

Introduction to Economic History :
Capital, Inequality, Growth

(Master APE & PPD)

(EHESS & Paris School of Economics)

Thomas Piketty

Academic year 2026-2027

Lecture 7: Material Accounting & Planetary Habitability:
Land Use, Forest Cover, GHG Emissions and Global Warming

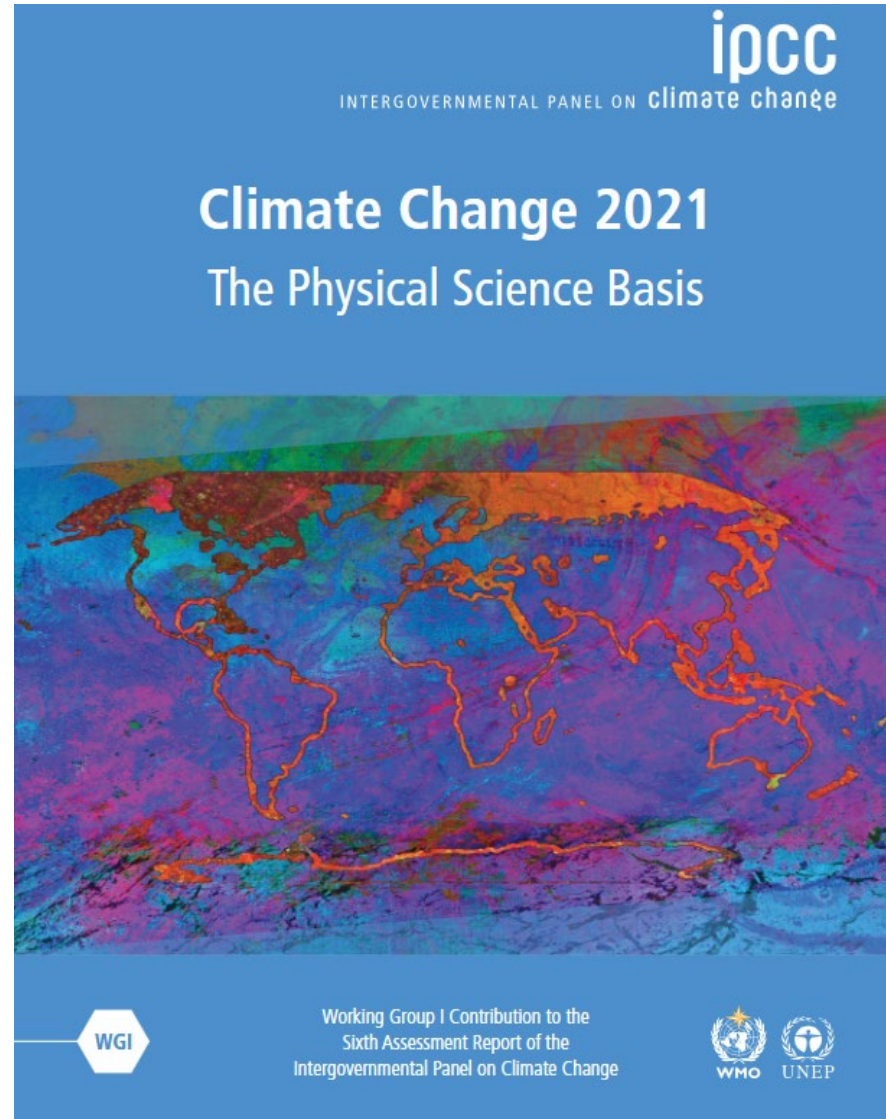
Roadmap of the lecture

- Global Warming, Carbon Emissions & Sea Levels in History: Why Did it Take so Much Time to Raise Climate Awareness?
- The Ghost Hectares of the Industrial Revolution: Deforestation and Fossil Fuel Extraction in the Long-Run
- The Mismatch between Responsibilities & Damages
- Energy Systems in Comparative & Historical Perspective
- Is Prosperity for All Countries Compatible with Planetary Habitability?
- Winners & Losers from Sustainable Convergence: Monetary Accounting vs Material Accounting

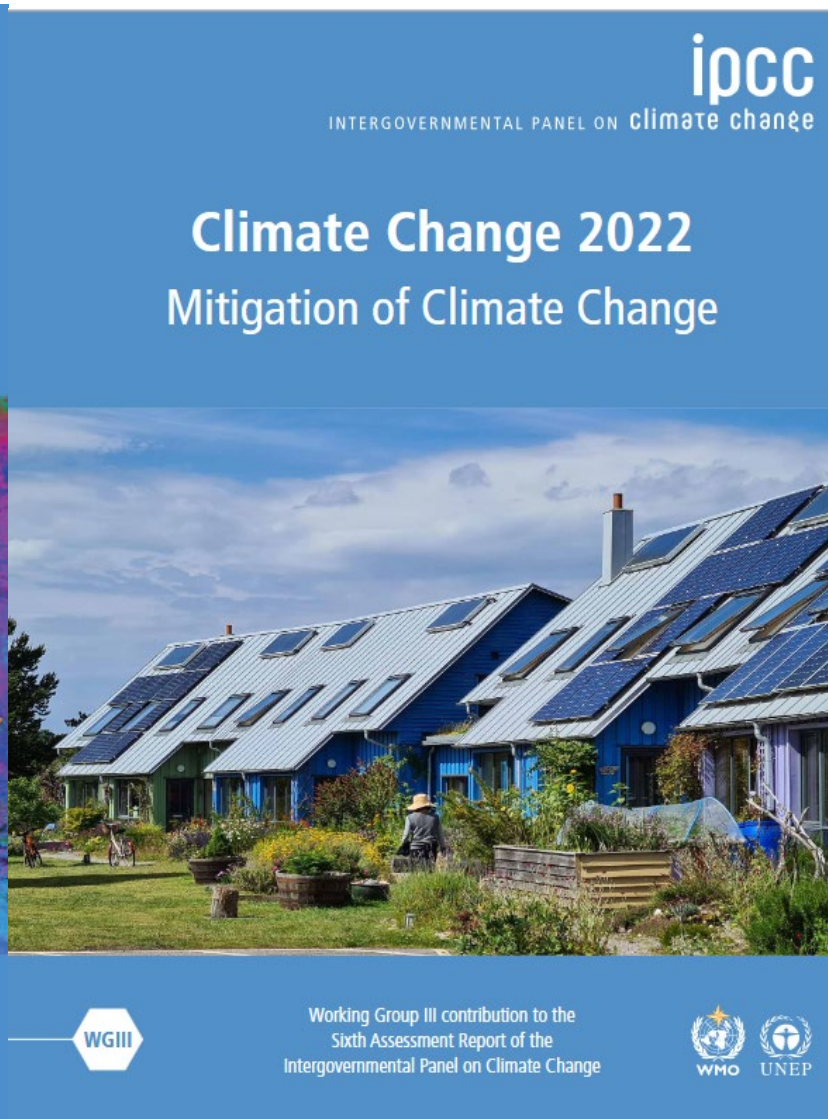
Short Bibliography

- IPCC 6th Assessment Report, 2021-2023. [WG1: The Physical Science Basis](#). [WG2: Impacts, Adaptation, Vulnerability](#). [WG3: Mitigation of Climate Change](#). [Synthesis Report](#) (AR1 1990, AR2 1995, AR3 2001, AR4 2007, AR5 2014, AR6 2022, AR7 2028) (IPCC created 1988, UNFCCC adopted at Rio Summit 1992)
- K. Pomeranz, [The Great Divergence - China, Europe and the Making of the Modern World Economy](#), 2000
- J.B. Fressoz, [More & More & More. An All-Consuming History](#), Penguin, 2025 (Sans transition. Une nouvelle histoire de l'énergie, Seuil 2024)
- L. Chancel, C. Mohren, [Climate Inequality Report 2025](#), WIL
- L. Chancel, [Energie et inégalités. Une histoire politique](#), Seuil, 2025
- * L. Chancel et al, [Prosperity Within Limits? Planetary Habitability, Global Convergence and Structural Transformation](#), WIL WP 2026 ([WSEED.world](#))
- [The Global Justice Report: A Plan for Equality & Prosperity Within Planetary Boundaries](#), WIL 2026 ([Global Justice Project](#))

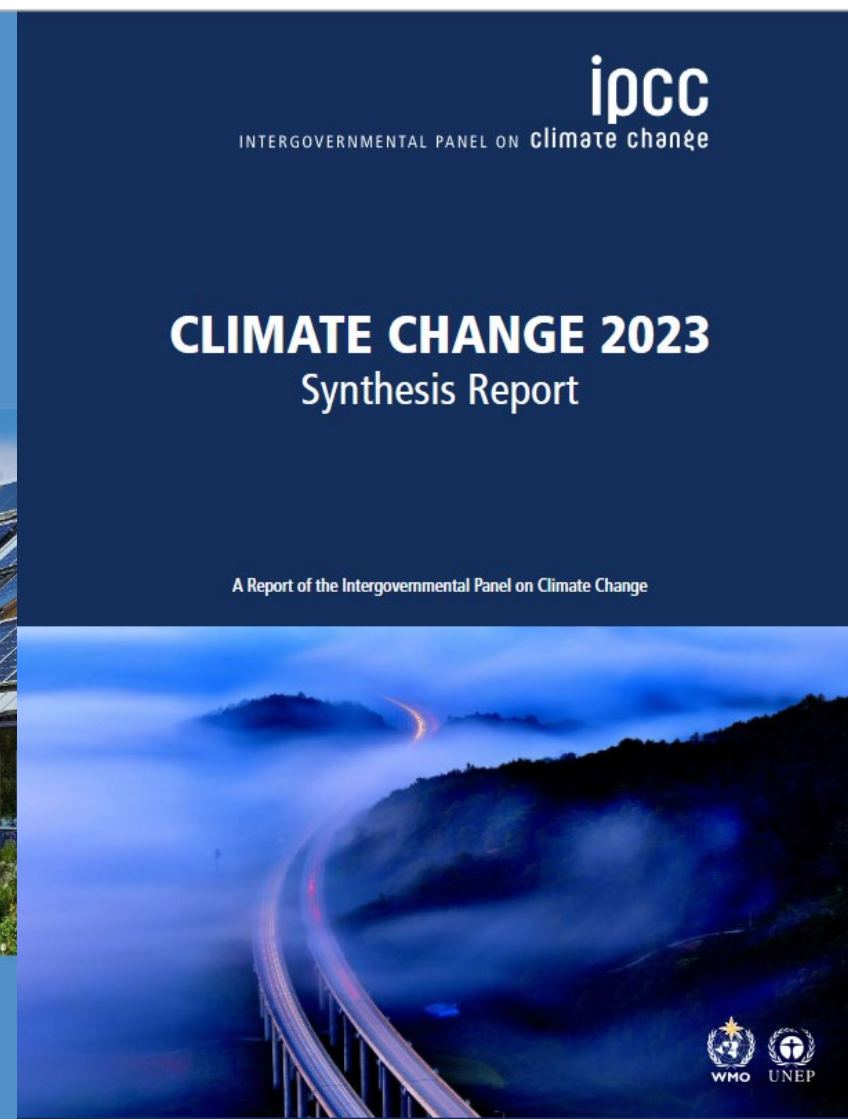
IPCC Reports AR1-AR6: Reference Work on Climate Change



IPCC, AR6, WG1, 2021

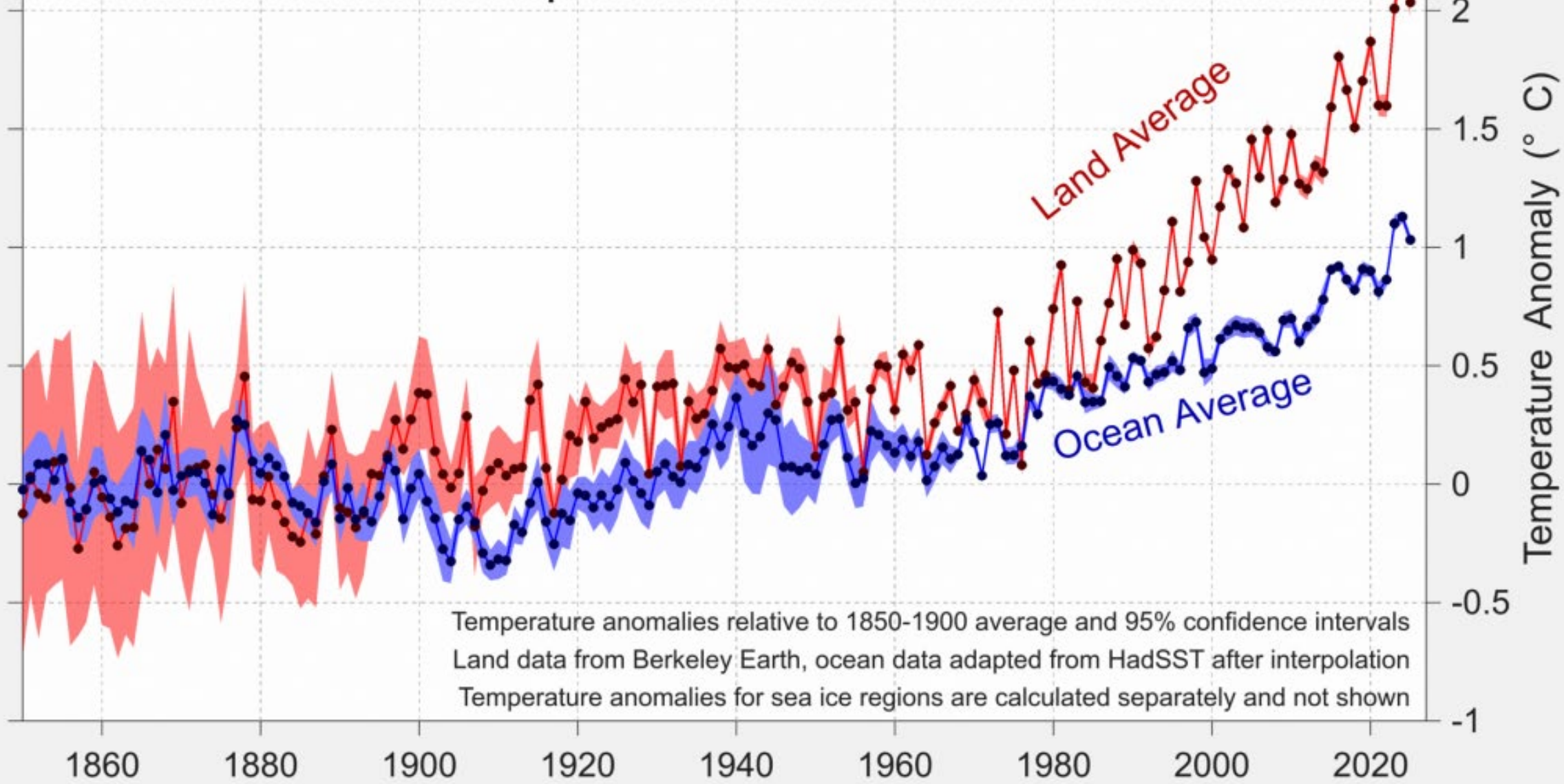


IPCC, AR6, WG3, 2022



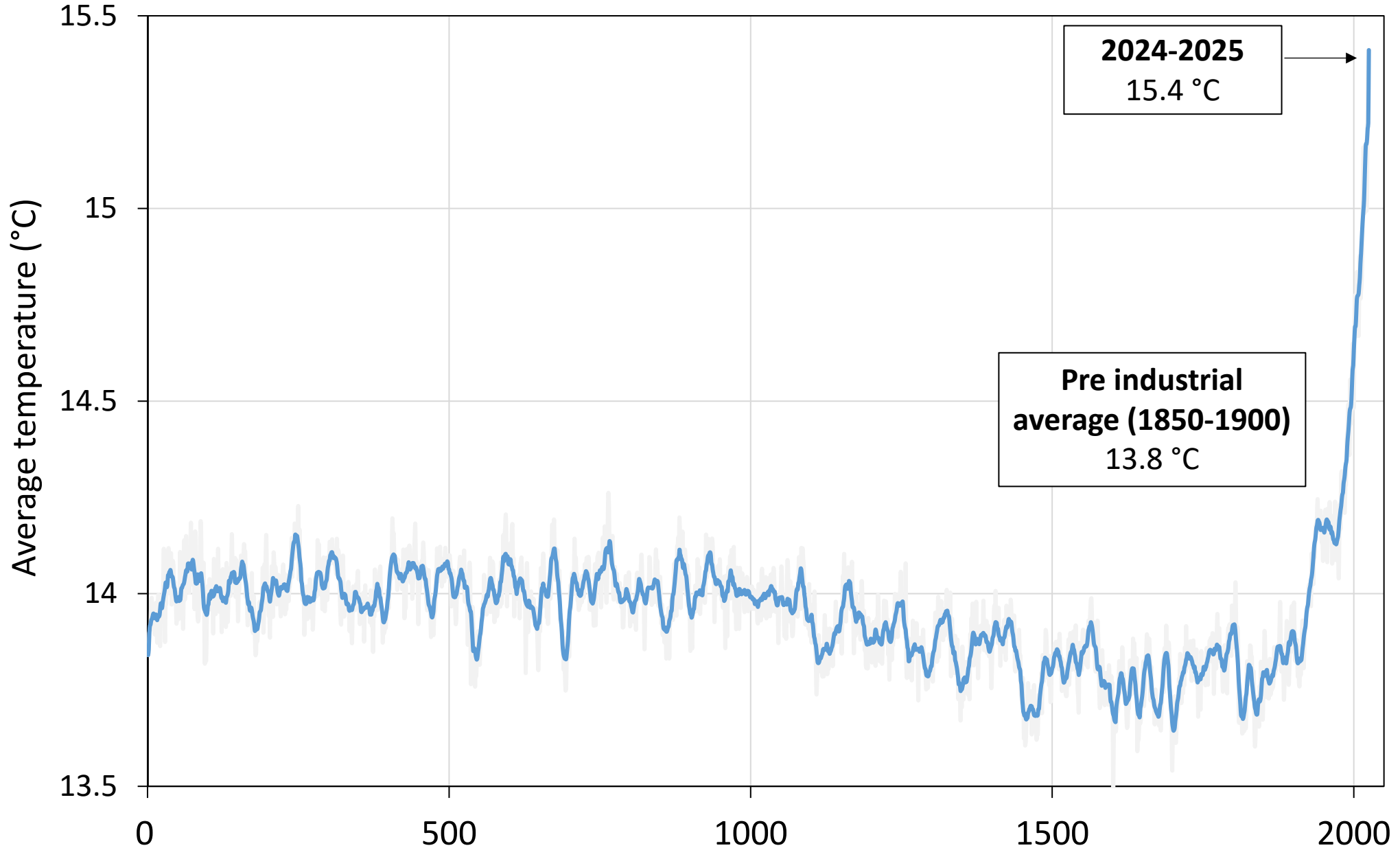
IPCC, AR6, Synthesis Report, 2023

Land and Ocean Temperatures 1850-2025

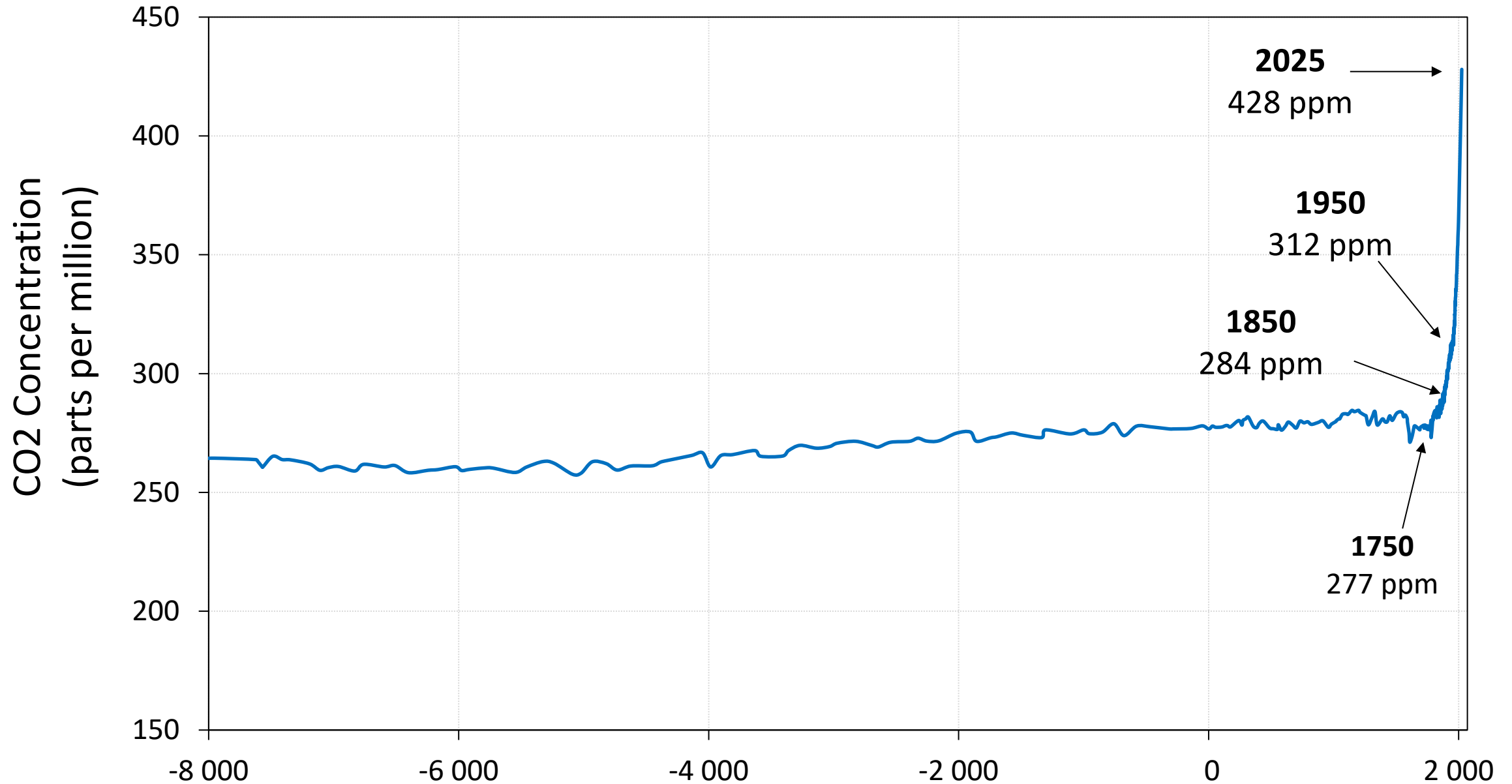


Temperature anomalies relative to 1850-1900 average and 95% confidence intervals
Land data from Berkeley Earth, ocean data adapted from HadSST after interpolation
Temperature anomalies for sea ice regions are calculated separately and not shown

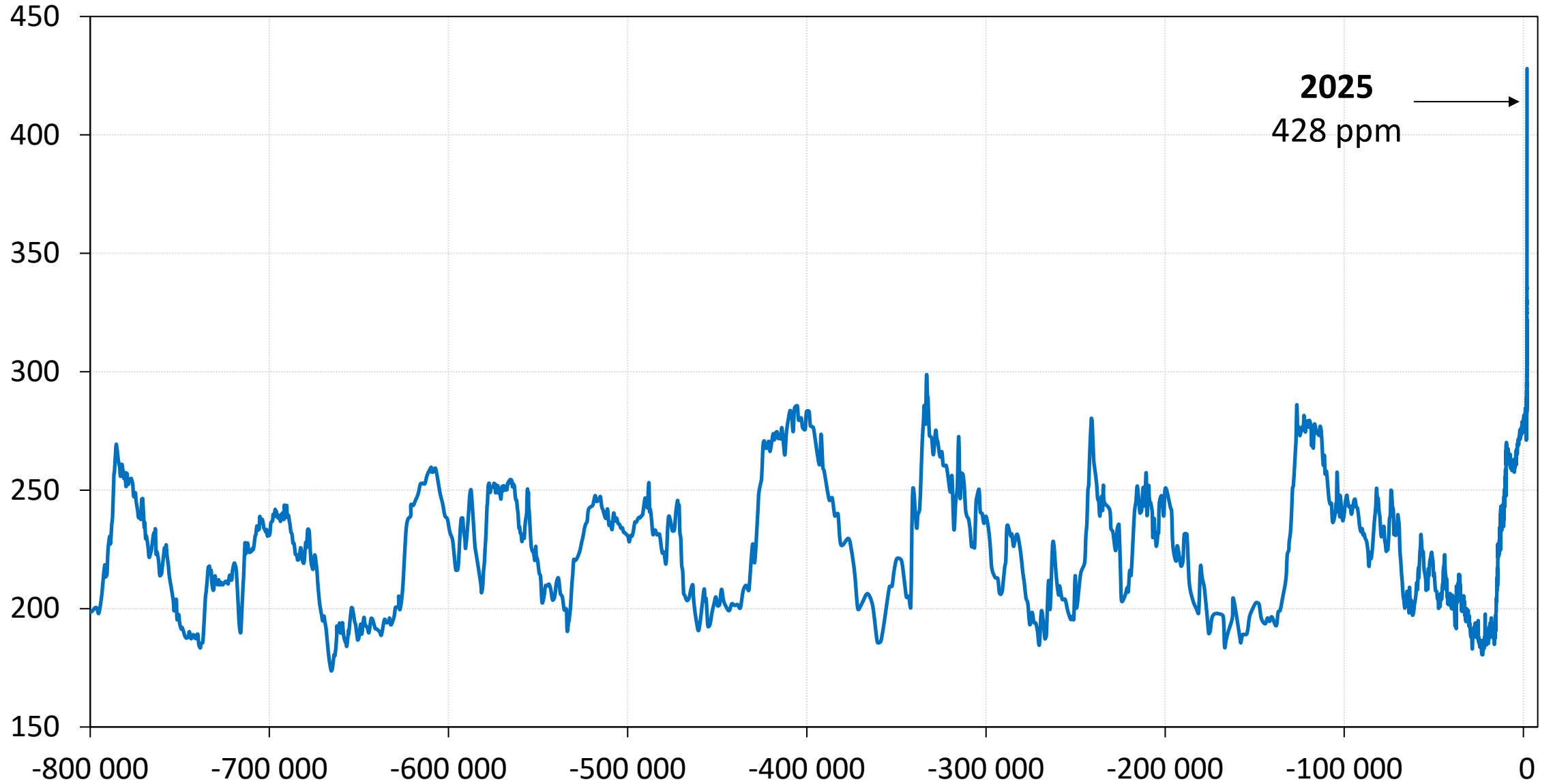
Global Warming 1850-2025 After the Little Ice Age (1500-1800)



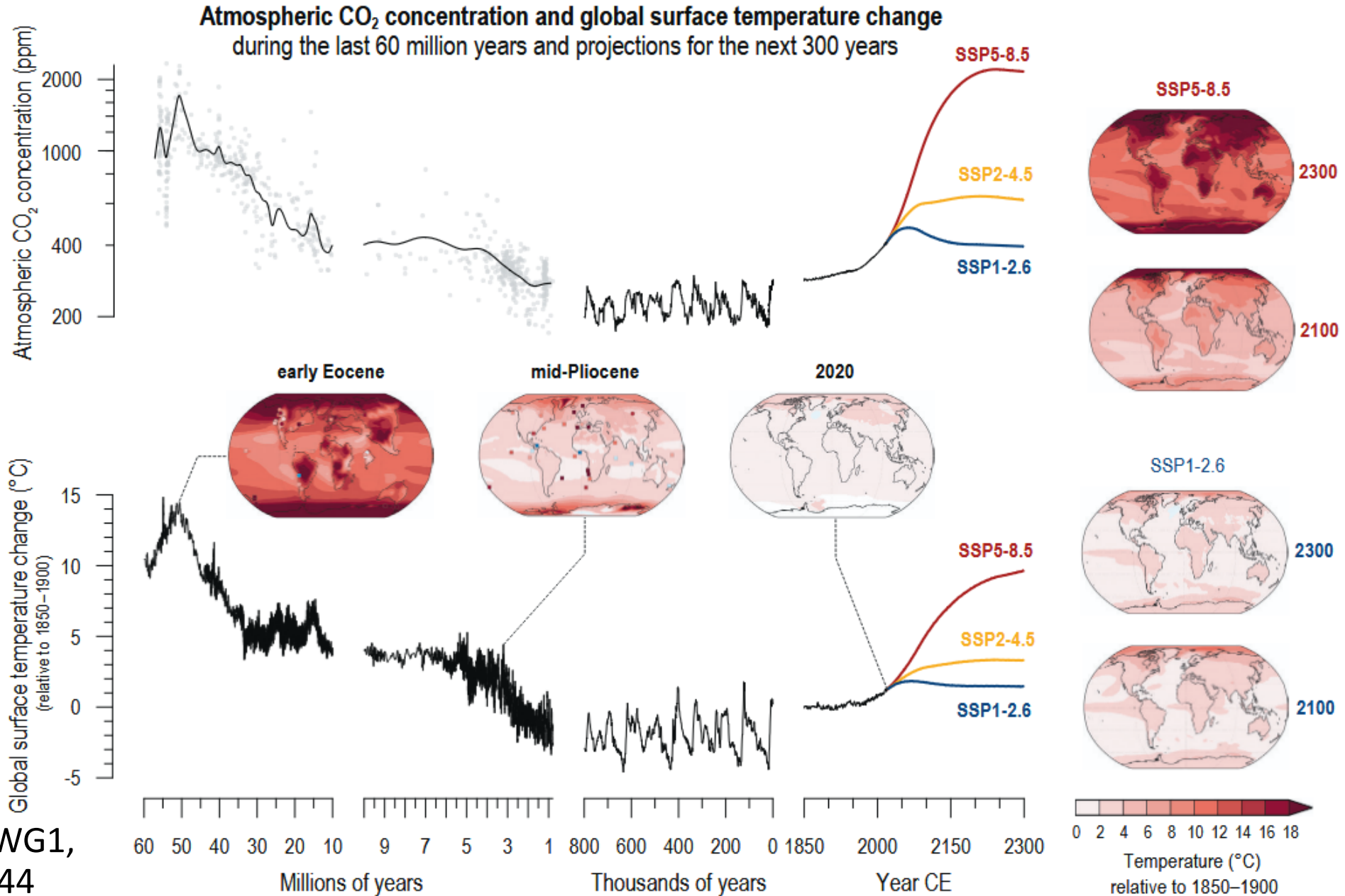
Global Warming Since 1850 Comes with Very Fast Rise in CO2 Concentration



Post-1850 CO2 Variations Are Much Larger Than in Previous Climate Cycles



Temperature & CO2 Variations: The Past 60 Million Years



Temperature, CO₂ & Sea Level Variations: The Past 60 Million Years

Reference period (*See Interactive Atlas for climate model output)	Age	CO ₂ (ppm)	Temperature (°C)	Sea level (m)
Recent past	1995–2014 CE	360 → 397	0.66 to 1.00	0.15 to 0.25
Approximate pre-industrial	1850–1900 CE	286 → 296	-0.15 to +0.11	-0.03 to 0.00
Last Millennium	850–1850 CE	278 to 285	-0.14 ~ 0.24	-0.05 to 0.03
Mid-Holocene*	6.5–5.5 ka	260 to 268	0.2 to 1.0	-3.5 to +0.5
Last Deglacial Transition	18–11 ka	193 → 271	not assessed	-120 → -50
Last Glacial Maximum*	23–19 ka	188 to 194	-5 to -7	-134 to -125
Last Interglacial*	129–116 ka	266 to 282	0.5 to 1.5	5 to 10
Mid-Pliocene Warm Period*	3.3–3.0 Ma	360 to 420	2.5 to 4.0	5 to 25
Early Eocene	53–49 Ma	1150 to 2500	10 to 18	70 to 76
Paleocene-Eocene Thermal Maximum	55.9–55.7 Ma	900 → 2000	10 to 25	not assessed

X to Y: *very likely* range (caveats in Figure 2.34)

X → Y: start to end of period, with no stated uncertainty

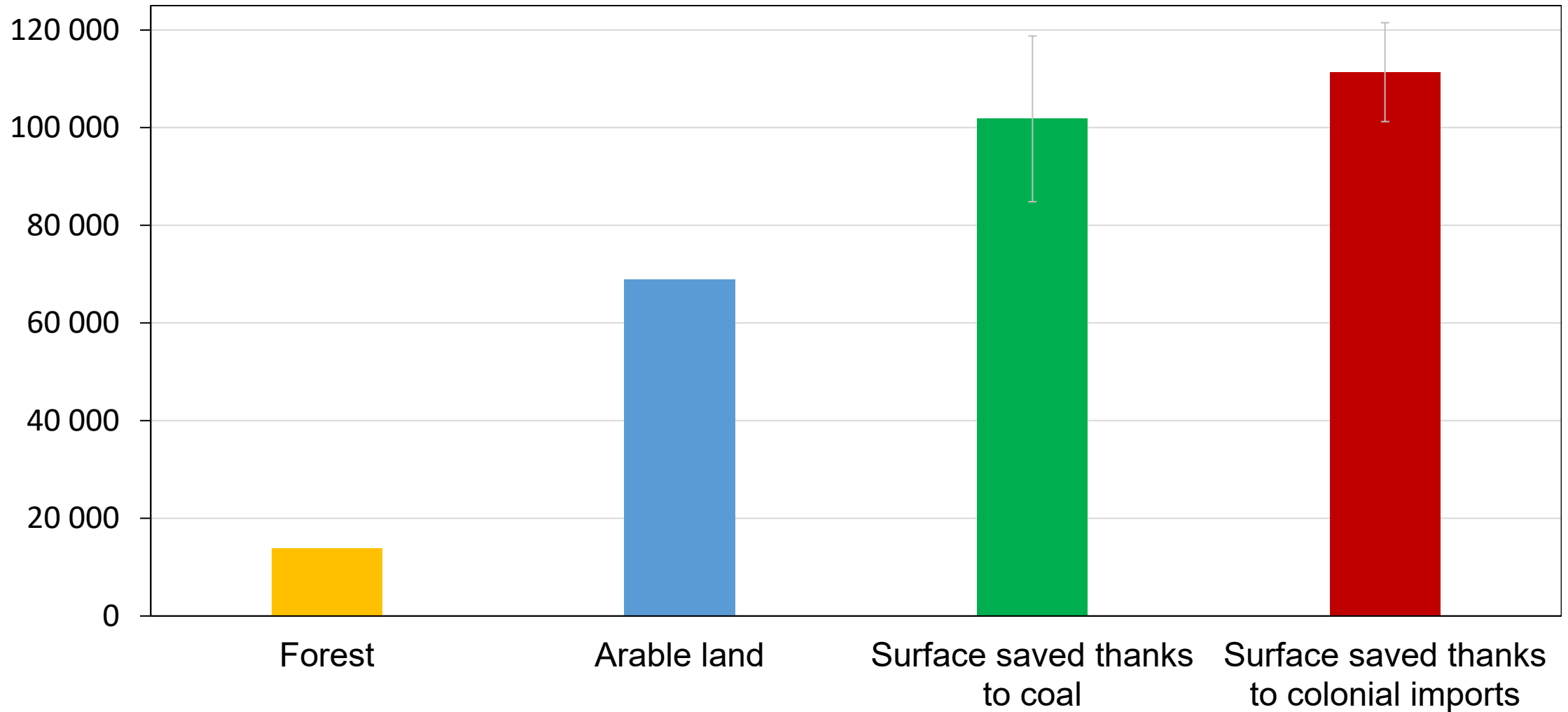
X ~ Y: lowest and highest values, with not stated uncertainty



The Ghost Hectares of the Industrial Revolution: Deforestation & Fossil Fuel Extraction in the Long-Run

- Pomeranz 2000: **Industrial Revolution made possible by massive deforestation & fossil extraction** (UK coal, US oil, etc.) & **by the colonial removal of the ecological constraint** (wood, cotton, minerals, etc.)
- A more sustainable & equitable Industrial Revolution is conceivable, but it would have involved a substantially different distribution of wealth, power and well-being between countries & social classes
- Deforestation played a major role early on, followed by coal, followed by oil and gas. About 70% of total emissions occurred since 1970 & 50% since 1990.
- **Land-use changes** (deforestation) & **agriculture** (esp. cattle) **still play a major role in GHG emissions today and in future prospects to reach net zero emissions by 2050-2100** (highly uncertain)

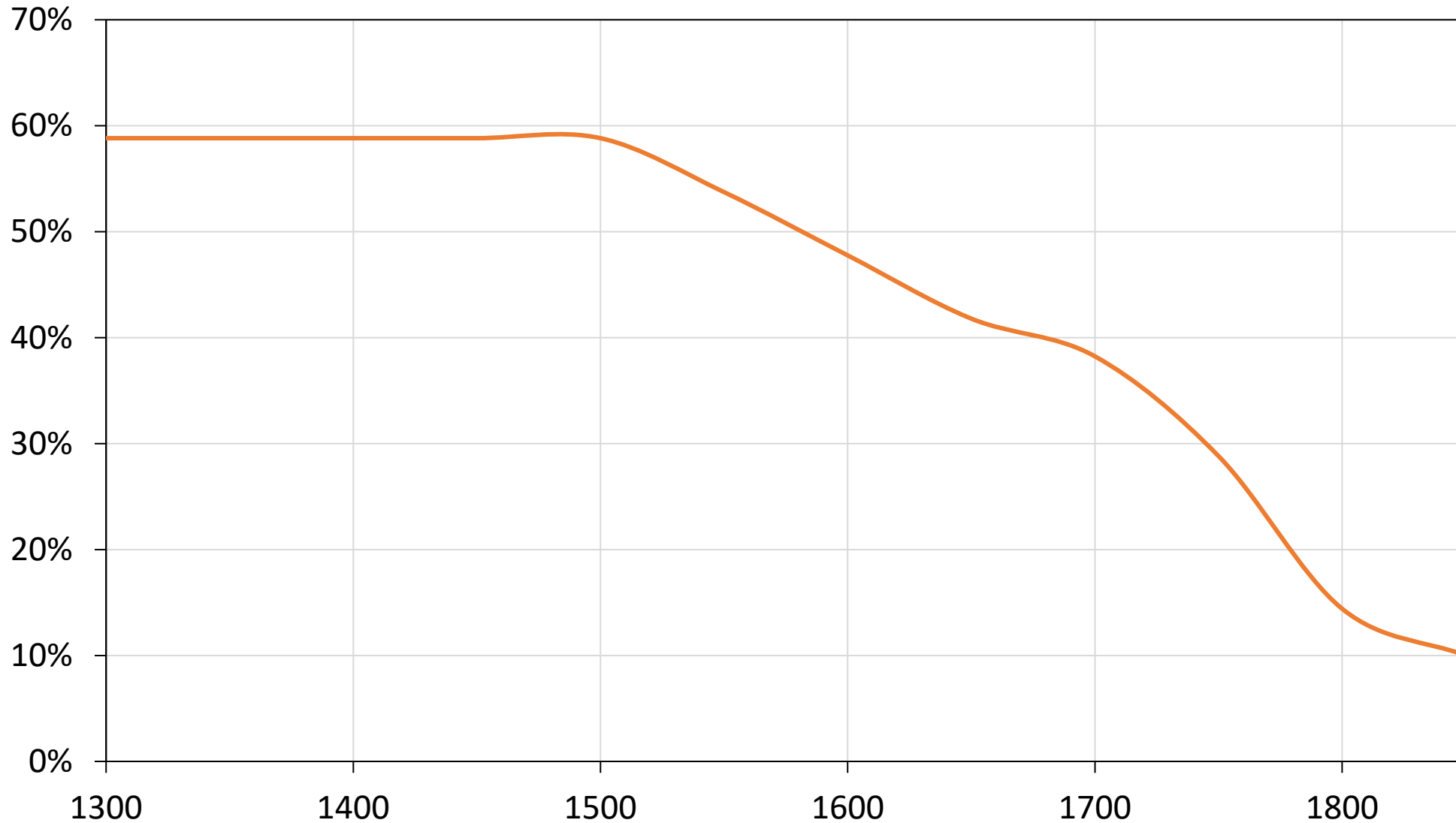
The Ghost Hectares of the Industrial Revolution (England 1830)



Source : Surface in km2. Chancel 2025 based on Pomeranz 2000.

