

Principles for a Post-growth Scenario of Ambitious Mitigation and High Human Well-being

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Abstract

Most climate mitigation scenarios maintain inequalities, and associate favourable social and climate outcomes with continuing economic growth. By contrast, post-growth scholarship advocates for reducing less necessary production, reorienting the economy toward human needs and ecological goals, and pursuing equitable convergence within and between countries. Here, we synthesise recent advances in post-growth research into core principles. Existing post-growth scenarios fall short of considering, let alone implementing, key principles of post-growth transformation. We assess feasibility barriers, finding that post-growth will face weaker geophysical and technological constraints, but stronger socio-cultural and political opposition, than growth-oriented scenarios. Advances in post-growth research, alongside international calls for mitigation rooted in fairness and equity, present a strong case for a holistic development of post-growth scenarios.

Editorial Summary

Post-growth scholarship seeks to address the limitations of growth-oriented mitigation scenarios, by exploring the potential of profound socioeconomic transformations. This perspective synthesises core principles for modelling post-growth futures.

Most existing climate mitigation scenarios modelled with established integrated-assessment models (IAMs) face major limitations. They assume all countries continually increase production and consumption (measured by GDP), regardless of whether this growth is actually needed for human well-being or other social goals. This creates challenges, because growth drives up demand for energy, land and material use¹. This is particularly problematic in the case of high-income economies and wealthy individuals²⁻⁶, which already have levels of energy and material use well beyond that necessary for well-being⁷⁻⁹. Many of these challenges have been addressed by recent advances in post-growth modelling, but these efforts have limited overlap with formal IAMs and are not represented in the literature assessed by the IPCC¹⁰.

To reconcile growth with the rapid emissions reductions stipulated by the Paris Agreement, most mitigation scenarios rely on several contentious assumptions.

First, these scenarios typically assume efficiency improvements that decouple growing GDP from energy use at historically unprecedented rates^{11,12}. While large efficiency improvements are indeed possible, increased production and consumption in growth-oriented economies diminishes the extent to which this approach can deliver substantial absolute reductions in energy use^{13,14}.

Second, the scenarios assume rapid, large-scale, global deployment of renewable energy, electrification, and storage sufficient to meet the high energy demand that characterizes high-income countries¹⁵. However, the scenarios do not address the problem of limited availability of rare-earth minerals, which may hinder renewable deployment at this speed and scale^{16,17}.

Third, the scenarios typically assume large-scale carbon sequestration. This approach has been criticized in the literature due to feasibility concerns, as it requires massive commitments of land, water, infrastructure and energy^{18,19}. This is linked with negative environmental impacts such as land use change and associated emissions^{20,21}, access to food²², and biodiversity loss²³.

Finally, policy-relevance of such scenarios has been challenged due to their assumption of continuing disparities between high-income countries in the Global North and lower income countries in the Global South²⁴. Human wellbeing requires sufficient levels of energy consumption, and some scenarios assume Global South consumption levels remain insufficient to secure basic needs^{25,26}. The issue of inequality, within and between countries, is critical. Recent studies estimate that the wealthiest 10% of the world's population is currently responsible for around half of anthropogenic greenhouse gas emissions^{4,27}. Without reducing inequalities, it is difficult to simultaneously avoid overshooting planetary boundaries and secure well-being universally²⁸⁻³⁰.

Recognizing these limitations in existing mitigation scenarios, post-growth and degrowth scholarship seeks to develop approaches focusing on profound structural changes in socio-economic systems, rather than relying solely on technological fixes and efficiency improvements, to ensure universal human well-being within planetary boundaries^{31,32}. Many of mitigation strategies proposed by the post-growth and degrowth literature overlap with those in the literature on demand-side solutions and sufficiency, which themselves show scenarios of

low-demand to be compatible with high well-being and ambitious mitigation^{33–35}. However, in contrast to the demand-side and sufficiency literature, which typically focus on decoupling the provisioning of services and goods from resource demand, post-growth and degrowth seek to reduce demand by repurposing production and allocation towards equitable human needs satisfaction.

Post-growth calls for prioritising environmental sustainability, social equity, and human wellbeing over economic growth^{10,36}. It encompasses different growth-critical visions of economic development, including steady-state economy³⁷, the doughnut economics³⁸, the wellbeing economy³⁹ and degrowth⁴⁰. Degrowth refers to the planned and equitable downscaling of economic activities that are ecologically destructive and do not contribute to human wellbeing, in order to reduce ecological pressures and free up resources for decent living for all⁴⁰.

Here, we use the term post-growth over degrowth to avoid potential misunderstandings concerning economic development in lower-income countries, where post-growth aims to rapidly build the provisioning systems and infrastructures required for human needs satisfaction. At the same time, our notion of post-growth remains coherent with degrowth's vision of reducing production for affluent classes and high-income countries. In this article, we deliberate on the underexplored post-growth scenario space, synthesise recent advances in post-growth research to derive seven principles and modelling features required for producing coherent post-growth scenarios, and discuss the feasibility of a post-growth transformation.

Existing climate mitigation scenarios

The Shared Socio-Economic Pathways (SSPs)⁴¹ framework, which has become central for research that integrates climate and societal futures⁴², encompass five narratives of socio-economic pathways. All five link human well-being and ambitious mitigation with continued economic growth⁴³. It is important to note that this relationship is not empirically tested nor explicitly modelled in IAMs, but rather a narrative assumption underpinning the marker quantifications of the SSPs⁴⁴. The high-growth scenarios (SSP1⁴⁵ and SSP5⁴⁶) are assumed to achieve higher education and healthcare, equality between genders, and social cohesion. In contrast, lower growth scenarios (SSP4⁴⁷ and SSP3)⁴⁸ are associated with high social inequalities, lower life expectancy, and lower education.

