Laboratory on Human-Environment Relations in Urban Systems
Swiss Mobiliar Chair in Urban Ecology and Sustainable Living

ENV 370 (GR A332 – GRB001)
Environmental system analysis and assessment – Evaluation et analyse environnementale systémique

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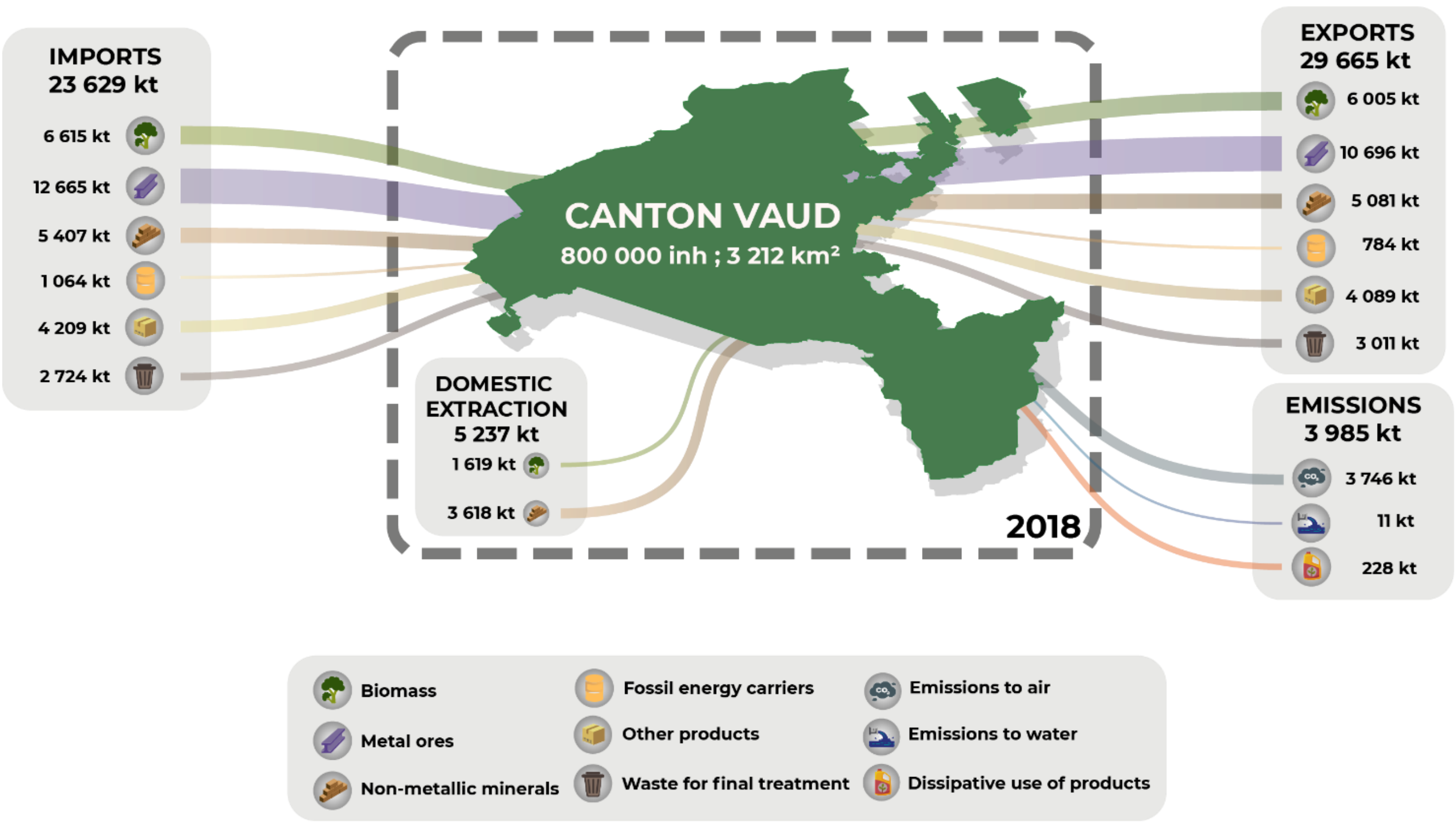
EPFL - Spring 2025

Welcome to the course

Aim of the course

Enable you to carry out environmental system analyses and assessments (through using different assessment methods for different scales)



Dr. Aristide Athanassiadis

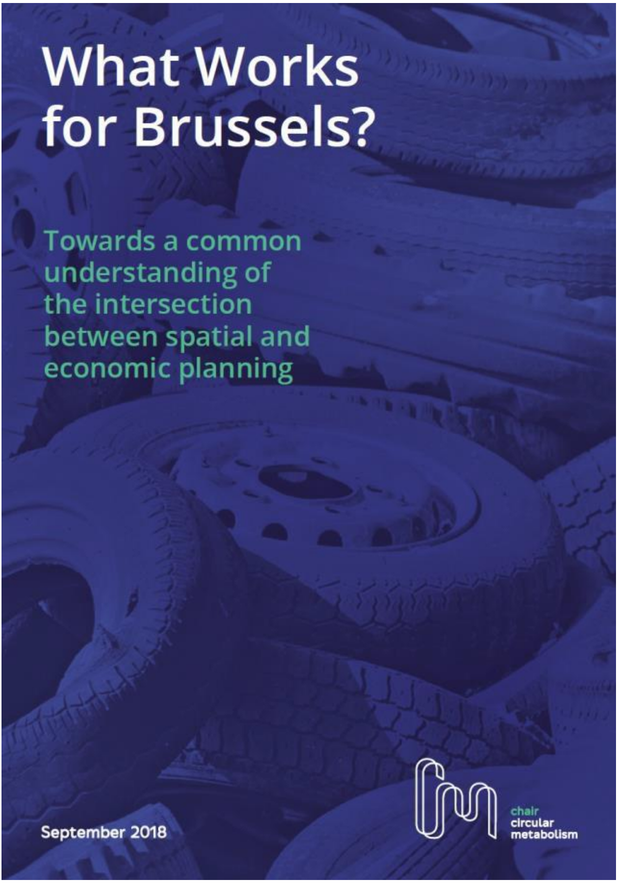
- **Current:** **Lecturer:** EPFL, Université Libre de Bruxelles, SciencesPo Paris
  Researcher and Co-Founder: Metabolism of Cities (online tools, podcast)
  Focus: Urban Metabolism, Circular Economy, Material Flow Analysis, Material stocks

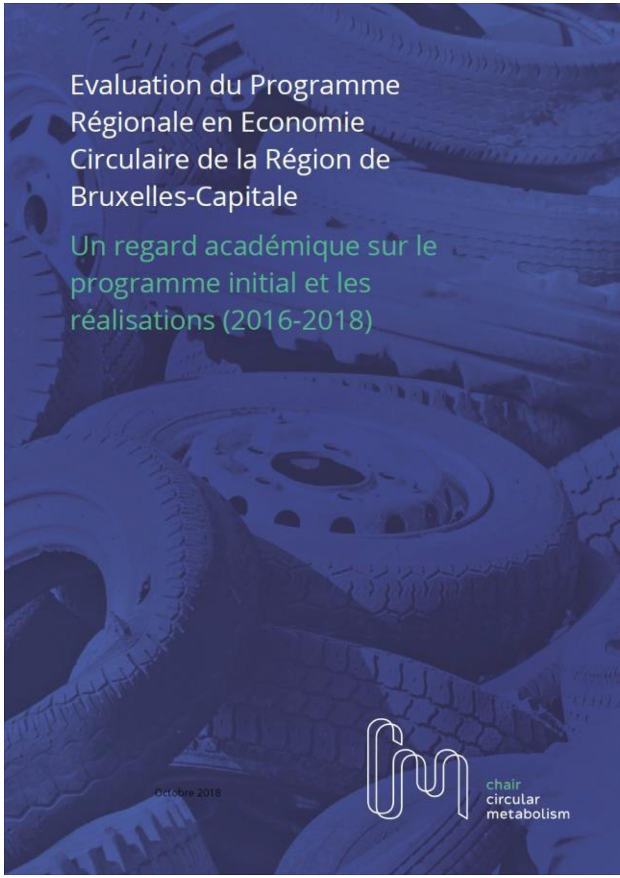
- **Positions held:** Collaborateur Scientif HERUS, EPFL, 2020-2023
  Chair of Circular Economy and Circular Economy, 2018-2020
  Postdoc Université Libre de Bruxelles, 2016-2018
  Research stays in Université Paris 1 Panthéon - Sorbonne; Université de Montréal, Ecole Polytechnique Fédérale de Lausanne

- **PhD:** **Université Libre de Bruxelles - The University of Melbourne, 2016**
  “Towards more comprehensive urban environmental assessment. Exploring the complex relationship between urban and metabolic profiles.”