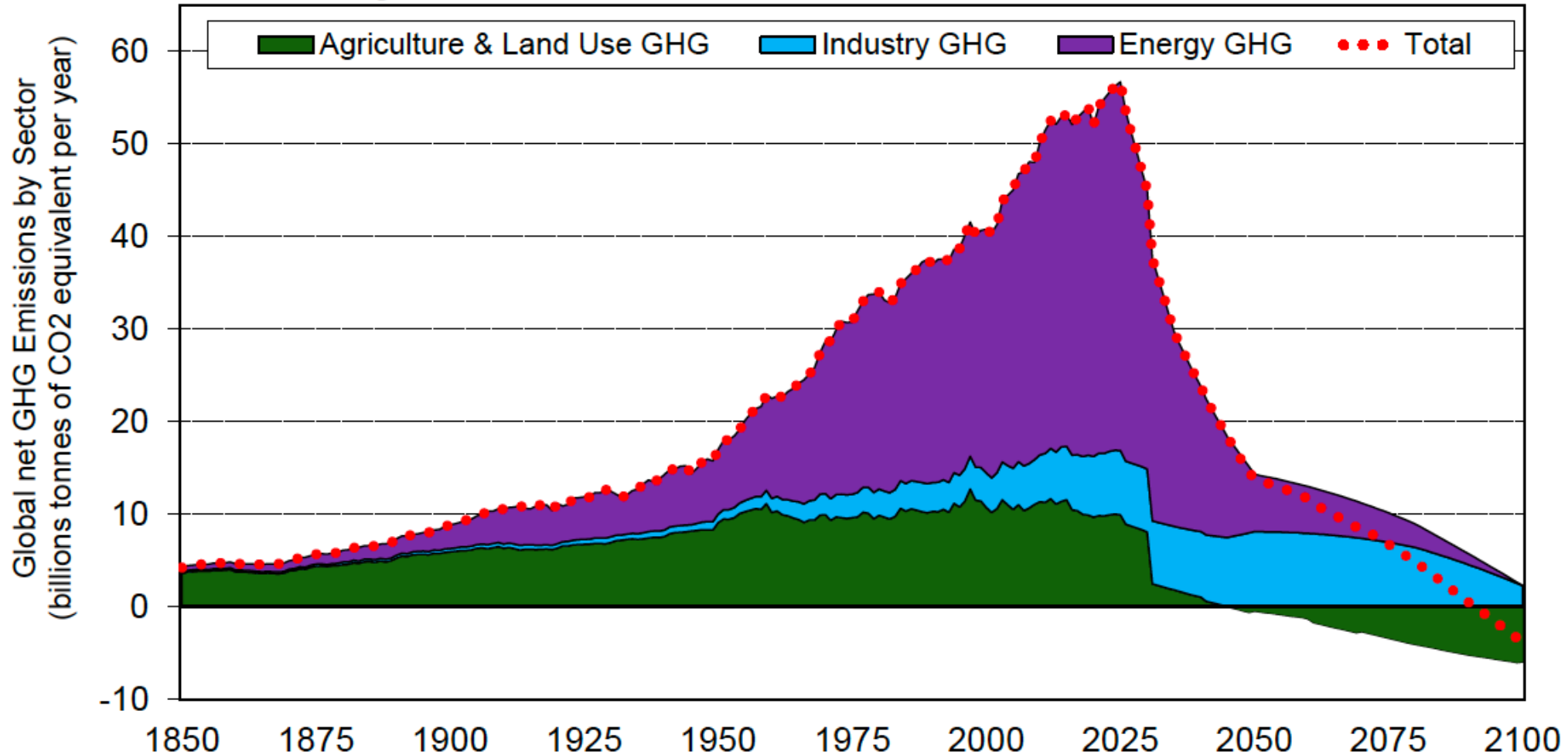
The Rise of Enclosures & the Fall of Commons

(Share of Commons in total Land Surface)



Source : Chancel 2025 based on Allen, Robert. "English and welsh agriculture, 1300-1850: outputs, inputs, and income." OUP 2005 (Table 1).

Sustainable Convergence and Fast Decarbonization: The Key Role of Fossil Fuels Phase-Out & Deforestation Ban



Interpretation. Under the sustainable convergence/fast decarbonization scenario, the sharp decline of GHG emissions over the 2026-2100 period is made possible by the rapid phase-out of fossil fuels (fall of Energy GHG) and a strict deforestation ban enforced in 2030, followed by gradual reforestation bringing world forest cover back to 1900 level by 2100 (leading to negative Agriculture & Land-Use GHG in 2050-2100, and slight negative total net GHG emissions by 2100). In contrast, Industry GHG (cement, waste, etc.) are more difficult to remove entirely.

Note: Observed series 1850-2025. Projected series 2026-2100 (Sustainable Convergence Scenario with Fast Decarbonization). **Sources and series:** wseed.world (X2)

Global GHG Emissions in 2025

	Emissions (GtCO ₂ e)	Emissions (% Total)
All sectors	56.7	100%
Fossil Fuels Energy	39.8	70%
<i>incl. Fossil CO₂ (coal/oil/gas burning)</i>	36.2	64%
<i>incl. Fossil other GHG (coal/gas production)</i>	3.6	6%
Agriculture & Land Use Changes	9.9	18%
<i>incl. Agr. Land Use CO₂ (deforestation)</i>	3.6	6%
<i>incl. Agr. Land Use other GHG (cattle)</i>	6.3	11%
Industrial Processes	6.9	12%
<i>incl. Industry CO₂ (cement, etc.)</i>	2.7	5%
<i>incl. Industry other GHG (chemicals, waste)</i>	4.2	7%

Interpretation. In 2025, 70% of GHG (greenhouse gases) emissions come from fossil fuels energy, 18% from agriculture & land-use changes and 12% from industrial processes. **Note.** For details on categories see online replication package. All greenhouse gases (CO₂ and other GHG: methane (CH₄), nitrous oxide (N₂O), etc.) are expressed in gigatonnes of CO₂ equivalents. **Sources:** wseed.world (X2)

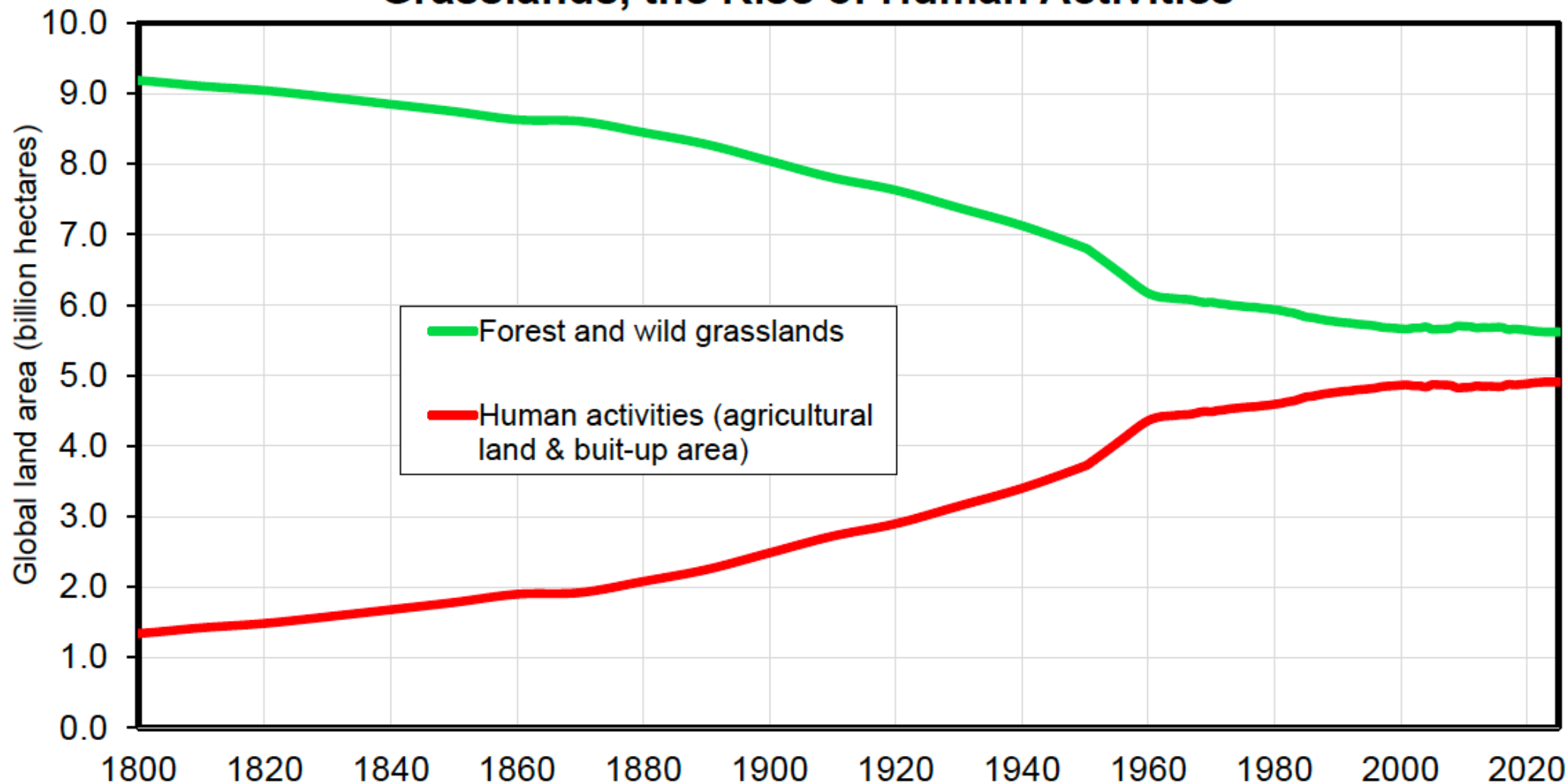
Global land area (2025)

	Area (billion hectares)	% total
Total land area	14.8	100%
<i>incl. Human activities</i>	4.9	33%
<i>incl. Built up area</i>	0.1	1%
<i>incl. Grazing land (cattle)</i>	3.2	22%
<i>incl. Cropland</i>	1.6	11%
<i>incl. Forest & wild grasslands</i>	5.6	38%
<i>incl. Forests</i>	4.1	28%
<i>incl. Wild grasslands & shrubs</i>	1.5	10%
<i>incl. Other Barren Land</i> (mountains, deserts..)	4.3	29%

Interpretation. Global land area amounts to about 14.8 billions hectares in 2025, including approximately 33% used by human activities (mostly grazing land and cropland), 38% in forests and wild grasslands and 29% in other barren land (mountains, deserts, etc.).

Sources and series: wseed.world (U1a)

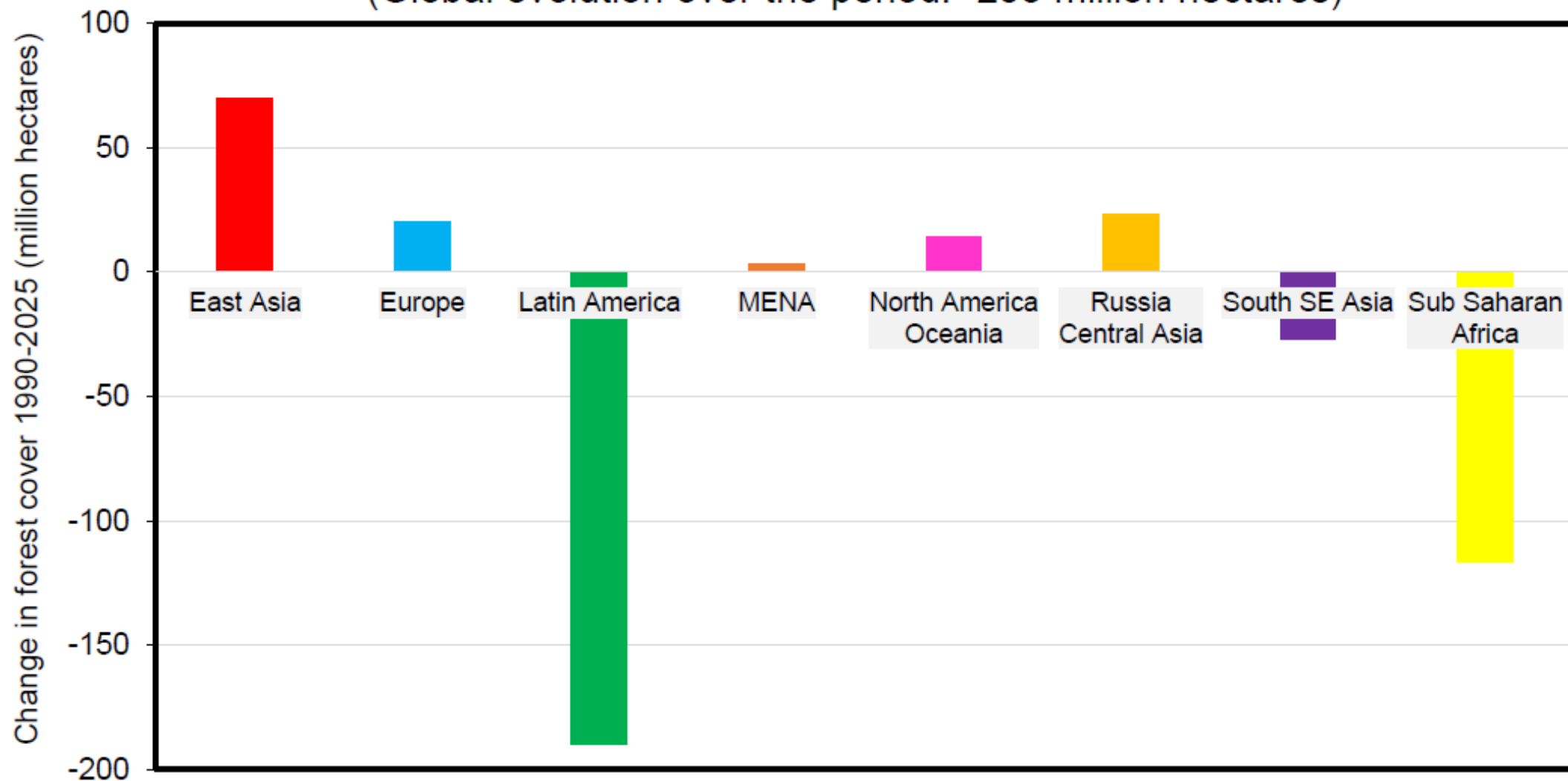
Global Land Use, 1800-2025: the Decline of Forest & Wild Grasslands, the Rise of Human Activities



Interpretation. Global land area covered by forest & wild grasslands declined from about 9.2 billion hectares in 1800 (incl. 5.2 for forest and 4.0 for wild grasslands) to 8.0 billion in 1900 (incl. 4.8 and 3.2) and 5.6 billion in 2025 (incl. 4.1 and 1.5). Land area covered by human activities rose from 1.3 billion in 1800 to 2.5 billion in 1900 and 4.9 billion in 2025 (including 4.8 for agricultural land and 0.1 for built-up area). **Note.** Total land area also includes about 4.3 billion in other barren land (mountains, deserts, etc.), which has been approximately constant over time. **Sources and series:** wseed.world (U1a)

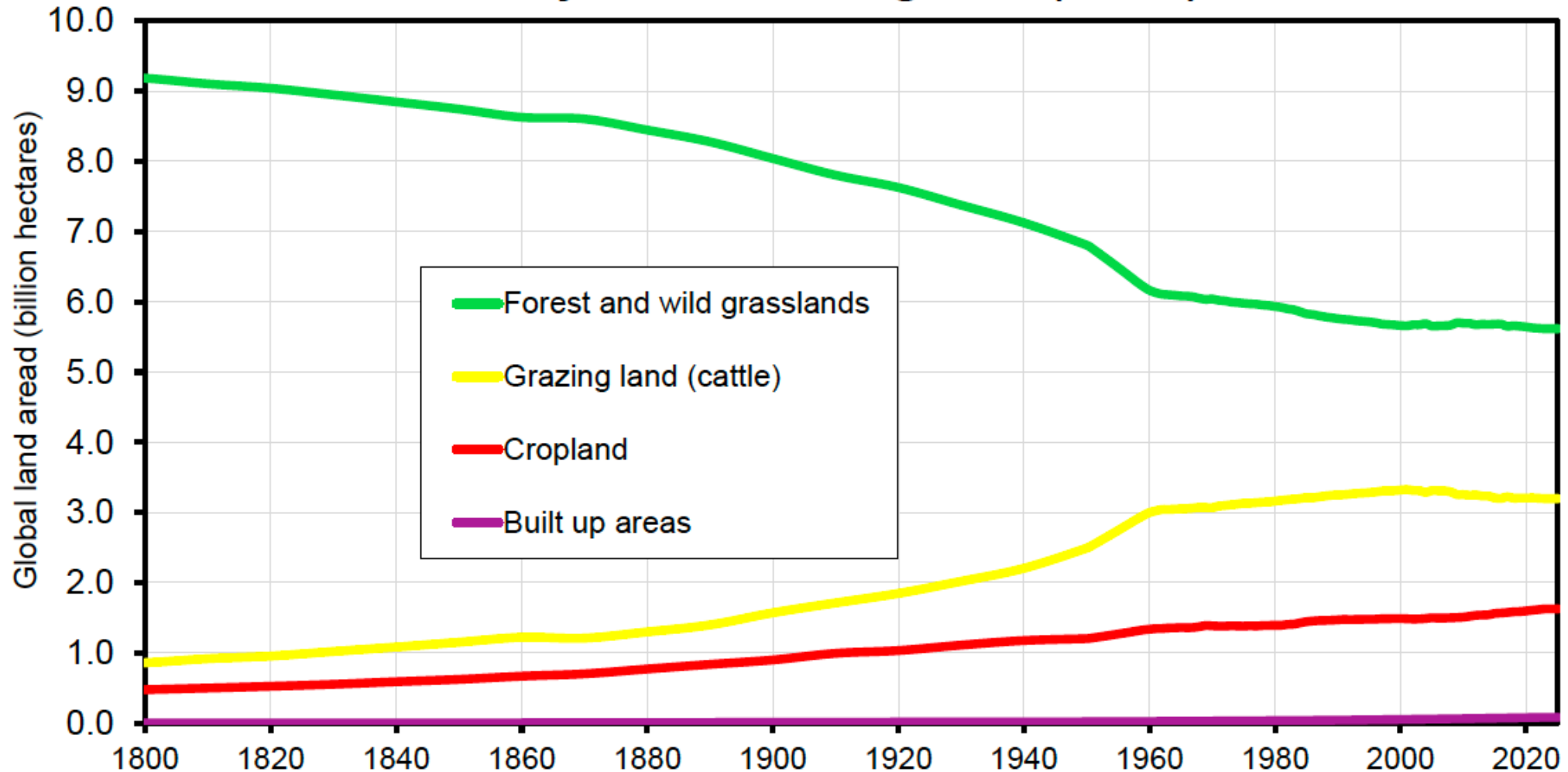
The Continuing Fall in Forest Cover 1990-2025

(Global evolution over the period: -203 million hectares)



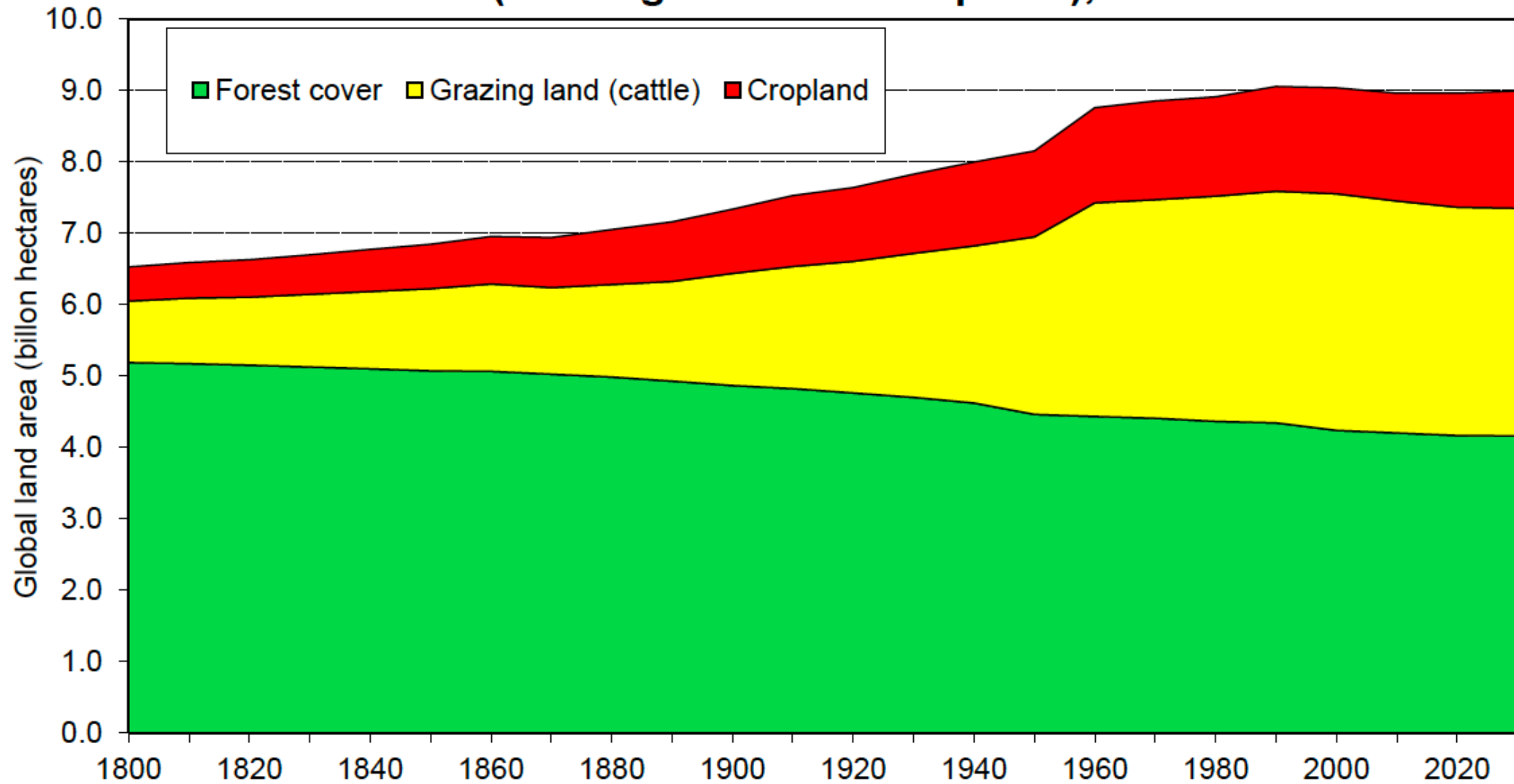
Interpretation. Global forest area declined by 203 millions hectares between 1990 and 2025 (in line with the long run decline of about 1.1 billion hectares observed between 1800 and 2025). This continued global forest decline results from large deforestation in the global South (Latin America, Sub-Saharan Africa, South & South-East Asia) and small reforestation in the global North (East Asia, Europe, North America, Russia). In addition, the areas which are currently under deforestation include denser forests with much stronger CO₂ absorption capacities per hectare (two to three times larger) than the areas under reforestation. **Sources and series:** wseed.world (U2)

The Great Transformation of Global Land Use 1800-2025: The Key Role of Grazing Land (Cattle)



Interpretation. Global land area covered by forest and wild grasslands declined from about 9.2 billions hectares in 1800 to 8.0 billions in 1900 and 5.6 billions in 2025. In the meantime land area covered by human activities rose from 1.3 billions in 1800 to 2.5 billions in 1900 and 4.9 billions in 2025 (including 3.2 for grazing land, 1.6 for cropland and 0.1 for built-up area). **Note.** Total land area also includes about 4.3 billions in other barren land (mountains, deserts, etc.), which has been approximately constant over time. **Sources and series:** wseed.world (U1b)

The Replacement of Global Forest Cover by Agricultural Land (Grazing Land and Cropland), 1800-2025



Interpretation. Global forest cover dropped from about 5.2 billions hectares in 1800 to 4.1 billions in 2025. In the meantime, agricultural land rose from 1.3 billions in 1800 (including 0.8 in grazing land and 0.5 in cropland) to 4.8 billions in 2025 (including 3.2 in grazing land and 1.6 in cropland). The expansion of agricultural land was made possible both by the decline of forest cover (deforestation) and the fall of wild grasslands.

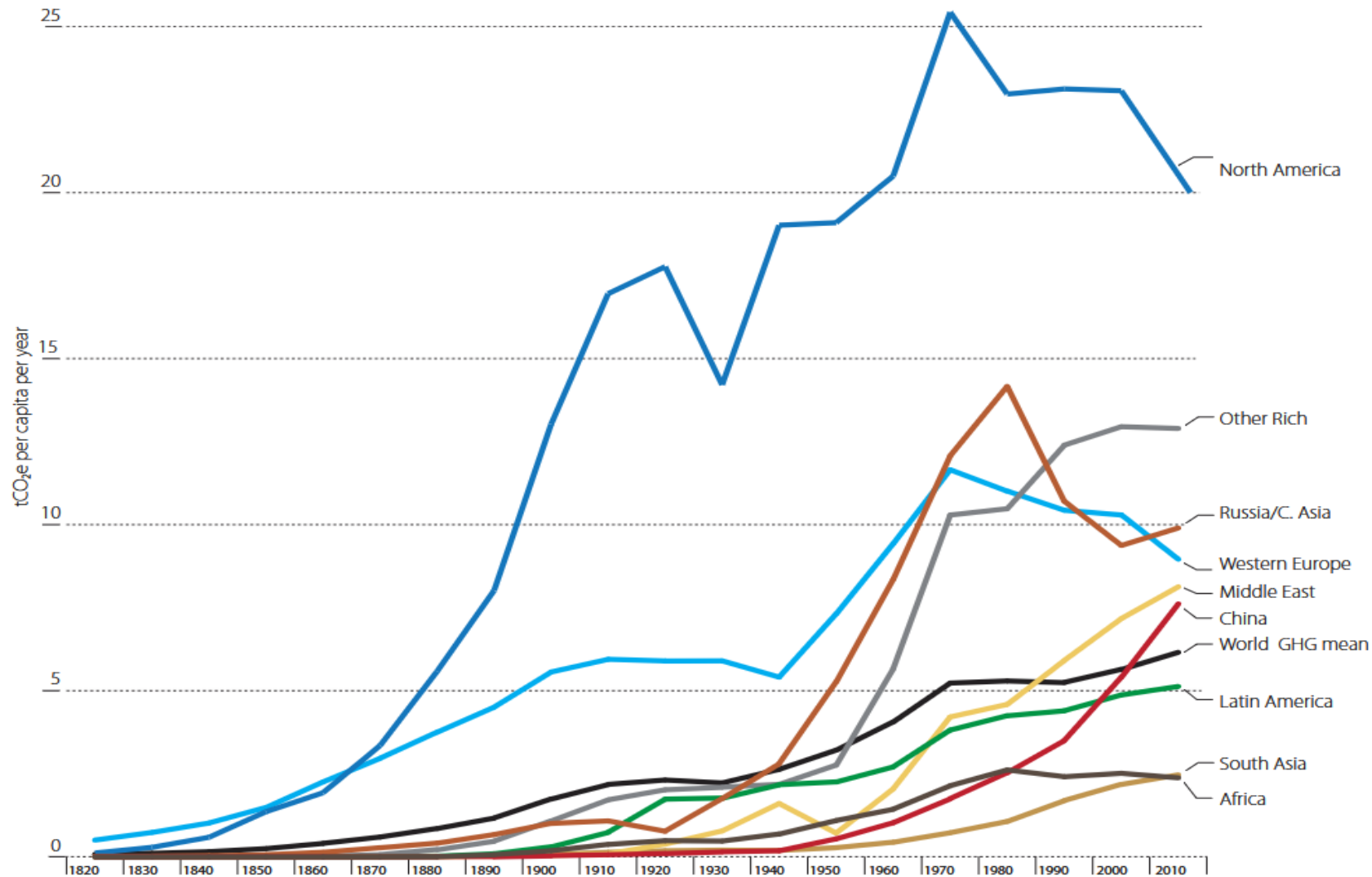
Sources and series: wseed.world (U1c)

The Mismatch between Responsibilities & Damages

- **The countries (& social classes within these countries) with the largest responsibilities in terms of emissions are not the same as those suffering the largest climate damages.** Even more true if we adopt capital ownership perspective rather than standard consumption perspective.
- **UNFC CC, Art.3.1: “Common But Differentiated Responsibilities and Respective Capabilities”** (UN Framework Convention on Climate Change, adopted in Rio 1992 → COPs until today, useful but blocked by unanimity rule)
- **The question of how to formalize and translate this principle into quantitative policies on climate finance and reparations remains unresolved and conflictual (North vs South).** See e.g. [Climate Equity Monitor \(India\)](#) & [Global Justice Project](#)
- **Need to develop new global initiatives: UNFC ITC (International Tax Cooperation)** (scheduled adoption 2027-28, majority rule, & without the US so far)
Or maybe **UNFC GJ (Global Justice)** ?

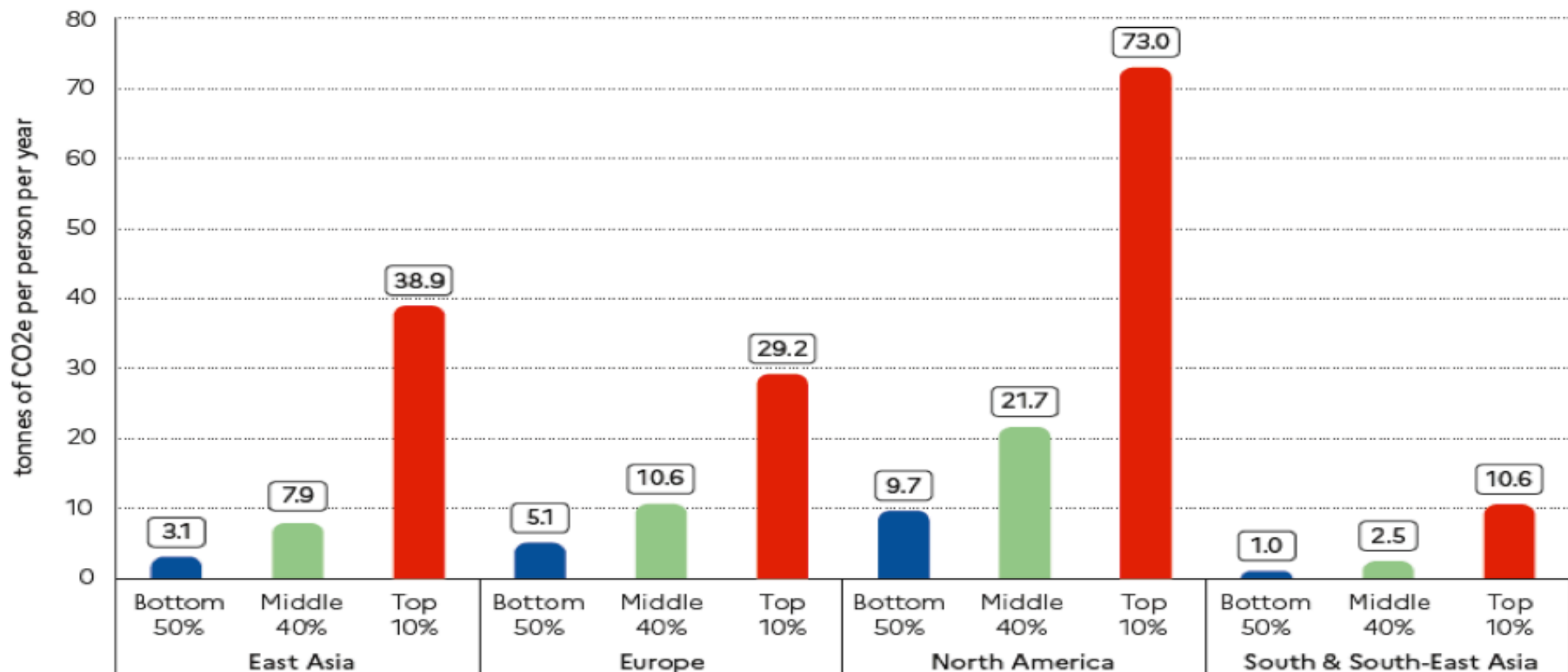
Per Capita Territorial CO₂e Emissions 1820-2020:

From 2-3 Tons in Africa & South Asia to 20+ Tons in North America
(≈70% of Historical Emissions 1820-2020 due to 15% of World Pop)



Chancel-
Piketty
2015
« From
Kyoto to
Paris »

Figure 15 Per capita emissions across the world, 2019



Interpretation: Personal carbon footprints include emissions from domestic consumption, public and private investments as well as imports and exports of carbon embedded in goods and services traded with the rest of the world. Modeled estimates based on the systematic combination of tax data, household surveys and input-output tables. Emissions split equally within households. **Sources and series:** wir2022.wid.world/methodology and Chancel (2021).

Emissions are highly concentrated among the rich, especially when looking at ownership.

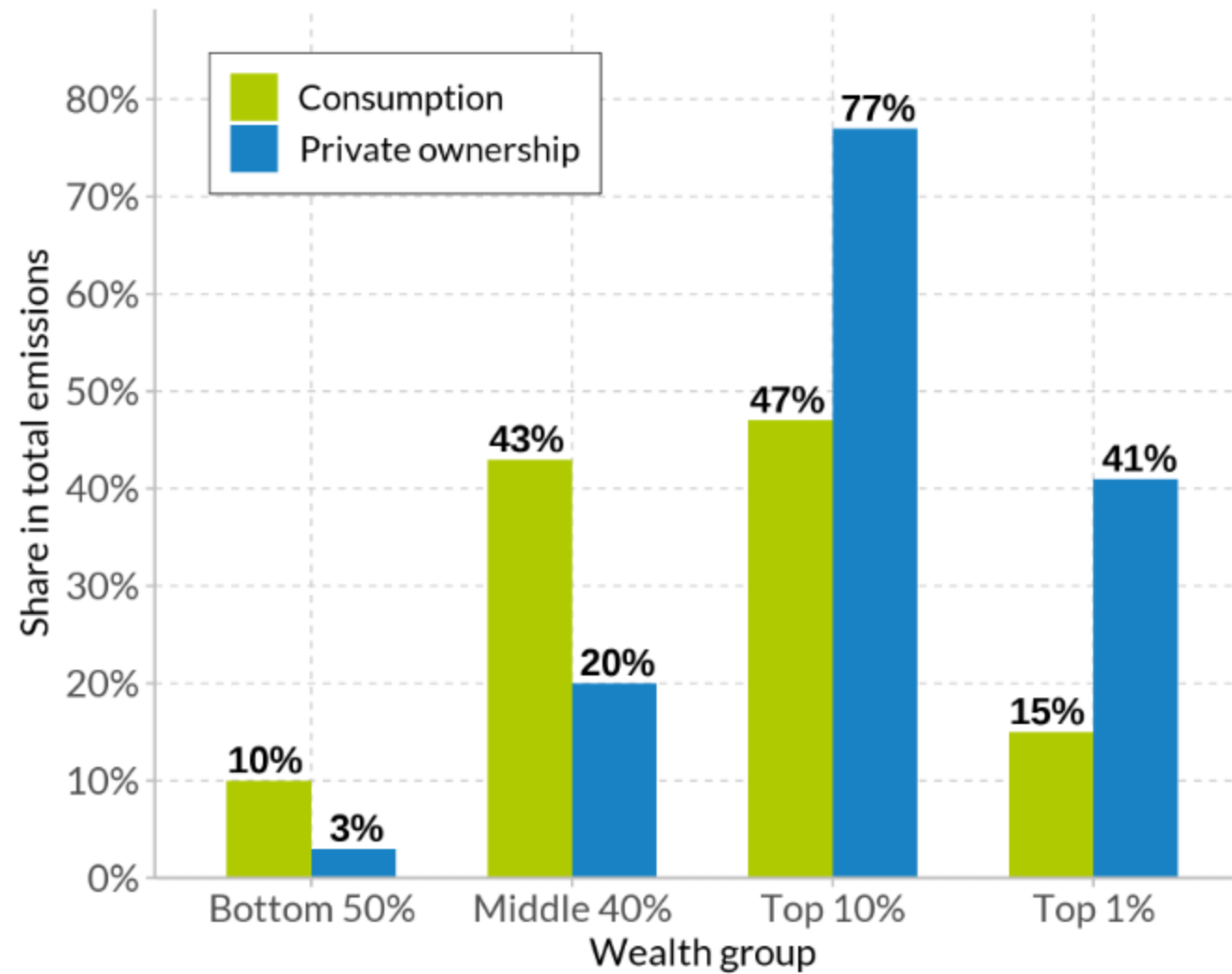
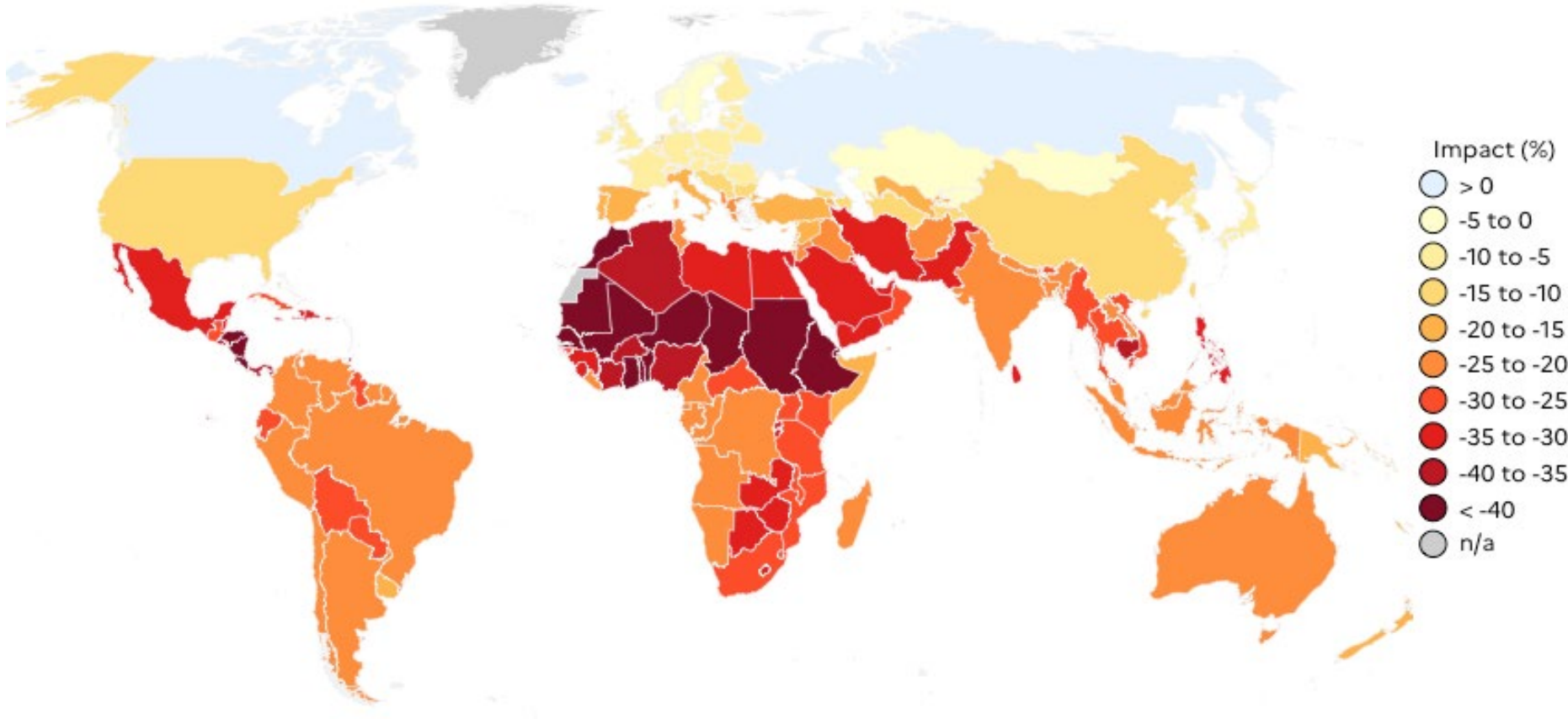


Figure 1.1. Emissions shares of global wealth groups

Impact of Climate Change on Agricultural Productivity 1960-2015



Source: Chancel Bothe Voituriez 2023, based on Ortiz Bobea et al. 2021

Relative climate losses are highly concentrated among the global bottom 50%.

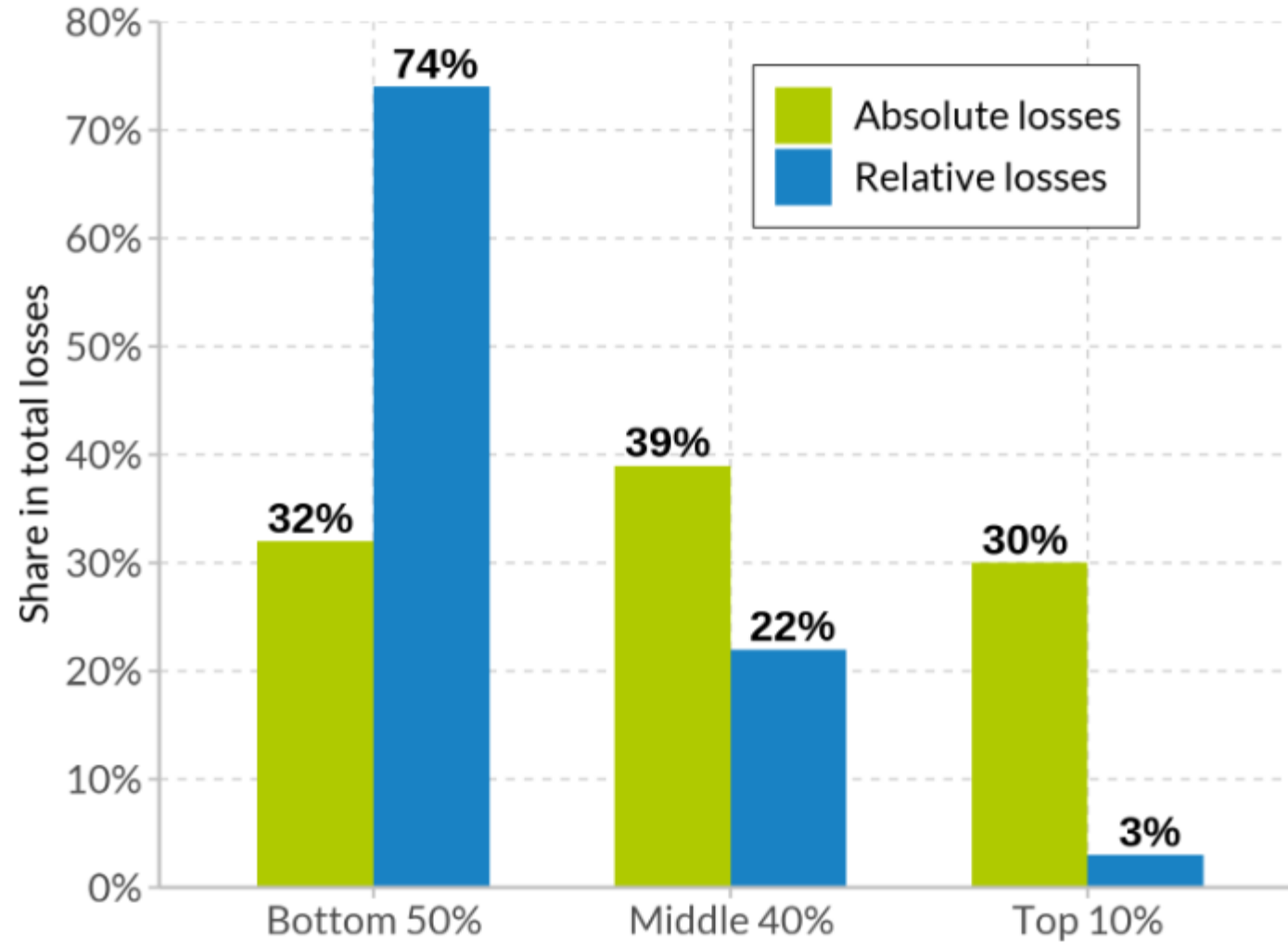


Figure 2.1. Distribution of climate losses in 2050

Triple climate inequality: the poorest lose the most, contribute the least, and lack the means to act.