Well-being is poorly represented in existing scenarios

Beyond the narrative descriptions of well-being, established IAMs typically model social wellbeing as a utility from consumption, assuming growing per-capita GDP always results in more consumption, hence higher utility and better social outcomes. Post-growth (and even mainstream economic) scholarship is critical of the growth-determined well-being approaches, arguing that GDP is a poor indicator of human well-being^{49,50}. GDP describes the monetary value of total production, but not what goods and services are produced, how they are distributed, and whether they satisfy human needs or compromise them. Moreover, the monetary value of production says nothing about less tangible needs such as meaningful relationships, autonomy, or security. Satisfaction of human needs requires access to sufficient housing, healthcare, education, transportation, electricity, heating/cooling, energy, water, sanitation, nutritious food, etc.⁵¹. The degree to which basic needs are met depends on whether production and distribution prioritise key provisioning systems, not the overall size of the economy.

Several recent extensions to the original SSP framework integrate social interventions that contribute to well-being independently from economic growth and are thus aligned with post-growth. Some introduce measures of income redistribution towards lower-income countries⁵², and poorer households^{53,54}. Others model profound shifts in consumption towards technologically advanced, energy-efficient, and lower consumption lifestyles^{55–57}. Kikstra et al.,⁵⁸ and Li et al.,⁵⁹ examine the implications of reducing average consumption levels for the energy system and climate mitigation in a high-income country. Bodirsky et al.⁶⁰, and Soergel et al.,⁶¹ model post-growth scenarios by combining a low-growth GDP trajectory with major changes in consumption, resulting from sufficiency measures, efficiency improvements, and lifestyle changes.

However, even as these studies loosen the dependency of social wellbeing upon economic output, their representation of post-growth remains limited by the growth-oriented methodologies embedded in IAMs. The reliance on utility-maximising, market-clearing, and cost-optimisation algorithms restricts the ability of these models to represent the fundamentally different systems of production and distribution envisioned in post-growth literature^{36,62,63}.

Several studies represent degrowth or post-growth by imposing exogenous pathways of negative per-capita GDP or income^{12,58,59,64}, thus pre-configuring post-growth as a form of economic recession. A more adequate approach would be to endogenously estimate the macroeconomic implications of post-growth interventions⁶⁵. While several SSP-derived studies have taken this direction by partially endogenizing changes in energy demand^{57,60,61}, economic production in these scenarios typically remains tied to exogenous GDP trajectories. Consequently, the scenario estimates are difficult to reconcile with post-growth principles, e.g., purchasing power is assumed to continue increasing in high-income countries even as consumption of goods and services decreases sharply across most consumption categories.

The MEDEAS model has been used in initial efforts to produce post-growth scenarios that endogenize the relationship between economic factors of production and GDP. However, the MEDEAS post-growth scenarios are articulated around a narrative of involuntary contraction, induced by tightening biophysical limits and climate damages⁶⁶. This contrasts to the more prevalent narrative of post-growth as a deliberate and purposeful rescaling of the economy, oriented toward improving human wellbeing while respecting ecological limits^{10,36}.

Finally, while scenarios represented in the IPCC AR6 database do assume income and consumption convergence between different global regions and within countries, none include pathways of truly equitable convergence between global regions even by 2100^{54,61}. This is all the more problematic because within-country inequality diminishes individual well-being⁶⁷, while the inequality between countries may deepen further as a result of unequal climate impacts⁶⁸.

We conclude that existing scenarios, while incorporating certain elements of post-growth, fall short of exploring the futures envisioned in the post-growth literature. This is both because they have yet to integrate the different mechanisms of post-growth transformation and because they then to implement them with insufficient ambition.

Economic activity is not considered as a mitigation lever

To address the mitigation challenges outlined in the baseline scenario quantifications, IAMs typically focus on technological change, offering a rich representation of low-carbon, energy-efficient, and negative emissions technologies. Economic damages from climate impacts are not considered in the representation of economic output⁶⁹. Economic growth and re-scaling of different economic activities are not considered as potential mitigation levers⁷⁰.

Moreover, the lower-growth SSP3 and SSP4 scenarios are associated with higher mitigation challenges, such as high population growth, slower innovation, and low priority for environmental regulation^{47,48}. The combination of higher mitigation challenges and slower technological change makes these lower growth scenarios incompatible with the goals of the Paris Agreement⁷¹.

Narratives assuming profound life-style changes that reduce energy-demand and emissions, e.g., shifts to plant-based diets and shared vehicle ownership, are reserved only for scenarios of moderate and high GDP growth (SSP1, SSP2, and SSP5)⁴⁴. Notable exceptions to the mitigation bias towards scenarios of high growth are the SDP-RC scenario, which combines low growth trajectories with lower mitigation challenges⁶¹, and Bodirsky's degrowth transformation of the food system⁶⁰.

The hypothesis, originally articulated in the *Limits to Growth* report⁷², that remaining within planetary boundaries may require halting aggregate economic growth, is not reflected in the mitigation scenario literature. To date, only a handful of heterodox growth-critical models^{66,73} explore futures where increasing scarcity of key materials, decreasing net energy return on investment, and limited substitutability pose serious challenges to the prospects of continued economic growth. In contrast, established IAMs typically assume that limited material resources do not constrain the space of feasible low-carbon energy transitions, nor limit future economic growth^{74,75}.

