices of 0.5, 0.25 and 0 in 2100, and under no, C6-consistent (3 °C, >50%) and stringent C4-consistent (2 °C, >50%) carbon prices—see Supplementary Fig. 1. For each run, MESSAGE supplies the optimal energy mix and GDP for all 11 regions. We use these two outputs to assess the scenario's feasibility and equity characteristics.

Scenario construction

Scenarios are constructed by combining assumptions on global income levels and income inequality, applied to a baseline trajectory of regional per-capita income and population.

Baseline. We start from the SSP2 baseline scenario of regional per-capita income $c_{t,r}^{\text{base}}$ and population $P_{t,r}$, defined over time t and regions r . Global mean income is computed as the population-weighted average as in Eq. (1). Inequality is measured using the Gini coefficient derived from the distribution of income across regions.

$$\mu_t^{\text{base}} = \frac{\sum_r c_{t,r}^{\text{base}} P_{t,r}}{\sum_r P_{t,r}} \quad (1)$$

Global income pathway. A target global income level is specified at a convergence year T_c . To construct a consistent trajectory, the baseline income pathway is adjusted such that it reaches the prescribed level while remaining as close as possible to the SSP2 baseline evolution. Formally, the target mean income path μ_t^{target} is obtained by solving Eq. (2), subject to: $\mu_{T_c} = \mu_{T_c}^{\text{target}}$, where the second term penalises changes in

curvature (i.e. deviations from the SSP2 baseline growth pattern).

$$\min_{\{\mu_t\}} \sum_t (\mu_t - \mu_t^{\text{base}})^2 + \lambda \sum_t (\Delta^2 \mu_t)^2 \quad (2)$$

This ensures a smooth adjustment that preserves the temporal structure of the baseline. Total global income in each year is then given as Eq. (3).

$$Y_t^{\text{target}} = \mu_t^{\text{target}} \sum_r P_{t,r} \quad (3)$$

Inequality pathway. A target inequality level is specified at the convergence year. A full trajectory is constructed by rescaling the baseline inequality path so that it reaches the prescribed level at T_c , while preserving its temporal shape. In contrast to earlier implementations, this inequality pathway is enforced consistently across all years.

Income redistribution. Given the target global income and inequality pathways, regional incomes are adjusted year by year. For each year, total global income Y_t^{target} is held fixed, and only its distribution across regions is modified, following a redistribution logic conceptually consistent with Oswald et al. 2021⁷².

Let baseline income shares be $s_{t,r}^0 = \frac{c_{t,r}^{\text{base}} P_{t,r}}{\sum_j c_{t,j}^{\text{base}} P_{t,j}}$, and equal per-capita shares $s_{t,r}^{\text{eq}} = \frac{P_{t,r}}{\sum_j P_{t,j}}$. Redistributed shares are defined as Eq. (4), where β_t controls the degree of inequality.

$$s_{t,r}(\beta_t) = s_{t,r}^{\text{eq}} \left(\frac{s_{t,r}^0}{s_{t,r}^{\text{eq}}} \right)^{\beta_t} / \sum_j s_{t,j}^{\text{eq}} \left(\frac{s_{t,j}^0}{s_{t,j}^{\text{eq}}} \right)^{\beta_t} \quad (4)$$

For each year, β_t is determined by solving Eq. (5), where $g_t(\beta_t)$ is the Gini coefficient implied by the redistributed income vector.

$$\min_{\beta_t} |g_t(\beta_t) - g_t^{\text{target}}| \quad (5)$$

This optimisation is performed independently for each year. Regional per-capita incomes are then recovered as Eq. (6). This ensures that global income remains fixed while inequality matches the prescribed trajectory.

$$c_{t,r}^{\text{ef}} = \frac{s_{t,r}(\beta_t) Y_t^{\text{target}}}{P_{t,r}} \quad (6)$$

Data availability

The SSP2 scenario inputs used in this paper are available in the online database <https://tntcat.iiasa.ac.at/SspDb>. The database defined for each scenario on the details of MESSAGE regions is also available within the ENGAGE Scenario Explorer at <https://data.ene.iiasa.ac.at/engage/#/workspaces/>. The processed data generated in this study are provided in the Supplementary Information/Source Data file. Source data are provided with this paper.

Code availability

The code of the MESSAGEix-GLOBIOM model is open sourced and available at https://github.com/iiasa/message_ix; the model documentation is available at <https://docs.messageix.org/projects/global/en/latest/>. The latest documentation for the MACRO economic model is available at https://docs.messageix.org/en/latest/model/MACRO/macro_core.html. The code of the FaIR: Finite Amplitude Impulse Response simple climate model is open sourced and available at <https://docs.fairmodel.net/en/v1.6.2/>.

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Author contributions

My.L. and Ma.L. designed the study. My.L. conducted the formal analysis and prepared all the figures. My.L. and Ma.L. prepared the first draft. My.L., Ma.L., J.K., L. K., J.H. and K.R. contributed to writing, editing, reviewing, and approved the final paper.

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Competing interests

The authors declare no competing interests.

Additional information

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