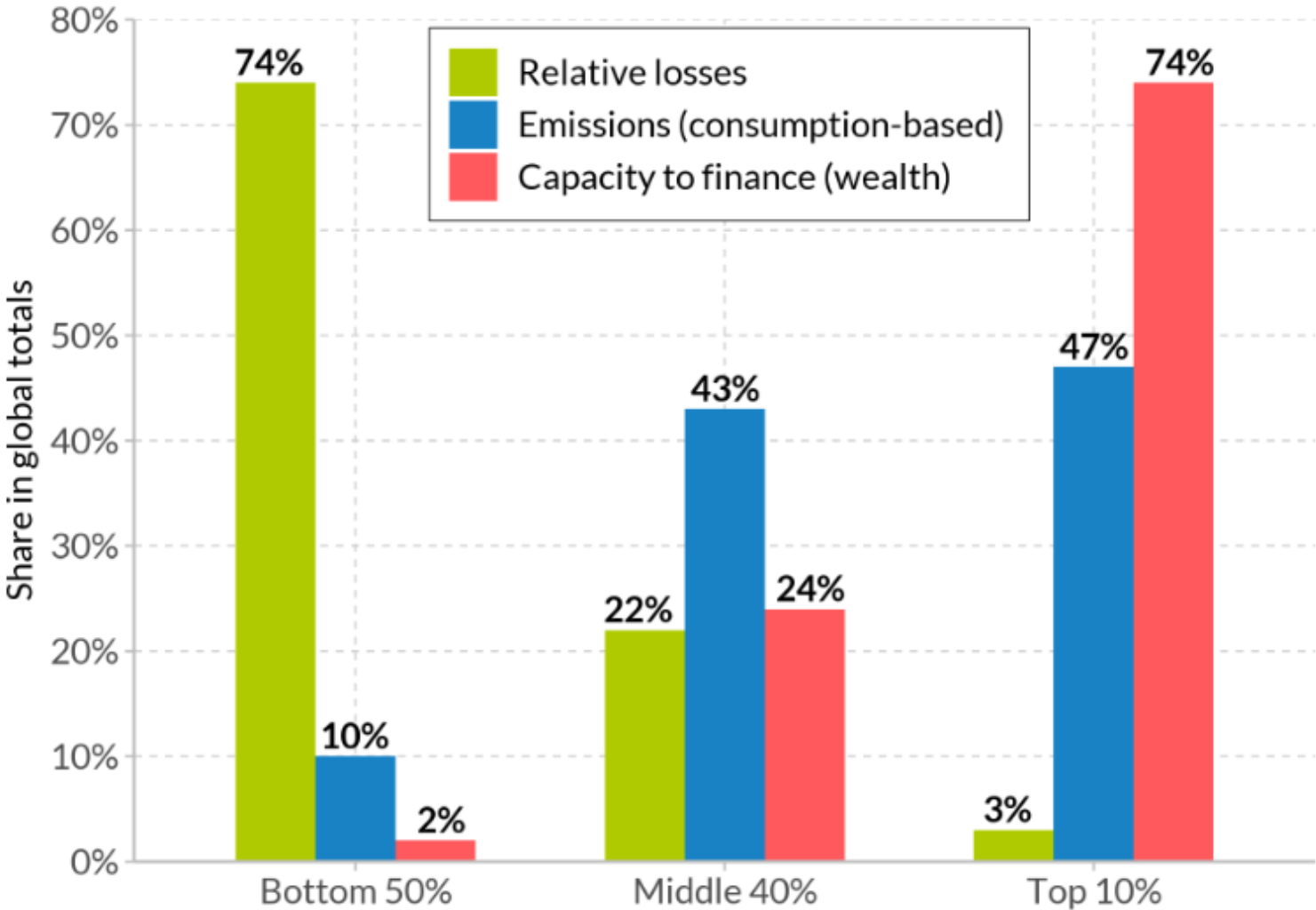


Figure I.1. Global climate inequality: relative losses, emissions, and capacity to finance

Energy Systems in Comparative & Historical Perspective



Jean-Baptiste
Fressoz

**SANS
TRANSITION**

Une nouvelle
histoire
de l'énergie



ÉCOCÈNE SEUIL

2024



2025



Jean-Baptiste Fressoz

**MORE
AND
MORE
AND
MORE**

'Gobsmacking'
ECONOMIST

An All-Consuming History

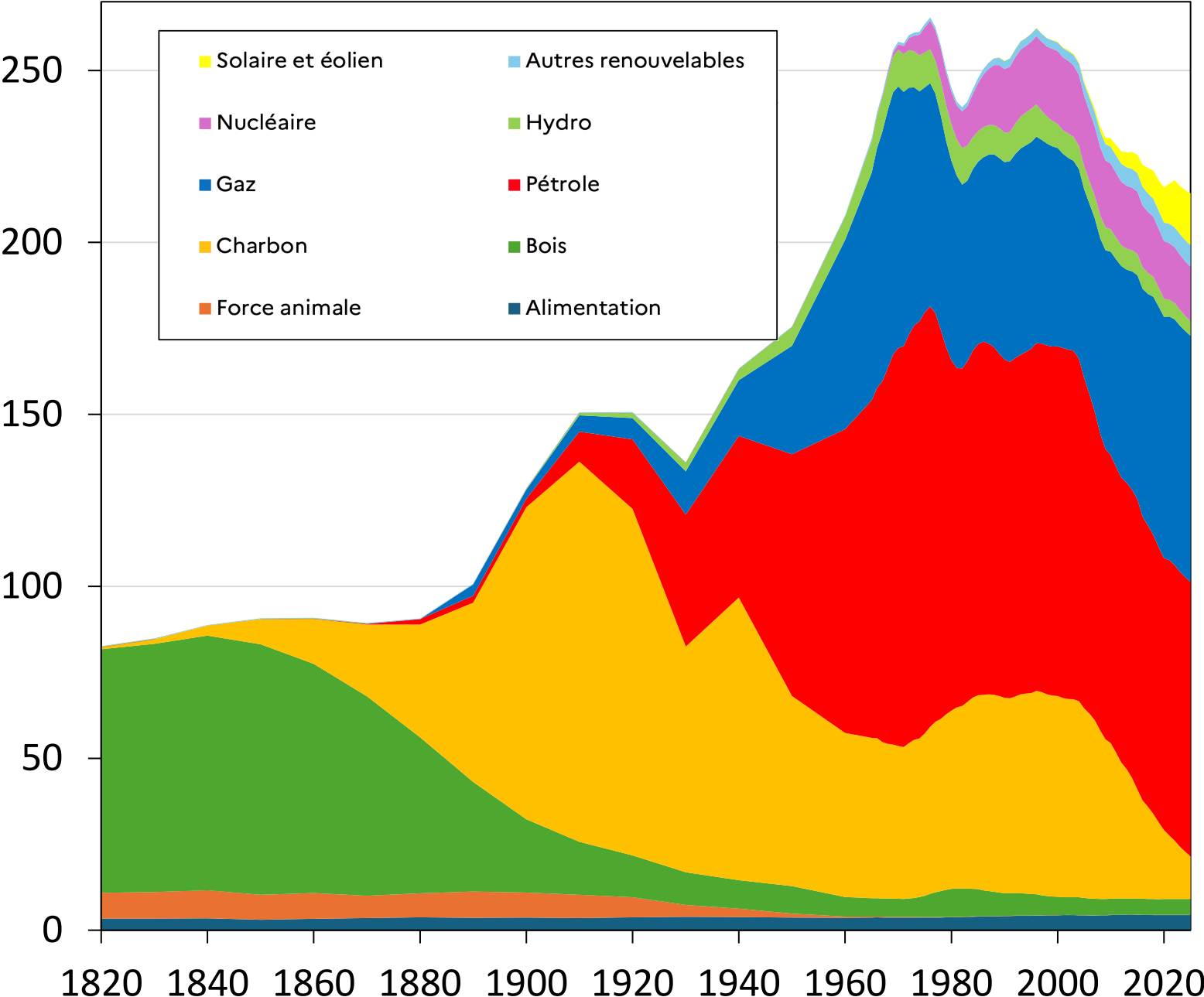
LUCAS **CHANCEL**

**ÉNERGIE
ET
INÉGALITÉS** ÉCO-HISTOIRES
**UNE HISTOIRE
POLITIQUE**

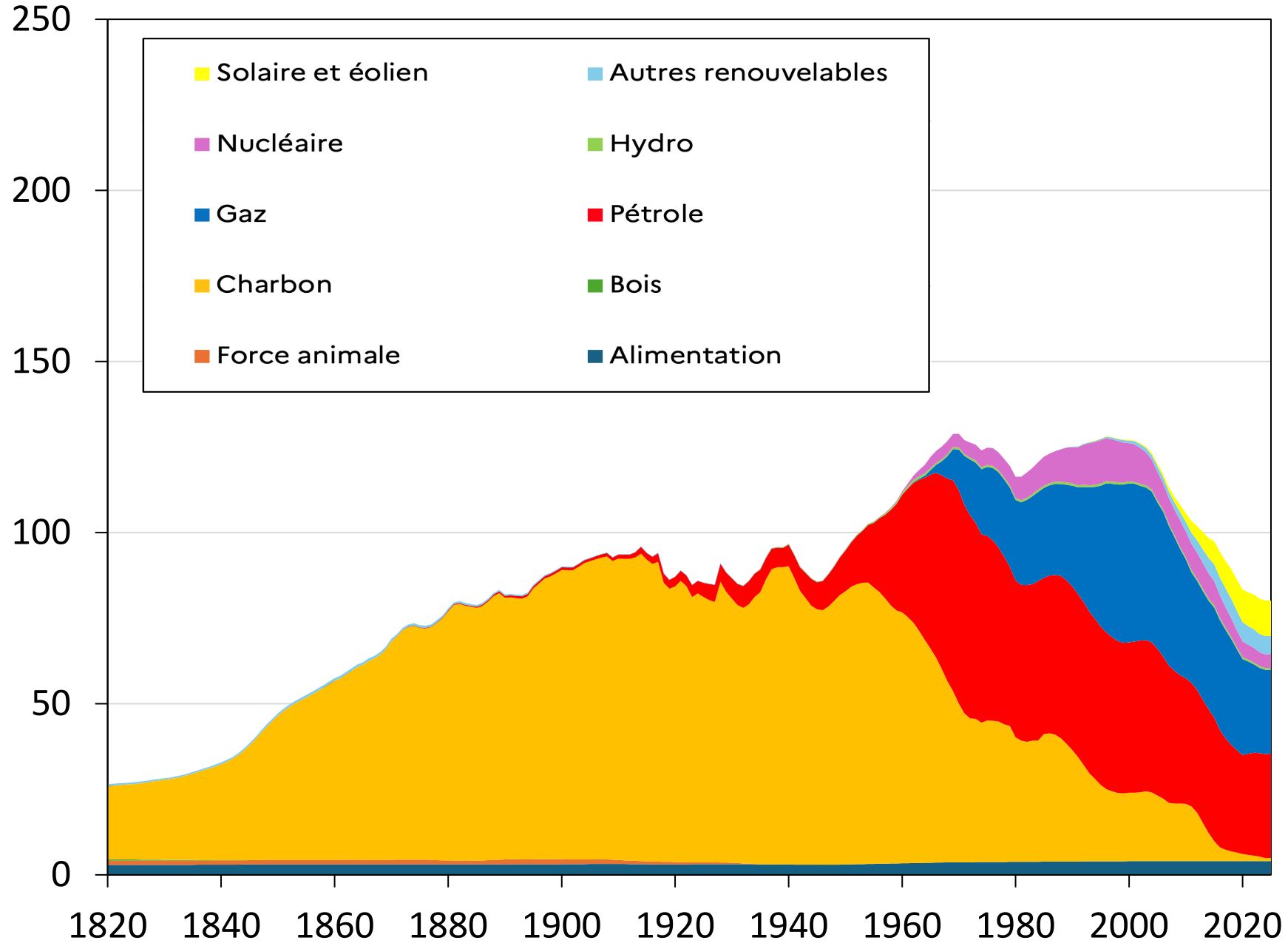
SEUIL

2025

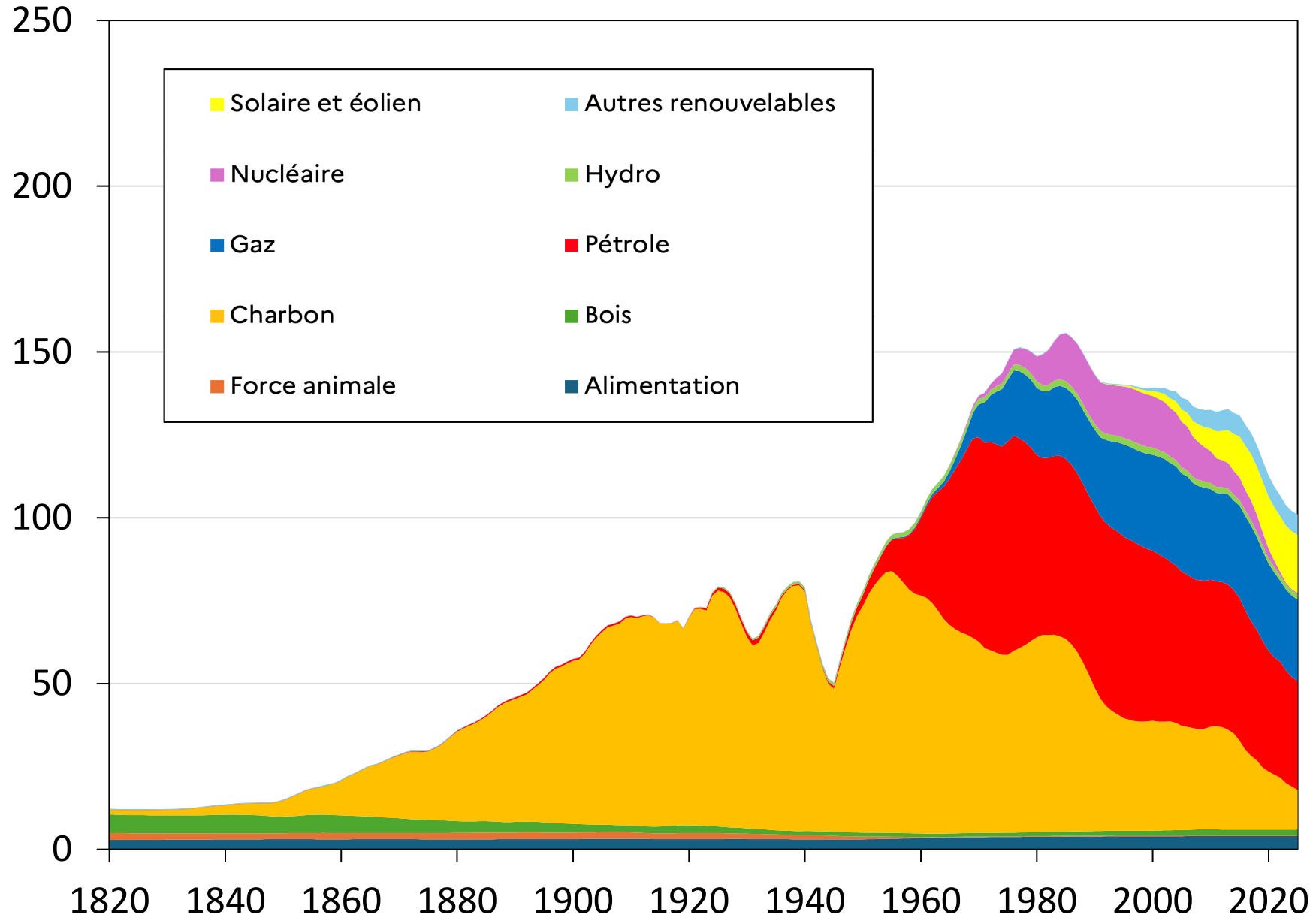
Energy Mix: USA (kWh per capita per day)



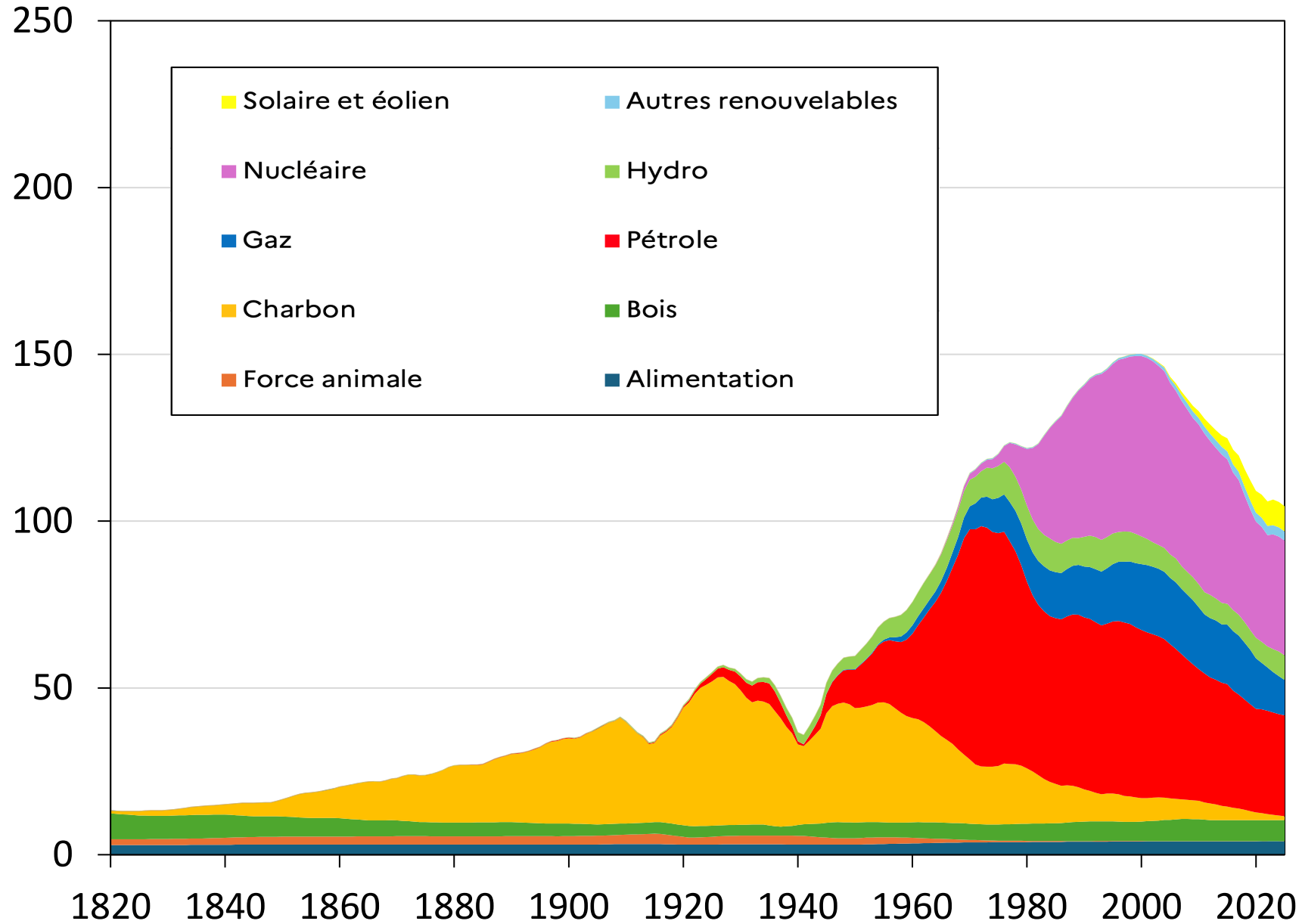
Energy Mix: UK (kWh per capita per day)



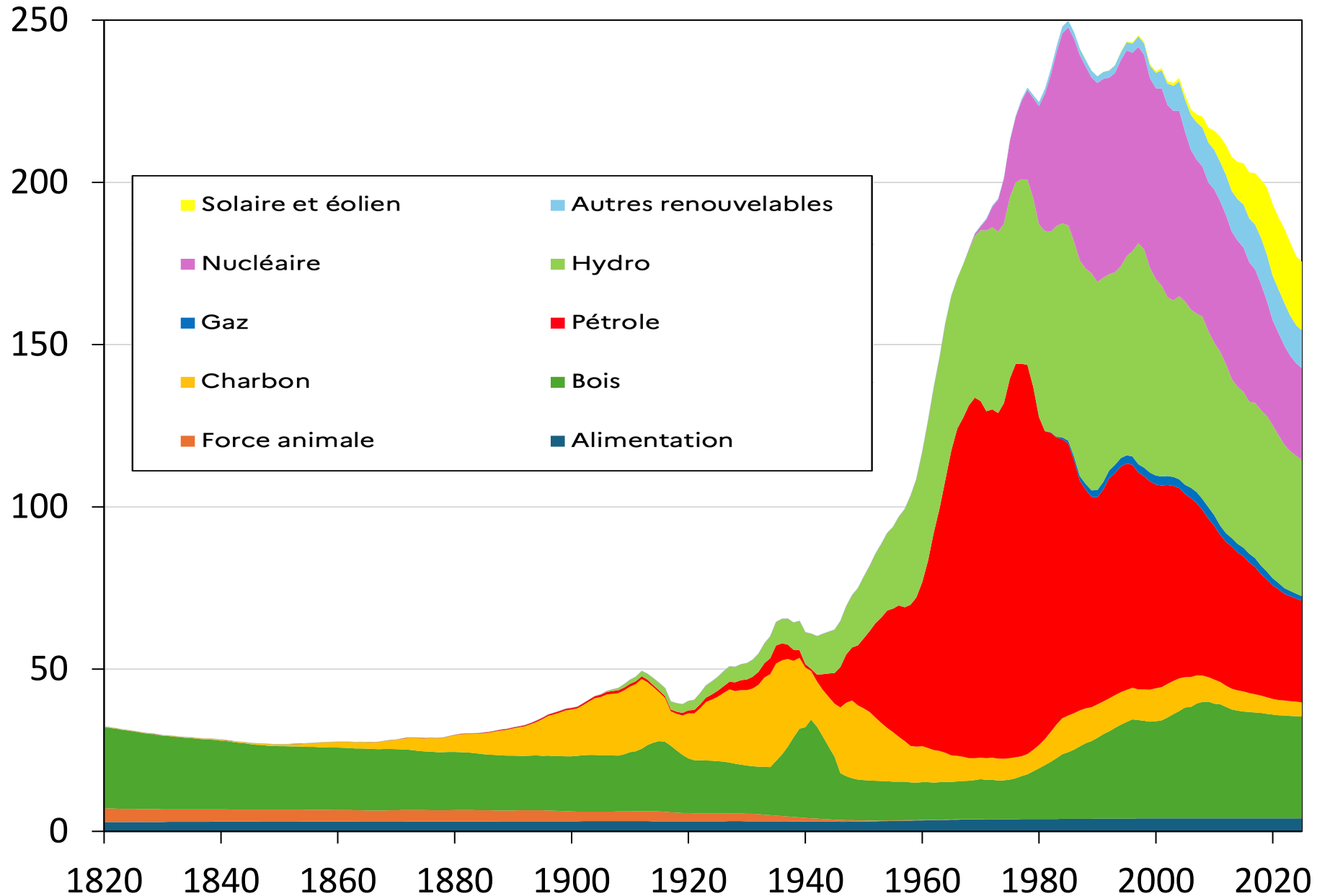
Energy Mix: Germany (kWh per capita per day)



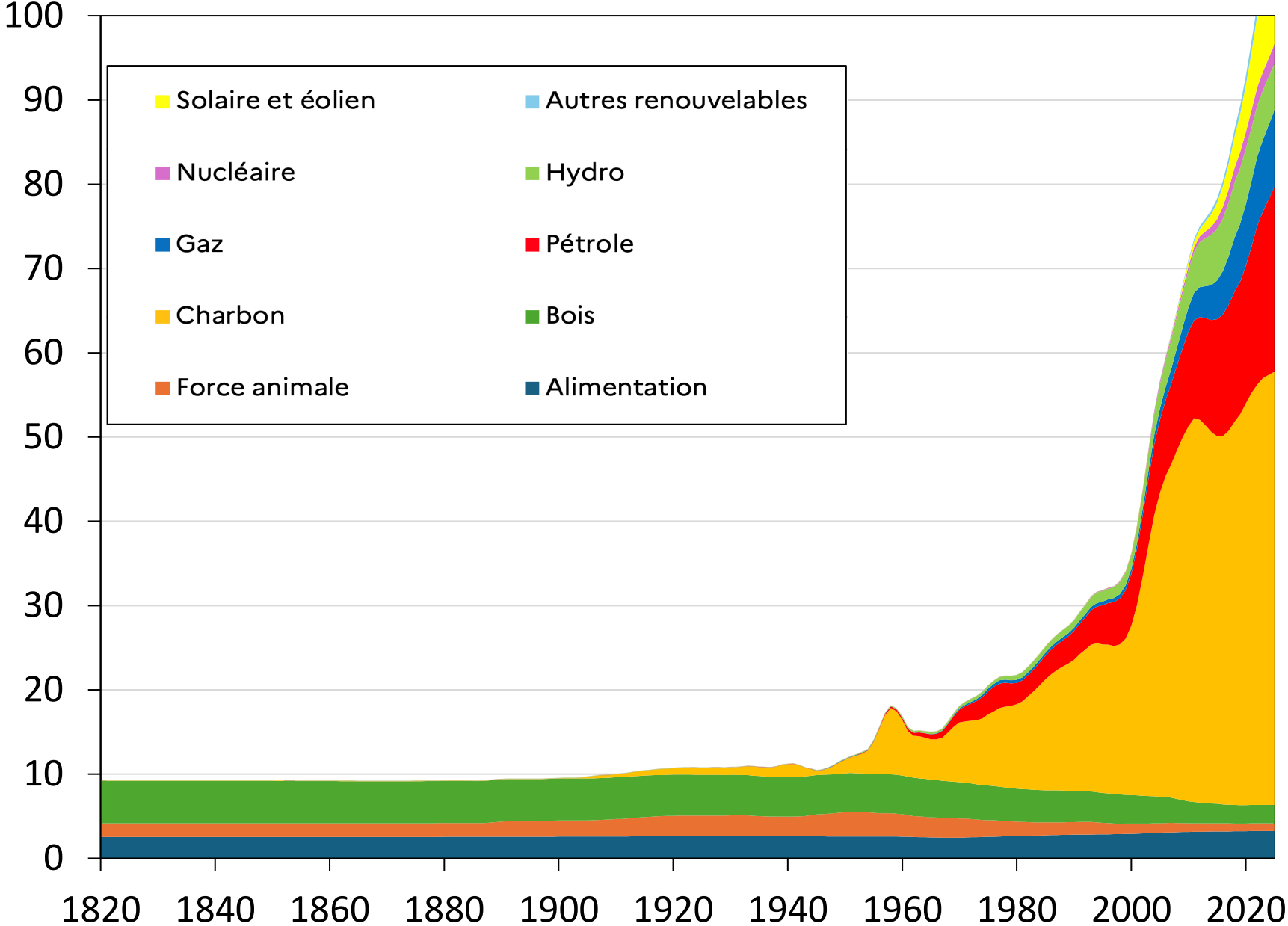
Energy Mix: France (kWh per capita per day)



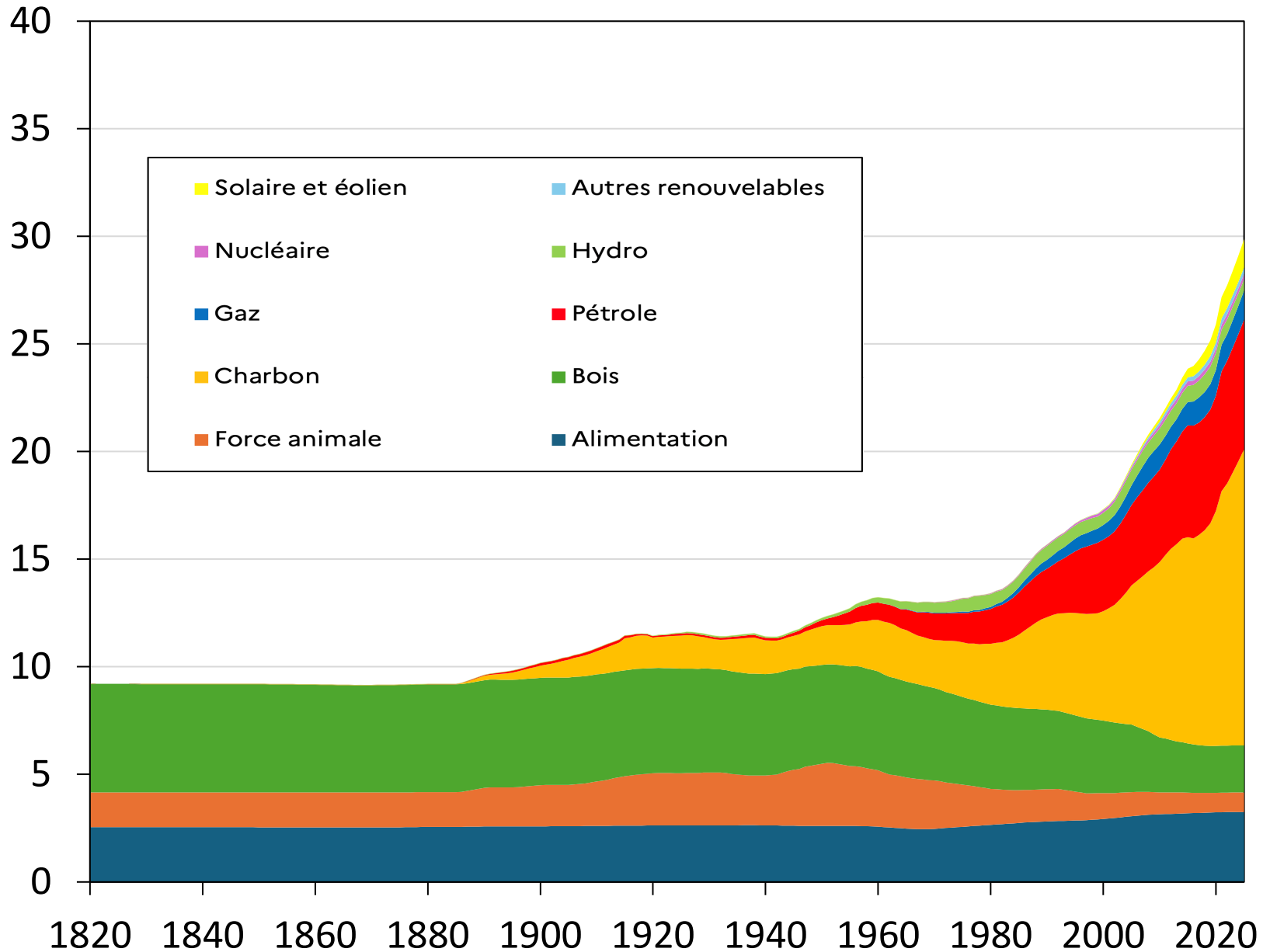
Energy Mix: Sweden (kWh per capita per day)



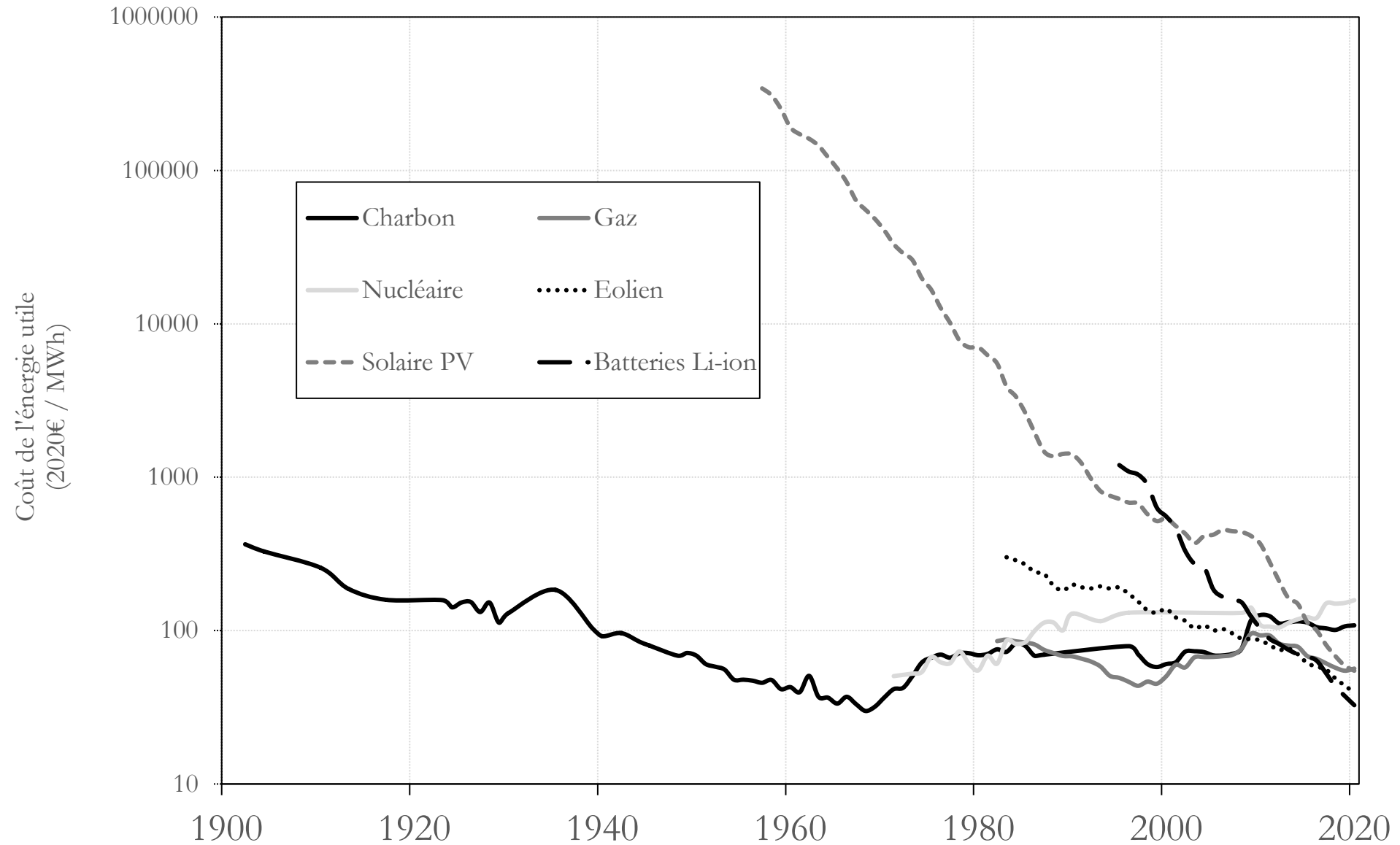
Energy Mix: China (kWh per capita per day)



Energy Mix: India (kWh per capita per day)



The Falling Cost of Solar & Wind Energy (2020 Euros/MWh)



Electricity ownership has followed remarkably diverse paths across countries and eras.

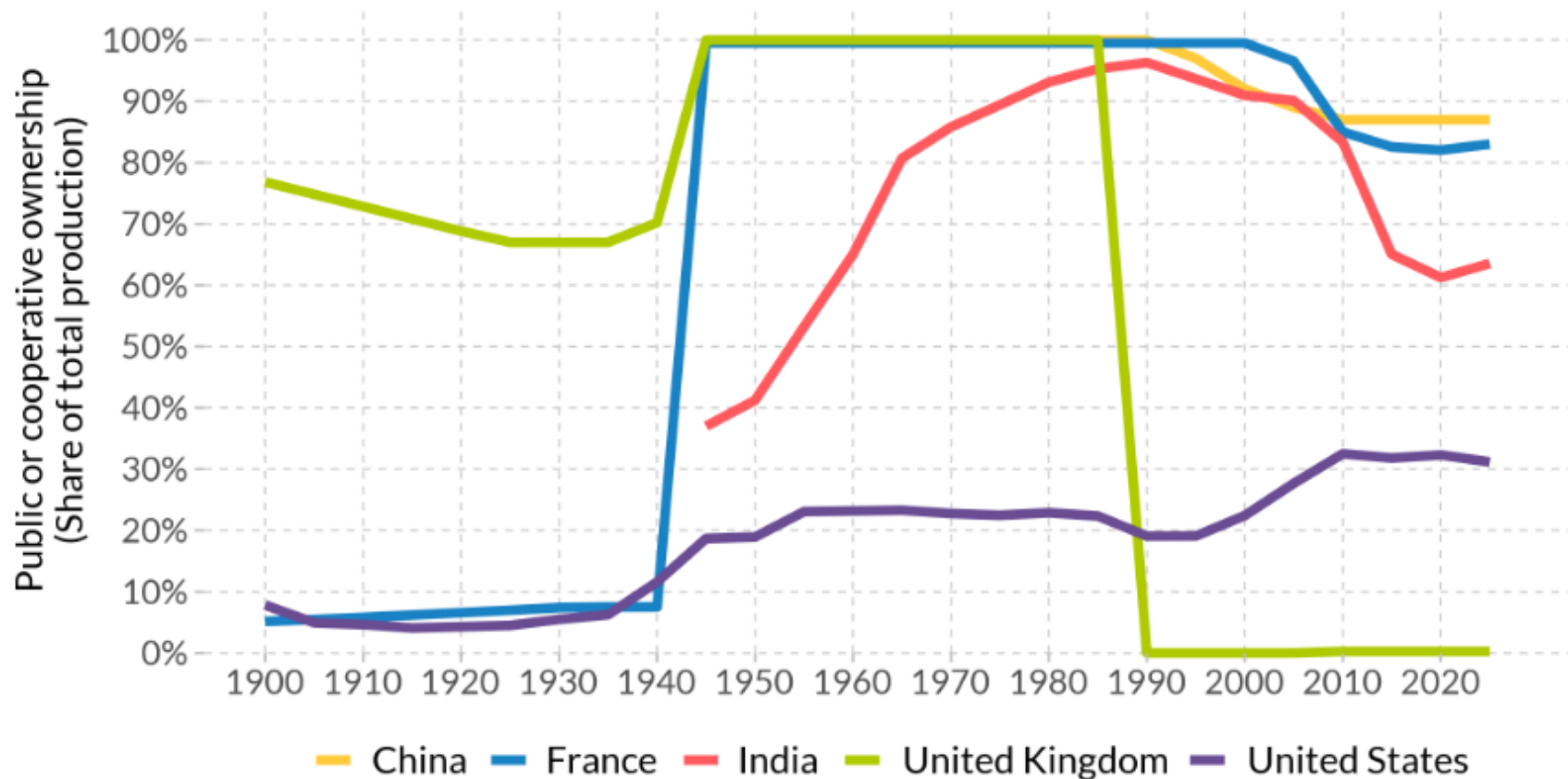
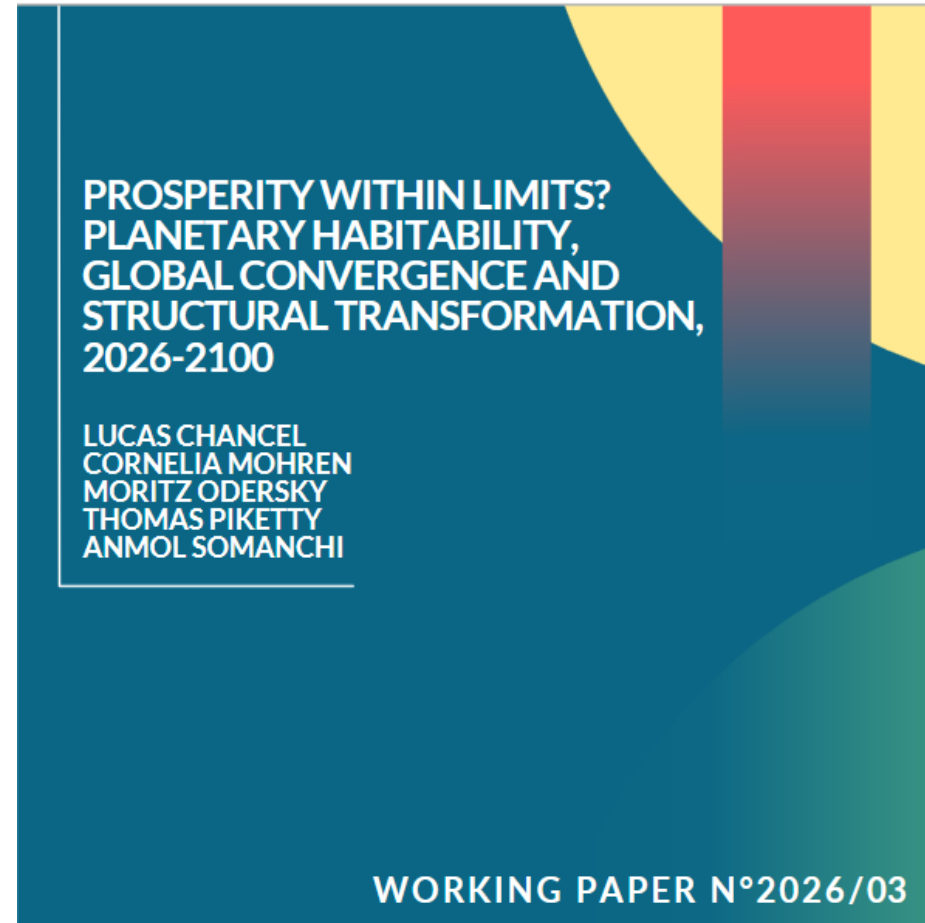
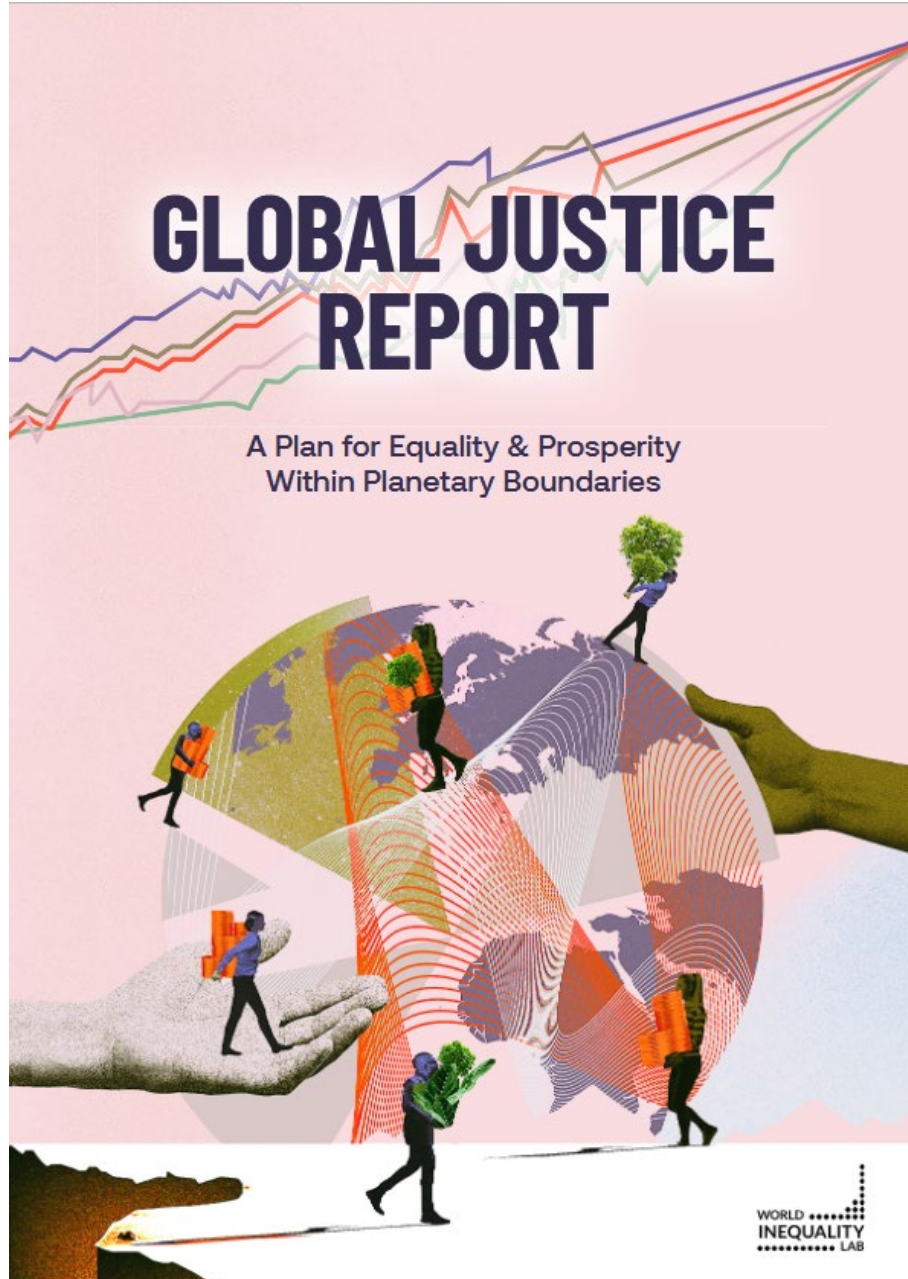


Figure 3.2. Share of the public sector in electricity production around the world, 1900–2025

Note: this figure shows the share of total electricity production under public (federal, state, and municipal) or cooperative ownership in various countries since 1900. **Data source:** Chancel, 2025.