There is growing recognition that future scenarios must consider radical systemic change, both as a strategy for mitigating escalating ecological challenges and as a consequence of their impacts^{76–78}. Notably, the Nature Futures Framework, adopted by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), sets out several aspirational narratives that envision cultural shifts towards non-extractivist relationships with nature, drawing explicitly on post-growth economic vision^{79,80}. Similarly, Lauer et al., present a scenario framework in which socio-economic development is fundamentally shaped by growing ecological impacts, deriving three of six narratives that include post-growth elements to confront the crisis⁷⁸.

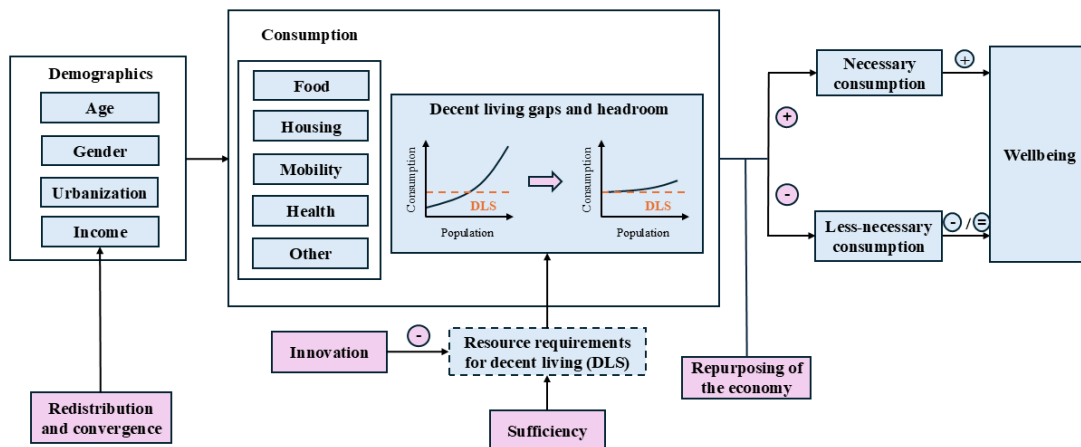
Thus far, these studies have focused on developing post-growth narratives, which may be amenable to the original SSP framework⁸¹. However, quantitative scenarios of these novel narratives will require substantial advances in modelling tools, as well as creation of new datasets that can capture socio-economic conditions for human well-being alongside an expanded range of ecological impacts.

Post-growth Principles and Modelling Requirements

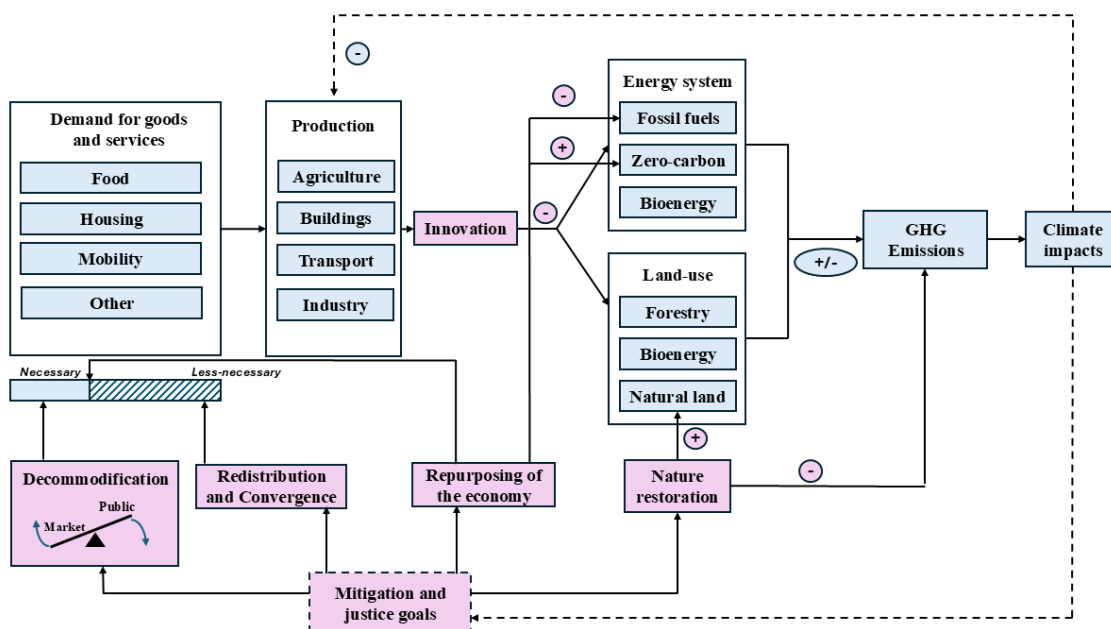
Post-growth literature proposes a range of interventions and organising principles to decouple well-being from and enable mitigation without economic growth. It argues that mitigation efforts deriving from radical socio-economic change may substantially reduce feasibility concerns associated with the technologically-led mitigation that prevails in existing scenarios^{12,82}. Post-growth also argues that less-necessary economic activity should be limited in order to avoid transgressing planetary boundaries.