MFA in reality

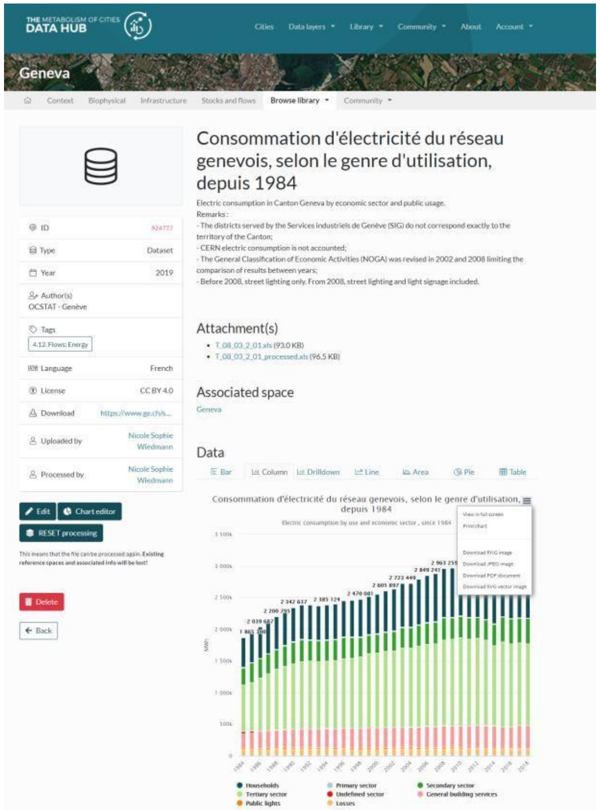
MFA in policy

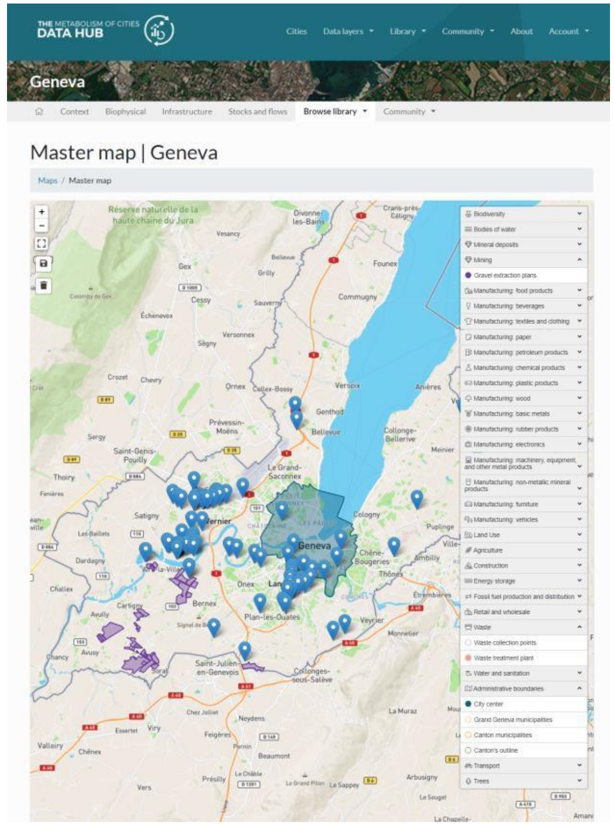


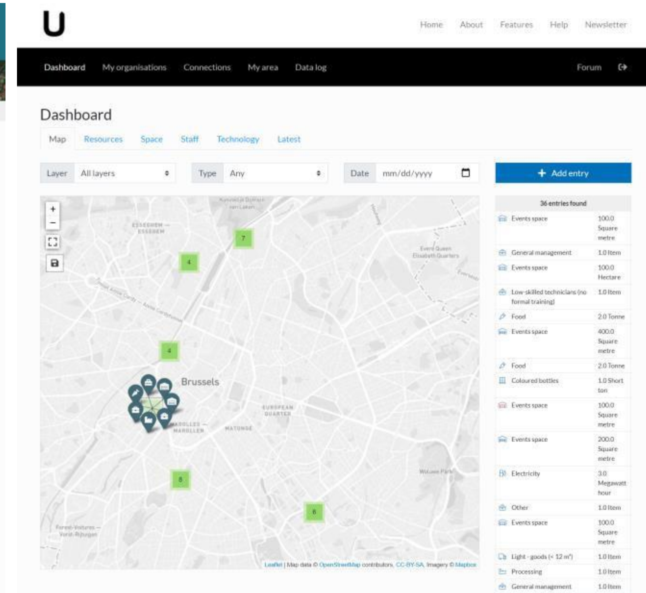


MFA in public – Circular Metabolism Podcast

MFA and tools







[WWW.METABOLISMOFCITIES.ORG](http://www.metabolismofcities.org)

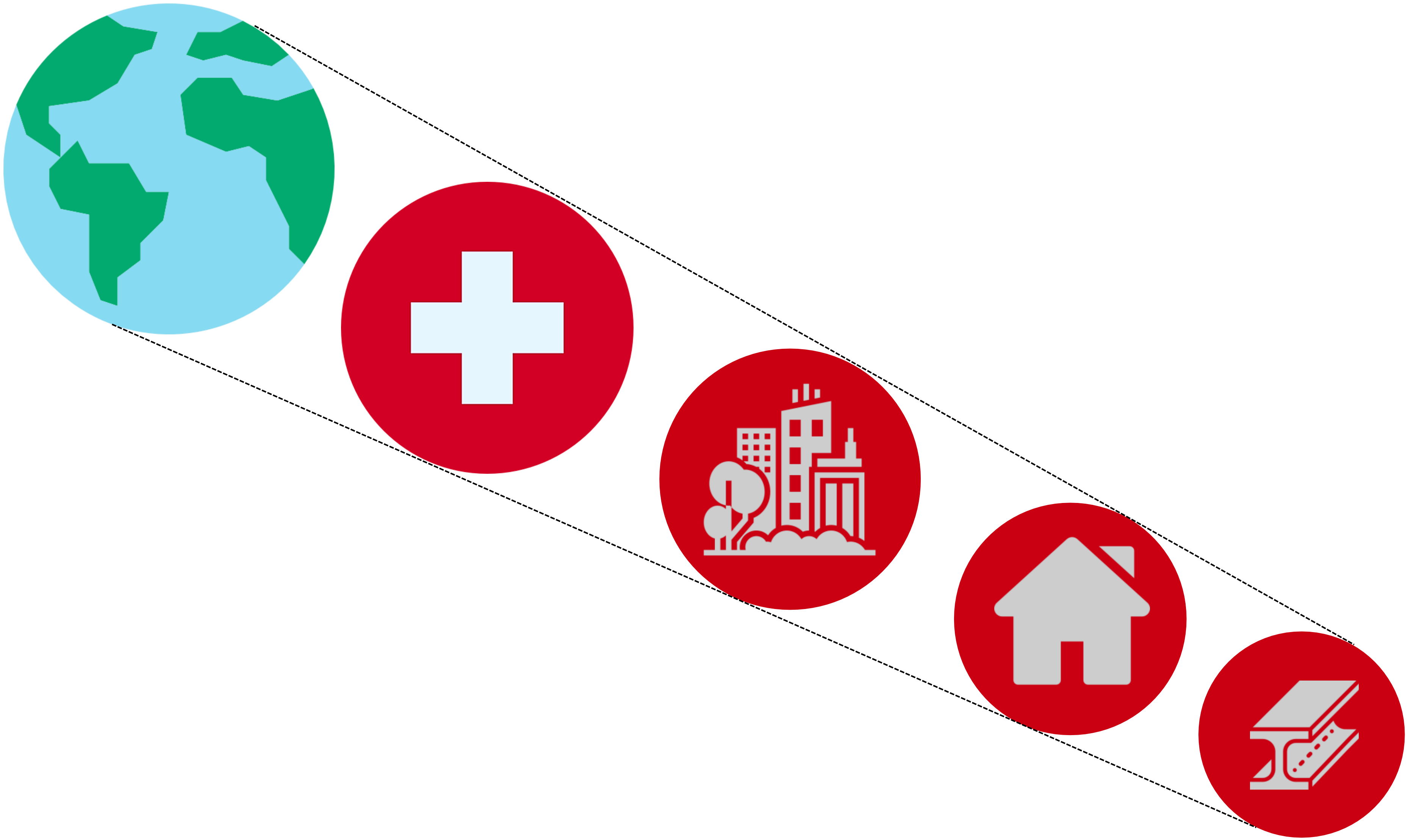
Welcome to the course – who are you/where are you from?

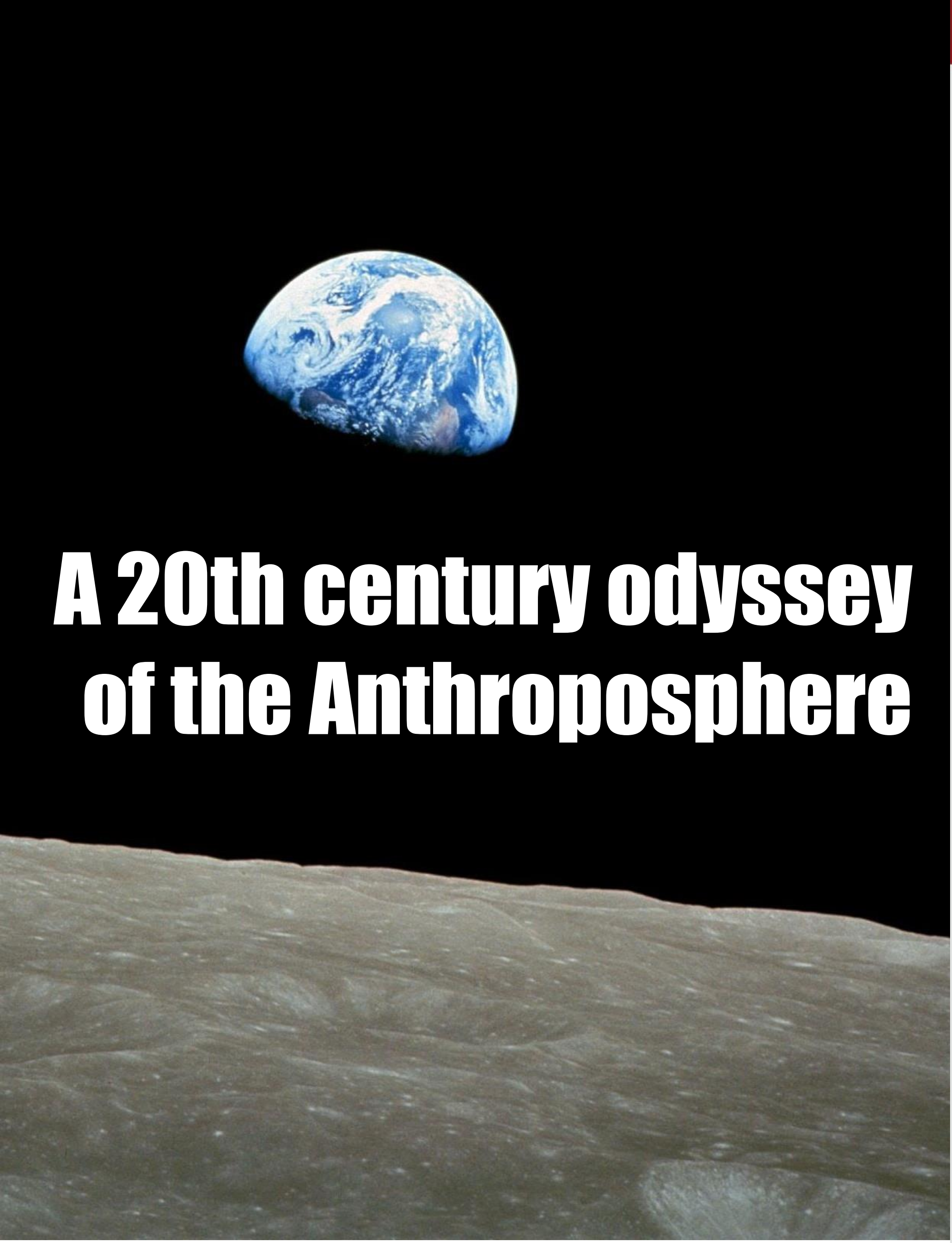
Welcome to the course –
what is your dream job after the BSc or MSc?