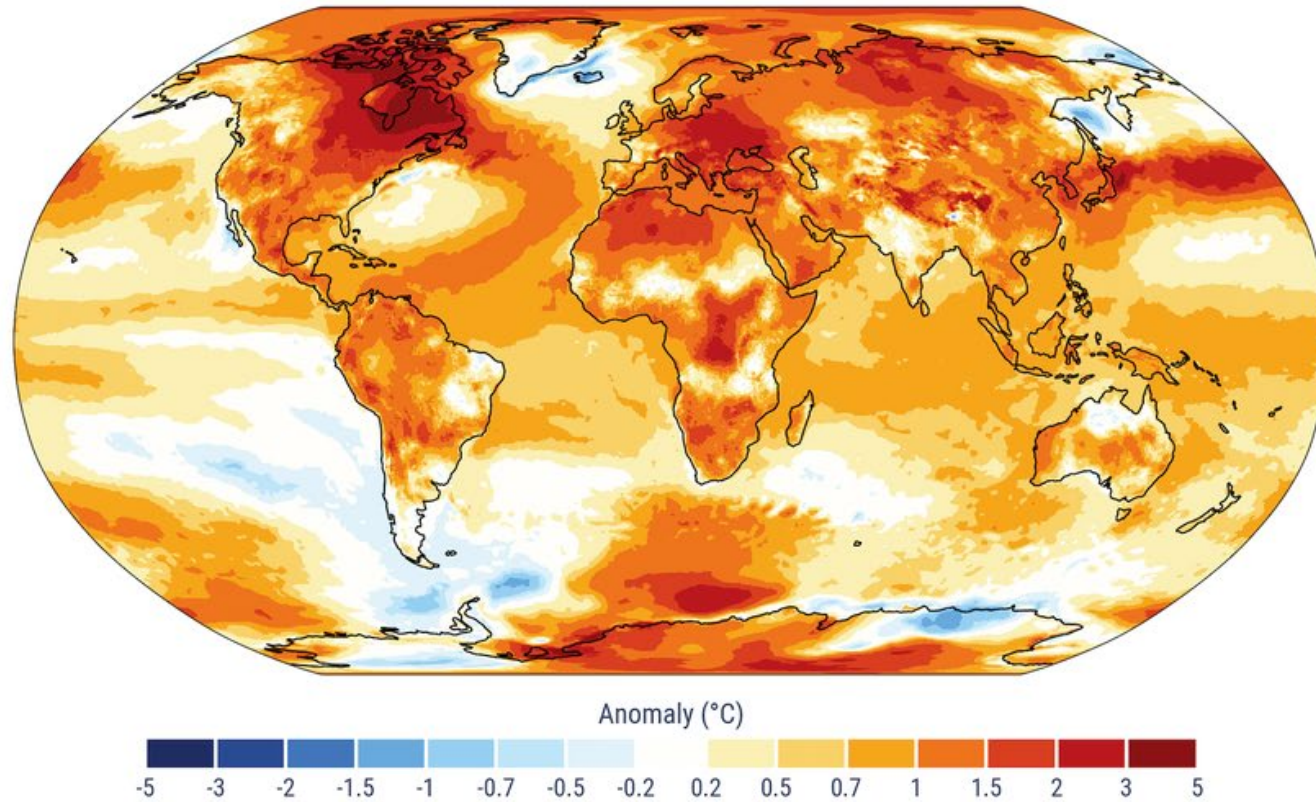
Is Prosperity for all Countries Compatible with Planetary Habitability?



FEBRUARY 2026



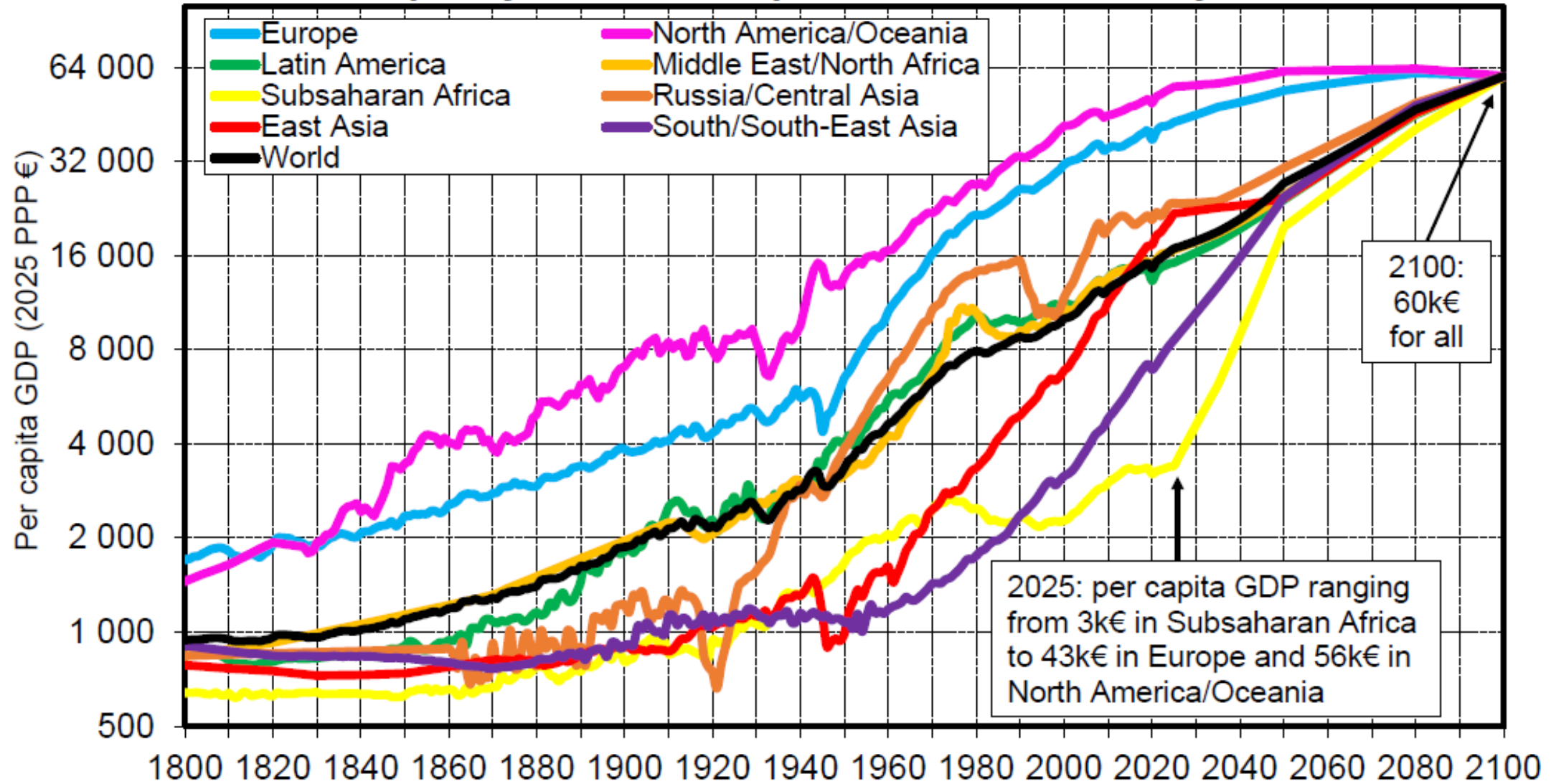
World Sectoral Economy-Environment Database (WSEED)



Surface air temperature anomalies in 2024, relative to the average for the 1991–2020 reference period. [Source: copernicus.eu](https://www.copernicus.eu)

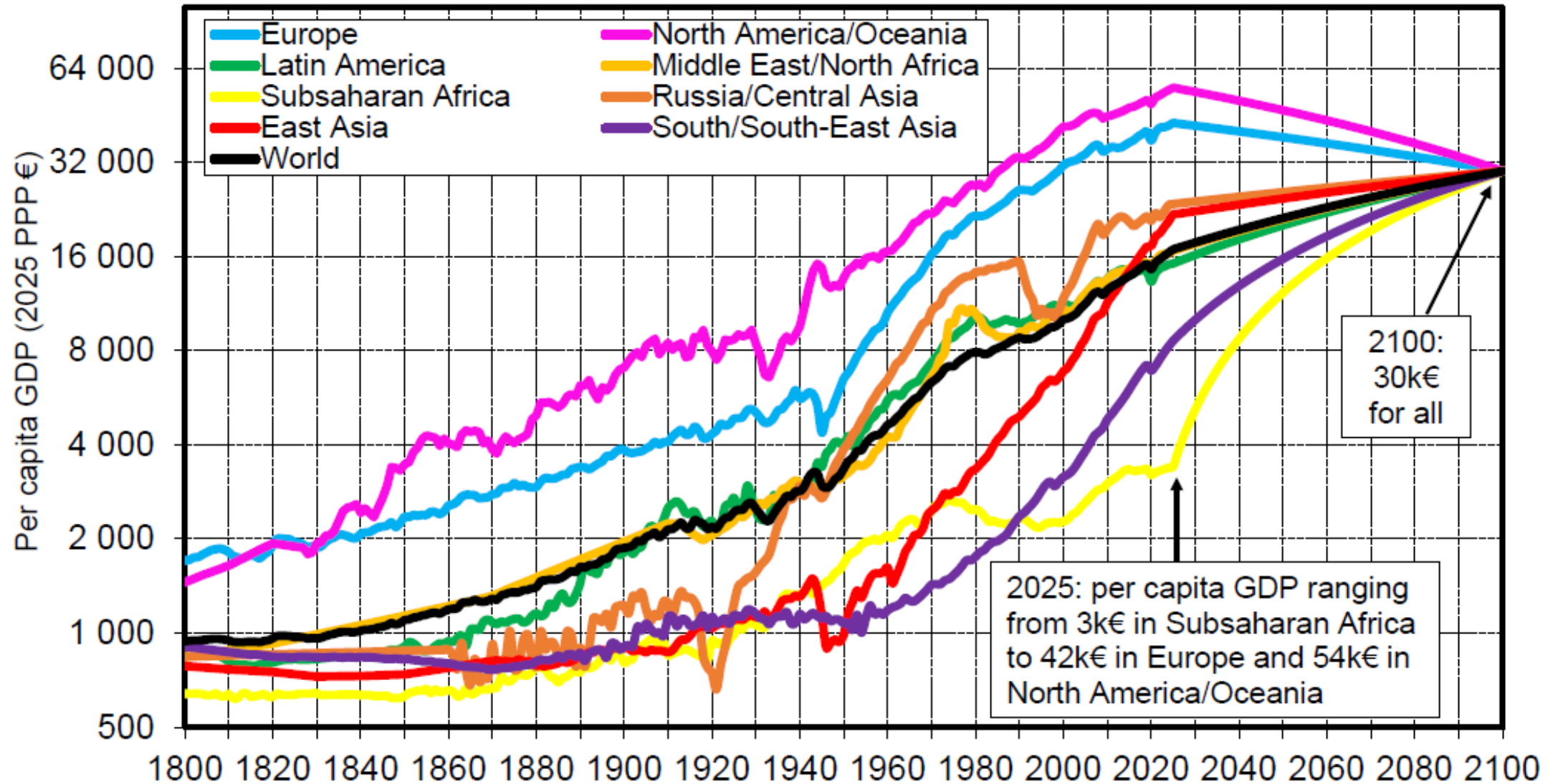
A new global economic-environment dataset with historic data (1970–2025) and projections for future scenarios (2026–2100).

Is Prosperity for All Compatible with Planetary Boundaries?



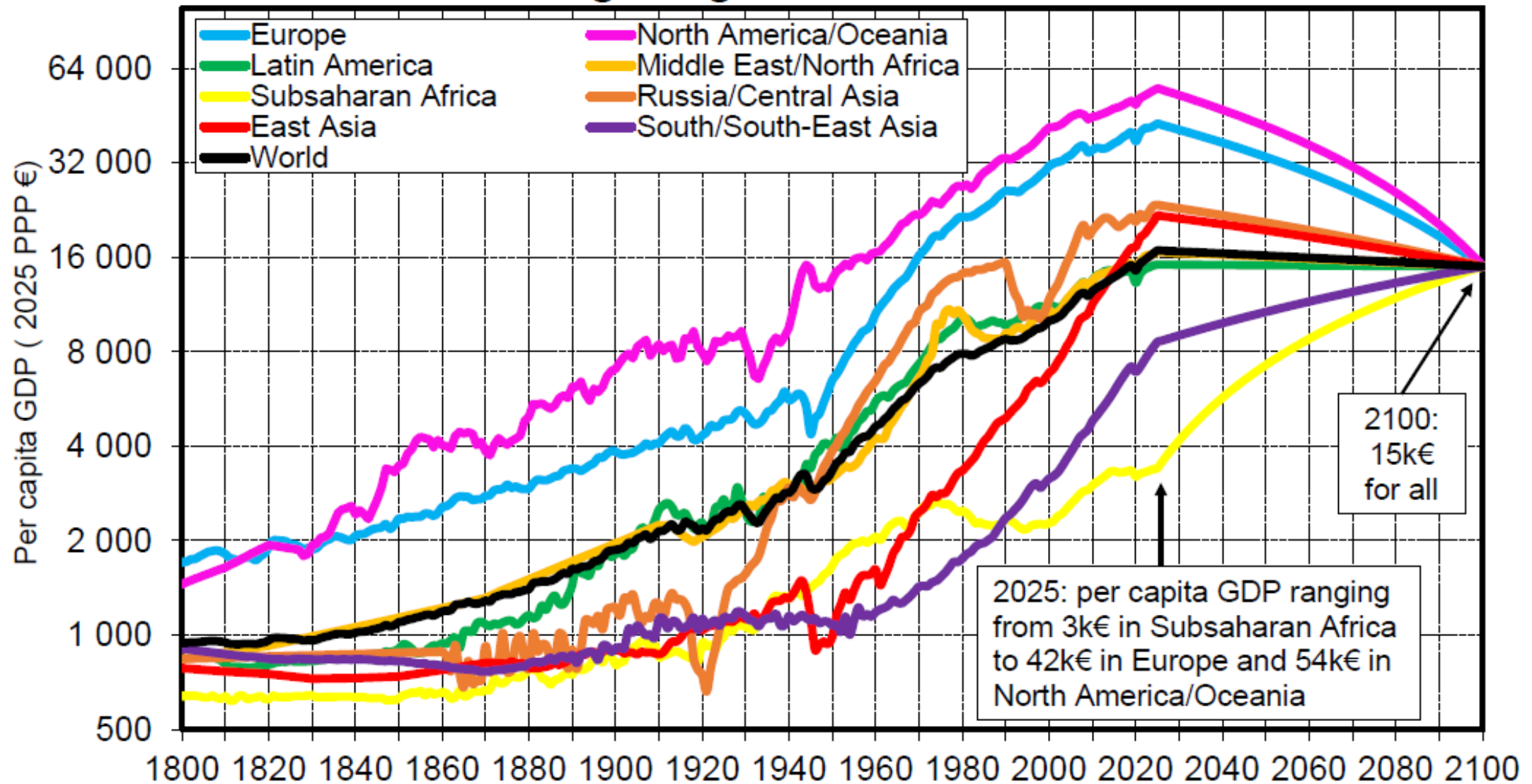
Interpretation. In this research, we ask whether high living standards for all (say, with per capita GDP around 60k€ PPP 2025 by 2100) are compatible with planetary boundaries. We find that the 60k target is possible only under very strict conditions: drastic reduction in labour hours, major shift from material to immaterial sectors, change in food habits and decarbonization of production. **Sources and series:** wseed.world (A1a)

Or Do We Need A Little Degrowth for Rich Countries?



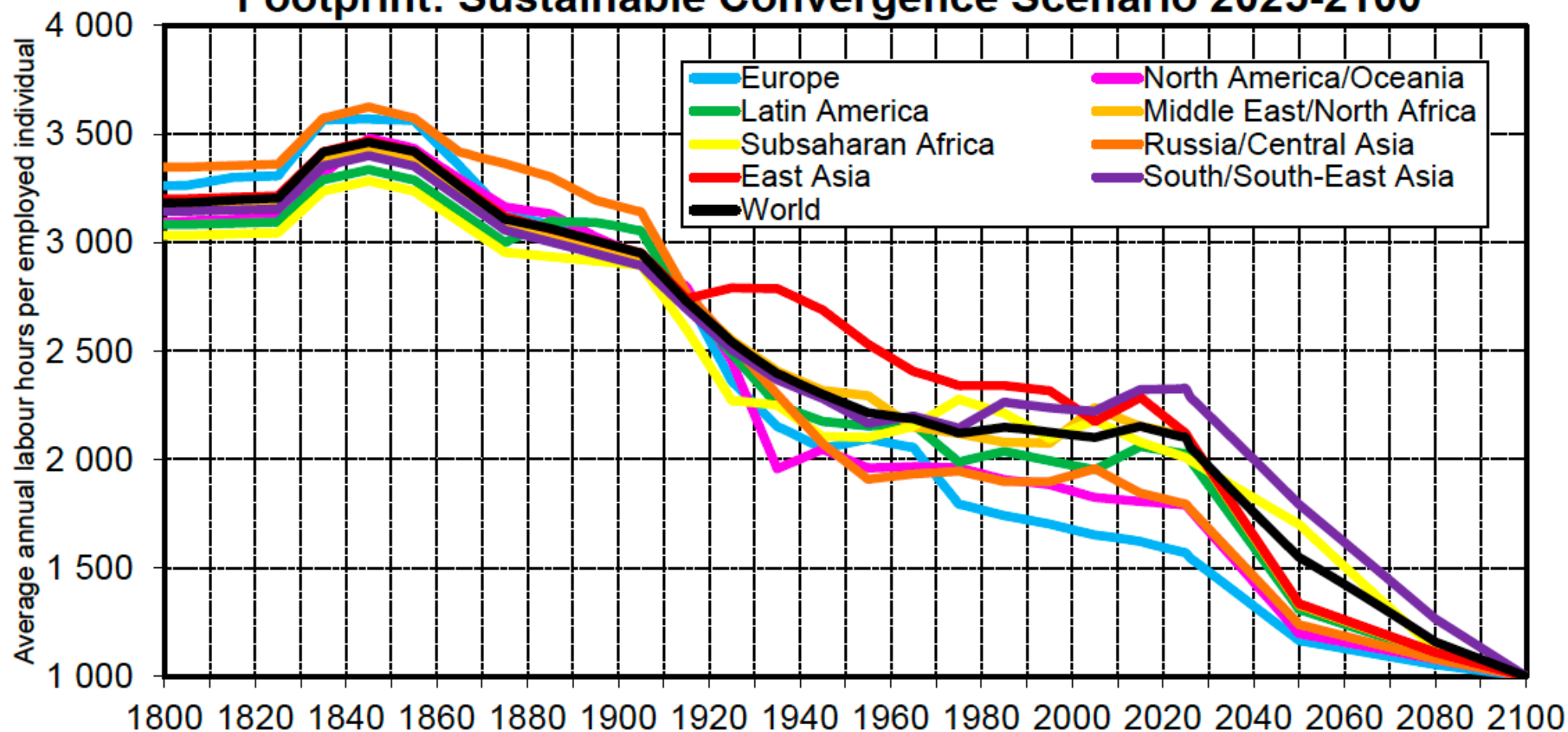
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Or a Large Degrowth for Rich Countries?



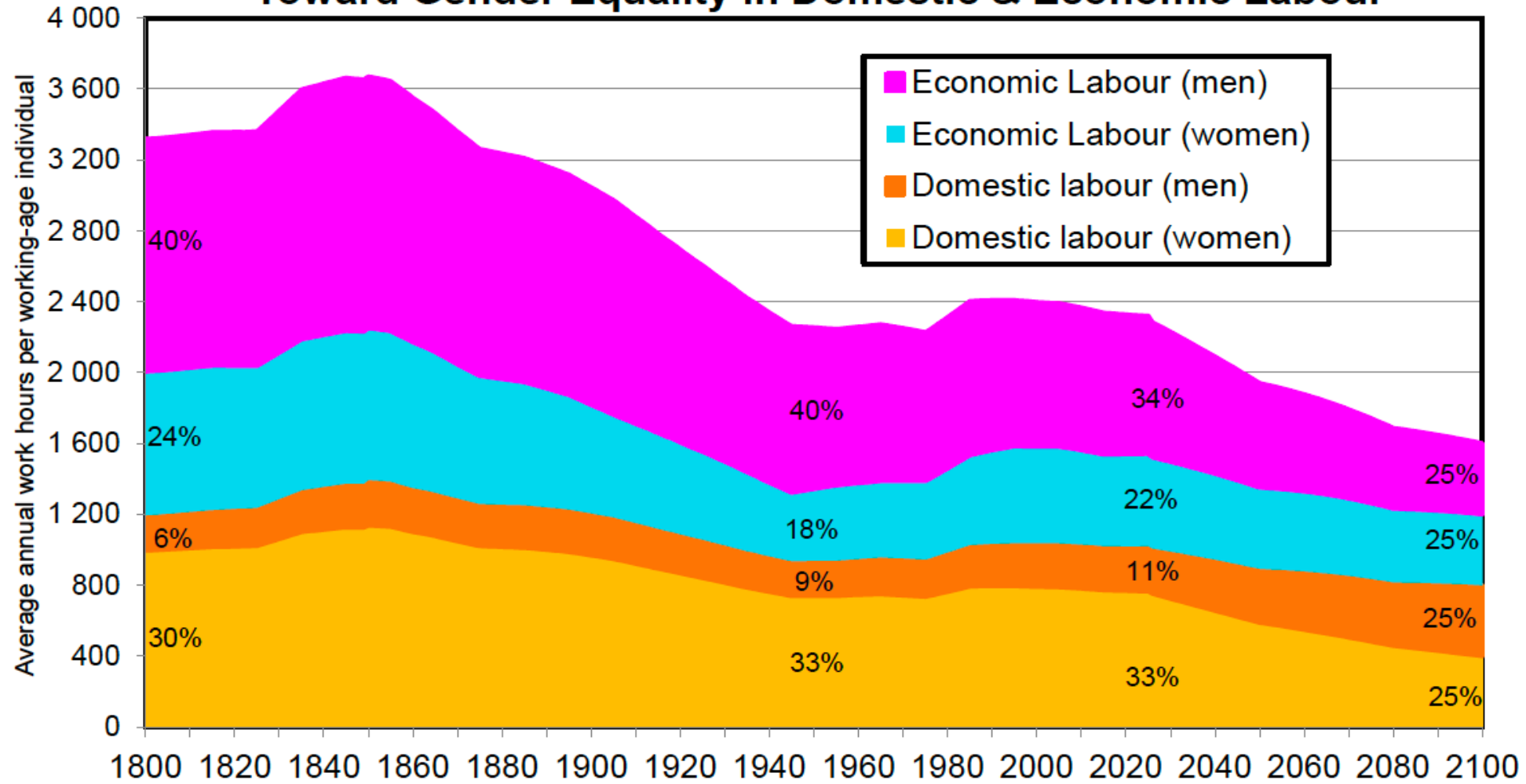
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Using Productivity Gains to Reduce Work Hours & Material Footprint: Sustainable Convergence Scenario 2025-2100



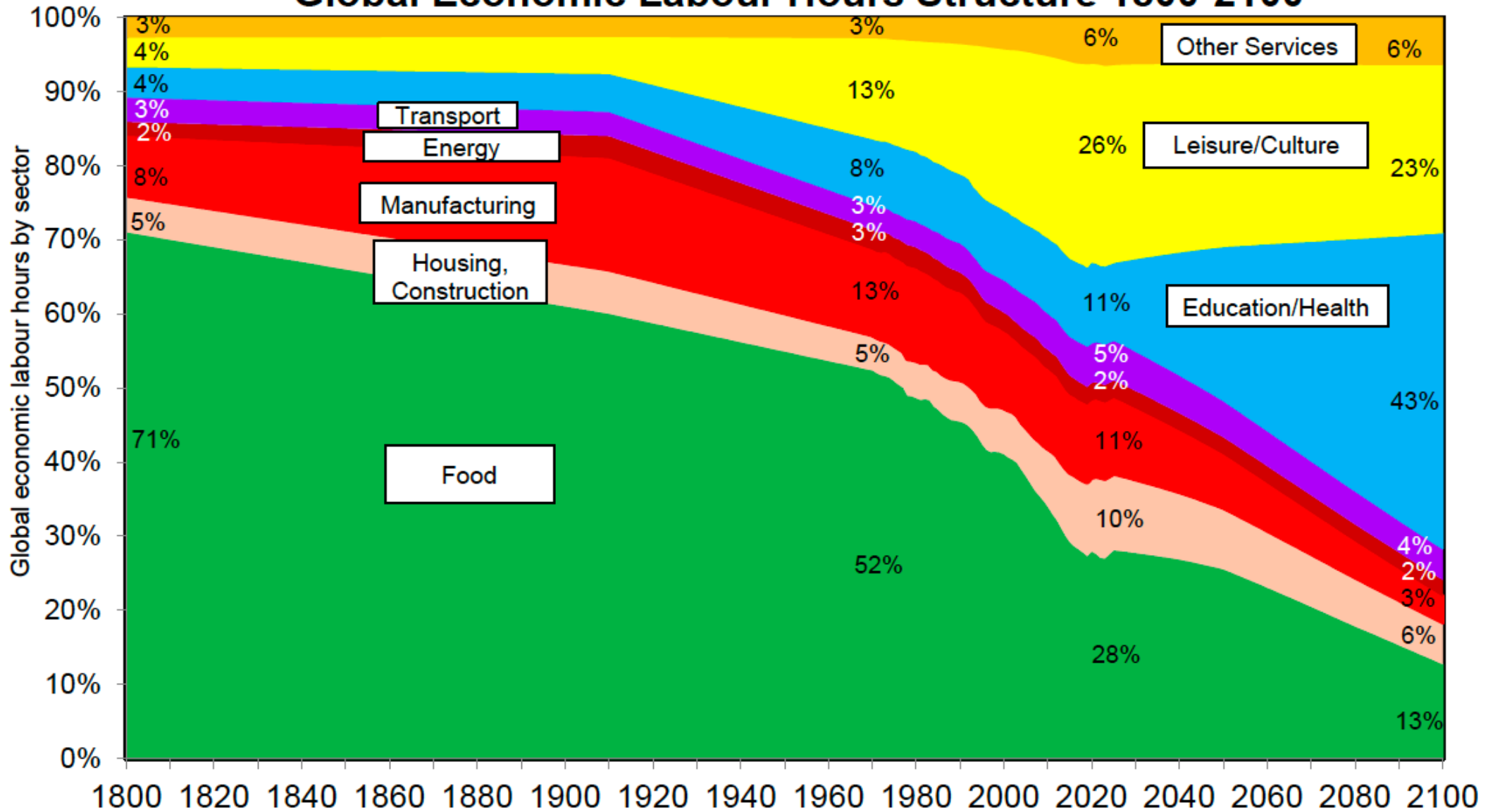
Interpretation. Under the Sustainable Convergence scenario, average annual labour hours decline from about 2100 to 1000 hours globally between 2025 and 2100. Note. Annual labour hours around 3000-3500 hours correspond to about 60-65 hours per week all year long. Annual hours around 2000 hours correspond to 40 hours per week during 50 weeks (2 weeks in paid vacation); annual hours around 1600 hours correspond to 35 hours per week during 47 weeks (5 weeks in paid vacation); annual hours around 1000 hours correspond to 25 hours per week during 40 weeks (12 weeks in paid vacation). **Sources and series:** wseed.world (E1a)

The Structural Transformation of Work 1800-2100: Toward Gender Equality in Domestic & Economic Labour



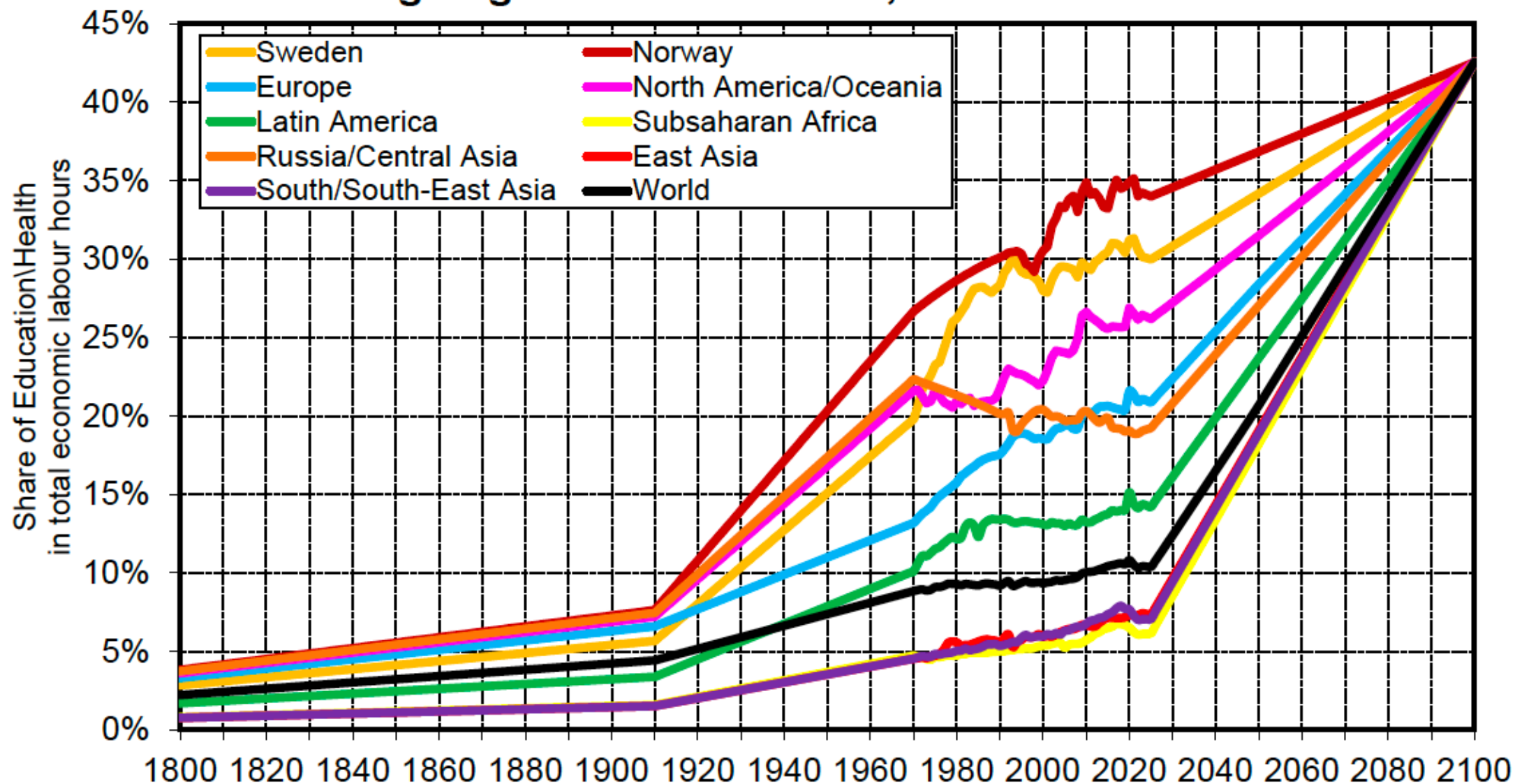
Interpretation. In the Sustainable Convergence scenario, working-age men and women are projected to supply the same quantity of economic labour and domestic labour and to receive equal average pay. This would represent a continuation of the trend toward gender equality observed between 1950 and 2025, albeit with a major acceleration. Sources and series: wseed.world (E1b)

Planetary Habitability & Structural Transformation: Global Economic Labour Hours Structure 1800-2100



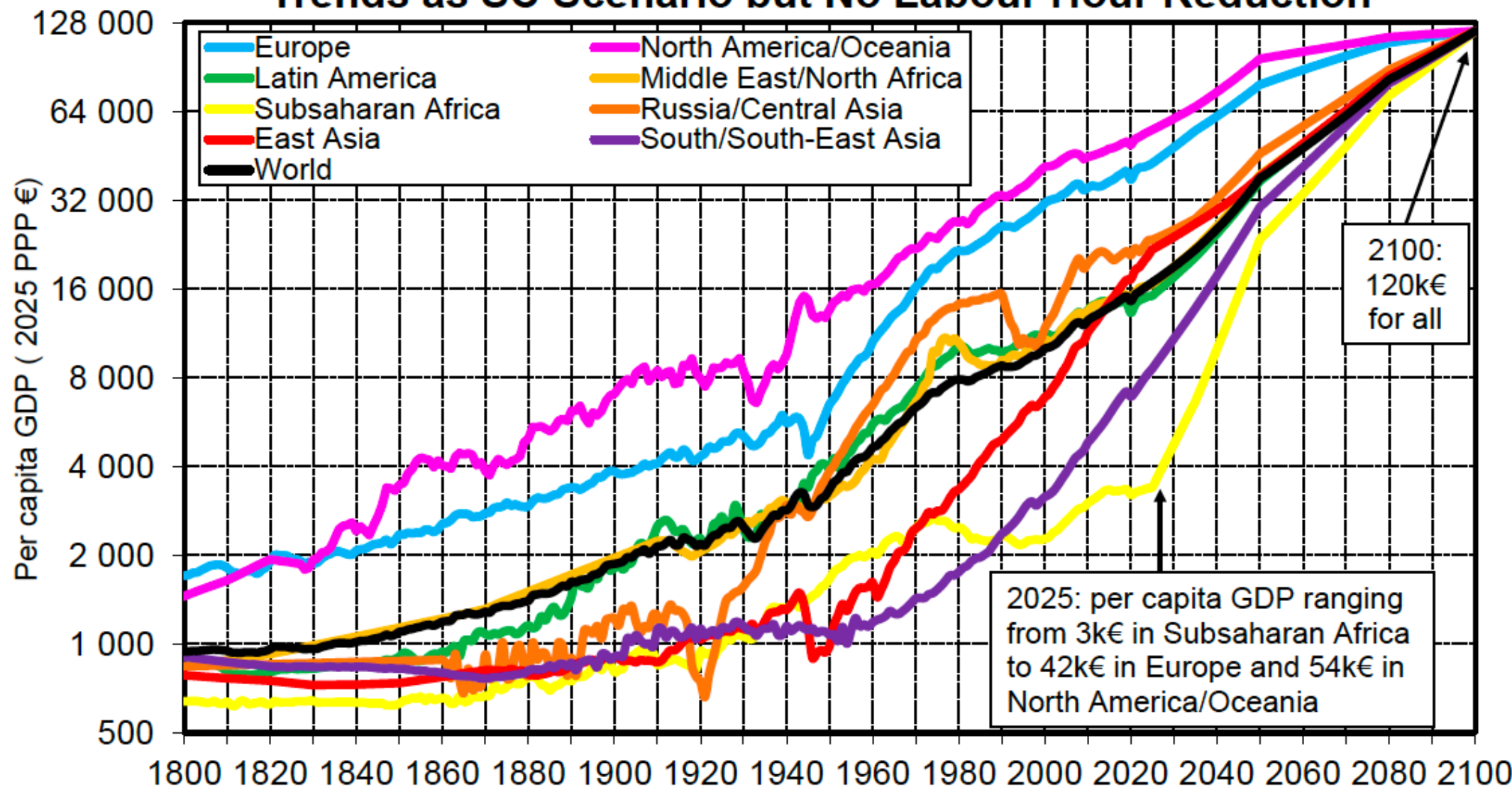
Interpretation. At the world level, the share of food production in total economic labour hours dropped from 71% in 1800 to 52% in 1970 and 28% in 2025, and is scheduled to drop to about 13% by 2100 in our benchmark scenario. Sources and series : wseed.world (E1)