Below we propose five key organising principles of post-growth scenarios: (i) wellbeing, (ii) sufficiency, (iii) reduced inequalities, (iv) repurposing of the economy, and (v) North-South convergence, supported by two transformative mechanisms: decommodification and growth-independent innovation. We combine these in our analytical framework of human wellbeing and mitigation (Figure 1). Finally, we summarise the main analytical concepts from post-growth literature related to wellbeing, consumption, production and the economy (Table 1).

199 a)



200 b)
201



202 **Figure 1: a) Representation of human wellbeing in a post-growth scenario.** In blue, the framework shows
203 fundamental categories and mechanisms of consumption. The framework distinguishes between the essential and
204 less-necessary consumption on the basis of the eudaimonic human needs approach. In purple the framework
205 depicts post-growth mechanisms that regulate consumption and its underlying resource requirements. **b)**
206 **Representation of mitigation in a post-growth scenario.** In blue, the framework shows the fundamental
207 categories and mechanisms that relate energy requirements for production and consumption with the GHG
208 emissions. Energy use as the principal emissions driver is moderated by post-growth mitigation measures (in
209 purple). The mitigation goals are defined externally and are therefore depicted with dashed boxes, while other
210 categories, mechanisms, and mitigation measures that can be modelled endogenously are depicted in solid boxes.

211 Well-being

212 Our post-growth conception and representation of well-being derives from the eudaimonic
213 needs-sufficiency framework⁸³, which defines needs as multidimensional, finite, non-
214 substitutable, and satiable prerequisites for wellbeing⁸⁴. Satiability means that it is possible to
215 completely satisfy a need, in contrast to the unlimited wants that underpin classical utility
216 theory and microeconomics⁸⁵. Empirical studies show that, beyond a certain level, increasing
217 material consumption does not substantially increase well-being^{50,86}. Accordingly, models
218 should be able to distinguish the production and consumption of essential goods and services,
219 which strongly support human need satisfaction, from the production and consumption of less
220 necessary goods and services, which have marginal or even negative effects on wellbeing⁸⁷.

221 Sufficiency

222 Sufficiency can be defined as a corridor between production and consumption *floors*
223 (sufficiency floors) where human needs are satisfied universally, and production and
224 consumption *ceilings* where economic activity remains within safe ecological limits^{88,89}. The
225 notion of a safe and just space for humanity has previously been illustrated via the concepts of
226 Doughnut Economics³⁸, and the Earth-systems boundaries⁹⁰.

227 To be consistent with our conception of well-being, a sufficiency floor must be multi-
228 dimensional, considering need satisfaction across a range of sectors including nutrition,
229 housing, health-care, mobility, clothing, and education^{28,91}. Decent living standards (DLS) is a
230 particularly suitable framework, as it fulfils this requirement and is amenable to the modelling
231 of environmental footprints. After estimating sufficiency floors for each category in terms of
232 energy⁸, material use⁹, and other metrics such as labour, total requirements for ‘decent living’
233 can be estimated.

234 Quantification of sufficiency ceilings requires consideration of various ecological goals,
235 socially-acceptable levels of inequality, and individual well-being^{92,93}. A post-growth scenario
236 should be able to quantify the share of population living above and below sufficiency floors
237 and ceilings⁵⁸, and the distribution of contributions to key environmental impacts (e.g.,
238 greenhouse-gas emissions and land-use change). Mechanisms aimed at reducing consumption
239 that overshoots sufficiency ceilings should prioritise the forms that are most environmentally
240 damaging, and which are most marginal with respect to wellbeing or are simply conspicuous
241 forms of consumption.

242 The DLS literature argues that basic needs could be satisfied universally with less than half of
243 the energy^{94,95} and materials^{96,97} currently consumed globally. The current decent living energy
244 (DLE) requirements, estimated at 170⁹⁸-210⁹⁵ EJ/year are substantially lower than the energy
245 demand projected even in the most stringent demand reduction scenarios in the IPCC database⁵⁷
246 (240 EJ/year by 2050). This suggests not only that universal wellbeing is achievable well within
247 planetary boundaries⁹⁹, but also that there is considerable headroom for additional consumption
248 between sufficiency floors and ceilings. Yet, the current economy remains far removed from
249 this aspirational goal. Only 30% of global final energy use (115 EJ/year) is allocated to essential

consumption required to meet DLS, while the remaining 70% (290 EJ/year) supports less-necessary consumption (Figure 2). Providing DLE to populations currently living below sufficiency thresholds, primarily in the Global South, would require 85 EJ/year, implying that current energy used for less-necessary consumption exceeds decent living energy for essential consumption by more than a factor of three.

Nonetheless, future modelling of post-growth scenarios, using the DLS framework, will require further methodological development. Existing DLS studies produce idealised estimates of resource requirements, relying on proxy data and strong normative assumptions regarding the consumption requirements for a decent life. Moreover, they typically adopt a per-capita or household accounting perspective that incompletely represents the energy and material requirements needed to support the functioning of provisioning and governance systems. Current DLS estimates should therefore be viewed as benchmark quantifications of the absolute minimum requirements for a decent life and, as such, represent a lower bound on broader conditions required to enable a good life. Post-growth scenarios require a dynamic framework that can simulate transitions from an existing wasteful, inefficient, and profit-oriented economic system to one where well-being and ecological limits are central. They must be capable of modelling how transformative policies and social dynamics can reorient provisioning towards sufficiency.