Welcome to the course –
Have you ever been to a climate strike?

Welcome to the course –
What is the science needed?

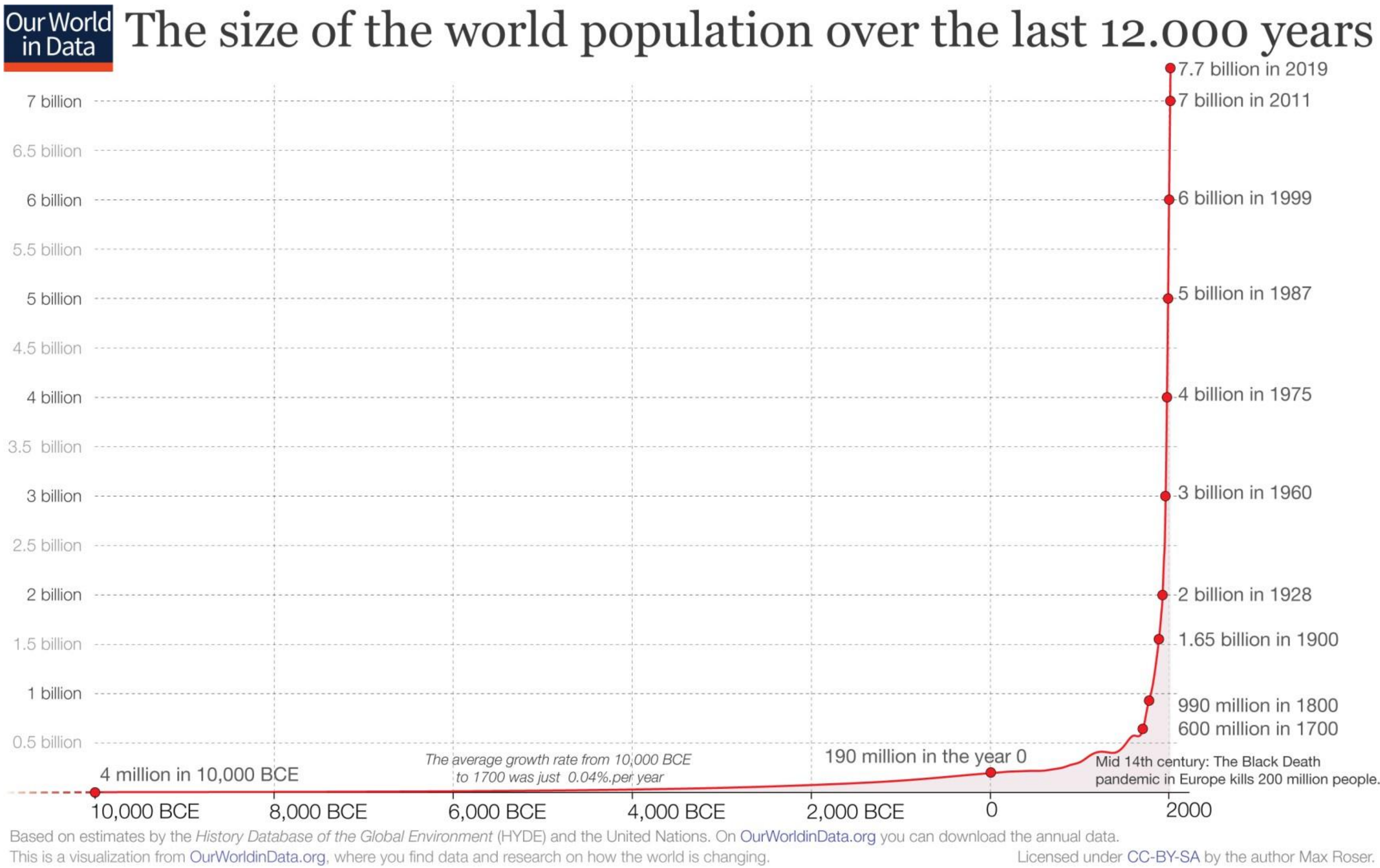
Link from Planet to Product





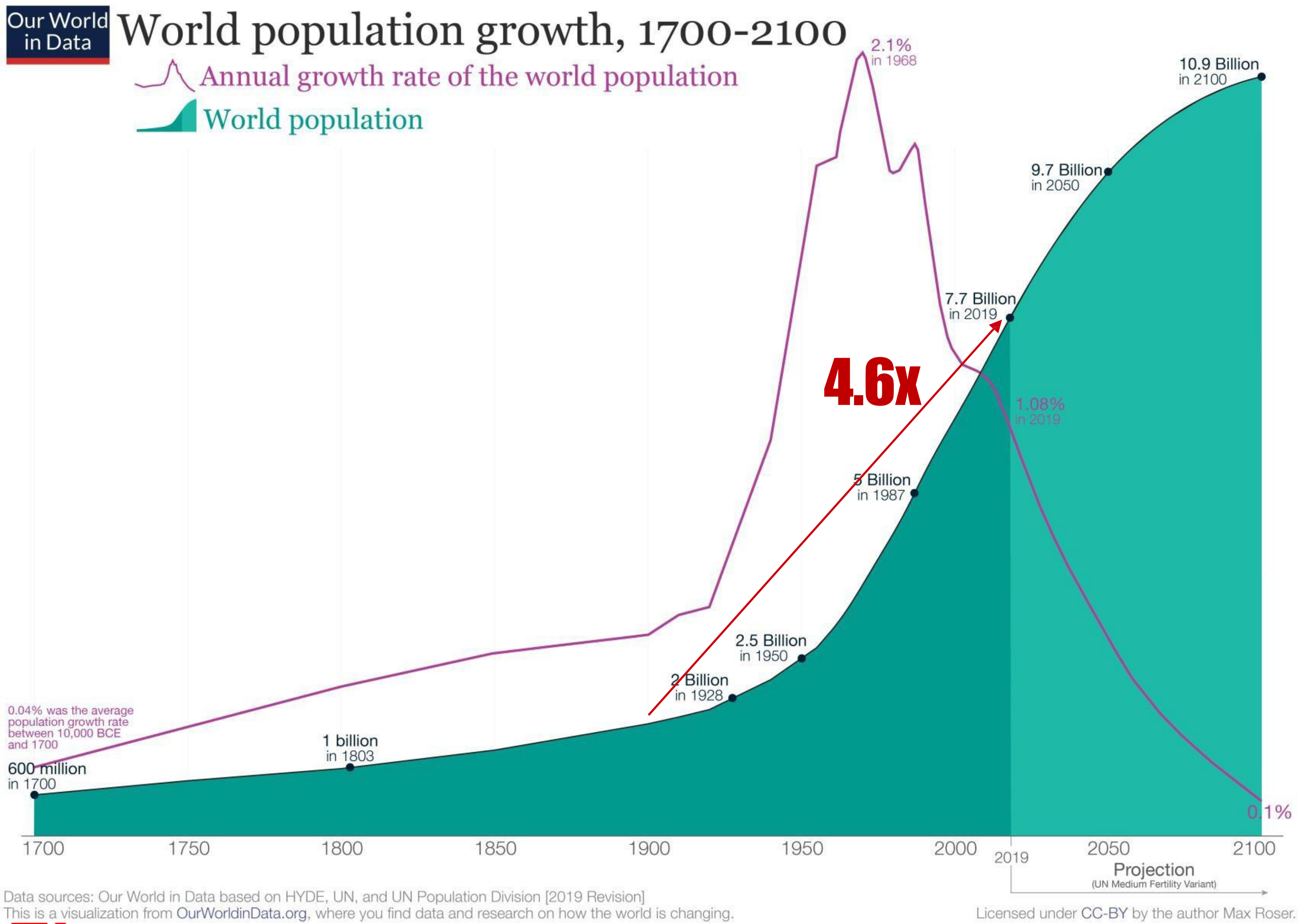
A 20th century odyssey of the Anthroposphere