The Ongoing Rise of Education, Health & Public Services



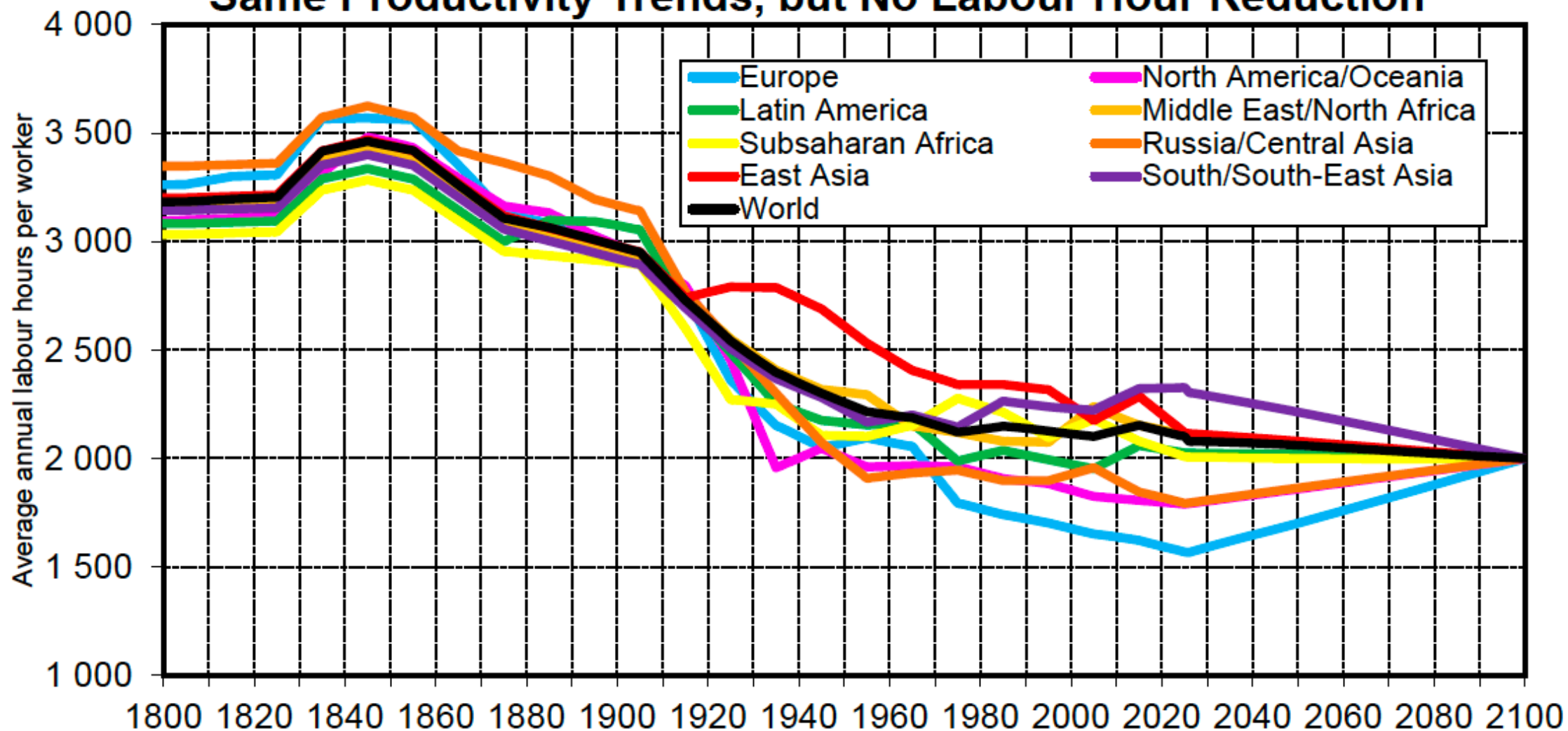
Interpretation. At the world level, the share of education, health and public services in total economic labour hours rose from 2% in 1800 to 8% in 1970, 11% in 2025 and is scheduled to rise to 43% by 2100 under the Sustainable Convergence scenario. In 2025, it is already around 30-35% of total economic labour hours in Sweden and Norway. **Sources and series:** wseed.world (E1m)

Productivist Convergence Scenario: Same Productivity Trends as SC Scenario but No Labour Hour Reduction



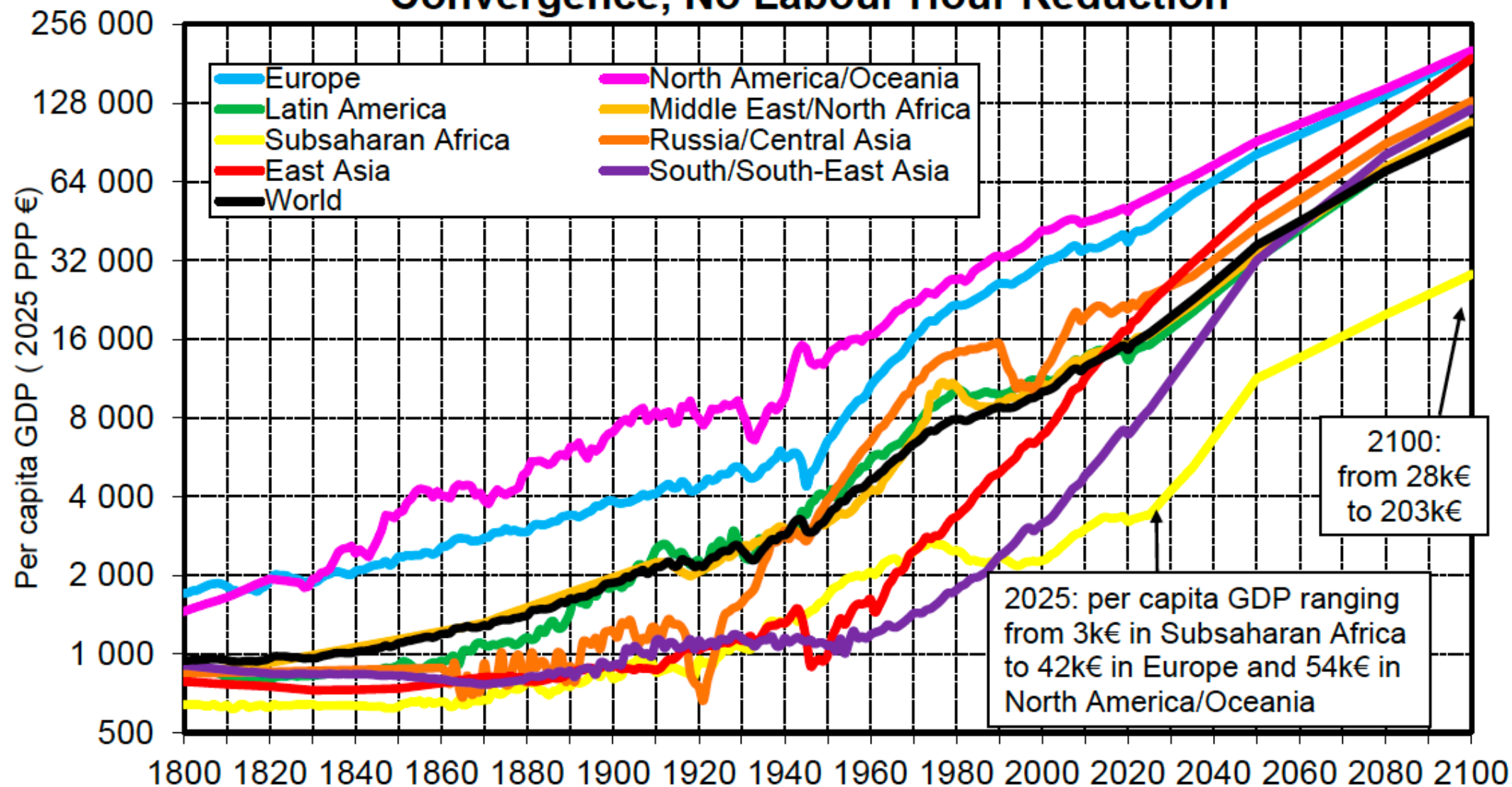
Interpretation. In the "productivist convergence" scenario, we assume the same productivity trends as in "sustainable convergence" but with no reduction in labour hours, resulting in much larger per capita GDP levels (120k€ rather than 60k€). Sources and series: wseed.world (A1d)

Productivist Convergence Scenario 2025-2100: Same Productivity Trends, but No Labour Hour Reduction



Interpretation. According to the Productivist Convergence scenario, productivity growth follows the same trend over the 2025-2100 period as in the Sustainable Convergence scenario (with hourly productivity equal to 125 Euros PPP 2025 in all countries by 2100), but without any major reduction of labour hours. I.e. annual labour hours per worker are assumed to converge in all countries toward 2000 hours over the 2025-2100 period (as compared to a world average equal to 2100 hours in 2025). Sources and series: wseed.world (E1i)

Persistent Inequality Scenario: Partial Productivity Convergence, No Labour Hour Reduction



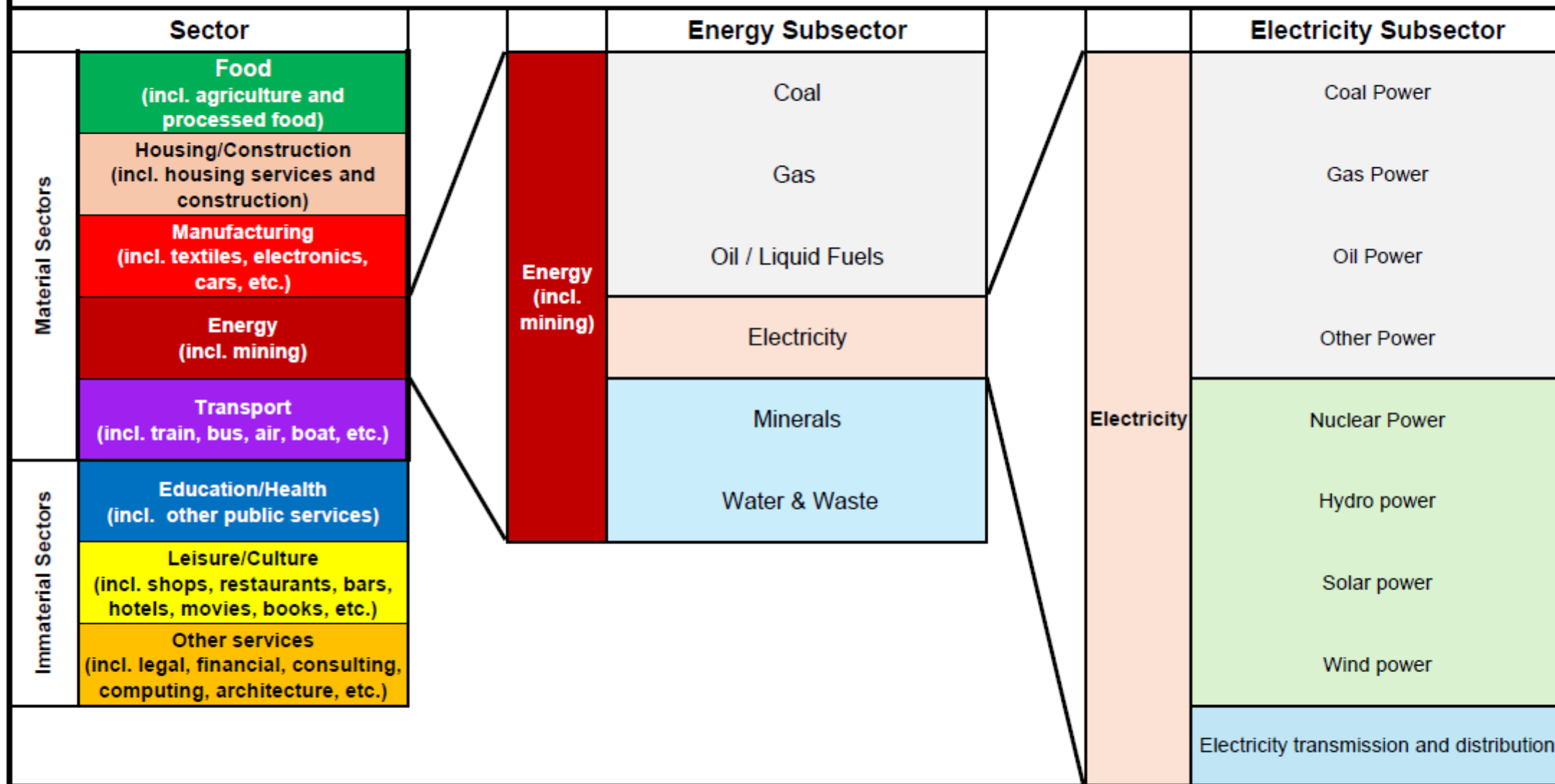
Interpretation. In the "persistent inequality" scenario, we assume partial convergence in productivity levels (following patterns observed over the 1990-2025 period) and no reduction in labour hours, resulting in persistent inequality in per capita GDP. Sources and series: wseed.world (A1e)

The Classification of Economic Sectors Used in the World Sectoral Economy-Environment Database (WSEED)

	Sector	ISIC 3 Code	ISIC 4 Code	Included Sectors and Industries
Material Sectors	Food (incl. agriculture & processed food)	A+B+D15-16	A+C10-12	Agriculture; fishing; forestry; Manufacturing of food, beverages, tobacco
	Housing/Construction (incl. housing services and construction)	F + K (part)	F + L (part)	Housing services; Construction
	Manufacturing (incl. textiles, electronics, cars, etc.)	D exc. D15-16	C exc. C10-12	All manufacturing except food products: e.g. textiles, electrical equipment, machinery, vehicles, paper, chemicals, metals, plastics, etc.
	Energy (incl. mining)	C + E	B + D+E	Electricity, oil, gas; Water treatment and supply; Sewerage and waste management; Mining and quarrying
	Transport (incl. train, bus, air, boat, etc.)	I	H	Land, water, air transport; pipelines; warehousing
Immaterial Sectors	Education/Health (incl. other public services)	L+M+N	O+P+Q	Education; Human health; Residential care and social work activities; Public Administration: public order, defense, foreign affairs
	Leisure/Culture (incl. shops, restaurants, bars, hotels, movies, books, etc.)	G+H+O+P	G+I+J+R+S+T	Wholesale & retail trade; Accommodation & food service activities ; Repair; Publishing, movie, broadcasting; Arts, museum, libraries; Sports & recreation
	Other services (incl. legal, financial, consulting, computing, architecture, etc.)	J+K	K+L+M+N	Financial, insurance, pension, IT, consultancy; Real estate (exc. Housing services); Legal, Accounting; Scientific R&D; Advertising, architectural, technical

Description. This research relies on the construction of a novel eight-sector database to analyse structural transformation and track sectoral emissions for the 57 WID core territories from 1970 to 2025. All sources are harmonized to eight equivalent sectors. These eight sectors (five "material" and three "immaterial") are partly based on ISIC classifications (International Standard Industrial Classification for all Economic Activities, United Nations), with a number of changes and adjustments. The distinction between material and immaterial sectors is based upon input intensity: material sectors have more input intensity and material footprint than immaterial sectors. This differs from traditional classifications and is arguably more suitable for the study of sustainable development and well-being. The extent to which the immaterial sectors are truly immaterial – and/or can become even more so in the future – is a central issue which is closely investigated in this research. **Source:** wseed.world (A0a)

The Structure of Economic Sectors & Energy Subsectors Used in WSEED



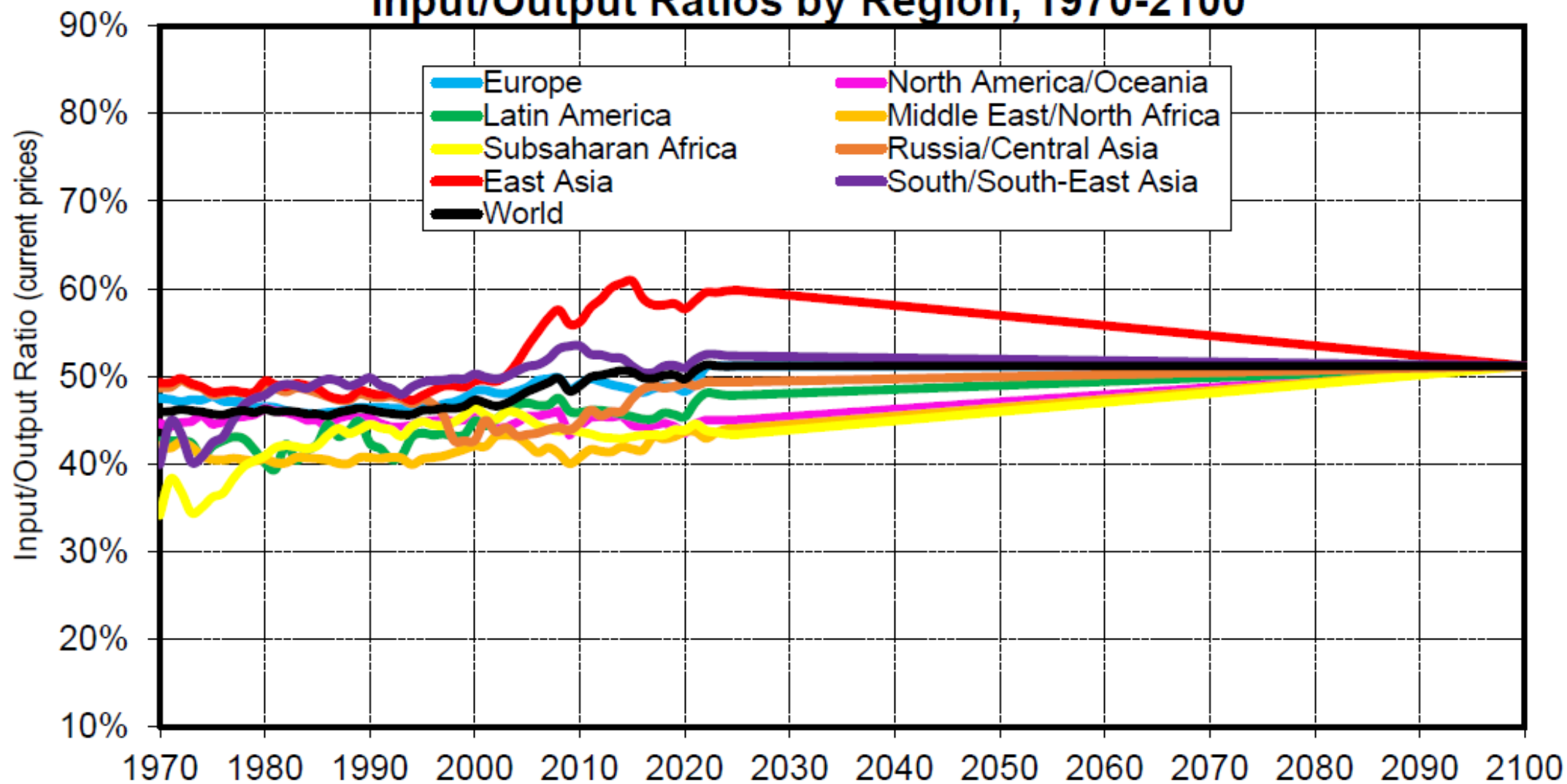
Description. For the projection framework and emission analysis, it is essential to model the energy sector in more detail. Thus, we employ additional data sources to break up the energy sector into subsectors. Thereby, we proceed on two levels breaking up energy and then the electricity sector further. We always assure that the aggregate is the sum of the subsectors. In our energy/emission projections, we work with the most disaggregated input-output structure whereby we model the energy transition as a shift to the electricity sector as well as to low-carbon sources within the energy and the electricity sector. **Source:** wseed.world (X1)

The Global Input-Output Matrix in 2025

Each column reports intermediate consumption inputs used by each sector as % of its total output	Total Economy	Food	Housing Services	Construction	Manufacturing Goods	Energy	Education/Health	Leisure/Culture	Transport	Other Services
Food	5%	35%	0%	1%	3%	1%	2%	5%	1%	0%
Housing Services	2%	0%	3%	1%	0%	0%	2%	4%	1%	2%
Construction	2%	0%	6%	8%	0%	1%	2%	1%	1%	1%
Manufacturing Goods	16%	6%	2%	29%	41%	6%	7%	6%	8%	5%
Energy	8%	3%	2%	5%	9%	38%	3%	3%	15%	2%
Education/Health	1%	0%	1%	0%	0%	0%	4%	1%	1%	1%
Leisure/Culture	7%	8%	2%	7%	9%	4%	7%	10%	9%	6%
Transport	3%	2%	0%	3%	3%	3%	2%	4%	13%	1%
Other Services	9%	3%	10%	7%	4%	4%	8%	10%	9%	23%
Total Intermediate Inputs	52%	57%	26%	61%	69%	57%	36%	44%	58%	42%
Sector Share in Output	100%	10%	5%	8%	22%	8%	12%	16%	4%	15%
Sector Share in GDP (value-added)	100%	8%	8%	6%	15%	7%	16%	19%	4%	18%
Sector Share in Intermediate Energy Use	100%	4%	1%	5%	25%	41%	5%	7%	8%	3%

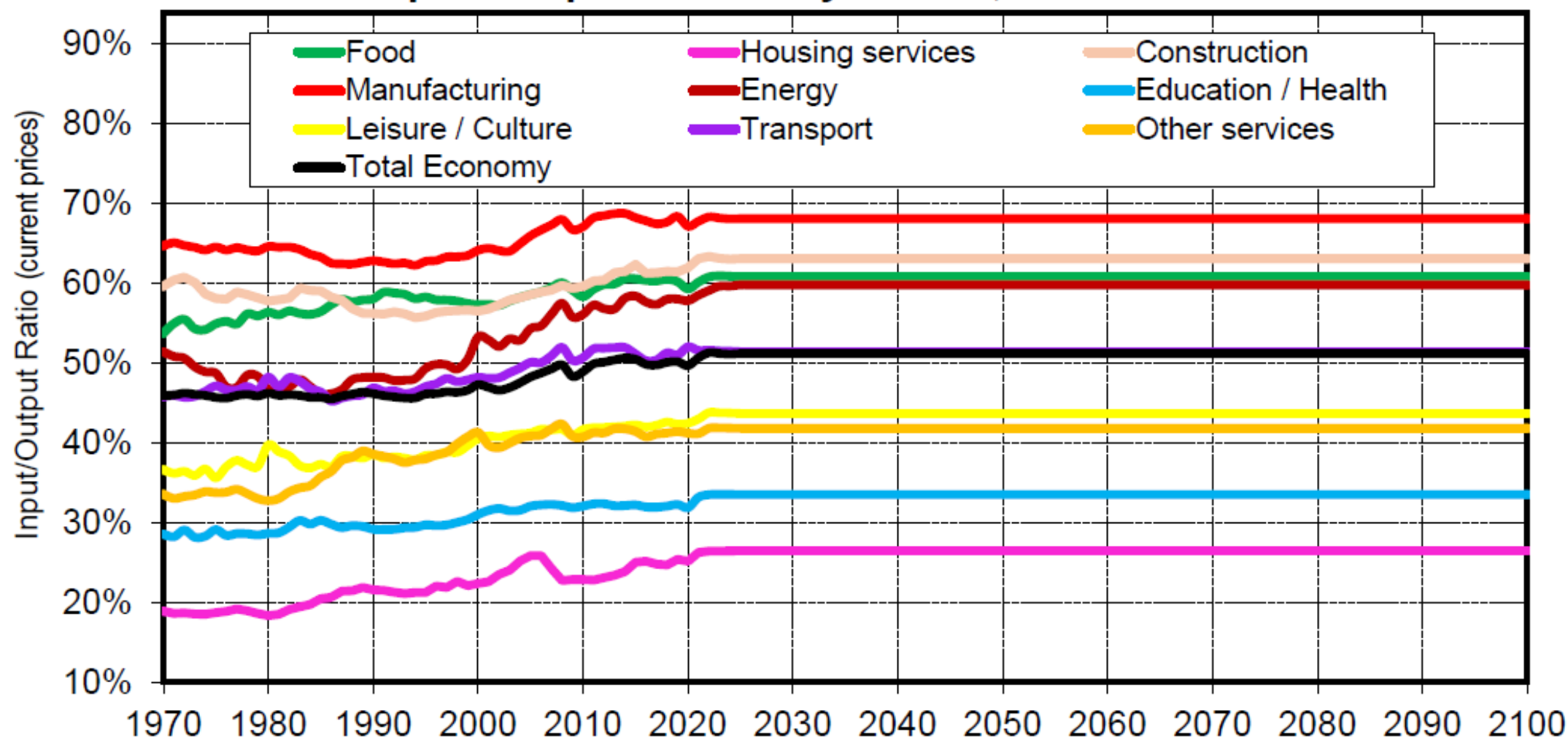
Interpretation. In order to produce 100€ of education/health, one spends 36€ in intermediate inputs (including 7€ in manufacturing goods and 3€ in energy). In order to produce 100€ in manufacturing goods, one spends 69€ in intermediate inputs (including 41€ in manufacturing goods and 9€ in energy). The material footprint of "immaterial" sectors is smaller than that of "material" sectors, but it should still be reduced substantially in order to become truly "immaterial". **Source:** wseed.world (O1a)

The Evolution of Input-Output Matrices: Input/Output Ratios by Region, 1970-2100



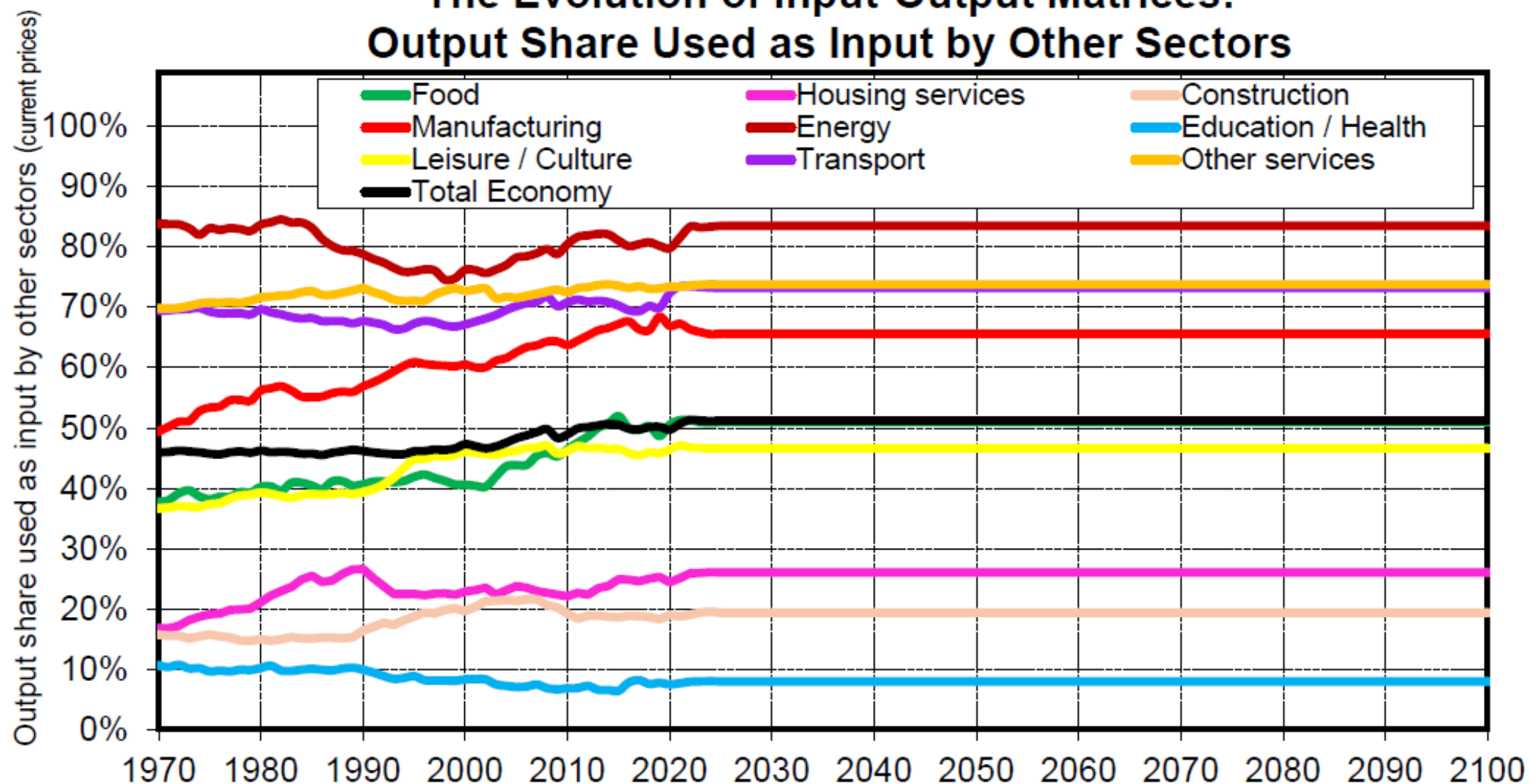
Interpretation. At the world level, intermediate inputs made on average 46% of total output in 1970 (all sectors combined). The global input-output ratio rose to 52% by 2025, with moderate variations across regions. East Asia's high ratio is due to the large manufacturing sector. In our benchmark simulations, we assume that this ratio will converge to 52% in all countries by 2100. **Sources and series:** wseed.world (00)

The Evolution of Input-Output Matrices: Input/Output Ratios by Sector, 1970-2100



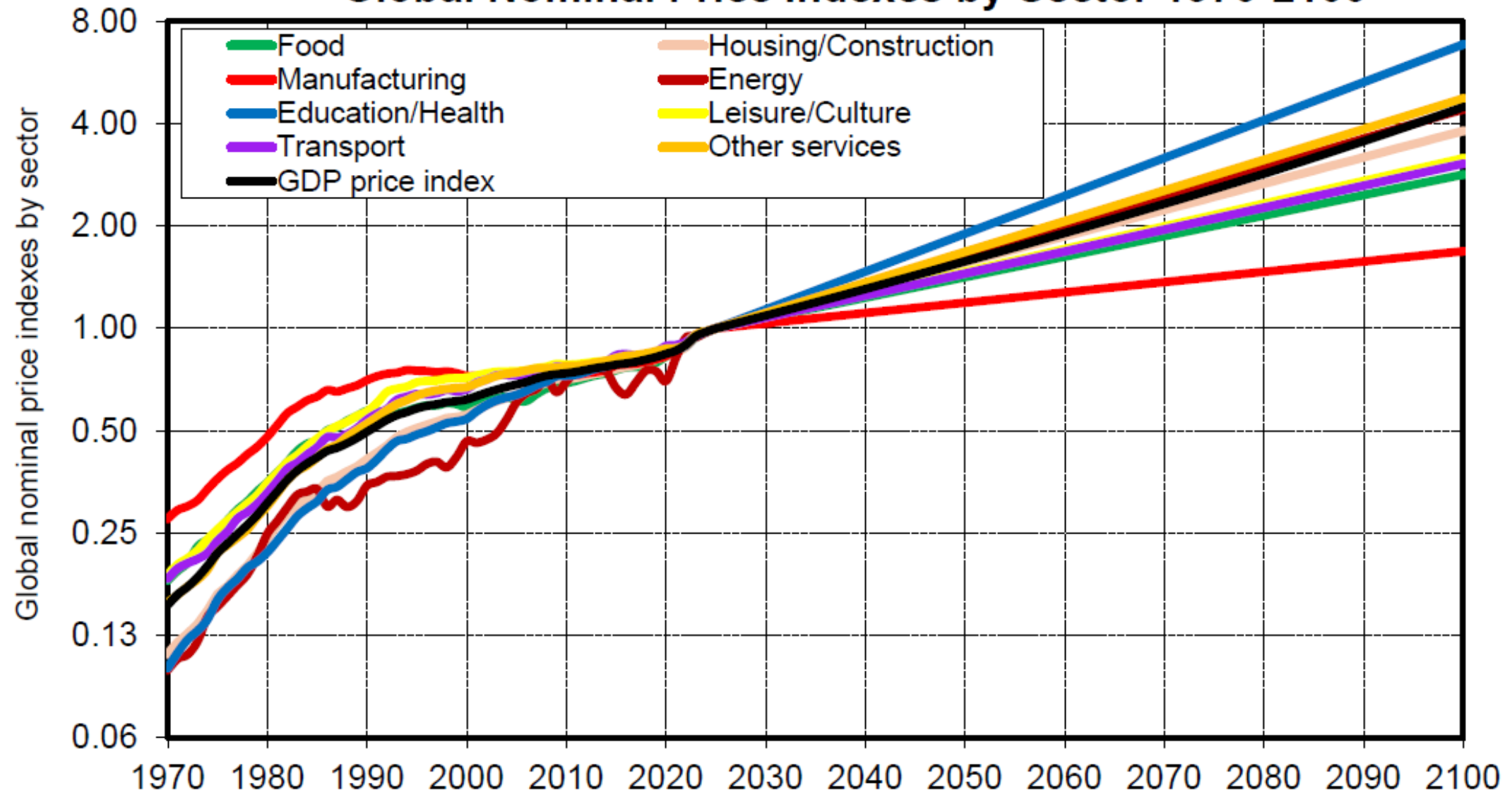
Interpretation. Material sectors like manufacturing, construction, food and energy have always been the most input-intensive (with input-output ratios around 60-70% in 2025), while immaterial sectors like education/health, leisure/culture and other services have always been much less input-intensive (with input-output ratios around 30-40% in 2025). In our benchmark simulations, we assume that each country converges by 2100 to the world average ratio observed in 2025 in each sector. **Sources and series:** wseed.world (O0i)

The Evolution of Input-Output Matrices: Output Share Used as Input by Other Sectors



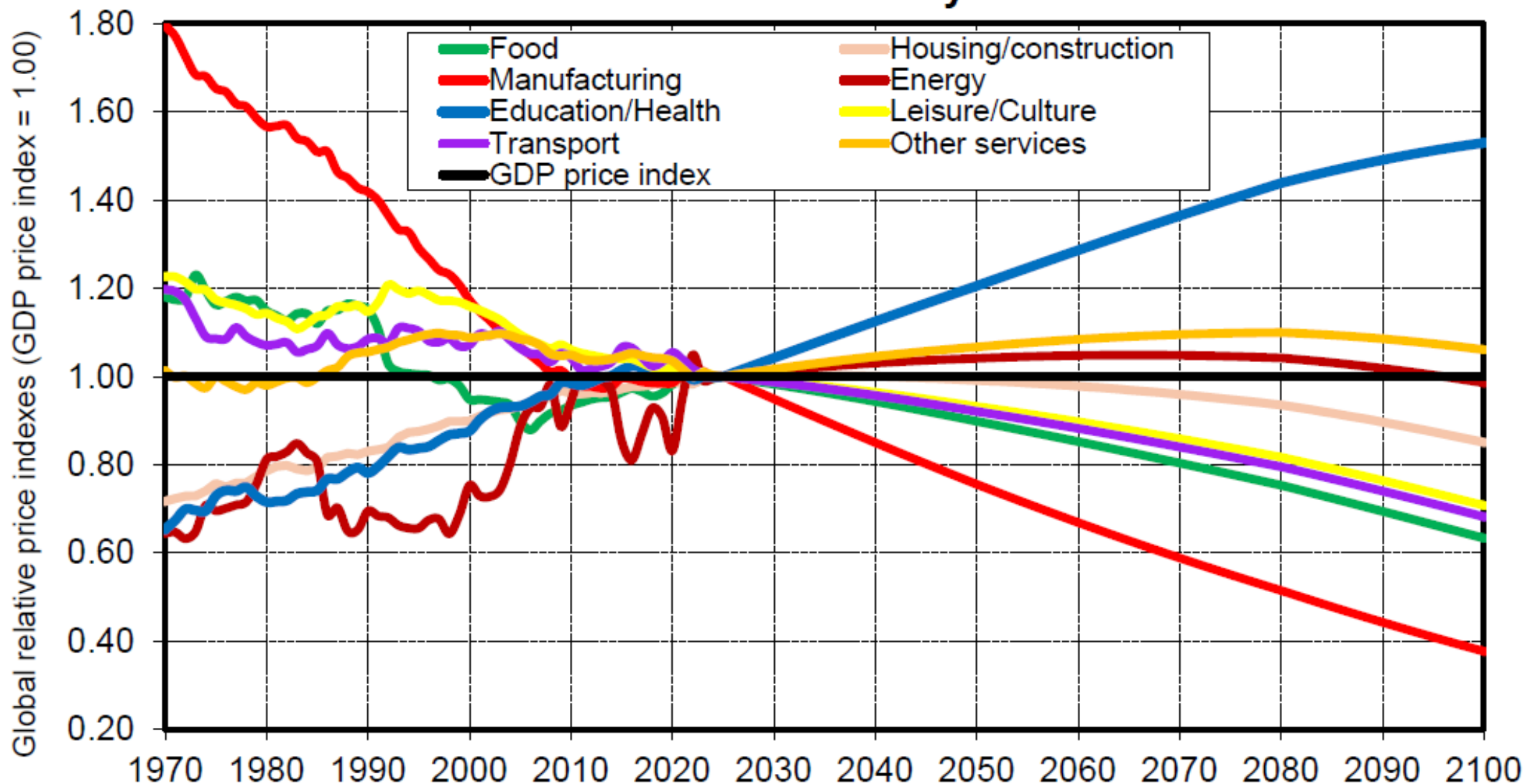
Interpretation. The share of each sector's output that is used as an intermediate input by other sectors (as opposed to the share that is used as final expenditure) has always been highest in energy (over 80% in 2025), followed by transport, other services and manufacturing (65-75%), food & leisure/culture (45-50%), construction & housing services (20-25%) and education/health (less than 10%). In our benchmark simulations, we assume that each country converges by 2100 to the average share observed in 2025 in each sector. **Sources and series:** wseed.world (00s)

Global Nominal Price Indexes by Sector 1970-2100



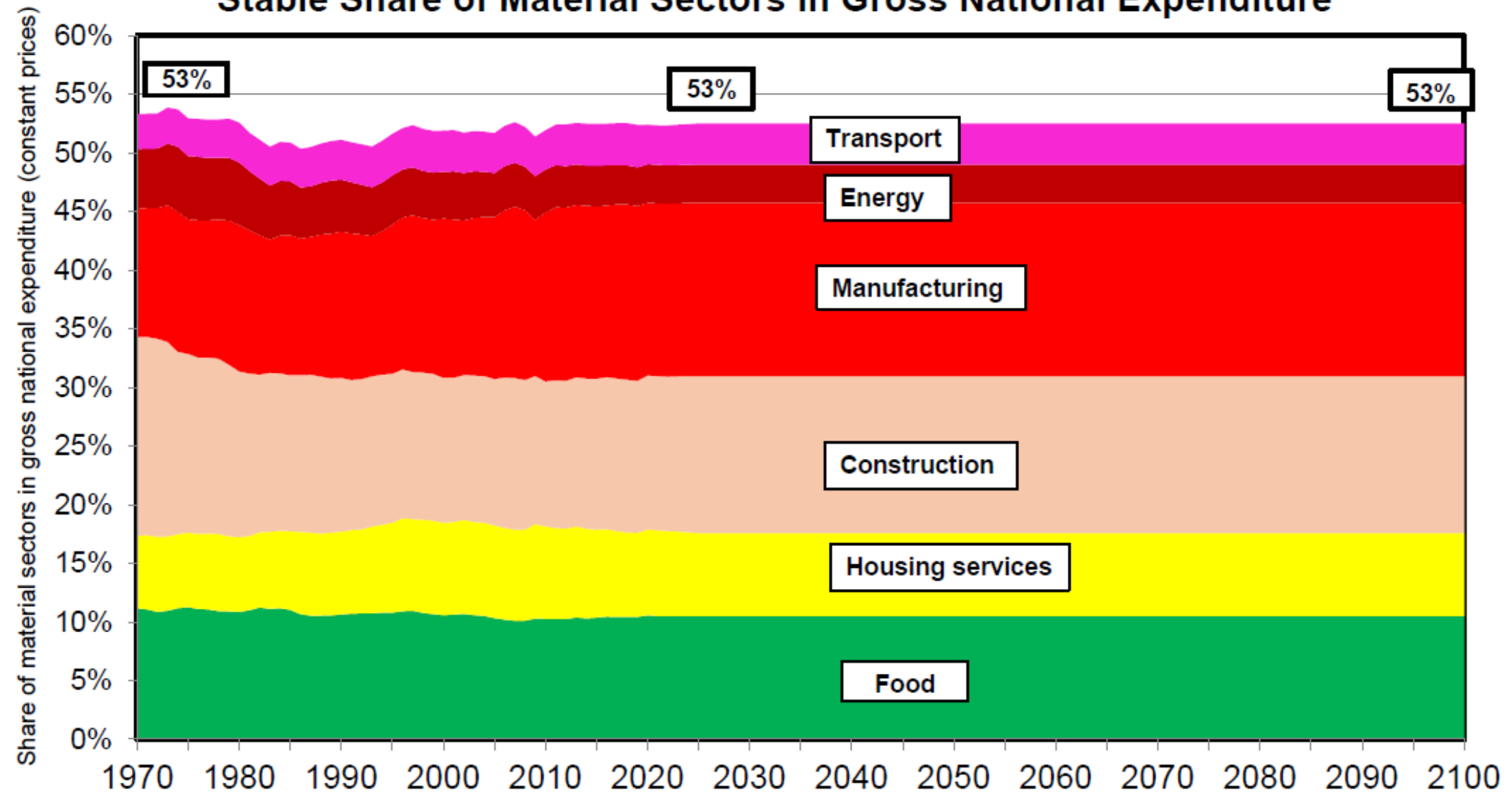
Interpretation. GDP price inflation has been 3.6% per year on average at the world level between 1970 and 2025 and is projected to be 2.0% over the 2025-2100 period. Inflation has always been lower in material sectors than in immaterial sectors (e.g. in manufacturing sector vs education/health), due to differential rates of technical change and is projected to follow the same pattern in 2025-2100. **Sources and series:** wiseed.world (C0a)