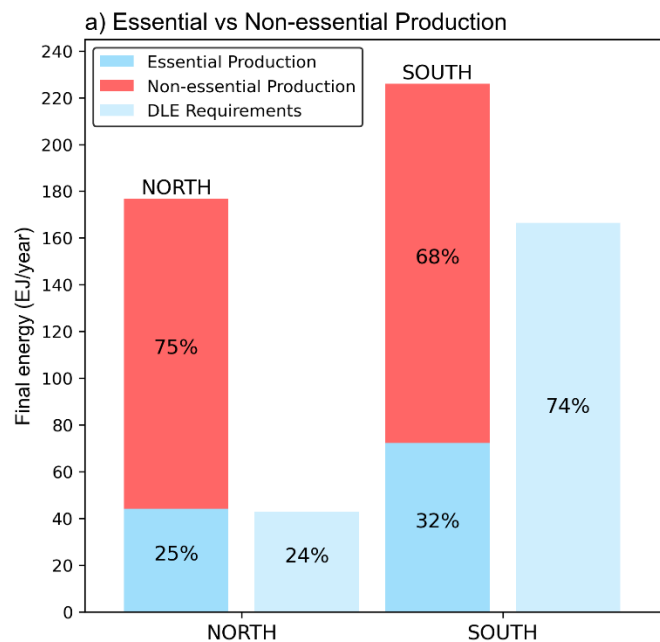


Figure 2: The break-down of energy use between the essential and less-necessary consumption for the Global North and South. The figure distinguishes between the energy that is currently supporting the provisioning of decent living standards, defined here as essential consumption (shown in dark blue), and less-necessary consumption (shown in red). The total energy required for decent living (DLE) in each region is represented in light blue. Notably, the Global North currently uses more energy for essential production than is required for meeting decent living standards, highlighting inefficiencies in current provisioning systems, while the essential consumption in the Global South does not meet even 50% of the respective DLE threshold. Estimates of energy used for essential consumption are taken from Kikstra et al.⁹⁸, and those for DLE requirements from Millward Hopkins et al.⁹⁵.

Reduced inequalities

Reducing socio-economic inequalities is a core principle of post-growth scholarship and hence of corresponding climate-economic scenarios. Current inequalities in energy, resource use, and emissions within and between countries are extremely large and primarily driven through economic dimensions of wealth, income and consumption^{3,4,100}. Currently, the top 1% use on average eight times more per-capita energy than the bottom 10% in the Global North, and forty times as much as in the Global South³. Without reducing these inequalities, it may be impossible to secure well-being for all while also avoiding overshooting planetary boundaries²⁸. However, until recently the SSPs did not consider radical economic convergence¹⁰¹, nor introduced measures to tackle the mitigation challenges caused by inequalities, as they typically only represent regionally-averaged energy use^{102,103}.

One key post-growth principle is to address affluence, and energy consumption of the rich, as a central climate mitigation lever, while ending poverty^{28,104}. This requires considering redistribution measures that drastically reduce inequalities within and between countries across various indicators, including income, energy consumption, material footprints, and even embodied labour. This, in turn, requires that models represent the distribution of consumption of goods and services for different needs satisfiers⁹⁸, and inequalities in less-necessary consumption such as excessive flying, oversized housing, and SUVs¹⁰⁵.

The notion of drastically reducing present-day inequalities does not imply that post-growth scenarios should aim for strict egalitarianism, seeking to completely eradicate existing inequalities. Scenarios should instead explore the conceivable range of ‘fair’ economic inequality within countries¹⁰⁶, which can be based on surveys of public values, and should also account for horizontal inequalities arising from heterogeneous needs. Some surveys on public perceptions of inequality indicate ratios from 2.5:1 to 8:1, between the income of the top 1% and the bottom 10%, could be considered “fair”^{106,107}. We illustrate the energy distributions for Global North and Global South, after assuming that the bottom decile is lifted to the DLS threshold and reducing the consumption ratios between the top 1% and the bottom 10% to 5:1 (Figure 3). Such “fair inequalities” result in average energy use in both the Global North and South at around 50 GJ per capita per year, narrowing the range of per-capita energy use in both regions to between 25 and 140 GJ. As a result, average consumption in the North decreases by 55%, while average consumption in the South increases by 70%.