A global development overview - population



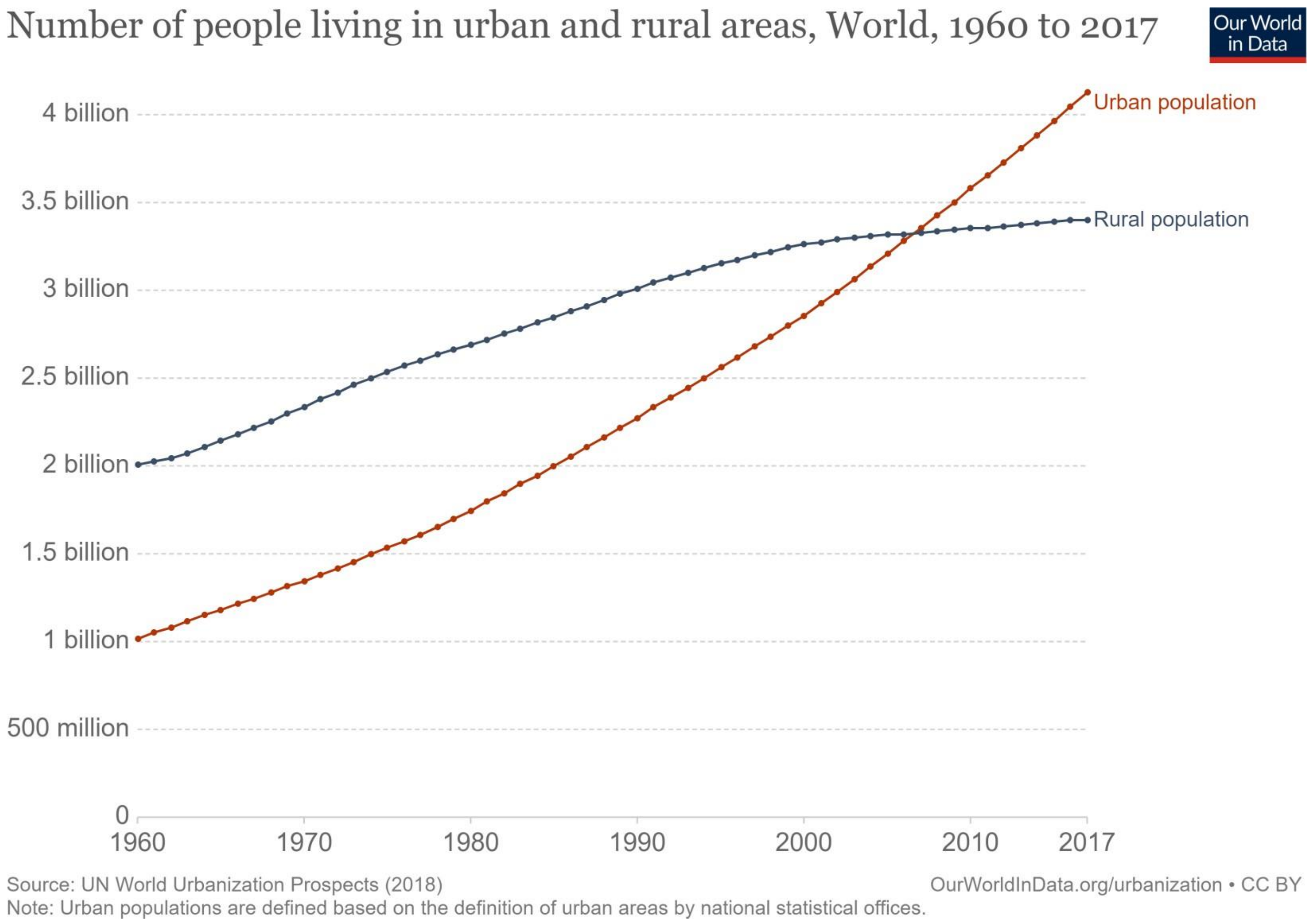
Source: https://ourworldindata.org/world-population-growth

A global development overview - population



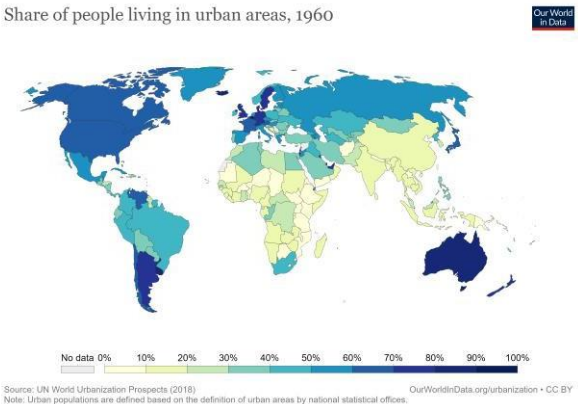
Source: https://ourworldindata.org/world-population-growth