Global Relative Price Indexes by Sector 1970-2100



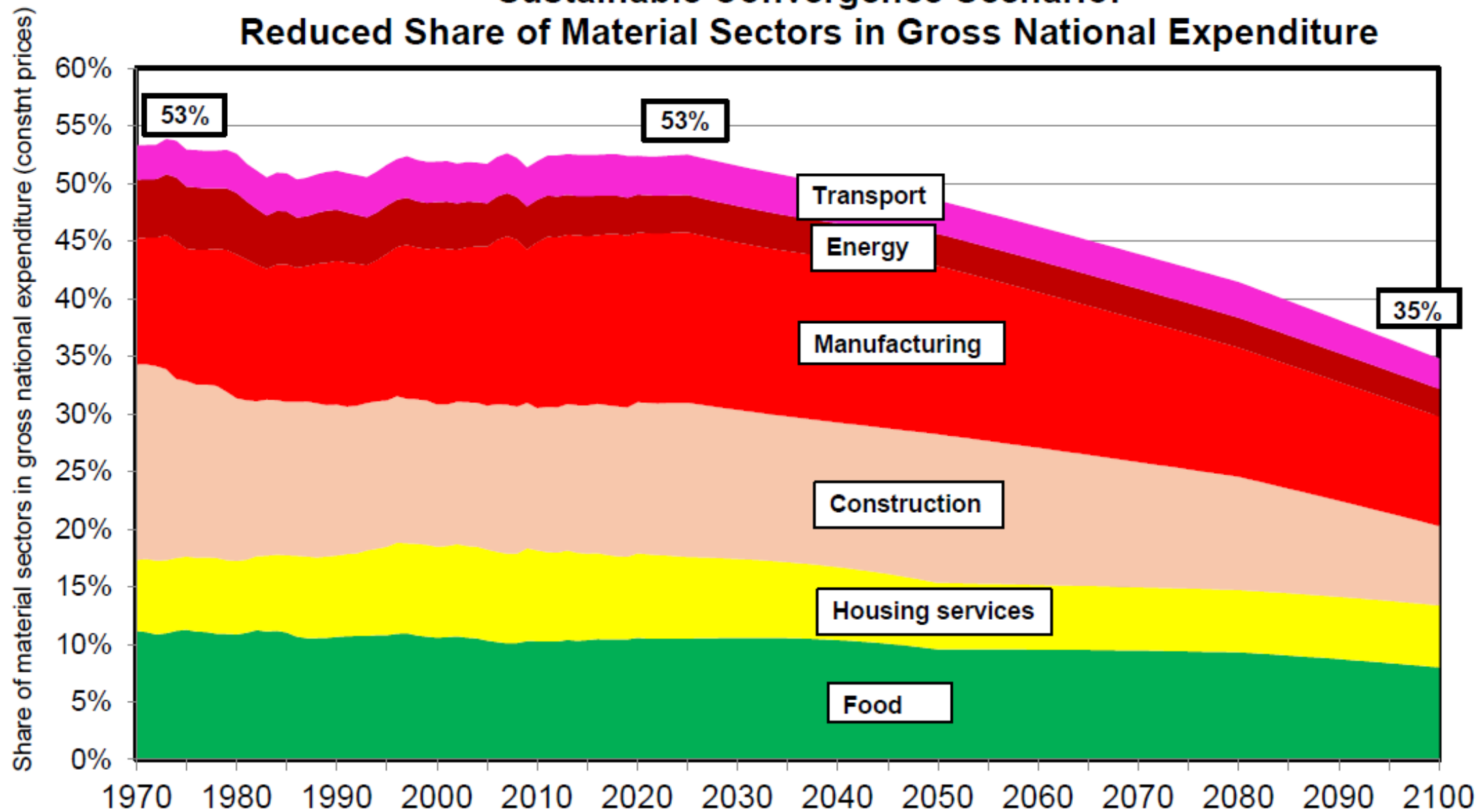
Interpretation. Price inflation has generally been smaller in material sectors than in immaterial sectors, due to differential rate of technical change, and is projected to follow the same pattern in 2025-2100. In effect, the relative price of manufacturing goods has been almost divided by 2 over 1970-2025 and is projected to be divided by more than 2 over 2025-2100. This corresponds in both cases to a relative price effect of about 0.5-1.0% per year relative to general GDP price index. **Sources and series:** wseed.world (C0b)

Productivist Convergence & Persistent Inequality Scenarios: Stable Share of Material Sectors in Gross National Expenditure



Interpretation. The share of material sectors in gross national expenditure (final consumption and investment) remained stable at 53% at the world level between 1970 and 2025. It is projected to remain stable around 53% between 2025 and 2100 according to our productivist convergence and persistent inequality scenarios. **Sources and series:** wseed.world (G0p)

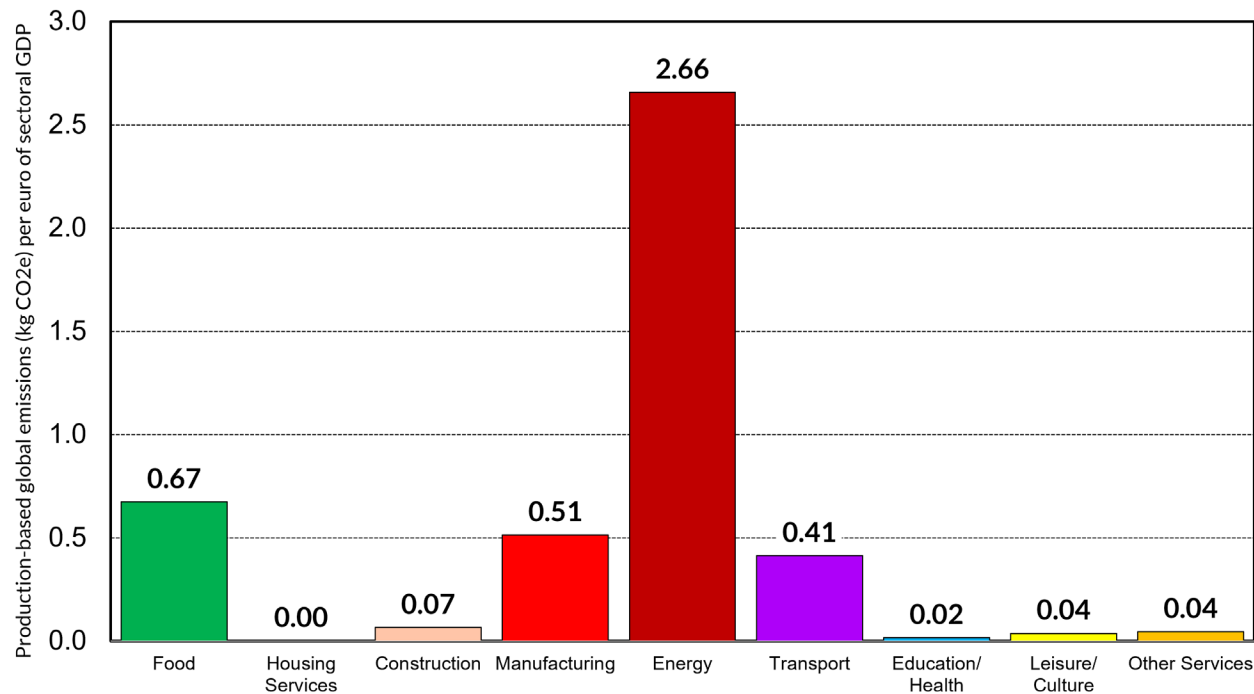
Sustainable Convergence Scenario: Reduced Share of Material Sectors in Gross National Expenditure



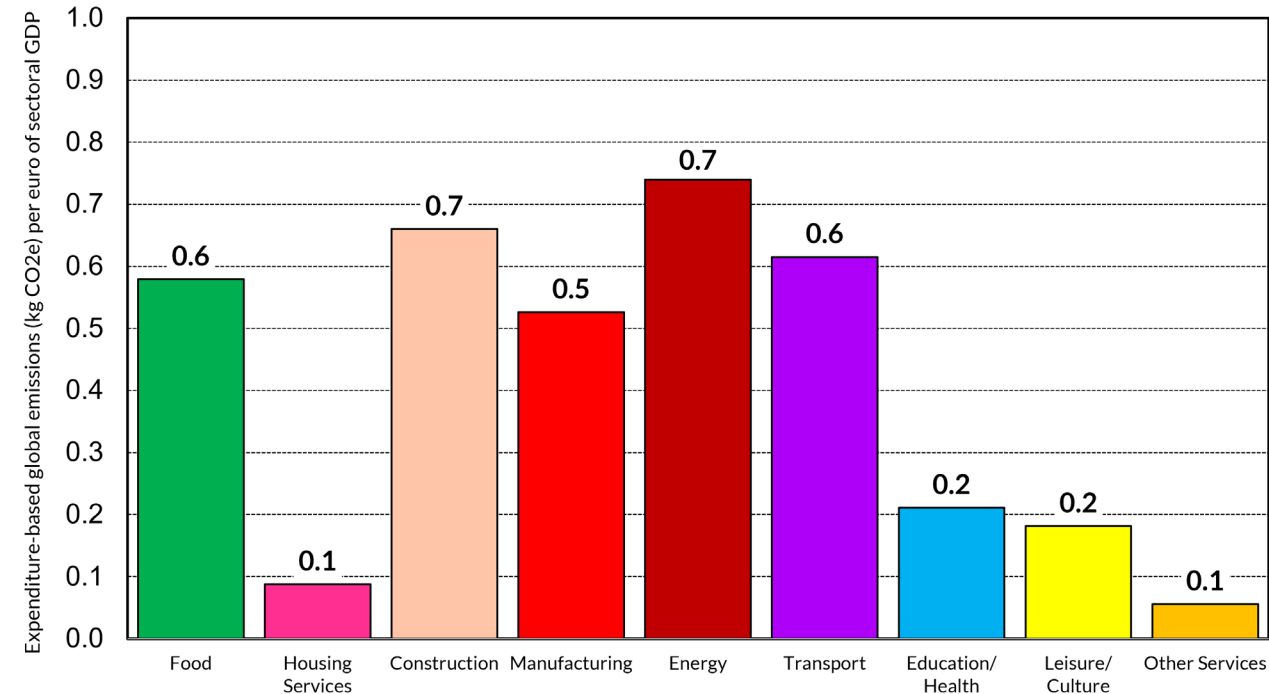
Interpretation. The share of material sectors in gross national expenditure (final consumption and investment) remained stable at 53% at the world level between 1970 and 2025. It is a projected to decline to 35% by 2100 according to our Sustainable Convergence scenario. This corresponds to a 30% reduction in the share of material sectors in consumption and investment expenditure. **Sources and series:** wseed.world (G0m)

Material Sectors Have a Much Larger Carbon Footprint

Production-based



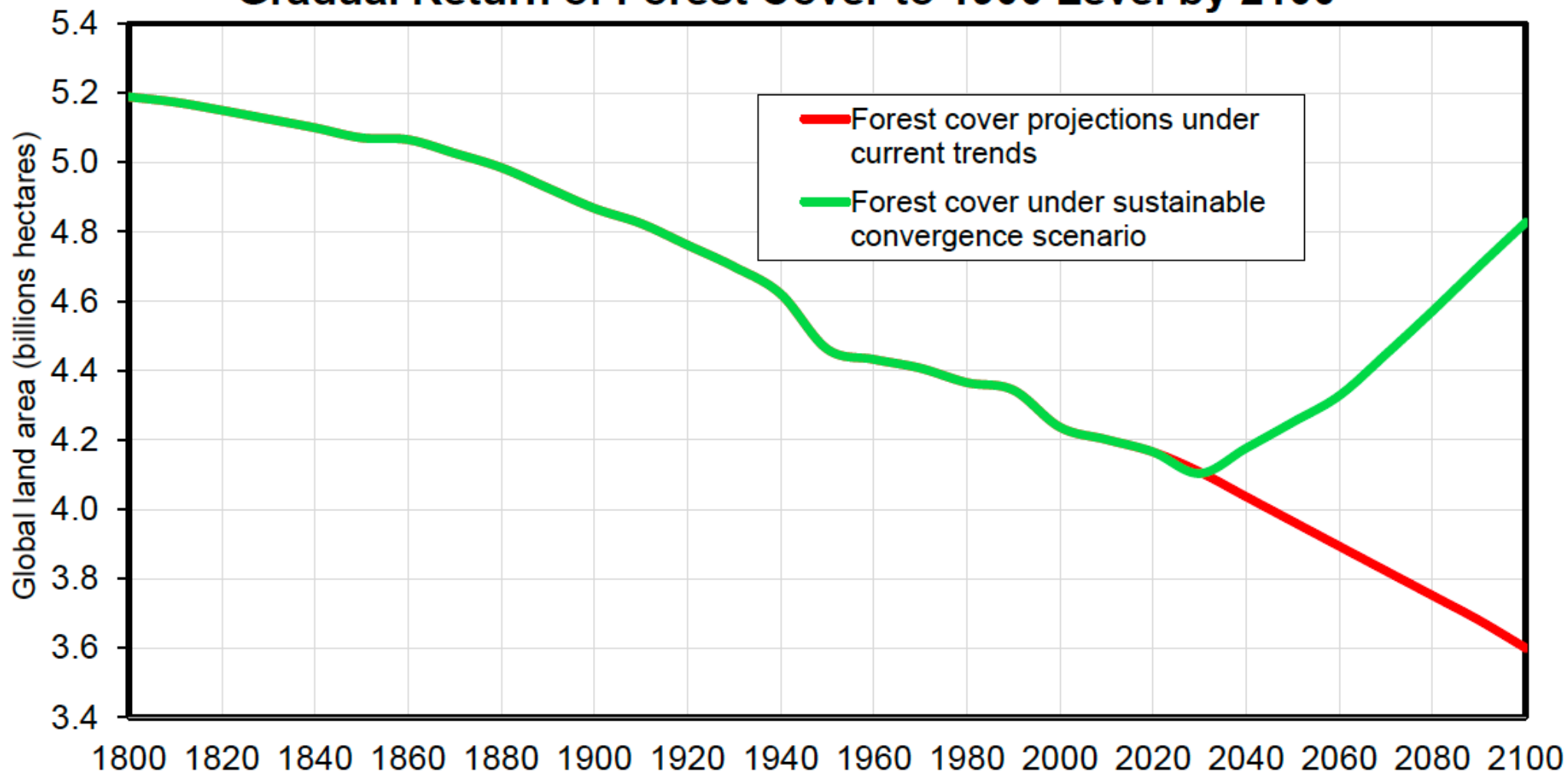
Expenditure-based



Interpretation. According to the production-based approach, global GHG emission intensities are a lot larger in material sectors and close to zero in immaterial sectors. This production-based perspective is partly artificial, however, as it ignores the intermediate inputs used by the various sectors. **Sources and series:** wseed.world (S3)

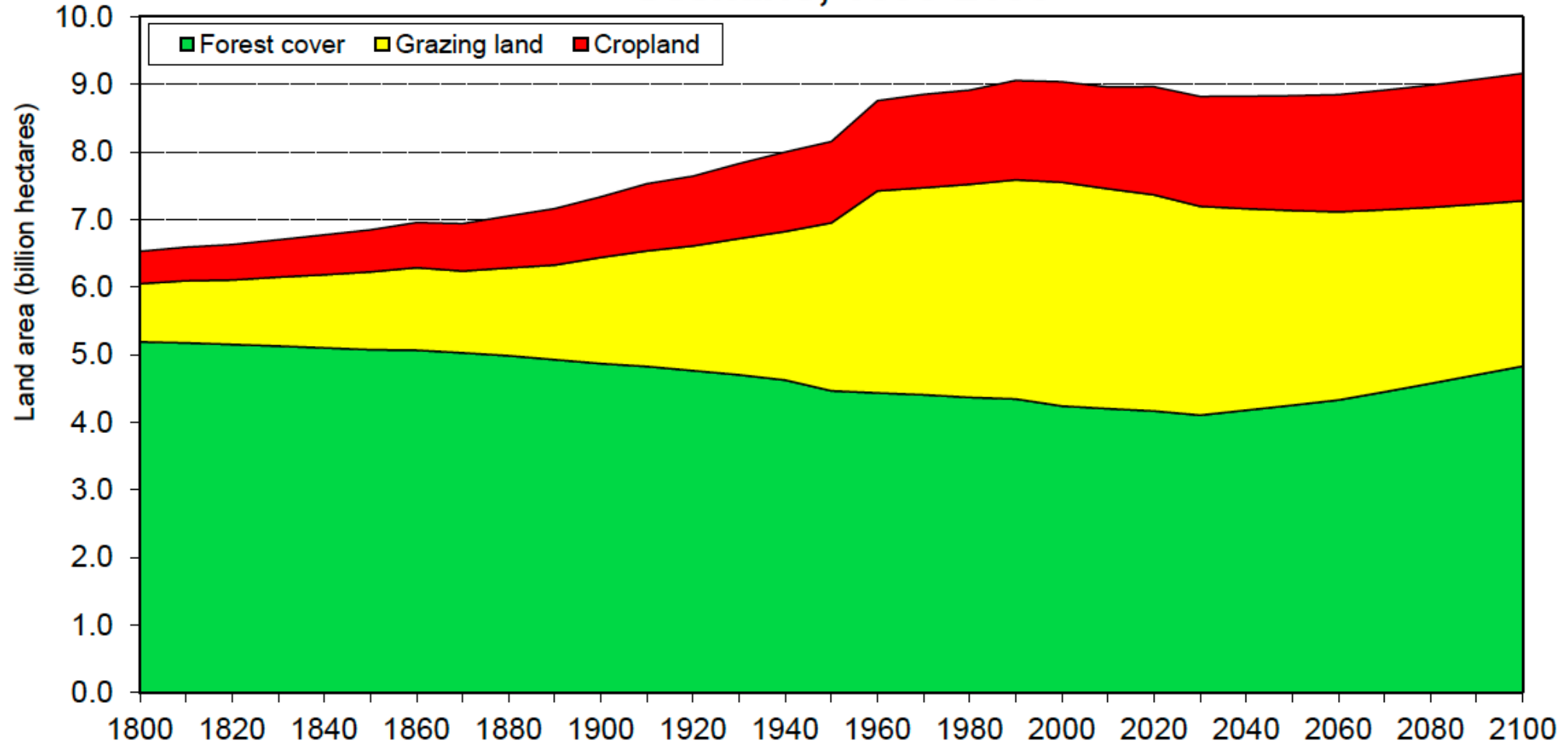
Interpretation. Because they take into account intermediate inputs, expenditure-based global GHG emissions intensities are more balanced across sectors than production-based intensities. But they also show large gaps: immaterial sectors have GHG intensities that are around three to four times smaller (per euro of sectoral GDP) than material sectors, which is already very substantial. **Sources and series:** wseed.world (S4)

Sustainable Convergence: Deforestation Ban in 2030 & Gradual Return of Forest Cover to 1900 Level by 2100



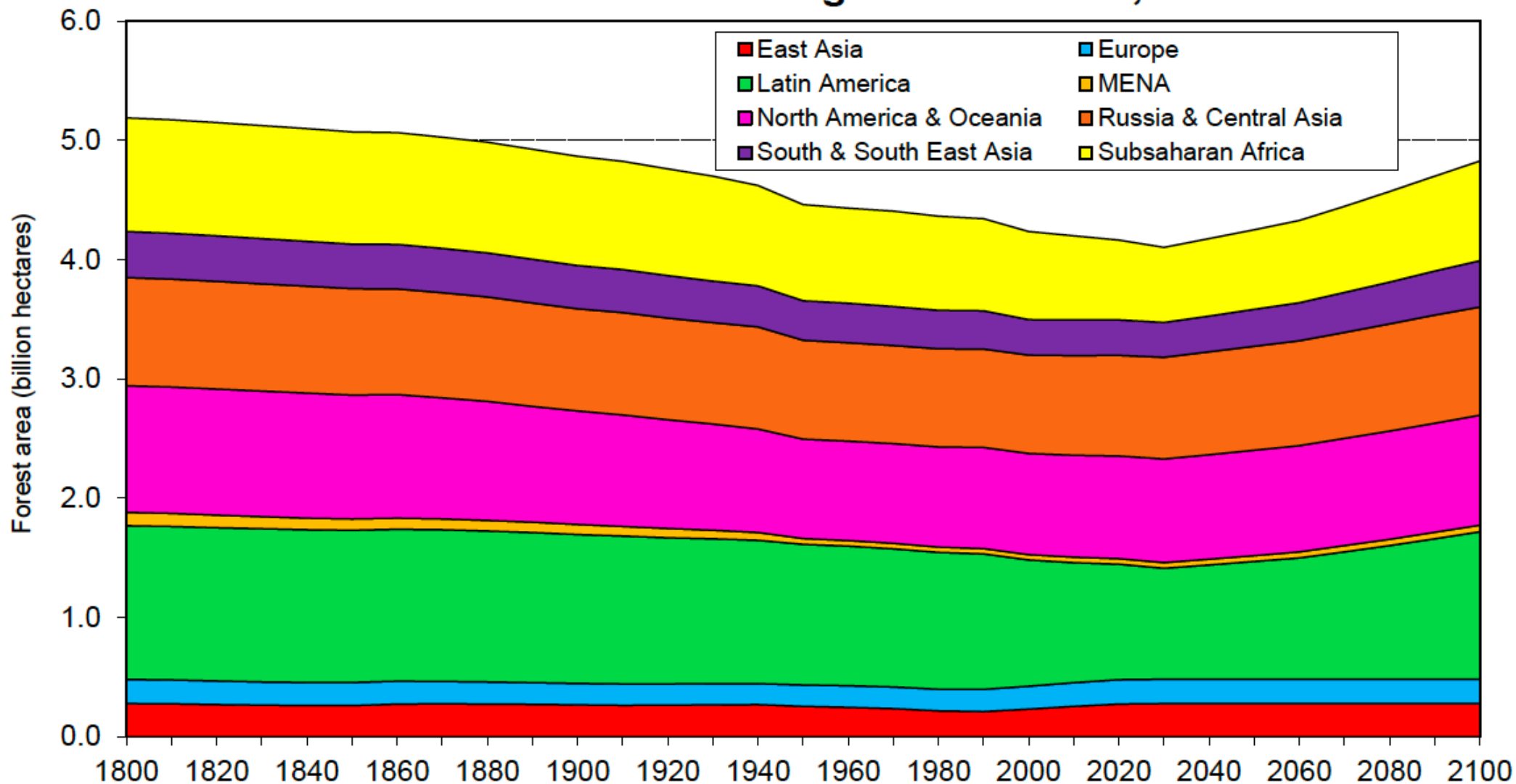
Interpretation. According to our Sustainable Convergence scenario, a complete ban on deforestation will be imposed in 2030 and a large reforestation plan will allow global forest cover to gradually rise from about 4.1 billion hectares in 2025 to 4.8 billion by 2100, i.e. approximately the same level as in 1900. In contrast, in the Productivist Convergence and Persistent Inequality scenarios, deforestation is expected to continue at the same speed as in recent decades, so that global forest cover will reach about 3.6 billion by 2100. Sources and series: wseed.world (U3)

Global Agricultural Land (Grazing Land and Cropland) and Forest Cover under the Sustainable Convergence Scenario, 1800-2100



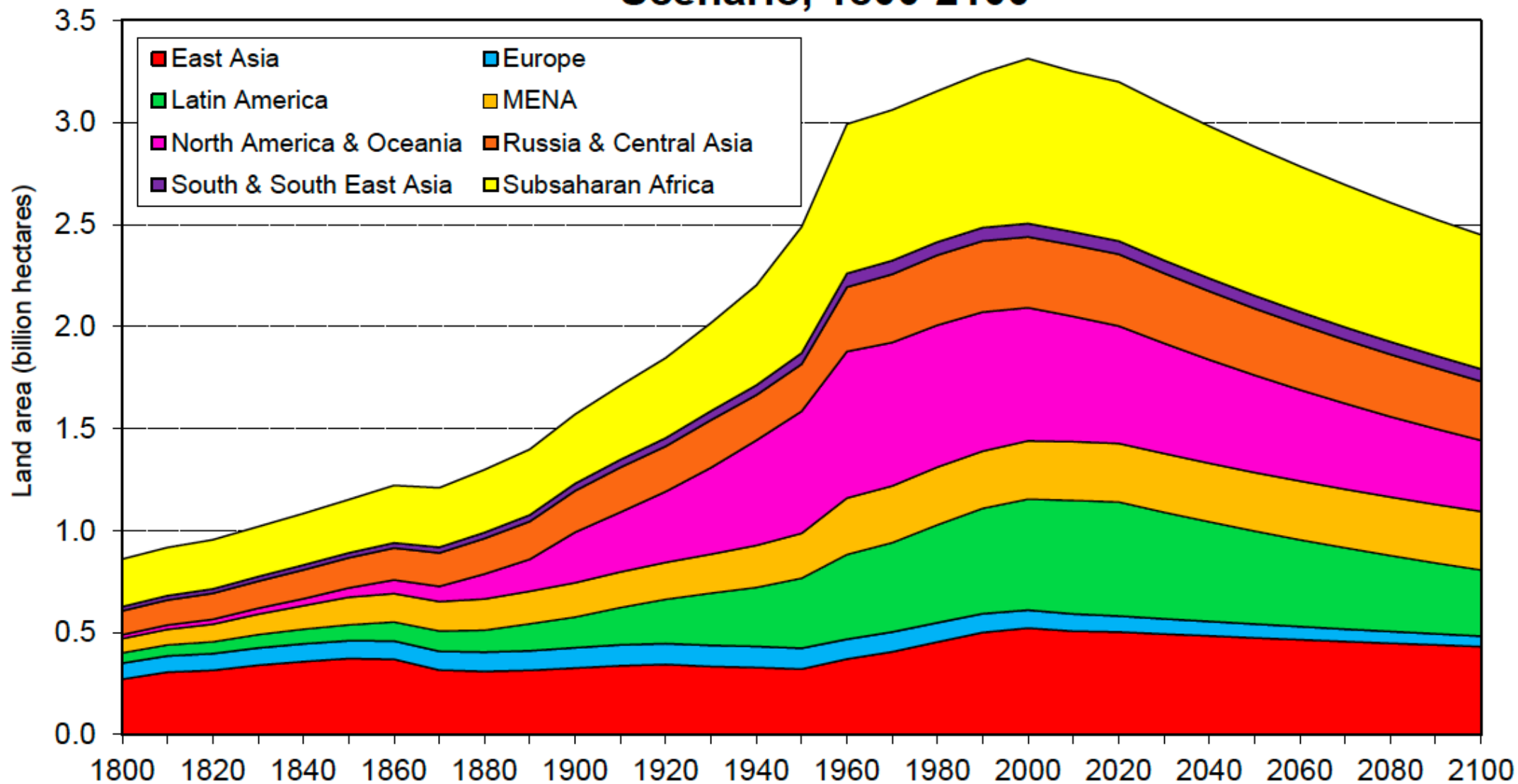
Interpretation. According to our Sustainable Convergence scenario, global forest cover rises from 4.1 billions hectares in 2025 to 4.8 billions by 2100 (i.e. approximately the same level as in 1900), while grazing land declines sharply from 3.2 to 2.4 billions and cropland rises moderately from 1.6 to 1.9 billions (in order to make up for the shift from meat to vegetables). Sources and series: wseed.world (U4)

Forest Cover by World Region Under Sustainable Convergence Scenario, 1800-2100



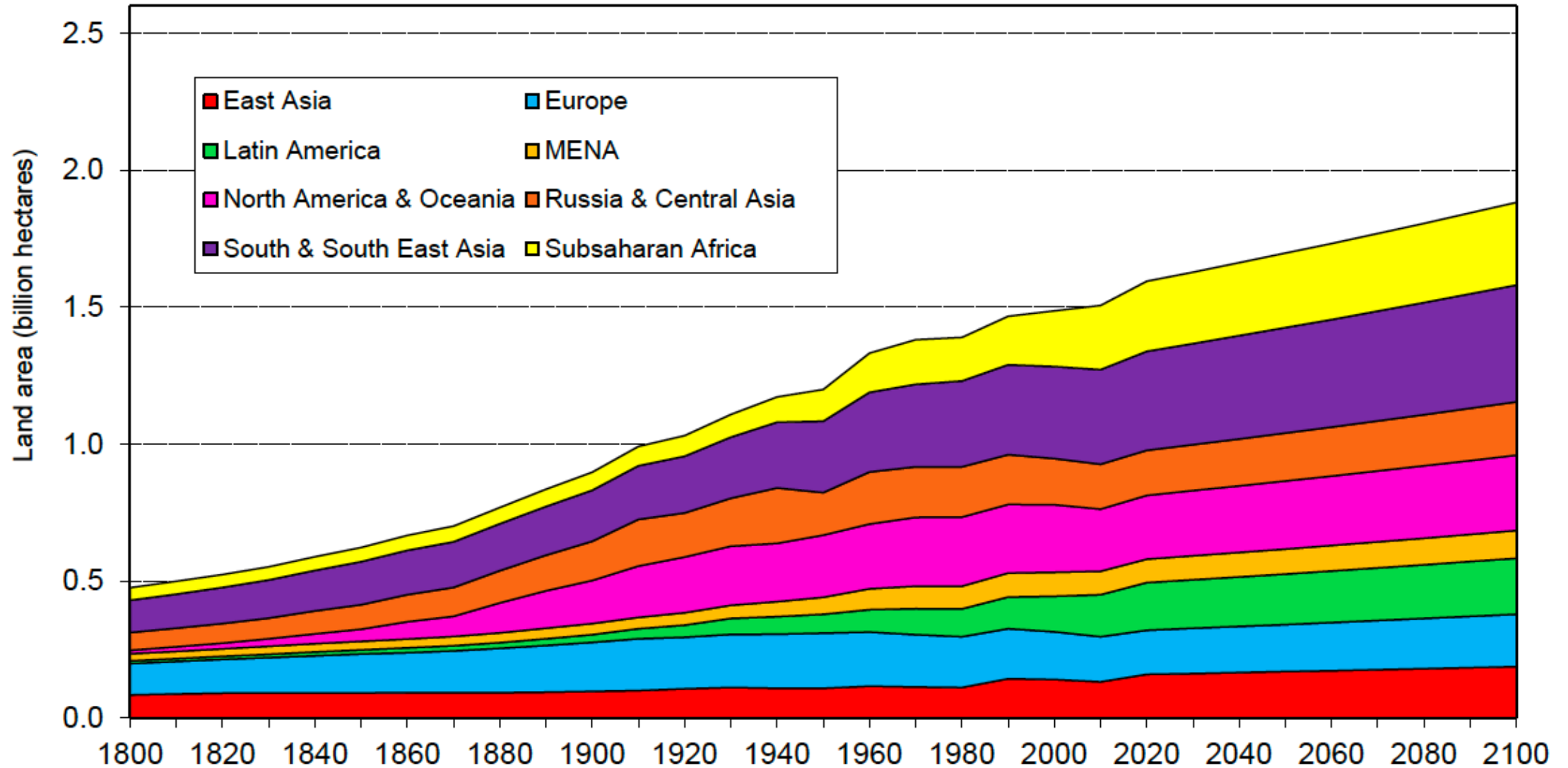
Interpretation. According to our Sustainable Convergence scenario, global forest cover rises from 4.1 billions hectares in 2025 to 4.8 billions by 2100 (i.e. approximately the same level as in 1900), with large increases in all regions. **Sources and series:** wseed.world (U5a)

Grazing Land by Region Under Sustainable Convergence Scenario, 1800-2100



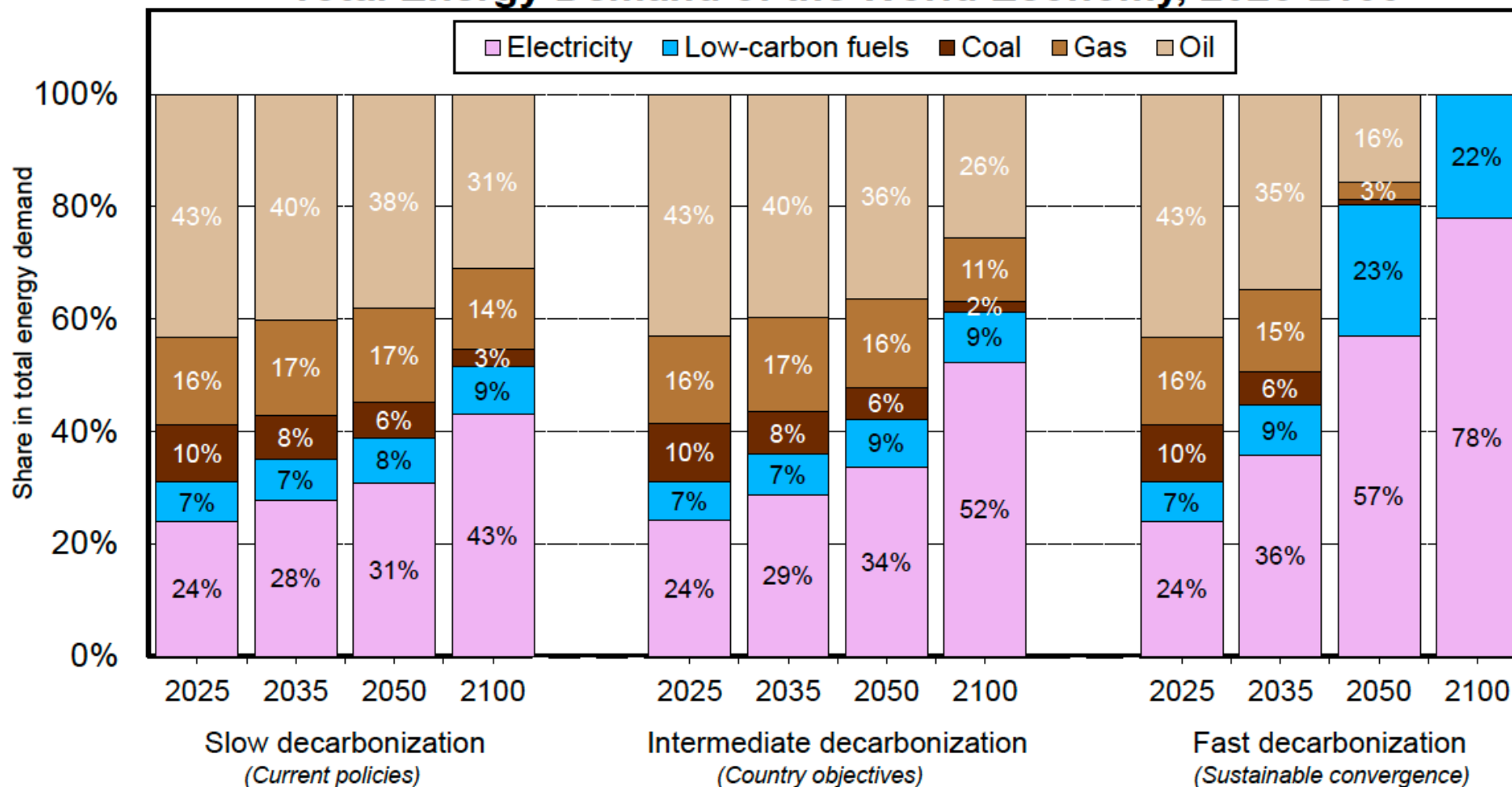
Interpretation. According to our Sustainable Convergence scenario, grazing land declines from 3.2 to 2.4 billions hectares between 2025 and 2100, with large declines in all regions. Sources and series: wseed.world (U5b)

Cropland by Region Under Sustainable Convergence Scenario, 1800-2100



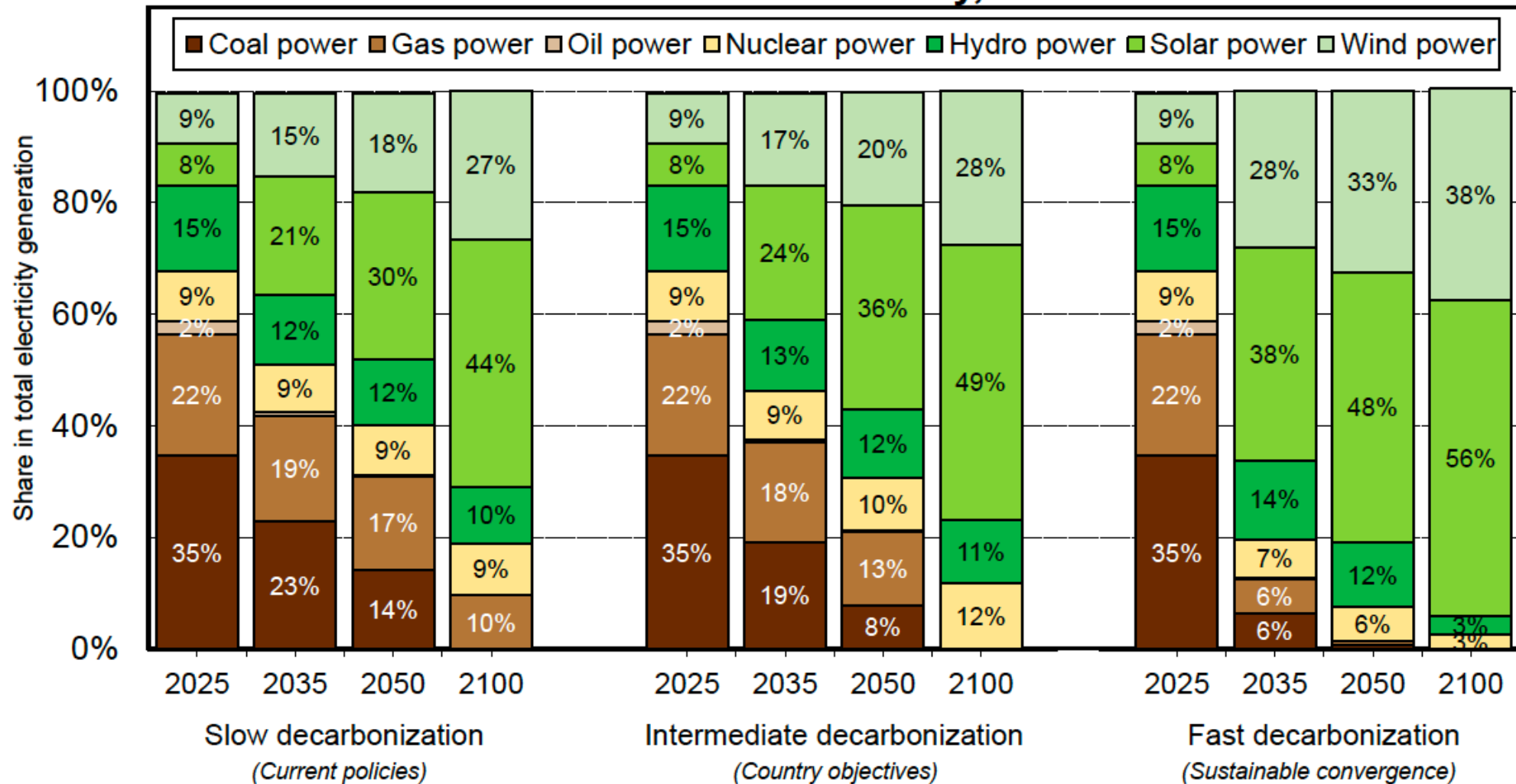
Interpretation. According to our Sustainable Convergence scenario, cropland rises moderately from 1.6 to 1.9 billions between 2025 and 2100 (in order to make up for the shift from meat to vegetables), with moderate increases in all regions. Sources and series: wseed.world (U5c)

Slow, Intermediate, and Fast Decarbonization Scenarios: Total Energy Demand of the World Economy, 2025-2100



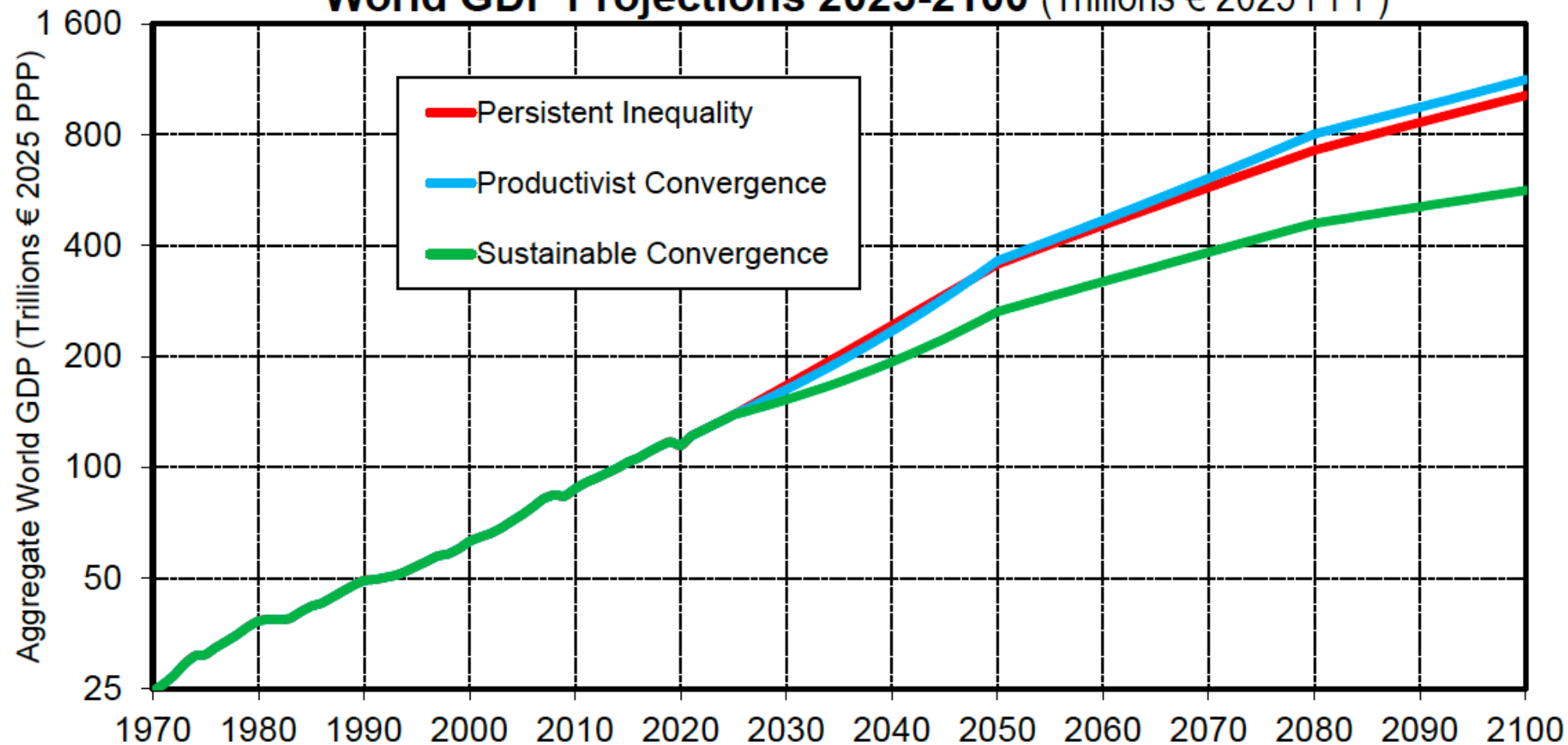
Interpretation. The Fast Decarbonization scenario (sustainable development) is characterized by large phase-out of fossil fuels (less than 20% of total energy demand of the world economy by 2050 and 0% by 2100) as compared to both the Slow decarbonization scenario (current policies) and the Intermediate decarbonization scenario (official country objectives). **Note.** "Electricity" includes district heat production (from CHP plants, heat pumps, and electric boilers), which accounts for 4% of total final energy demand in 2025, compared to 20% for electricity strictly speaking. **Sources and series:** wseed.world (T1)