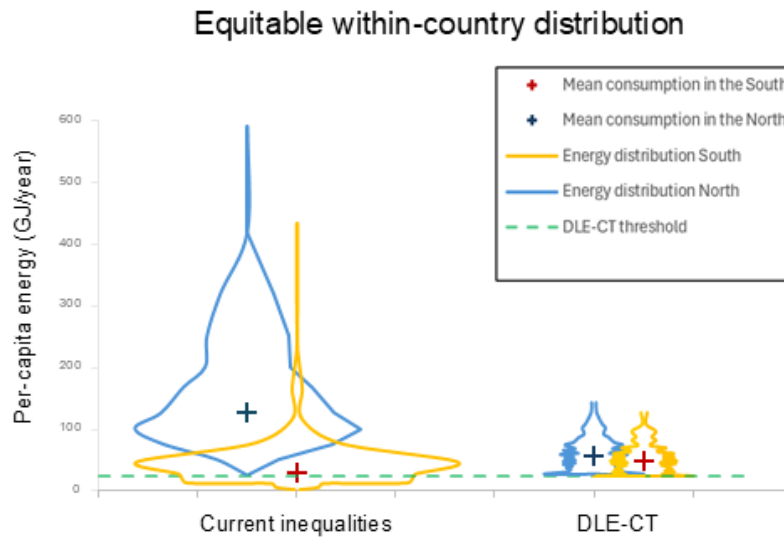


Figure 3: Final energy distribution in the Global North and Global South. “Teardrop diagrams”, previously used in Millward-Hopkins et al.¹⁰⁸, indicate the energy use distribution, with the width illustrating the proportion of the population across different levels of energy consumption, and the crosses the mean consumption. The figure presents the present-day distribution of energy use alongside the ‘Decent Living Energy – Current Technologies’ (DLE-CT) scenario, which assumes all individuals meet or exceed current minimum energy requirements for decent living, shown as a green dashed line. The concept of ‘fair inequalities’ is represented crudely here by a 5:1 ratio between the top 1% and bottom 10% of the population in both the Global North and South, a value used in previous work based upon data across 40 countries¹⁰⁶. The data for present-day current inequalities scenario is from Oswald et al.³. The DLE-CT data are from Millward-Hopkins et al⁹⁵.

Realigning the economy with human needs and ecological goals

Post-growth does not call for reduced economic activity in *all* sectors, but specifically in sectors of destructive and less-necessary production (e.g., weapons, SUVs, luxury consumption, industrial meat)^{109,110}. Meanwhile, socially necessary forms of production (e.g., renewable energy, public services, healthy and nutritious food, efficient and affordable housing, public transit, etc.) should increase where required.

Existing scenarios provide a general picture of economic development in different world regions, but give little sectoral detail on structural changes to production, distribution, and trade^{111,112}. Economic output (GDP) is typically only provided at the level of total aggregate production. In line with this representation of the economy, post-growth has often been interpreted as a scenario of low or negative GDP growth. However, this representation is erroneous in that it conflates post-growth with stagnation or recession¹¹³. Post-growth emphasizes that it is not only the scale of aggregate production and consumption that matters, but its *composition*, and how it can support universal need satisfaction with low energy and material use. In an adequate representation of post-growth, GDP reflects the balance between necessary increases in essential services, and reductions of less-necessary production.

To this end, the models need improved sectoral granularity. A higher-definition image of the economy is crucial for studying flows of energy, materials and environmental pressures between different sectors and countries¹¹⁴. Moreover, while the DLS literature has established

the economic domain of essential production for human needs, the quantification of less-necessary production has thus far been reduced to the residual between total production and essential production. A methodological framework to differentiate types of less-necessary production, such as the “in-between”, and “excess” production categories proposed by Bärnthaler⁸⁸, according to ecological and well-being criteria, remains to be developed.

North-South Convergence

Post-growth scholarship emphasises that most countries in the Global South need to increase energy and material use to achieve decent living standards for all¹¹⁵. Eventually, full convergence in per-capita energy and material services should be achieved between the Global North and South. While some level of within-country inequalities between individuals can be justified for meritocratic or utilitarian reasons – as most people consider a degree of inequality to be fairer than strict egalitarianism – the same ethical justifications cannot be applied to inequalities between countries or aggregate IPCC regions¹⁰⁸. There is thus no ethical justification for bringing Global South countries *only* to a basic minimum standard of living and allowing wealthier countries to consume well beyond those levels.

High-income economies must thus reduce their aggregate energy and material consumption, by scaling down destructive and less-necessary forms of production and consumption, in order to create space for growth in the Global South. Efficiency improvements alone are insufficient to deliver either equitable convergence in an acceptable time frame^{11,14}, or emissions reductions consistent with the Paris Agreement⁶.

Some models assume that demand reductions in the Global North will have negative impacts on development in the South⁶⁴. However, this outcome can be prevented by ensuring Global South countries have the latitude to implement public finance and industrial policy to reorganize their own production away from servicing consumption in the North so as to prioritize national and regional development objectives instead. China adopted this approach with considerable success, in response to the Western demand decline following the 2008 crisis¹¹⁶.

When estimating the speed of equitable convergence, post-growth scenarios should consider disparities in both living standards and historical responsibilities arising from cumulative emissions¹¹⁷ and ongoing colonial unequal exchange^{115,118,119}. Models should adjust the mitigation burdens of different countries to their historical emissions¹²⁰, and include reparations, dedicating a share of Northern economic production to the build-up of Southern low-carbon infrastructure and essential provisioning systems, and fund protection against and reconstruction from climate impacts. Given the heterogeneity within both the Global North and South, equitable convergence should not be approached as a uniform process between two homogenous blocks. Instead, it should reflect distinct historical trajectories, standards of living, and roles that specific countries have played in enabling or constraining the development of other countries.

Ensuring a fair distribution of resources within the sustainable consumption space means that everyone has access to at least the minimum requirements for a decent standard of living. However, 53% of the population in the Global South currently falls below decent living thresholds. Currently, average energy use in the global North is approximately 125 GJ per capita per year, with individual consumption ranging from 25 GJ to nearly 600 GJ³ (Figure 3). In contrast, the Global South averages less than 30 GJ per capita per year, with individual consumption ranging from as low as 2 GJ to as high as 430 GJ.

Considerations of embodied labour are also indispensable for post-growth scenarios, as labour time per person, together with compensation for labour time, is central for assessing well-being. While labour in the Global North, despite notable growth in labour productivity, still adheres to the norm of the 40-hour work week, working time in the Global South is systematically longer and compensated considerably worse even at the same skill level¹¹⁸. Moreover, the Global North draws an excess of resources and labour from the Global South and studies of “unequal exchange” suggest that the wealth of the Global North is thus dependent on exploitation in the Global South¹¹⁹. Labour inequalities are not only “symptomatic”, but intertwined with how the global economy operates and distributes resources.