A global development overview - (urban) population

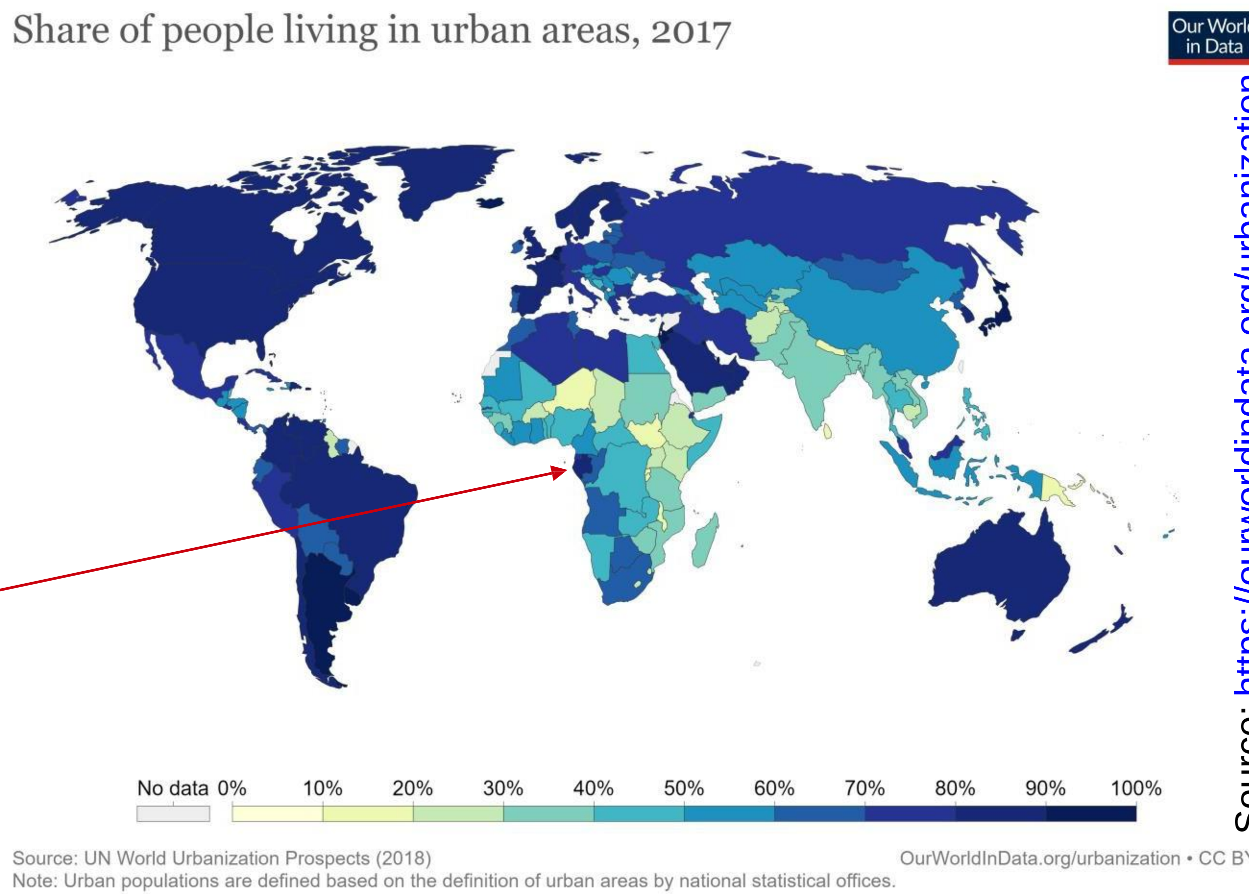


Source: https://ourworldindata.org/urbanization

A global development overview - (urban) population

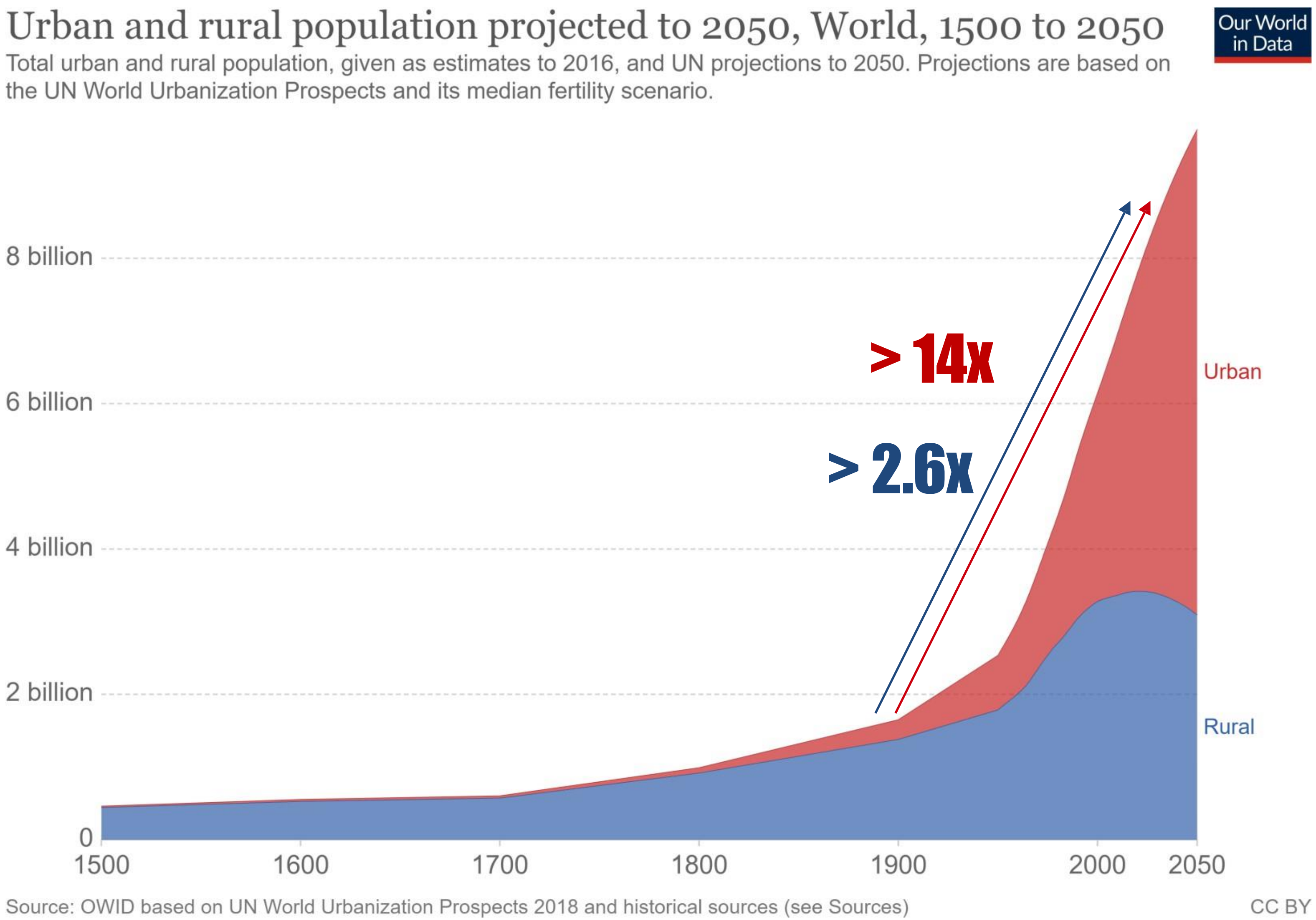


Look at Gabon



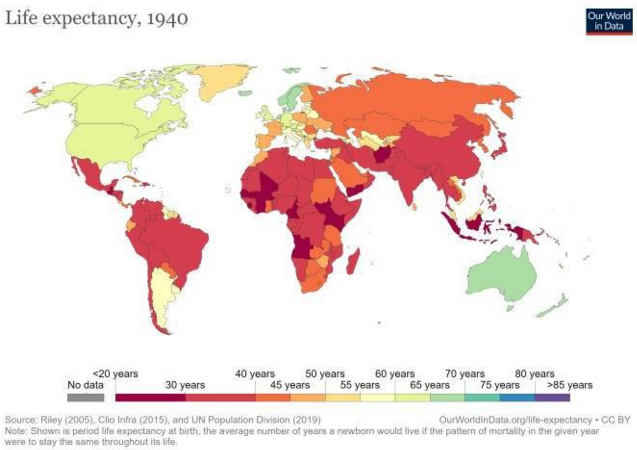
Source: https://ourworldindata.org/urbanization