Slow, Intermediate, and Fast Decarbonization Scenarios: Generation of Electricity, 2025-2100



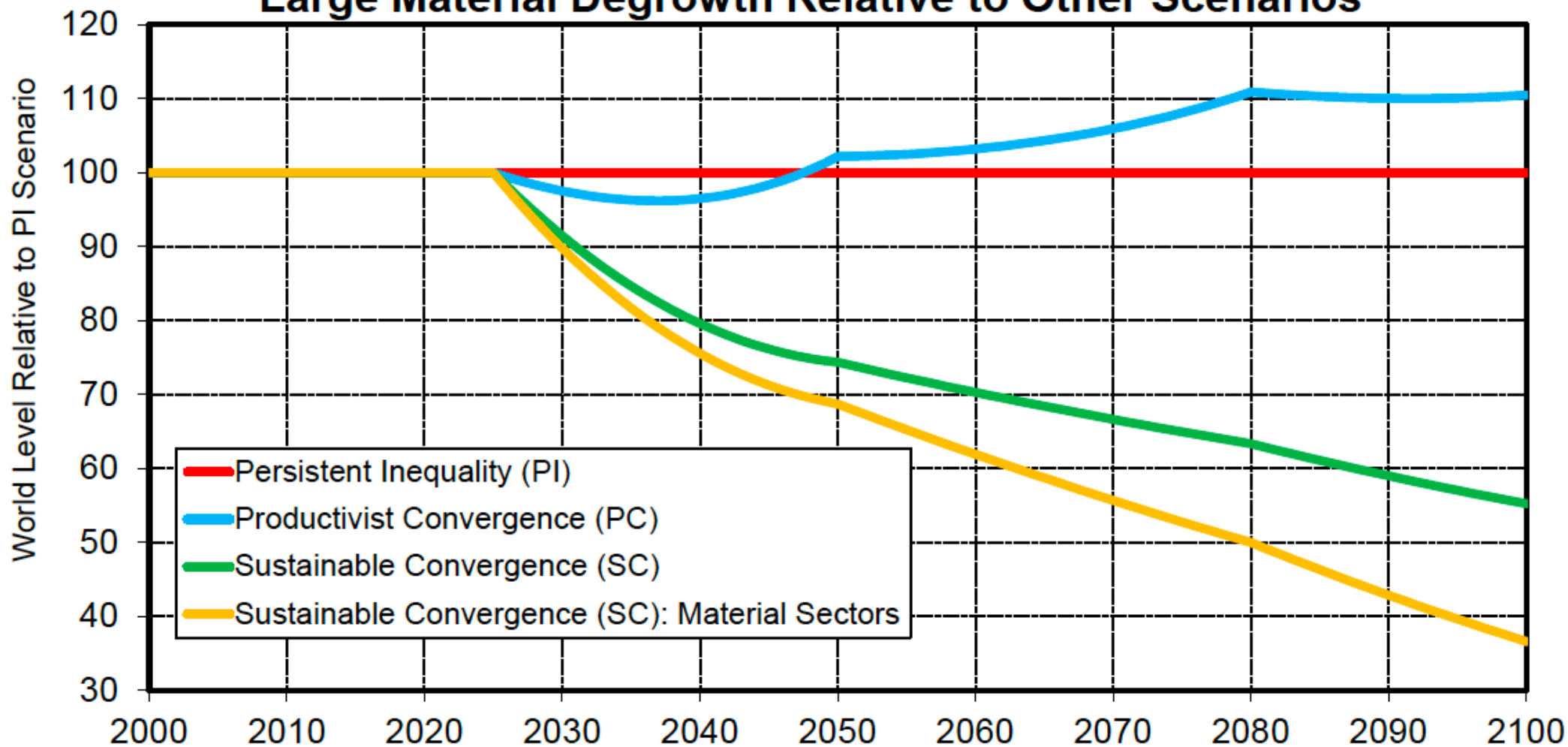
Interpretation. Under the sustainable convergence scenario (FD), the decarbonization of electricity should accelerate considerably as compared to both current policies (SD) and official country objectives and pledges (ID). In particular, fossil fuel power should represent less than 1% of total electricity generation by 2050 (vs 31% and 21% according to SD and ID scenarios). Sources and series: wseed.world (T4)

Sustainable Convergence vs Other Scenarios: World GDP Projections 2025-2100 (Trillions € 2025 PPP)



Interpretation. According to the sustainable convergence scenario, aggregate world GDP rises from 139T (Trillions Euros 2025 PPP) in 2025 to 565T in 2100, vs 1023T in the persistent inequality scenario and 1130T in the productivist convergence scenario. In effect, the real growth rate of world GDP, which was equal to 3.2% per year between 1970 and 2025, is projected to slow down to 1.9% per year between 2025 and 2100 in the sustainable convergence scenario, vs 2.7% and 2.8% per year in the other two scenarios. Sources and series: wseed.world (R0a)

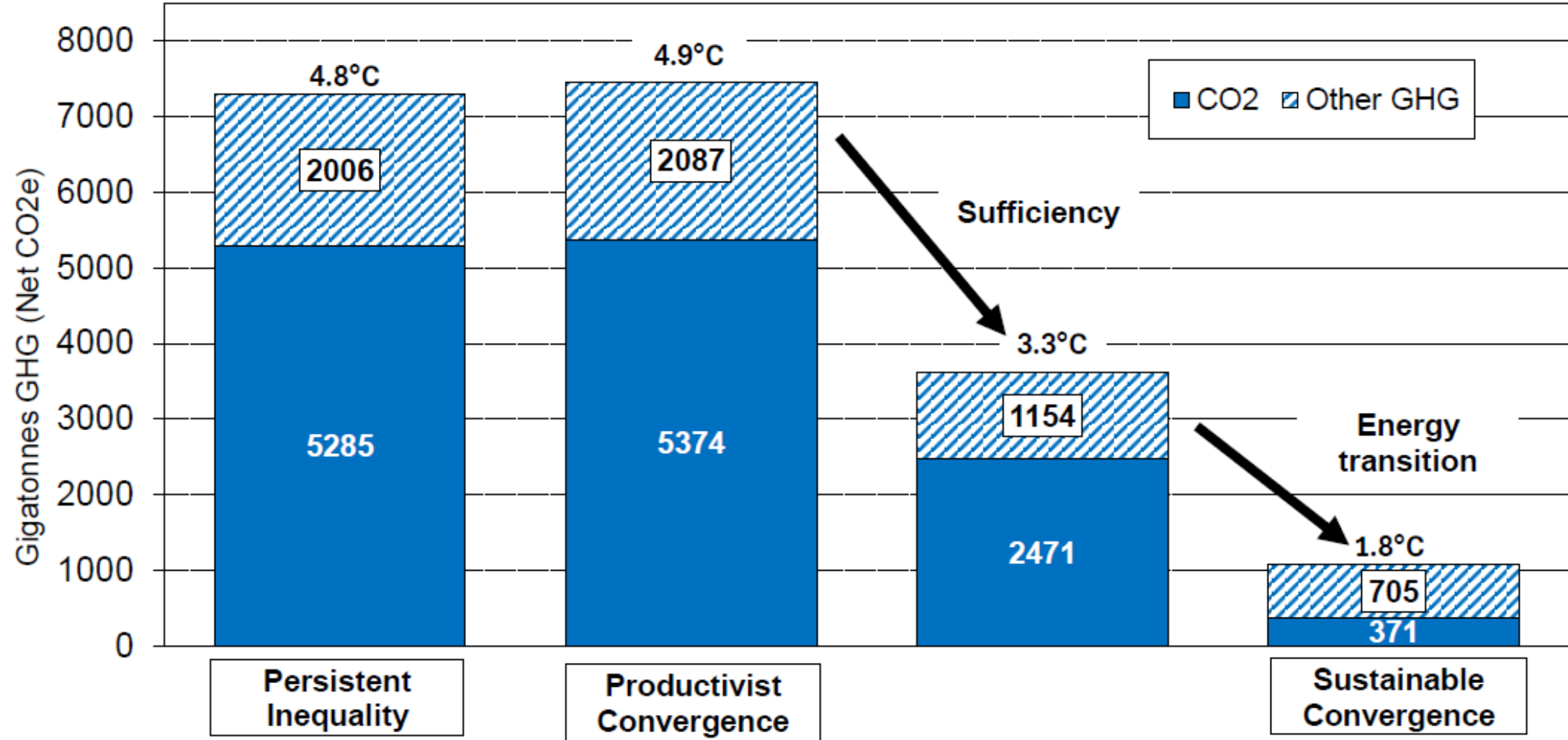
Sustainable Convergence Scenario: Large Material Degrowth Relative to Other Scenarios



Interpretation. According to the Sustainable Convergence scenario, aggregate world GDP is projected to be equal to 73% of the PI level (Persistent Inequality scenario) in 2050 and 55% in 2100. The fall is even larger if we focus on material sectors (food/agriculture, construction/housing, manufacturing, energy/mining, transport), where total world expenditure (final consumption and investment) in the SC scenario is projected to be equal to 67% of PI level in 2050 and 37% in 2100. Sources and series: wseed.world (R0b)

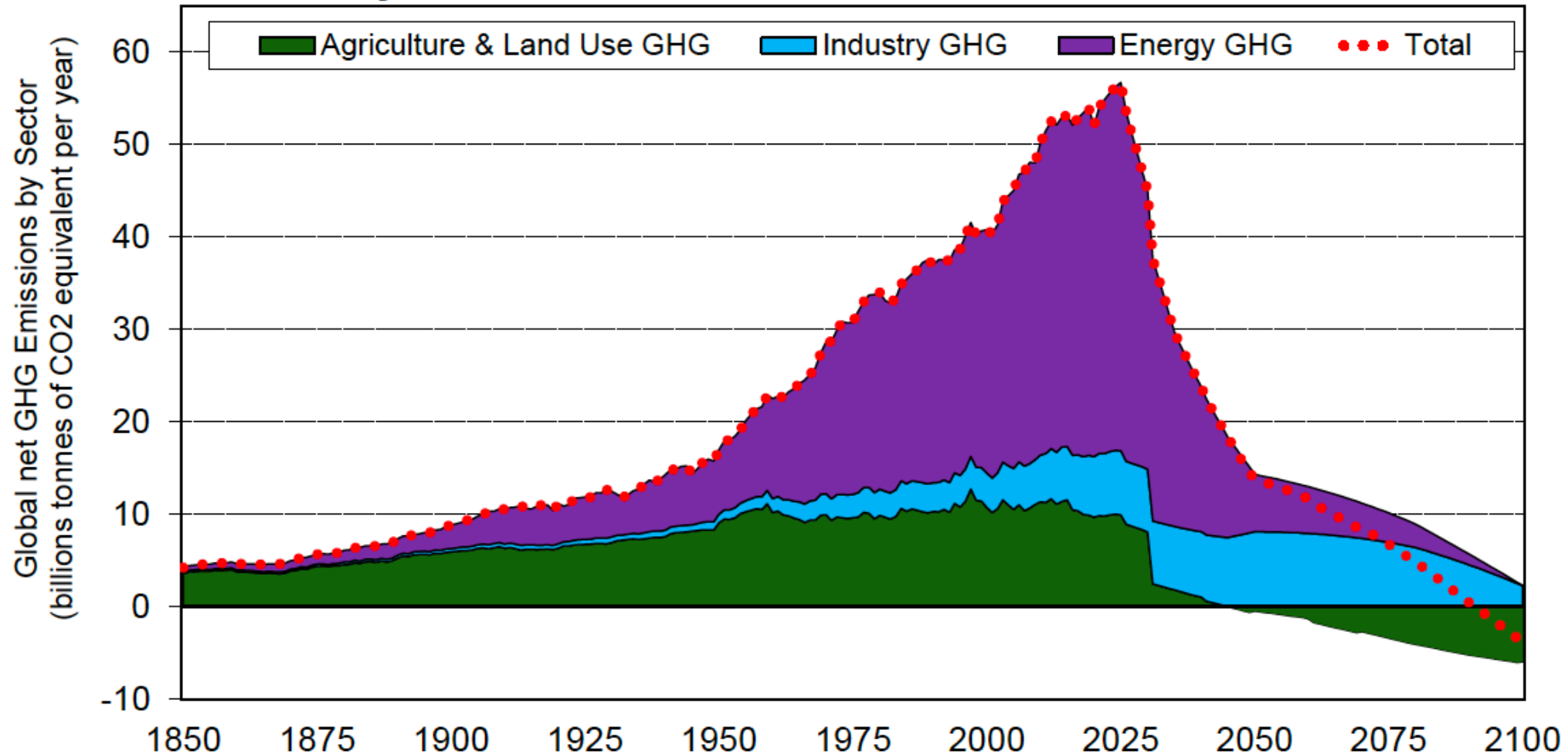
Sufficiency & Energy Transition Are Complementary

(Projected Emissions & Temperature of Core Scenarios 2026-2100)



Interpretation. In order to reduce GHG emissions and keep warming below 2°, both socioeconomic sufficiency - including labour hours reduction, shift to immaterial consumption, change of food habits & implied reforestation - and energy system transformation play an indispensable and complementary role. **Notes.** The figure shows projected cumulative emissions and temperature rise of the core scenarios, where persistent inequality and productivist convergence come with slow decarbonization and sustainable convergence with fast decarbonization.. **Sources and series:** wseed.world (X1)

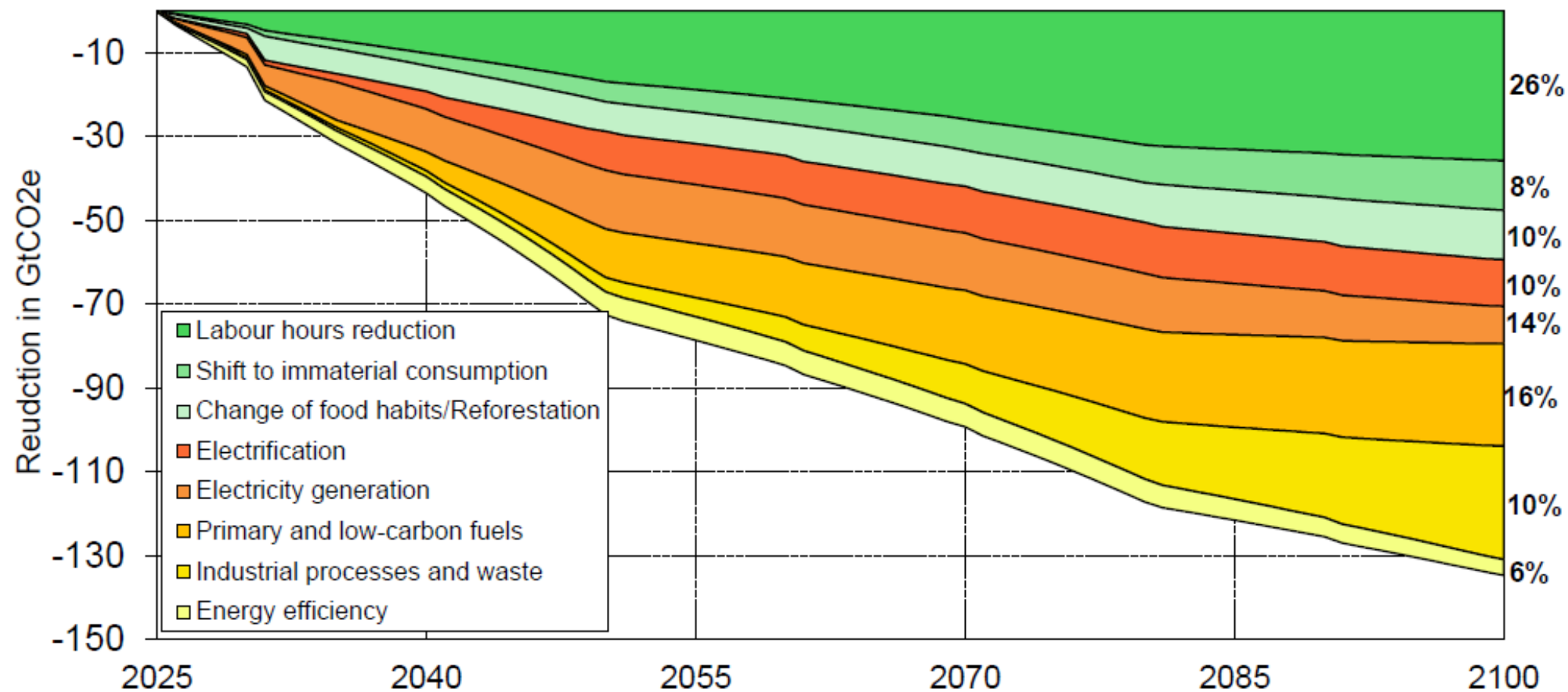
Sustainable Convergence and Fast Decarbonization: The Key Role of Fossil Fuels Phase-Out & Deforestation Ban



Interpretation. Under the sustainable convergence/fast decarbonization scenario, the sharp decline of GHG emissions over the 2026-2100 period is made possible by the rapid phase-out of fossil fuels (fall of Energy GHG) and a strict deforestation ban enforced in 2030, followed by gradual reforestation bringing world forest cover back to 1900 level by 2100 (leading to negative Agriculture & Land-Use GHG in 2050-2100, and slight negative total net GHG emissions by 2100). In contrast, Industry GHG (cement, waste, etc.) are more difficult to remove entirely.

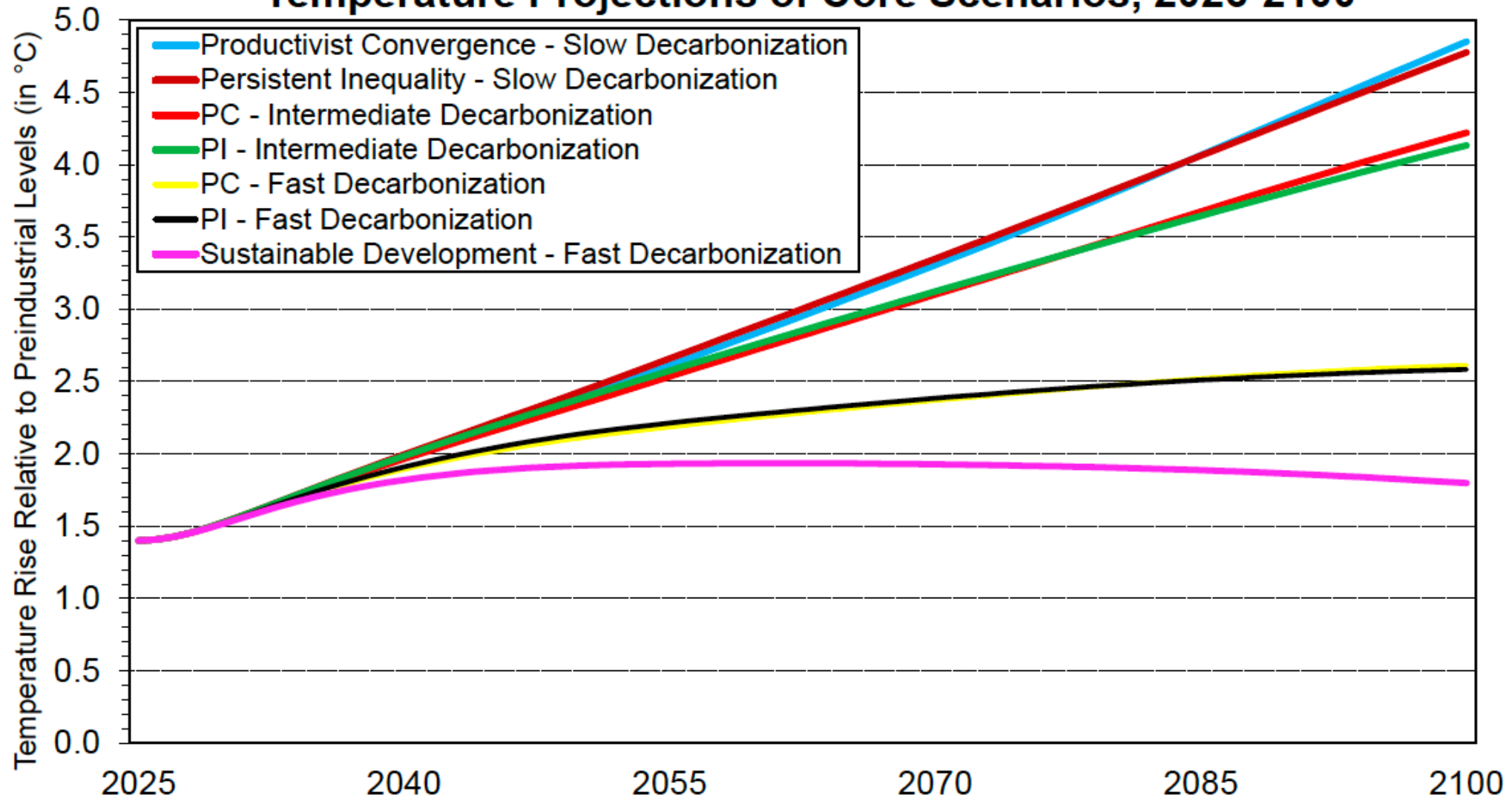
Note: Observed series 1850-2025. Projected series 2026-2100 (Sustainable Convergence Scenario with Fast Decarbonization). **Sources and series:** wseed.world (X2)

Sufficiency & Energy Transition Are Complementary (Decomposition of Emissions Reduction Drivers 2026-2100)



Interpretation. In order to reduce GHG emissions and keep warming below 2°, both socioeconomic sufficiency - including labour hours reduction, shift to immaterial consumption, change of food habits & implied reforestation - and energy system transformation play an indispensable and complementary role. **Notes:** The figure shows Shapley decomposition of the annual difference in emissions (in GtCO_{2e}) between the Productivistst Convergence - Slow Decarbonization Scenario and the Sustainable Convergence - Fast Decarbonization Scenario. Percentage values on the right show contribution over entire 2025-2100 period. **Sources and series:** wseed.world (X3)

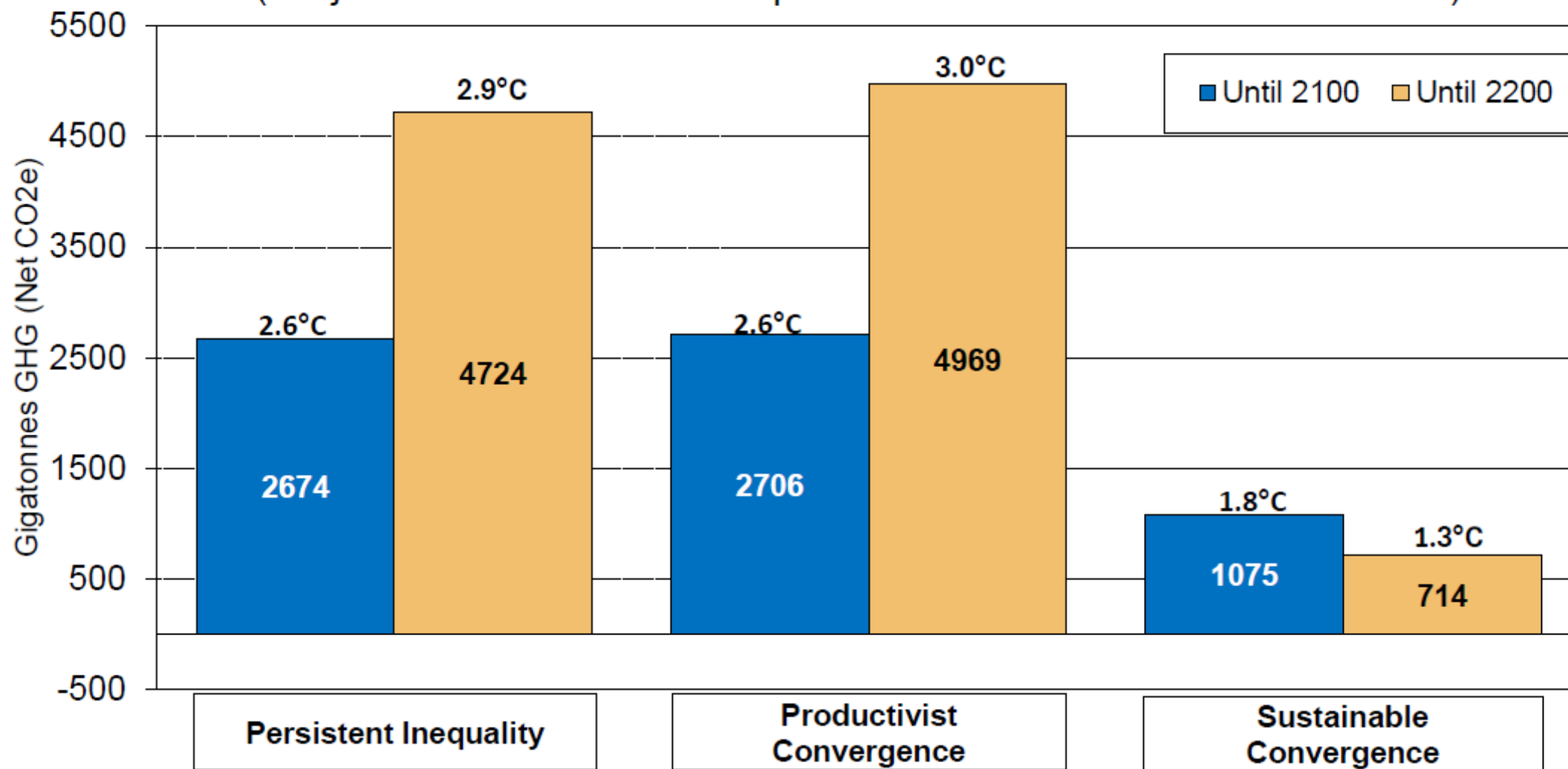
Temperature Projections of Core Scenarios, 2026-2100



Interpretation. The Sustainable Development/Fast Decarbonization scenario is the only one leading below 2°C by 2100. The PC and PI scenarios under Slow Decarbonization (current policies) lead to 4.8-4.9°C, while the PC and PI scenarios with Intermediate Decarbonization (official country commitments) lead to 4.1-4.2°C. The PC and PI scenarios with Fast Decarbonization lead to 2.6°C, but such a policy mix appears to be very unlikely. In any case, emissions and temperature rise would continue after 2100 under this scenario (no net zero emission).

Sources and series: wseed.world (X4)

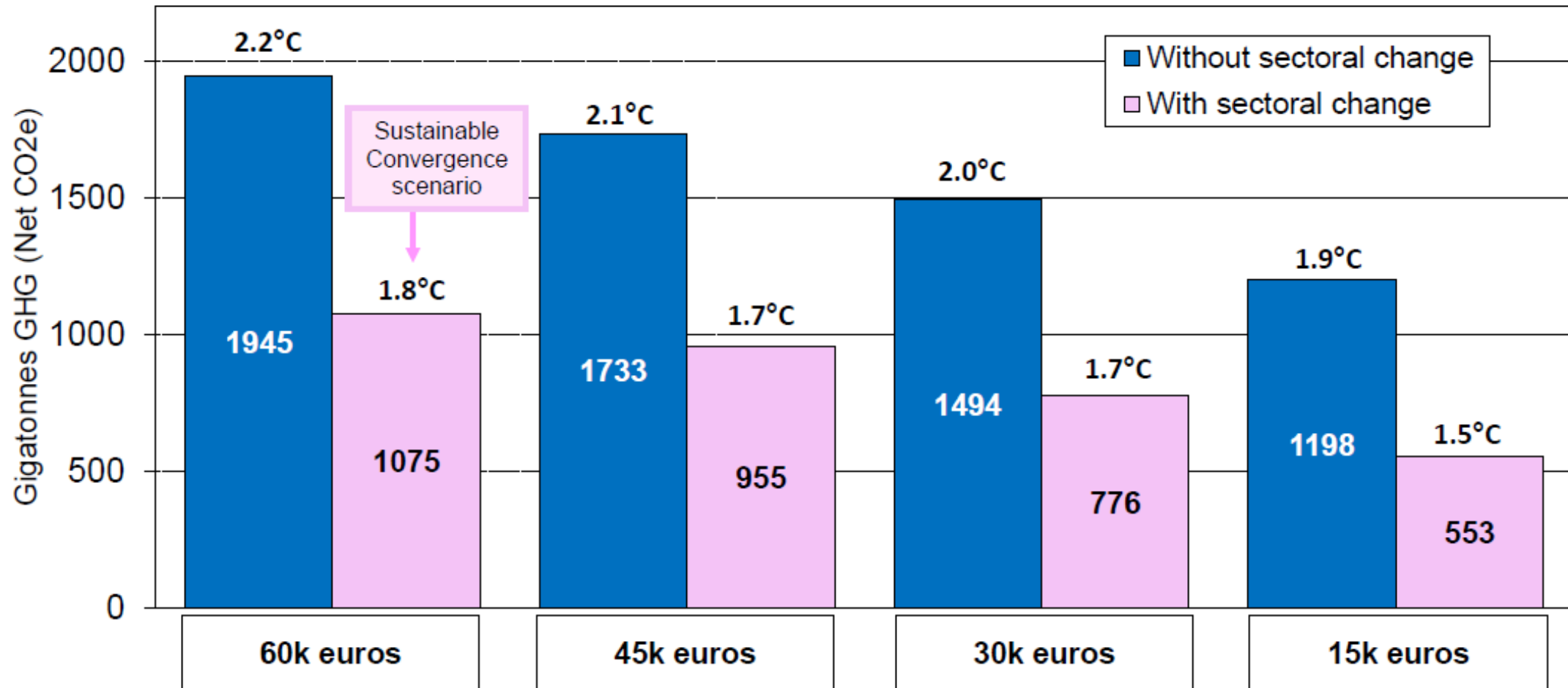
Without Sufficiency, Emissions Will Continue After 2100 (Projected Emissions & Temperature under Fast Decarbonization)



Interpretation. In the unlikely situation where the PI and PC scenarios are combined with Fast Decarbonization, positive emissions and temperature rise will continue well beyond 2100. **Note.** The 2200 values are a simplistic approximation where we hold 2100 net emissions constant. They illustrate that Persistent Inequality and Productivist Convergence have not reached net zero by 2100. **Sources and series:** wseed.world (X5)

Targeted Sufficiency Can Be More Effective Than Large Uniform Degrowth

(Projected Emissions & Temperature Under Fast Decarbonization)

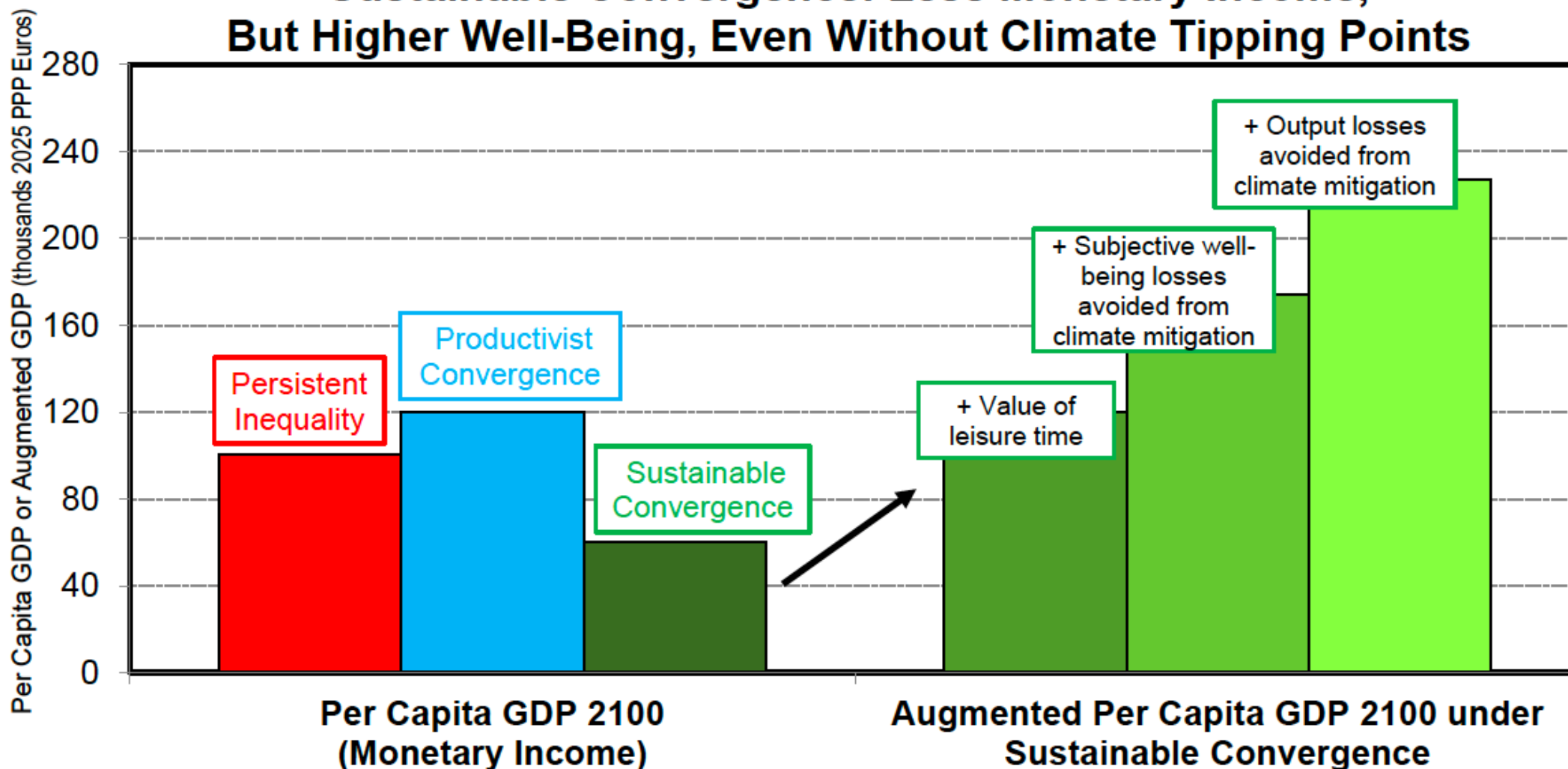


Interpretation. Targeted sufficiency, i.e. global convergence of all countries to 60k Euros 2025 PPP in per capita GDP by 2100, together with sectoral change (consumption shift to immaterial sectors, change in food habits & implied reforestation), leads to 1.8°C temperature rise in 2100, i.e. less than the 1.9°C associated to large uniform degrowth (15k for all in 2100) but no structural change. **Note.** It might be difficult to combine 15k with structural change, as this implies large reduction in average food intake. **Sources and series:** wseed.world (X7)

Winners & Losers from Sustainable Convergence: Monetary Accounting vs Material Accounting

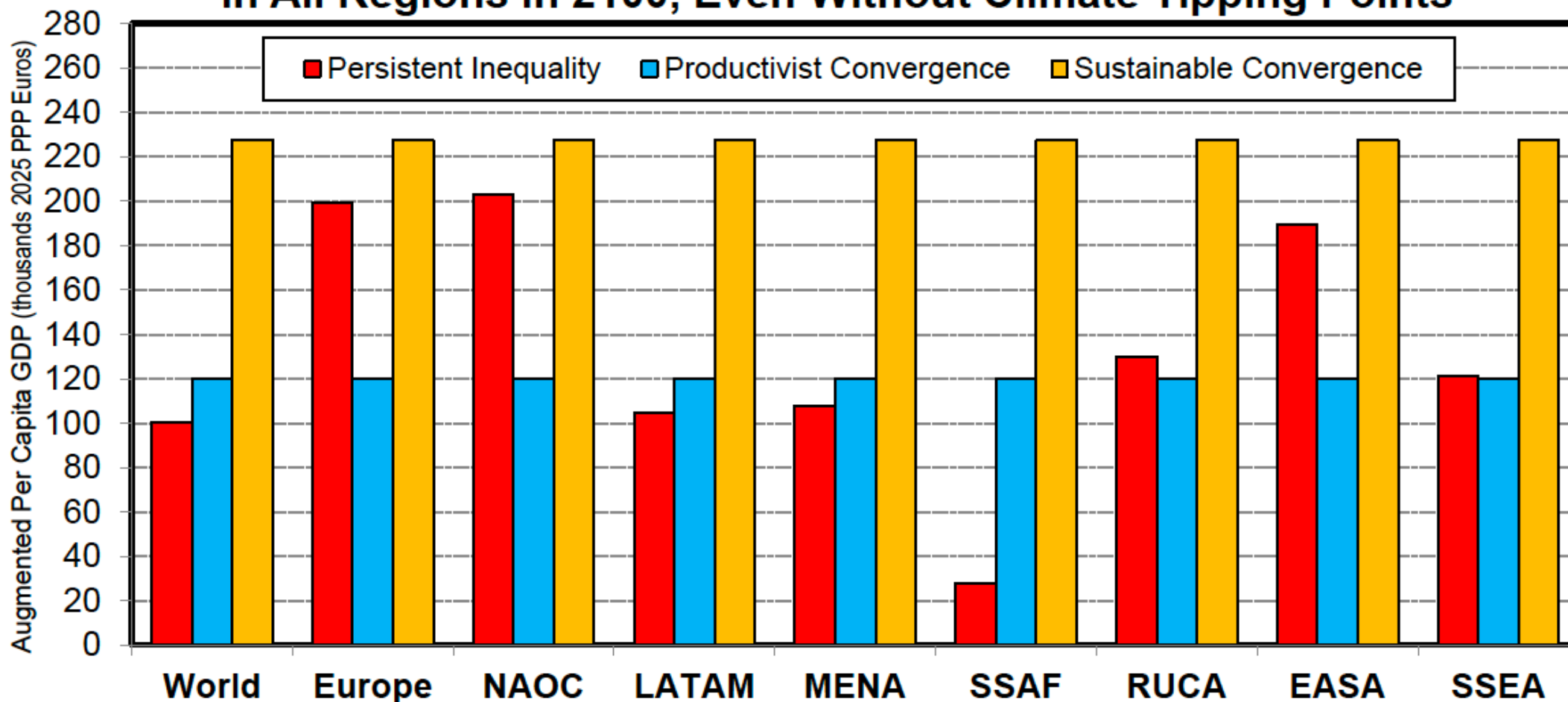
- Thanks to inequality compression, the **bottom 90% of the population benefits from rising monetary incomes**
- Once the **value of leisure and planetary habitability (well-being loss + GDP loss due to warming)** is taken into account, **more than 99% of the world's population is better off** in 2100 than today, including in the richest regions.
- Well-being loss: see Dietrich-Nichols [More than a feeling: A global economic valuation of subjective wellbeing damages resulting from rising temperatures](#), 2025 (12% well-being loss per degree)
- GDP loss: see Bilal-Kanzig, "[The Macroeconomic Impact of Climate Change: Global vs. Local Temperature](#)" 2026 (20% GDP loss per degree: we take 10%)
- **But there can be many more losers** (not only among the very rich) **in comparison to high-growth, high warming scenarios**, especially among people with small valuations for leisure and planetary habitability

Sustainable Convergence: Less Monetary Income, But Higher Well-Being, Even Without Climate Tipping Points



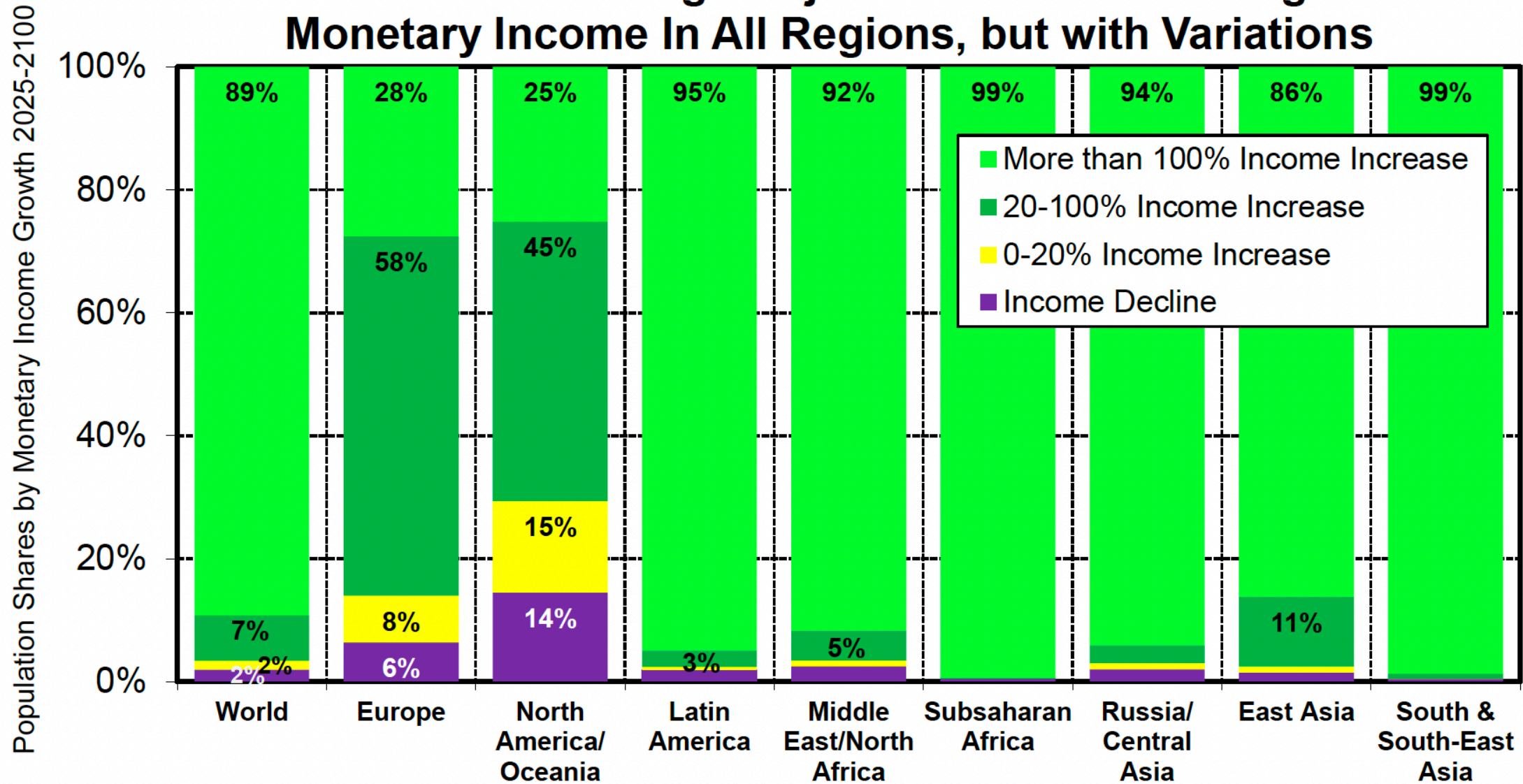
Interpretation. The Sustainable Convergence (SC) scenario leads to lower per capita GDP than other scenarios in 2100 but to higher well-being, once we include the value of extra free time (leisure) and a lower-bound estimate of the value of planetary habitability, as measured by the impact of lower temperatures on subjective well-being and output. This ignores potential catastrophic climate events and tipping points, which are nearly impossible to value in monetary terms. **Sources and series:** wseed.world (R1a)