Decommodification

Post-growth aims to fully or partially decommodify provisioning for human needs, because public and collective service provision can be more efficient in meeting basic human needs than market economies^{121–123}. Existing IAMs typically mediate the relationship between production and needs satisfaction through income, thus obfuscating the importance of public goods and services, which can be accessed independently of income. For a holistic representation of access to services in a post-growth scenario, models should represent the functioning of partially or fully de-commodified public systems, and show how they can be delinked from GDP. Modelling of decommodification would make it possible to explore alternative approaches to improving social wellbeing without growth.

Growth-independent innovation

Innovation can support post-growth objectives by enabling sufficient provisioning for need satisfaction while reducing demand for resources, energy, and land. Most existing scenarios associate low GDP growth with slower innovation of mitigation technologies and lower energy efficiency. This assumption can be challenged¹²⁴. Economic conditions for rapid innovation and technology can be achieved through targeted investment, irrespective of trends in aggregate output. Empirical analysis of renewable energy deployment¹²⁵ during the past fifteen years, which have coincided with a substantial slowdown of GDP growth¹²⁶, demonstrates that innovation and growing investment can occur even in conditions of lower aggregate growth. Models could improve the modelling of innovation, by focusing on sector-specific investment and non-economic drivers of innovation and technology adoption^{15,127}.

438 **Table 1: An overview of the main post-growth narrative assumptions and modelling**
439 **requirements for their representation.**

Postgrowth interventions	Narrative elements	Basic representation	Advanced representation
Well-being	<ul style="list-style-type: none"> - Universal human needs satisfaction - Alternative economic paradigms (Doughnut, Wellbeing, Foundational economics, Universal Basic Services, Universal Basic Income) 	<ul style="list-style-type: none"> - Representation of essential material need satisfiers. 	<ul style="list-style-type: none"> - Sociodemographic differentiation of needs and their satisfaction (age, gender, race, historical injustices) - Non-material requisites for well-being (equity, fairness, employment, relationships, climate resilience)
Sufficiency	<ul style="list-style-type: none"> - Decent Living Standards (DLS) - Differentiation between essential and less-necessary consumption 	<ul style="list-style-type: none"> - Satisfaction and DLS gaps in key sectors (food, housing, mobility) - DLS thresholds as a function of climatological, geographical, socio-economic and infrastructural factors 	<ul style="list-style-type: none"> - Expanded sectoral representation of DLS satisfaction and gaps (energy, material, land and labour requirements) - Detailed specification of essential and less-necessary consumption baskets
Reduced inequalities	<ul style="list-style-type: none"> - Sustainable Consumption Corridors - Redistribution, and reduction in within-country inequality - Wealth/income caps 	<ul style="list-style-type: none"> - Aggregate inequality indicators (GINI, Theil indices ...) of income, energy and emissions. 	<ul style="list-style-type: none"> - Inequality distributions across the population (rather than single inequality indicators) - Inequality of consumption and wealth in different sectors and services - Inequality across key sociodemographics (income, age, and gender)

Realigned economy	<p>Improvement of essential production:</p> <ul style="list-style-type: none"> - Industrial policy, sector-specific investment for innovation - Democratic planning - Build-up of DLS infrastructure and provisioning systems <p>Down-scaling of less-necessary (positional) and damaging production:</p> <ul style="list-style-type: none"> - Fossil fuels, intensive animal farming, military <p>Bolstering of alternative economic forms:</p> <ul style="list-style-type: none"> - Collective/cooperative business models - Sharing economy, right to repair - Decommodification and expanded access to public goods <p>Advancement in labour rights:</p> <ul style="list-style-type: none"> - Worktime reduction - Just transition - Job guarantee in social and ecological sectors 	<ul style="list-style-type: none"> - Assessment of re-scaling and reorganisation in the main sectors: industry, transport, buildings, agri-food and energy systems - Assessment of changes in the system efficiency of service provision - Diffusion of existing, improved, and new technologies - Differentiation between essential and less-necessary production - Representation of labour and land requirements for production 	<ul style="list-style-type: none"> - Investment and finance implications of re-scaling and reorganisation in the sectors - Endogenous technology diffusion depending on costs and investments. - Detailed sectoral representation of production, trade, and consumption in different countries/regions - Representation of material requirements. - Differentiation between essential, excess and “in-between” production. - Labour by sector and skill level, including in care and reproductive work
North-South convergence	<ul style="list-style-type: none"> - Equitable convergence between the Global North and Global South - End to unequal exchange, increased economic sovereignty and autonomy. - Reparations for closing the DLS gaps in the Global South, accelerating low-carbon transition, and improving climate resilience. 	<ul style="list-style-type: none"> - Accounting of inequalities and unequal exchange in monetary terms, embodied energy, embodied labour, and embodied land between Global South and Global North - Estimating the necessary finance and capital needs for closing the DLS gaps, and accomplishing climate mitigation targets. 	<ul style="list-style-type: none"> - Accounting of materials & emissions embodied in trade - Accounting of unequal exchange at sectoral level and including the estimates of embodied materials - Modelling of climate change impacts on DLS thresholds and gaps

Discussion

Post-growth scenarios seek to explore novel approaches for enhancing human well-being within planetary boundaries, without relying on continued economic growth. However, it remains unclear which narrative elements should be considered for these scenarios, and how to represent them in models. Here, we argue that post-growth scenario modelling should go beyond simplistic representations of stagnating or declining GDP and lay out the basic characteristics for a coherent post-growth representation: (i) wellbeing, (ii) sufficiency, (iii) reduced inequalities, (iv) realigning of the economy, (v) North-South convergence. We define the narrative elements behind each principle, and the modelling requirements to represent them in integrated assessment and energy system models.