A global development overview - (urban) population

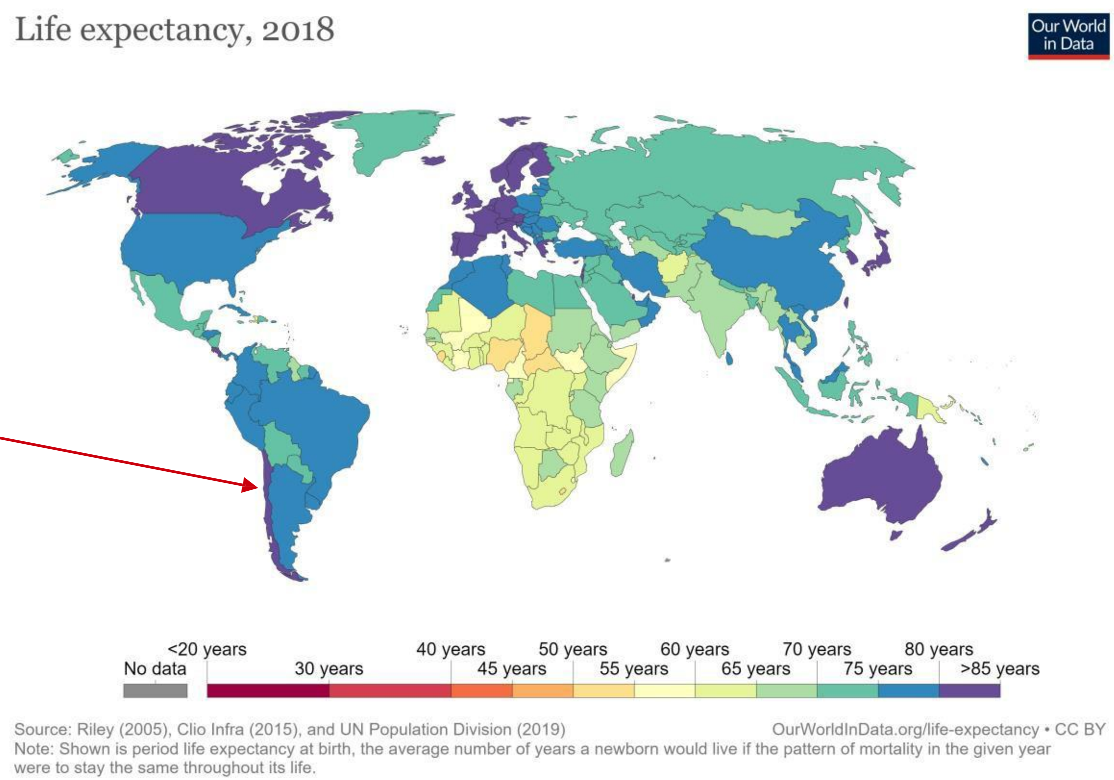


Source: https://ourworldindata.org/urbanization

A global development overview - life expectancy

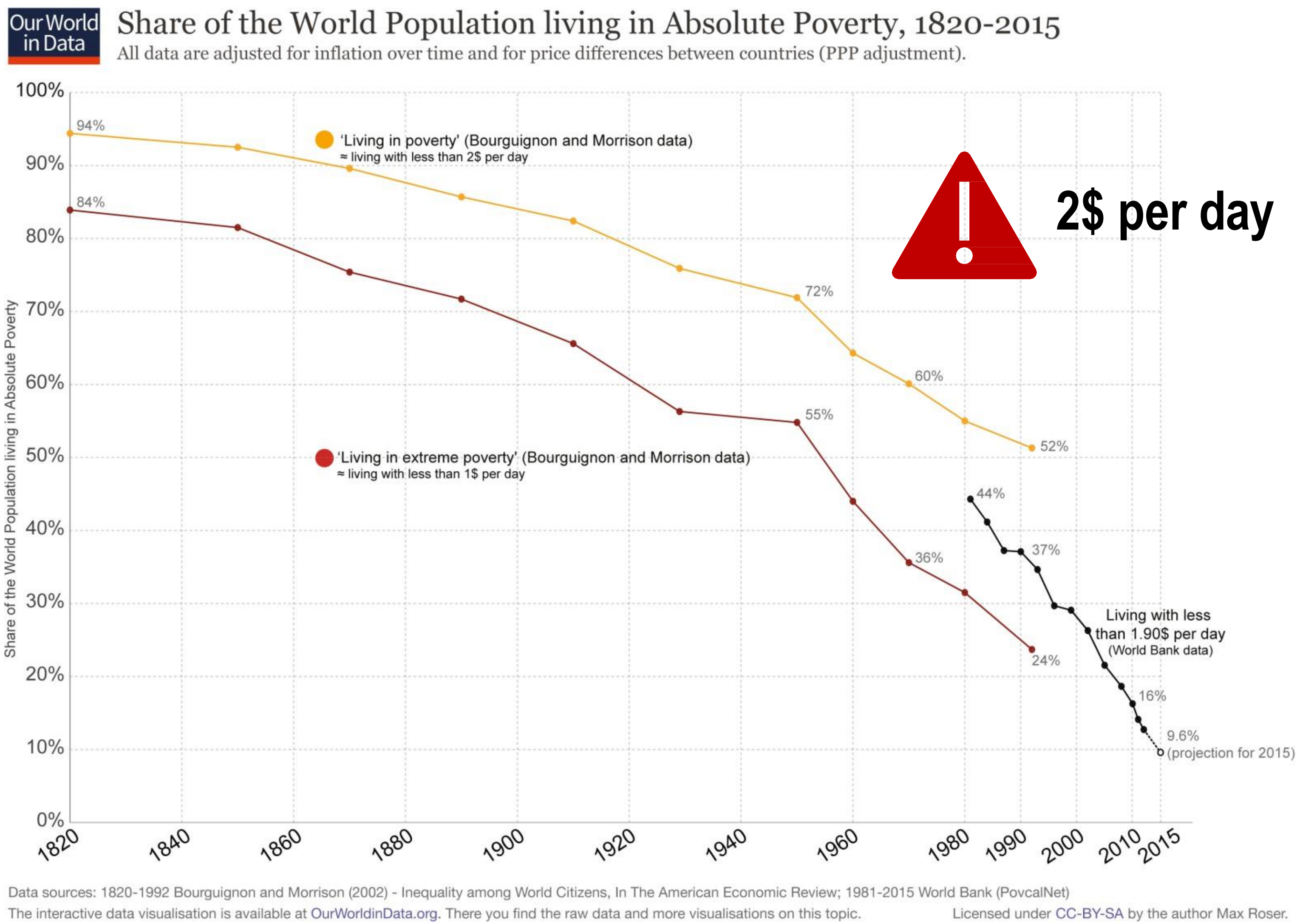


Look at Chile



Source: https://ourworldindata.org/life-expectancy

A global development overview - poverty



2$ per day

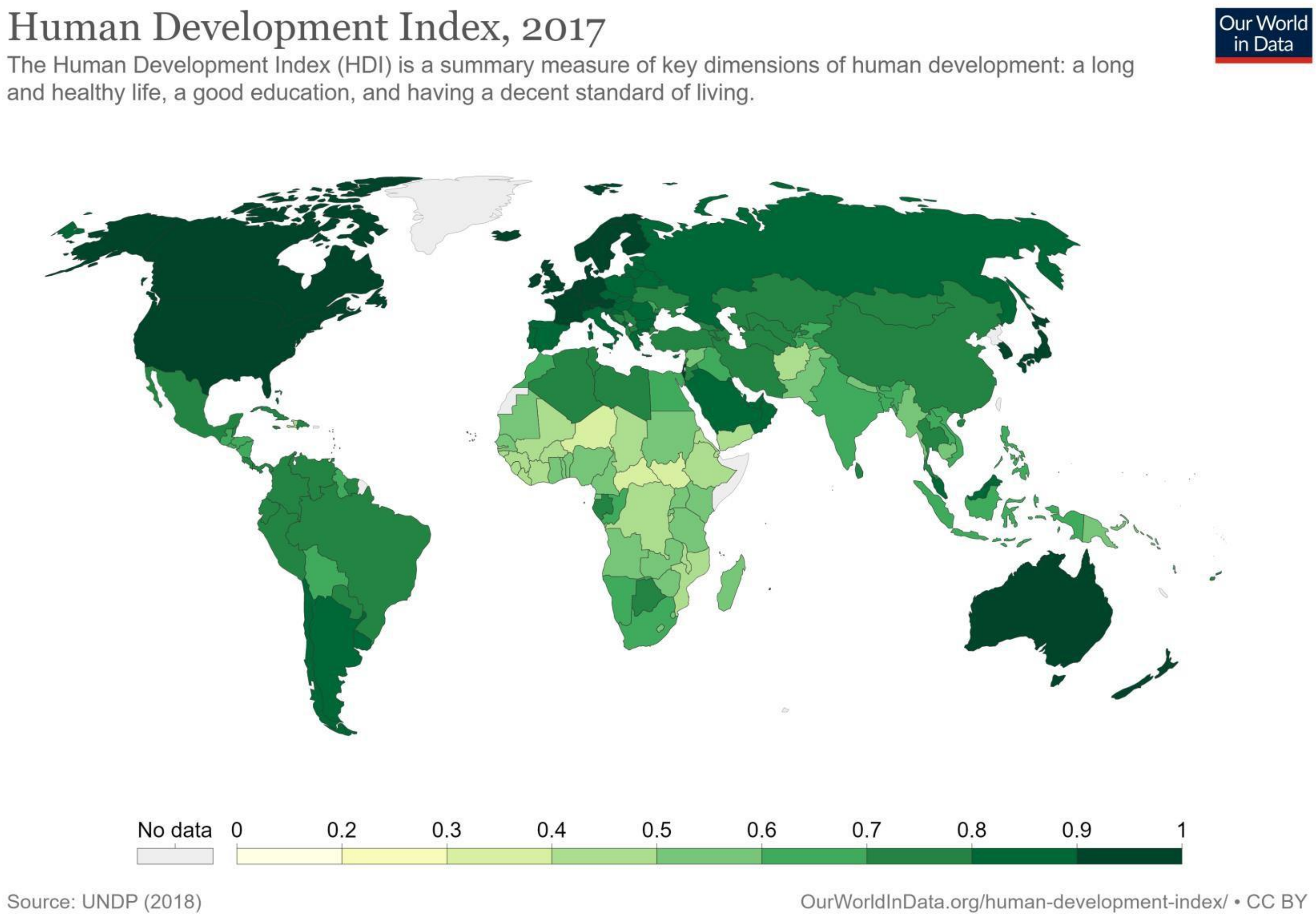
Source: https://ourworldindata.org/extreme-poverty

A global development overview - Human Development Index

The Human Development Index (HDI) is an index that measures key dimensions of human development. The three key dimensions are:

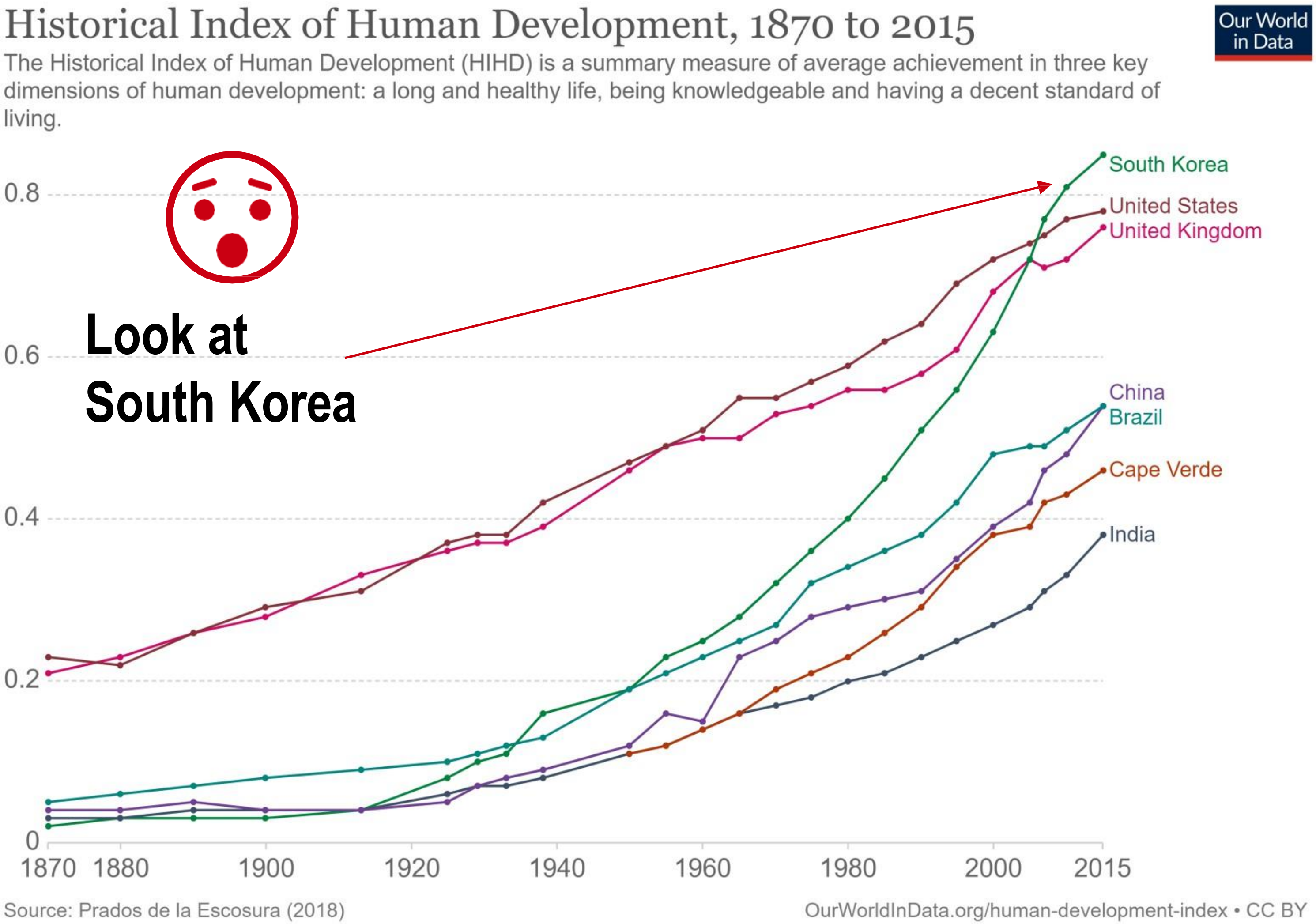
- **A long and healthy life** – measured by *life expectancy*.
- **Access to education** – measured by *expected years of schooling* of children at school-entry age and *mean years of schooling* of the adult population.
- **And a decent standard of living** – measured by *Gross National Income per capita* adjusted for the price level of the country.

A global development overview - Human Development Index



Source: https://ourworldindata.org/human-development-index

A global development overview - Human Development Index



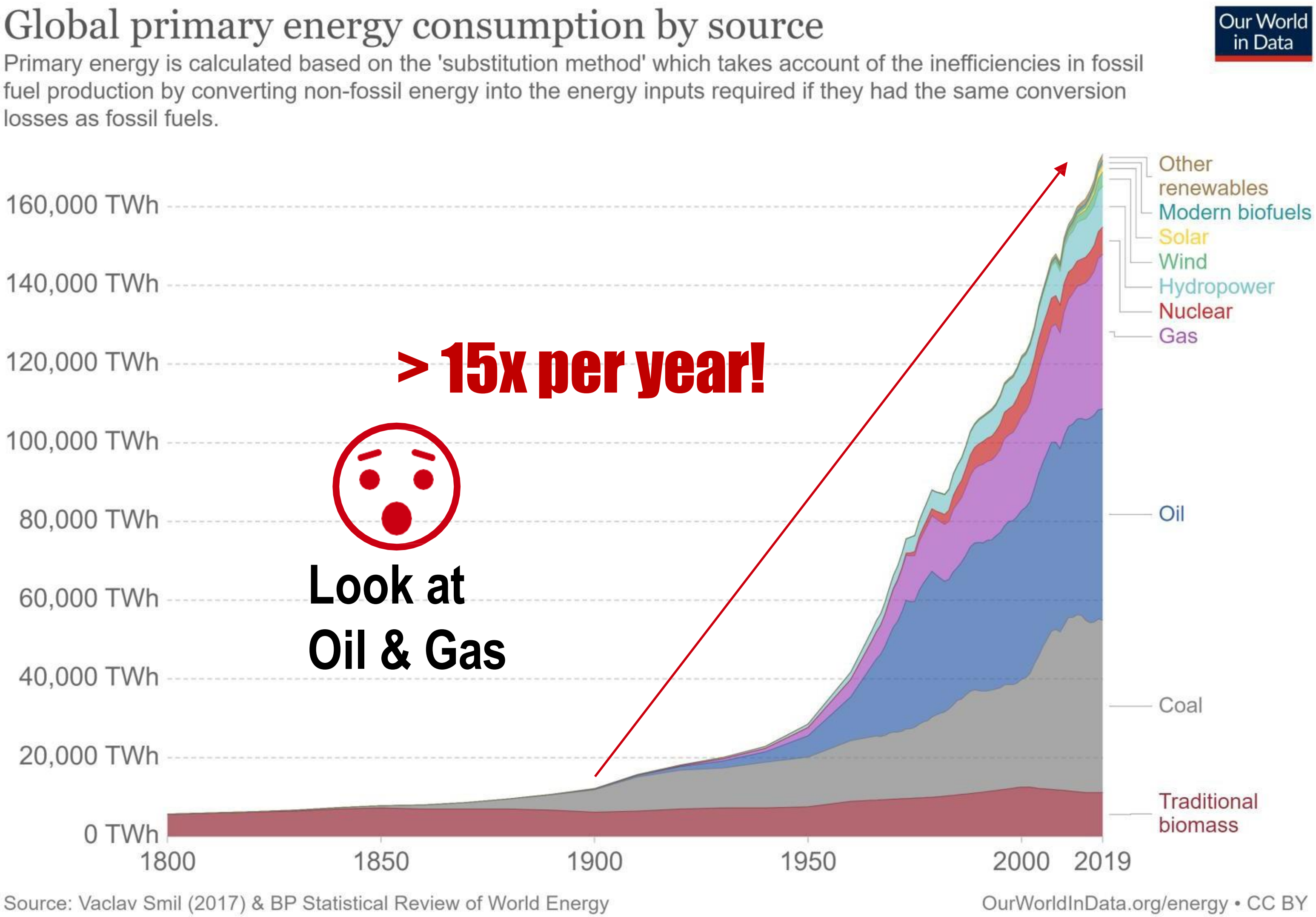
Source: https://ourworldindata.org/human-development-index

The world is healthier & more prosperous than ever

BUT...