Sustainable Convergence: Higher Well-Being in All Regions in 2100, Even Without Climate Tipping Points



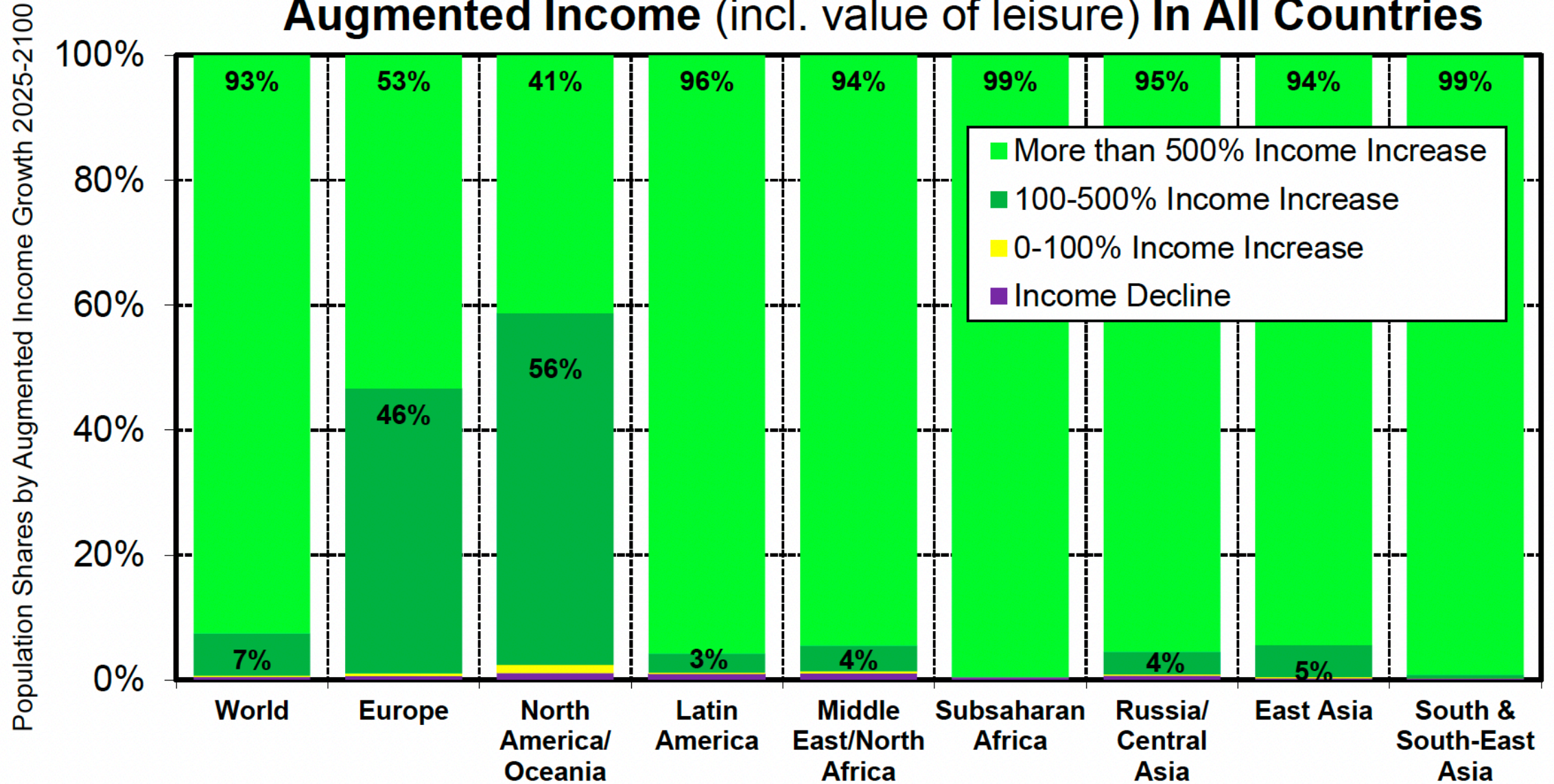
Interpretation. The Sustainable Convergence (SC) scenario leads to higher augmented per capita GDP (comprehensive well-being indicator, including value of extra free time and planetary habitability) than other scenarios in all world regions in 2100. However the gap is relatively small for the world's richest regions, & can even turn negative for some countries during the transition period 2025-2100. This ignores potential catastrophic climate events and tipping points, which are nearly impossible to value in monetary terms. **Note.** NAOC: North America/Oceania. LATAM: Latin America. SSAF: Sub-Saharan Africa. RUCA: Russia/Central Asia. EASA: East Asia. SSEA: South & Southeast Asia. **Sources and series:** wseed.world (R1b)

Global Justice: Large Majorities Benefit from Higher Monetary Income In All Regions, but with Variations



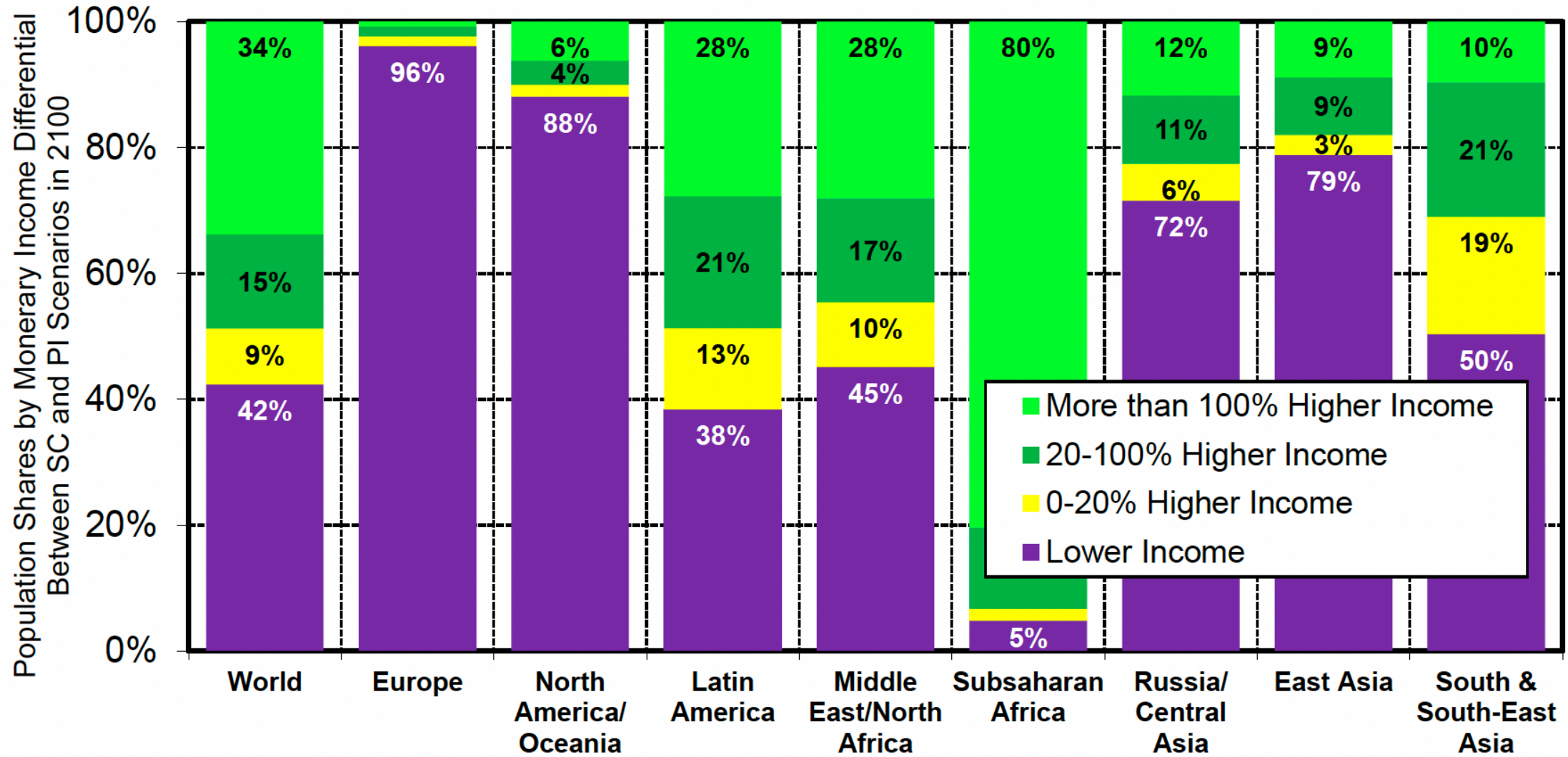
Interpretation. According to the Global Justice Platform, large majorities of the population in every region benefit from rising monetary income between 2025 and 2100. At the world level, 89% of the population double their income or more, 7% increase their income between 20% and 100%, 2% by 0-20% and 2% face an income decline. However the fraction of the population declining income rises to significantly higher levels in the richest regions (6% in Europe and 14% in North America/Oceania). **Sources and series:** gjp.wid.world (O2a)

Global Justice: Large Majorities Benefit from Much Higher Augmented Income (incl. value of leisure) In All Countries



Interpretation. If we include plausible lower-bound estimates for the valuation of free time (leisure), we find that over 99% of the population in all regions benefit from very large rise in “augmented income” between 2025 and 2100. **Sources and series:** gjp.wid.world (O2b)

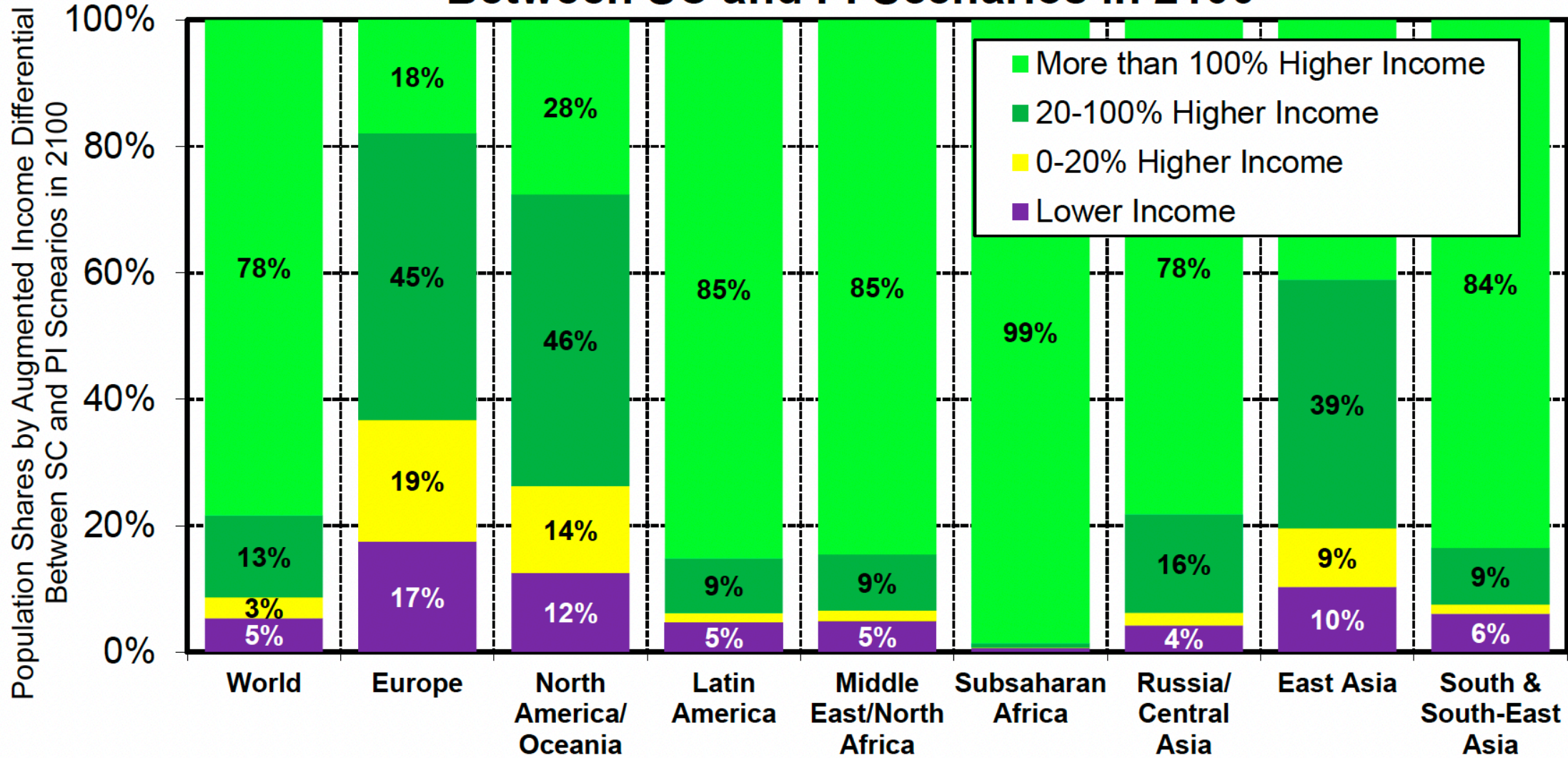
Population Shares by Monetary Income Differential Between SC and PI Scenarios in 2100



Interpretation. According to our projections, 42% of the world population has lower monetary income in 2100 under sustainable convergence (SC) as compared to persistent inequality (PI) scenario. This fraction is as large as 88-96% in the world's richest regions.

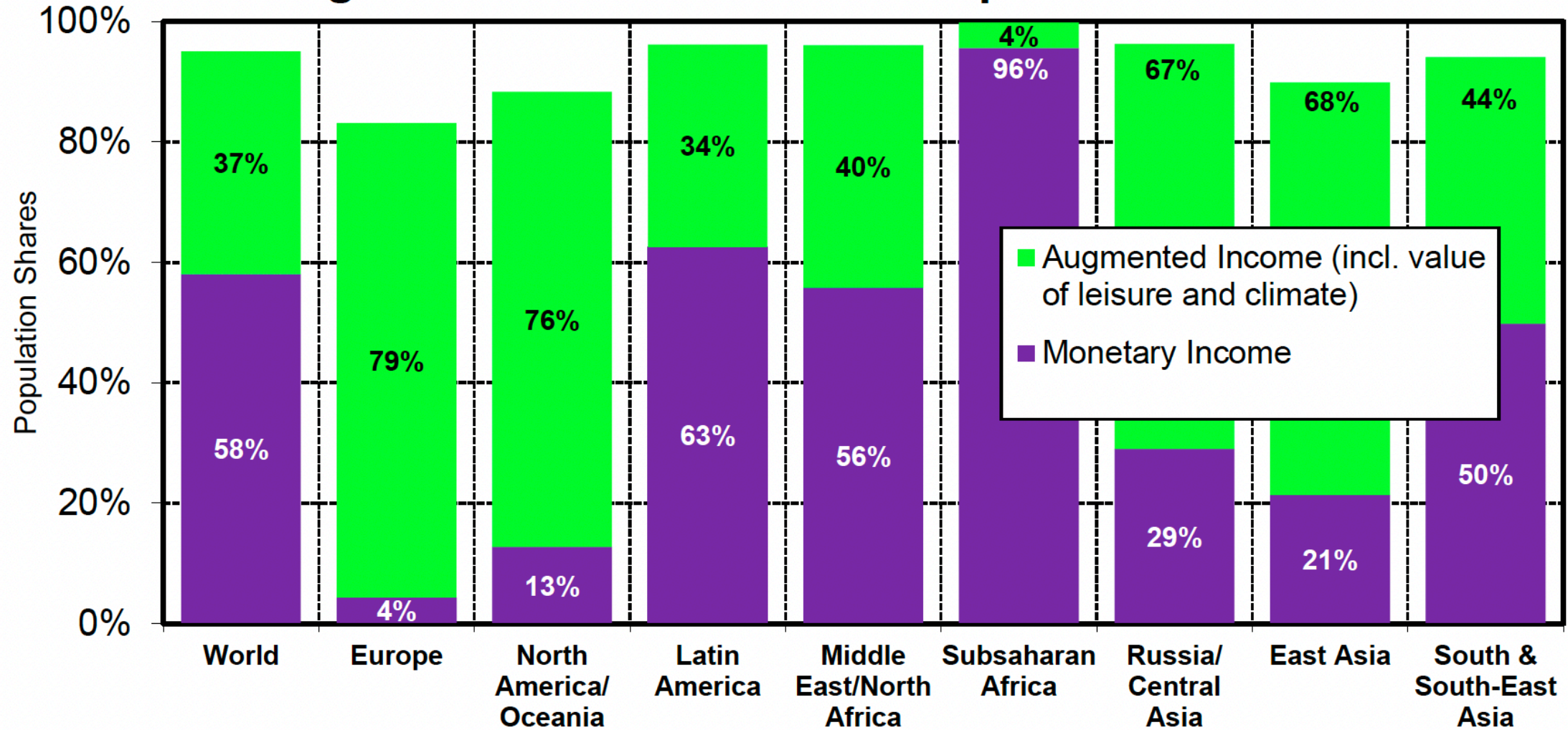
Note. Under SC scenario, all countries converge to 60k Euros (PPP 2025) in per capita GDP by 2100. Under PI scenario, there are persistent gaps between countries, from 28k in Subsaharan Africa to 203k in North America/Oceania. **Sources and series:** gjp.wid.world (O3a)

Population Shares by Augmented Income Differential Between SC and PI Scenarios in 2100



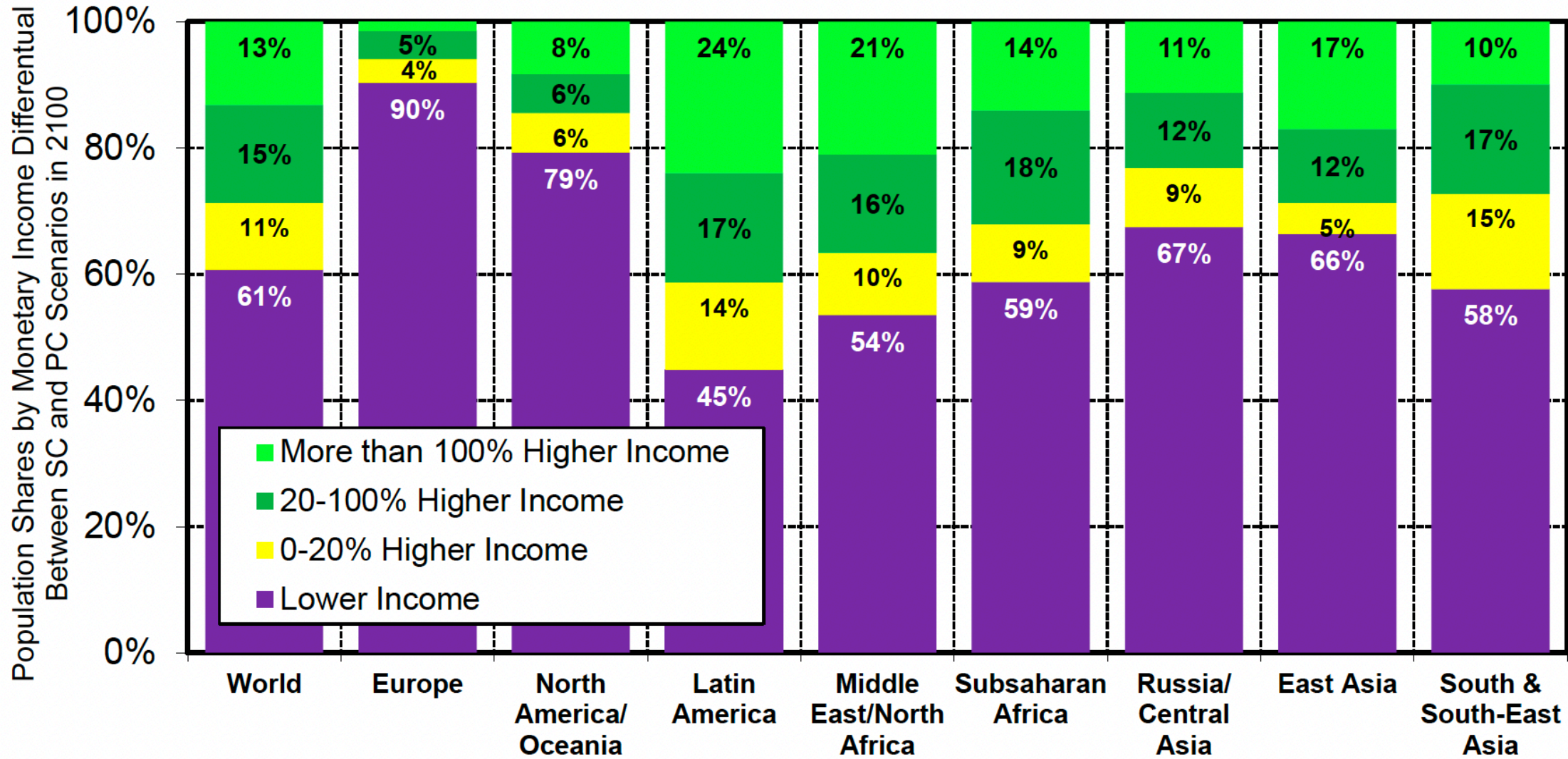
Interpretation. According to our projections, 5% of the world population has lower augmented income (incl. valuation for leisure and climate) in 2100 under sustainable convergence (SC) as compared to persistent inequality (PI) scenario. This fraction rises to 12-17% in the world's richest regions. **Note.** Under SC scenario, all countries converge to 60k Euros (PPP 2025) in per capita GDP by 2100. Under PI scenario, there are persistent gaps between countries, from 28k in Subsaharan Africa to 203k in North America/Oceania. **Sources and series:** gjp.wid.world (O3b)

Global Justice: Large Majorities Benefit from Higher Augmented Income in 2100 Compared to PI Scenario



Interpretation. The fraction of world population benefiting from sustainable convergence (SC) relative to persistent inequality (PI) scenario jumps from 58% to 95% once we include the value of leisure and climates. This fraction jumps from 4% to 83% in Europe and from 13% to 89% in North America/Oceania. **Note.** Under SC scenario, all countries converge to 60k Euros (PPP 2025) in per capita GDP by 2100. Under PI scenario, there are persistent gaps between countries, from 28k in Subsaharan Africa to 203k in North America/Oceania. **Sources and series:** gjp.wid.world (O3c)

Population Shares by Monetary Income Differential Between SC and PC Scenarios in 2100

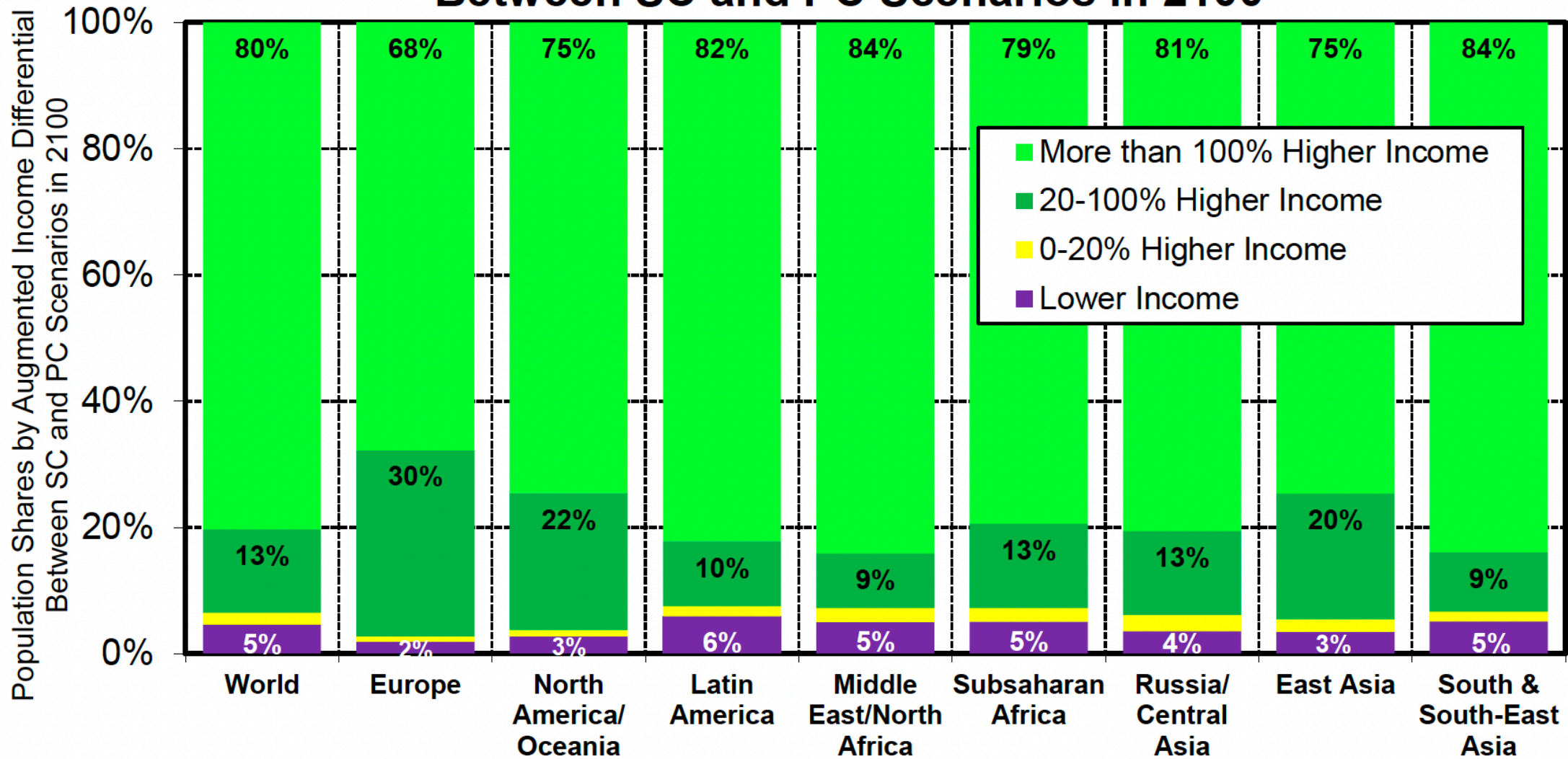


Interpretation. According to our projections, 61% of the world population has lower monetary income in 2100 under sustainable convergence (SC) as compared to persistent inequality (PI) scenario. This fraction is as large as 79-90% in the world's richest regions.

Note. Under SC scenario, all countries converge to 60k Euros (PPP 2025) in per capita GDP by 2100. Under PC scenario, all countries converge to 120k Euros.

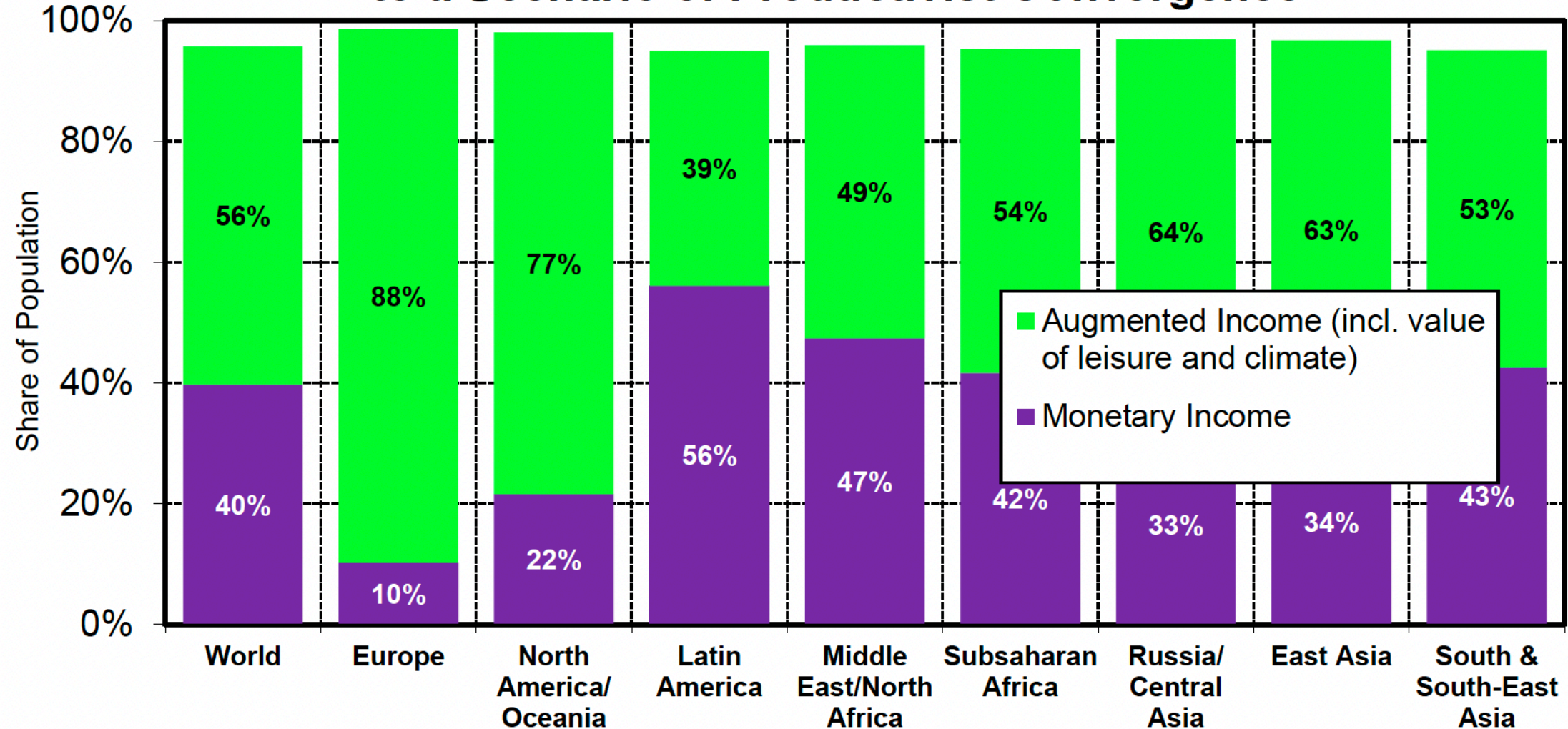
Sources and series: gjp.wid.world (O4a)

Population Shares by Augmented Income Differential Between SC and PC Scenarios in 2100



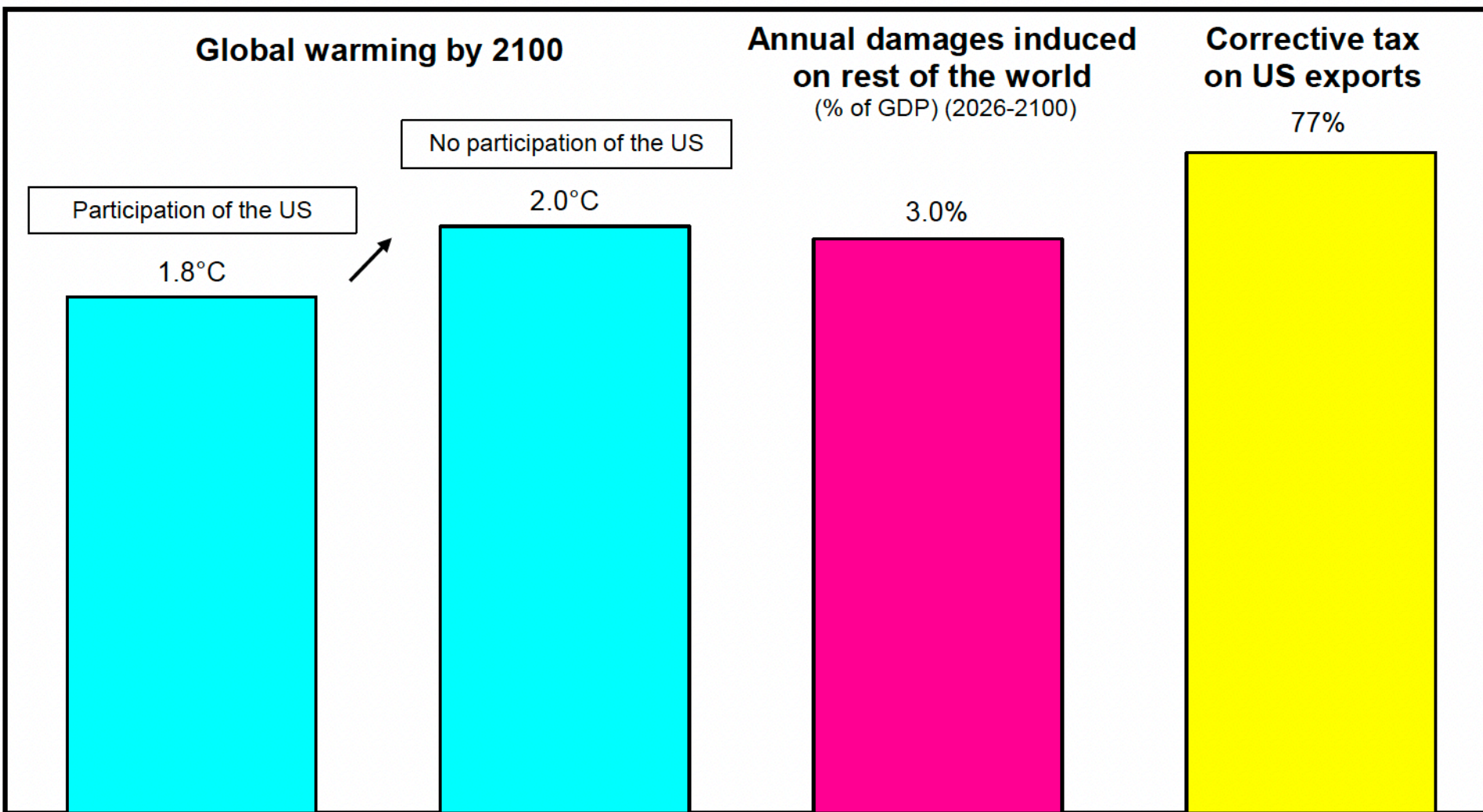
Interpretation. According to our projections, 5% of the world population has lower augmented income (incl. valuation for leisure and climate) in 2100 under productivist convergence (PC) as compared to persistent inequality (PI) scenario. This fraction equals 2-3% in the world's richest regions. **Note.** Under SC scenario, all countries converge to 60k Euros (PPP 2025) in per capita GDP by 2100. Under PC scenario, all countries converge to 120k Euros. **Sources and series:** gjp.wid.world (O4b)

Share of Population With Higher Income in 2100 compared to a Scenario of Productivist Convergence



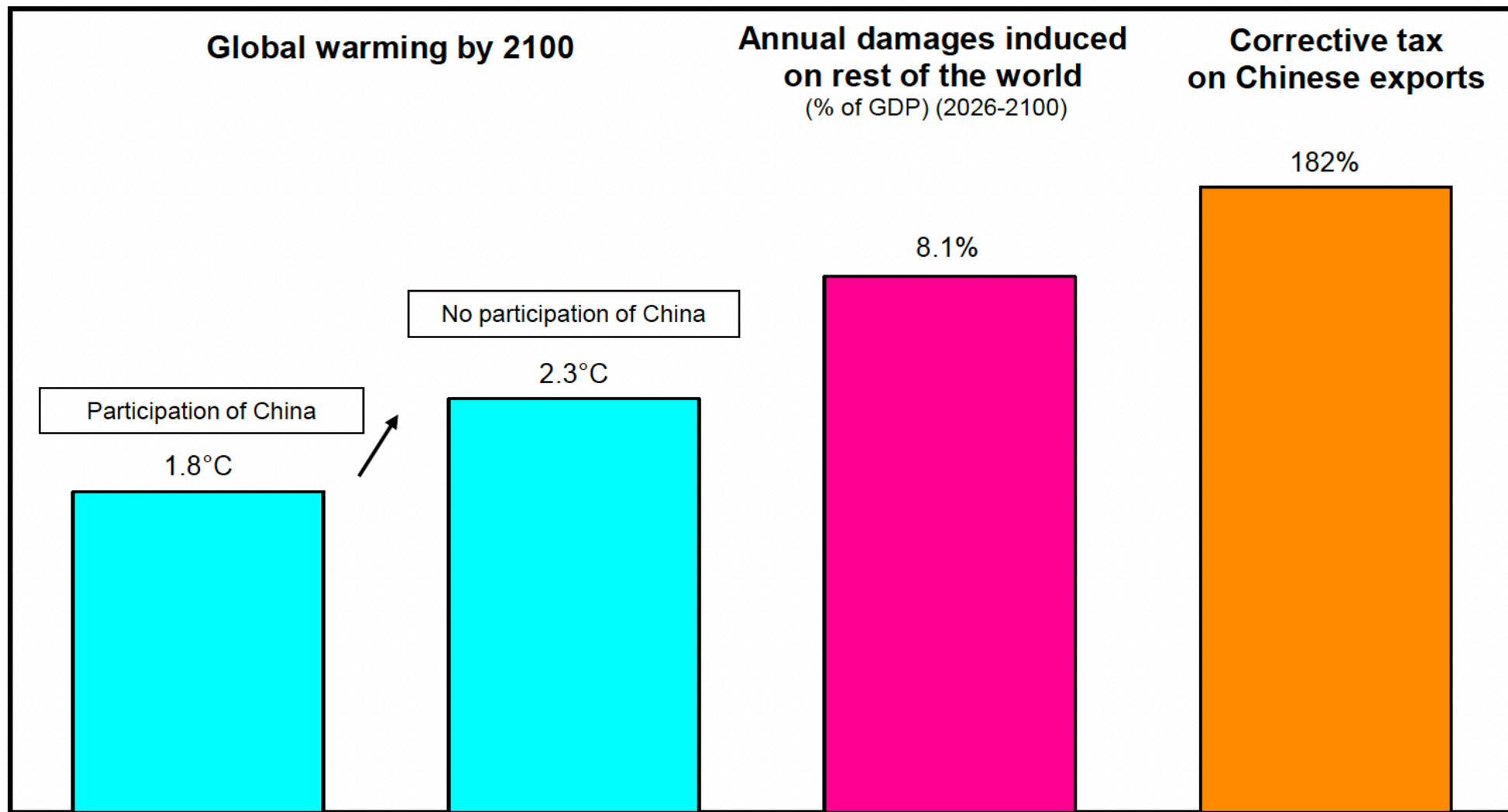
Interpretation. The fraction of world population benefiting from sustainable convergence (SC) relative to productivist convergence (PC) scenario jumps from 40% to 96% once we include the value of leisure and climates. This fraction jumps from 10% to 98% in Europe and from 22% to 99% in North America/Oceania. **Note.** Under SC scenario, all countries converge to 60k Euros (PPP 2025) in per capita GDP by 2100. Under PC scenario, all countries converge to 120k Euros. **Sources and series:** gjp.wid.world (O4c)

The Global Justice Platform without the US: Climate Impact and Corrective Tax



Interpretation. The figure shows the climate and economic consequences of US non-participation in the Global Justice Platform, assuming all other countries comply. US defection raises global warming by 2100 from 1.8°C to 2.0°C. The additional warming inflicts annual damages of 3.0% of GDP on the rest of the world (income and welfare losses, 2026–2100). A corrective tariff of 77% on US exports would fully compensate affected countries for these damages. **Sources and series:** gjp.wid.world (U1)

The Global Justice Platform without China: Climate Impact and Corrective Tax



Interpretation. The figure shows the climate and economic consequences of non-participation of China in the Global Justice Platform, assuming all other countries comply. The defection of China raises global warming by 2100 from 1.8°C to 2.3°C. The additional warming inflicts annual damages of 8.1% of GDP on the rest of the world (income and welfare losses, 2026–2100). A corrective tariff of 182% on Chinese exports would fully compensate affected countries for these damages. **Sources and series:** gjp.wid.world (U2)

Conclusion of Lecture 7

- **The Industrial Revolution & the rise of the West and global material growth** over the 1800-2025 period came with enormous fossil fuel extraction & GHG emissions and major threats to planetary habitability
- **Shared prosperity for all countries is possible but requires large changes in development model.** This is likely to lead to major conflicts between countries & social classes in 21c. Hopefully economic & social research can help find solutions, by combining monetary & material accounting framework.