It should be recognised that the transformative potential of post-growth depends on a radical departure from current social, economic and institutional organisation, which raises questions about the feasibility of these scenarios¹⁰. Measures to reduce inequalities and downscale positional consumption will face resistance from affluent classes that would see their power and control over the economy and politics diminish¹²⁸. In high-income countries, the downscaling of socially and ecologically damaging sectors, expansion of public provisioning, ending of unequal exchange and payment of damages to lower-income countries require an enhanced regulatory role of the state domestically and a commitment to reparative diplomacy internationally¹²⁶. These shifts are expected to encounter opposition from pro-capitalist, imperialist and market-oriented actors.

While these barriers may raise doubts about the feasibility of post-growth scenarios, they should be positioned in relation to the barriers faced by growth-oriented scenarios. Socio-cultural challenges, stemming from resistance by incumbent fossil-fuel industries, opposition to low-carbon lifestyles, and the expanding regulation required to reduce emissions, are not unique to post-growth. Rather, these barriers are also evident in countries advancing growth-compatible climate policies¹²⁹.

Moreover, post-growth's barriers are categorically different from the constraints associated with many growth-oriented scenarios. For example, the immense resources required for realising negative emissions face hard geophysical limits, constraining feasible mitigation regardless of their social acceptability and affordability^{130,131}. By contrast, post-growth mitigation may appear unfeasible under the present socio-cultural and neoliberal economic context. However, the functioning of socio-economic systems can change as a result of democratic deliberation and social struggles. In fact, post-growth interventions may prove more effective because they open new avenues for action, engage with new actors, and operate synergistically with measures already implemented¹³². Moreover, radicality does not necessarily imply a lack of legitimacy, as demonstrated by the growing support for post-growth principles in European countries and United States¹³³.

There are reasons to believe that post-growth could become a viable transformation pathway. By decreasing the demand for both energy and materials, post-growth, like scenarios of sufficiency and lower demand, is likely to be associated with lower geophysical and

technological feasibility concerns for mitigation than most growth-oriented scenarios^{61,82}. Furthermore, reduced energy and material import dependency can be advantageous for many countries.

Post-growth scenarios also provide a framework with more equitable energy and decarbonisation pathways by assuming convergence between the Global North and Global South countries^{26,115}. The political appeal of post-growth in lower-income countries may be bigger insofar as it creates conditions for a rapid closure of the basic need gaps. Nonetheless, the appeal of sufficiency may vary, as growth aspirations in some countries and by some people may extend beyond the equitable and sustainable thresholds. Integrating the five post-growth principles and the two supporting mechanisms into models should enable to assess possible trade-offs and synergies of post-growth interventions between different feasibility dimensions in a more robust way and at a high sectoral and geographical granularity.

Perhaps, the real challenges for modelling of post-growth lay not in keeping socio-cultural and economic feasibility concerns in check, but in assessing uncertainty surrounding transition that entails qualitative breaks from the rules and mechanisms that define the current socio-economic system¹³⁴. This is compounded by the lack of historical precedent and scarcity of data and methodologies for studying sufficiency-oriented and decommodified provisioning. To address these challenges, we suggest several research avenues for testing the viability of post-growth under existing socio-economic and institutional constraints.

First, models should represent current dependencies between economic growth and well-being, to test policies and interventions that can decouple one from another^{135,136}. Second, modelling frameworks should not only assume but also represent the emergence of conditions for social change, such as public acceptability and proactive governance, to improve the representation of real-world transition dynamics¹³⁷. Exploring how different levels of support for post-growth policies affects their implementation, diffusion, and feasibility would be particularly relevant. Finally, scenario feasibility frameworks¹³⁸ should include dimensions relevant to post-growth, such as international fairness, and social desirability of envisaged scenarios¹³⁹.

The narrowing of the safe and just corridor for humanity¹⁴⁰ should spur the modelling community to explore a broad range of target-seeking scenarios. In doing so, new innovative modelling approaches must be attempted, which are expected to come with improved understanding of the role that social systems and inequalities play in transitions. Our work intends to spur the imagination on how to approach the design of new methodologies in the models. Post-growth scenarios are not only urgent for opening new horizons of hope, but also for providing valuable insights into the challenges of realising ambitious social and ecological transformations.

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Conflict of Interests

The authors declare no competing interests that could have influenced the writing of this article.

Author Contributions

A.S. conceptualised the project and led the investigation, analysis, and writing. A.S. and J.M.H. undertook the quantitative review, for which J.K., J.M.H. and Y.O. provided data. V.F.R. led development of the analytical modelling framework. J.S., J.H. J.M.H., V.F.R., and Y.O. contributed to writing the initial draft. All authors participated in reviewing and editing the article.

Extended Data

The data underlying the figures 2 and 3 are available in an online data repository, accessible at: https://osf.io/p3u5a/overview?view_only=12ae7bd3758e47b882d34abf77d0ea55

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