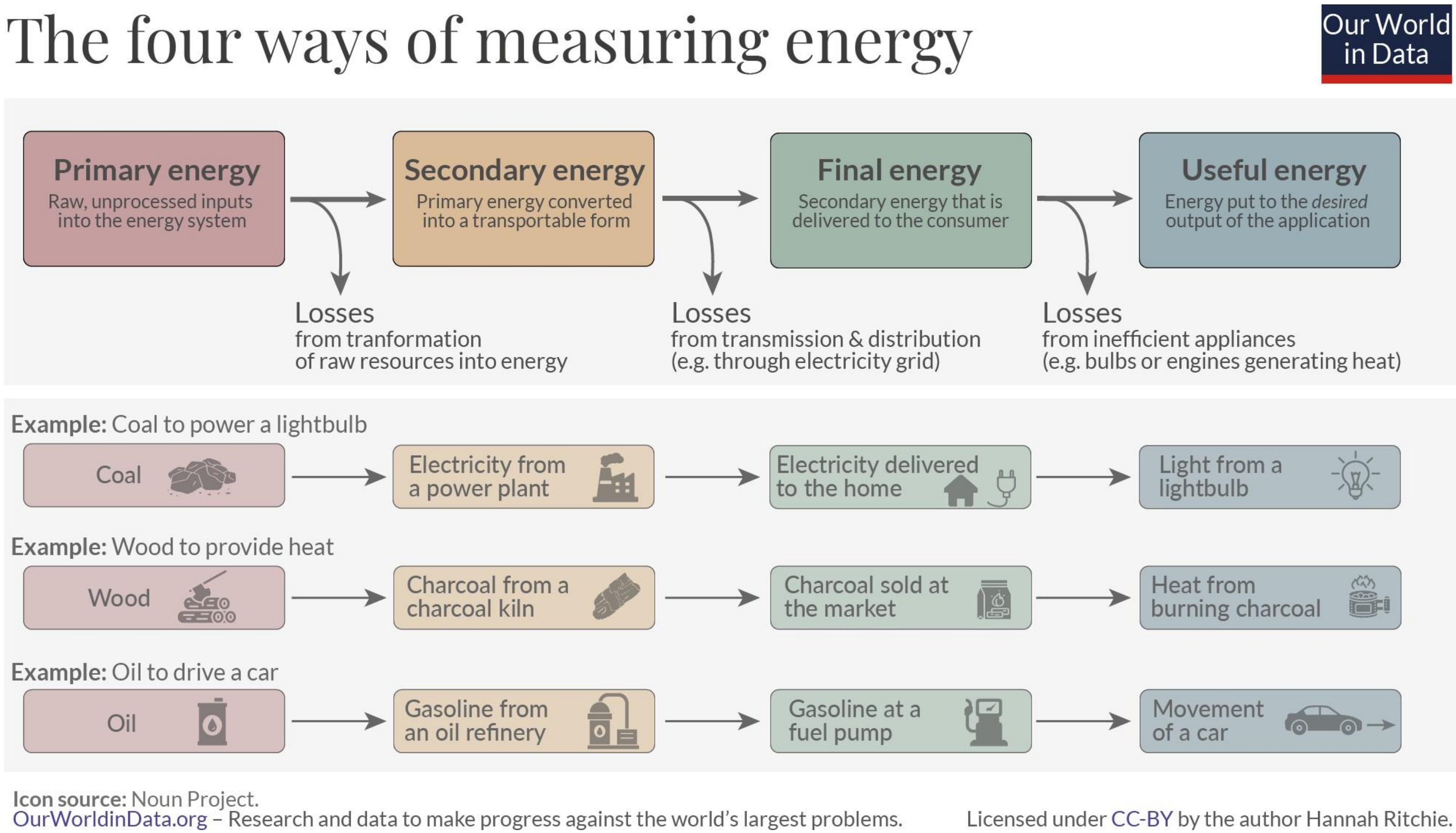

50th ANNIVERSARY EDITION
CLINT EASTWOOD
THE GOOD THE BAD and THE UGLY
co-starring
LEE VAN CLEEF
also starring
ELI WALLACH
in the role of TUCO
directed by
SERGIO LEONE

A global development overview –energy



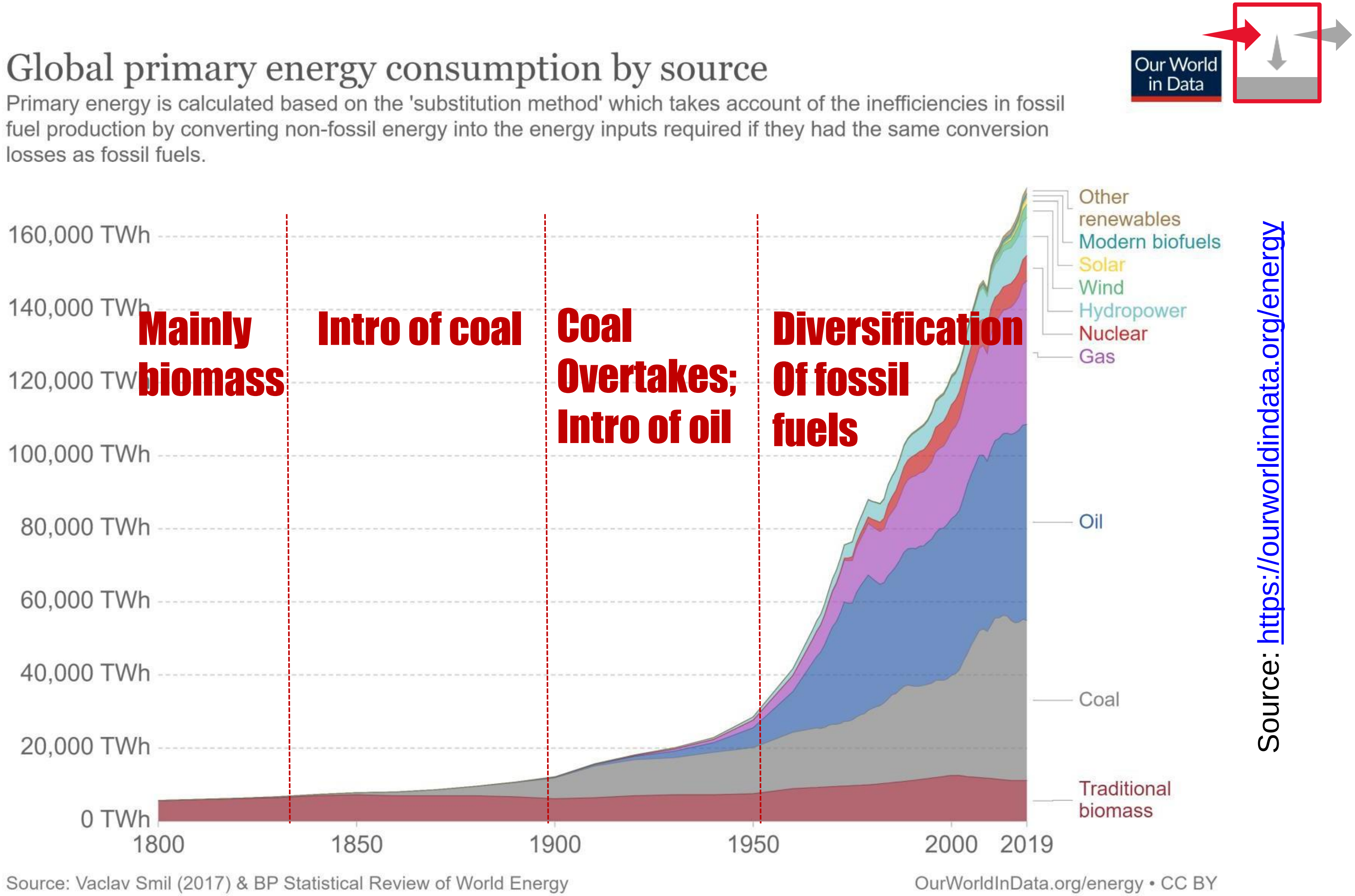
Source: https://ourworldindata.org/energy

A global development overview – wasteful energy ?



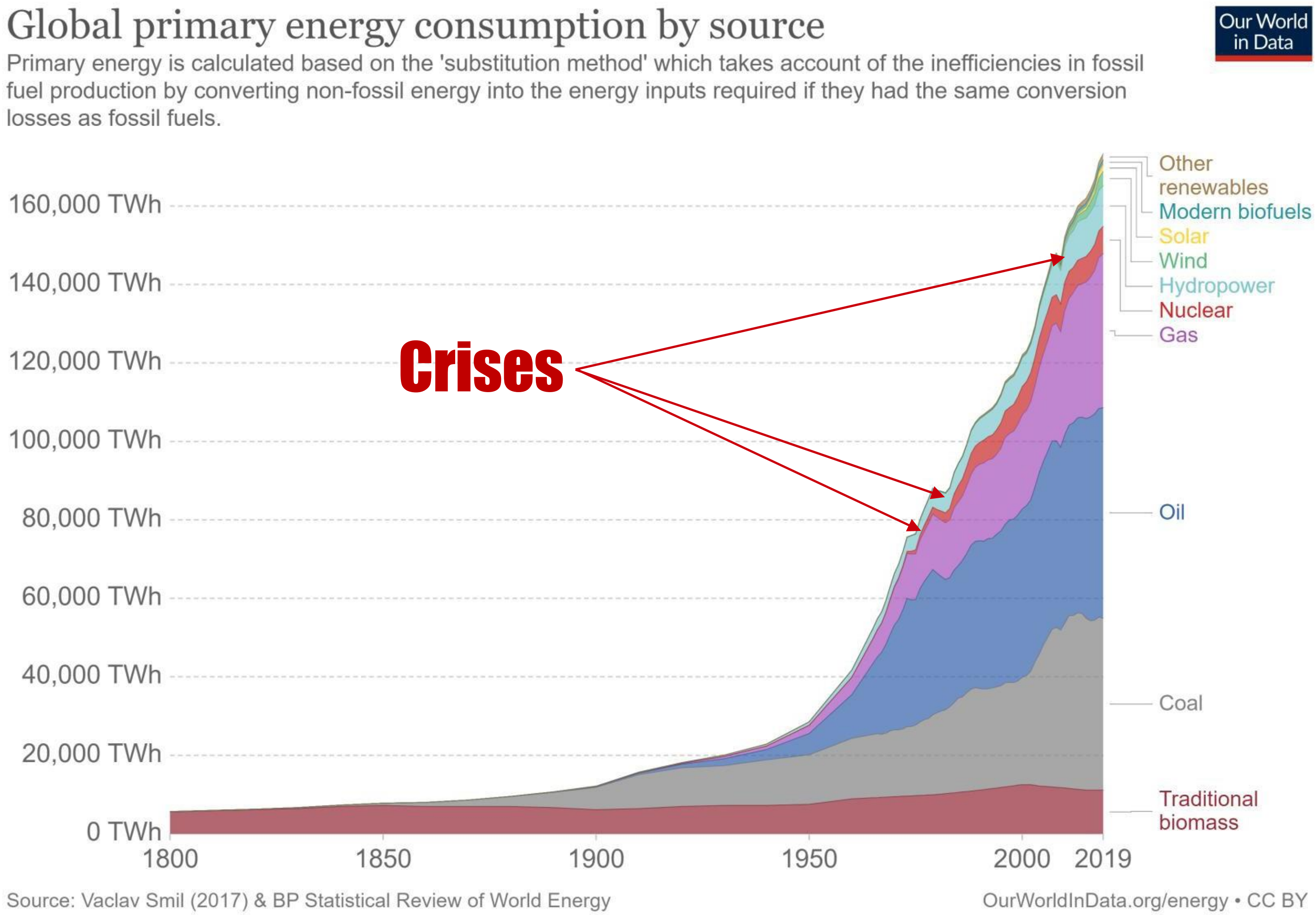
Source: https://ourworldindata.org/energy

A global development overview – energy transition or accumulation ?



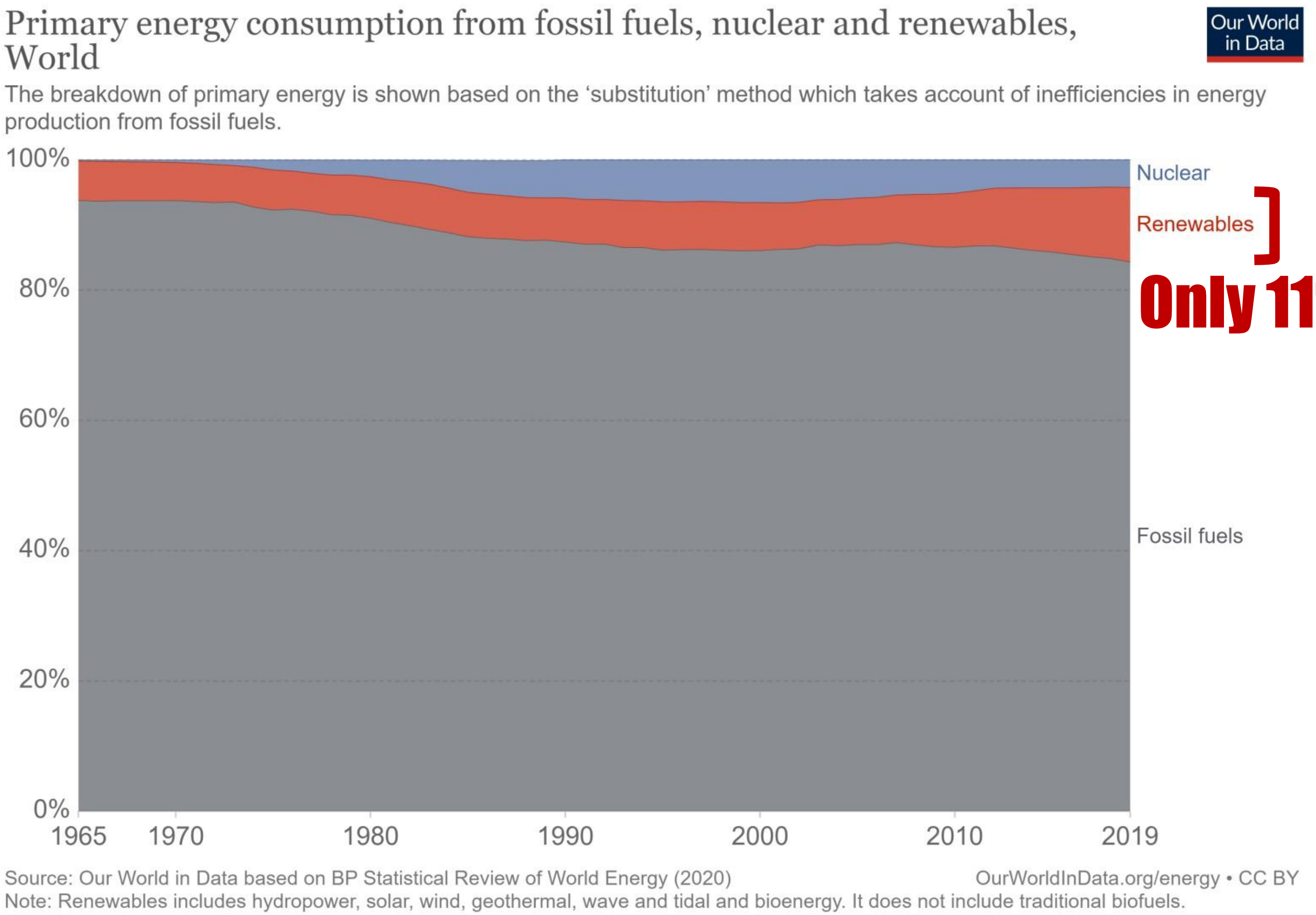
Source: https://ourworldindata.org/energy

A global development overview – energy



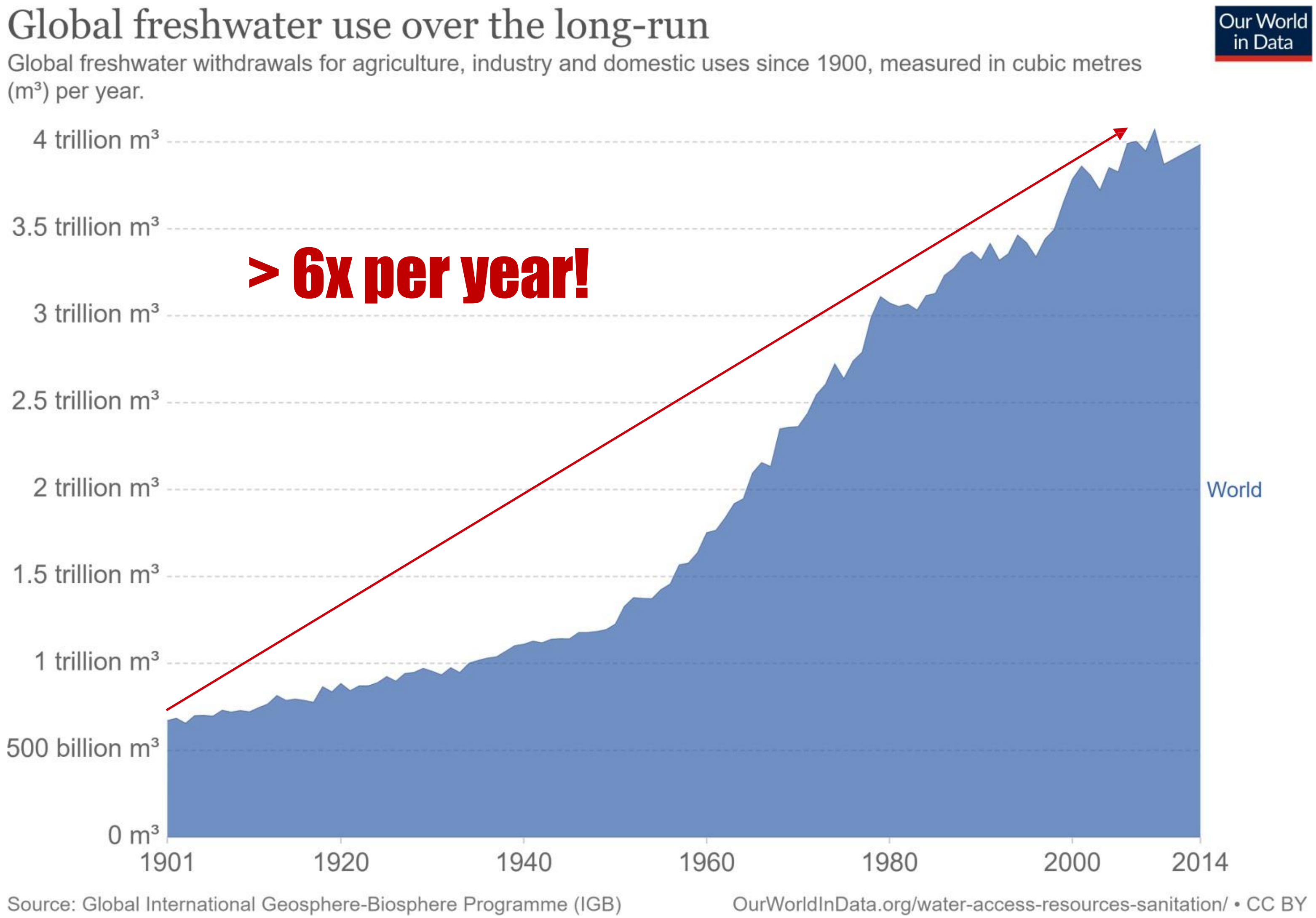
Source: https://ourworldindata.org/energy

A global development overview – what about renewable energy ?



Source: https://ourworldindata.org/energy

A global development overview – water



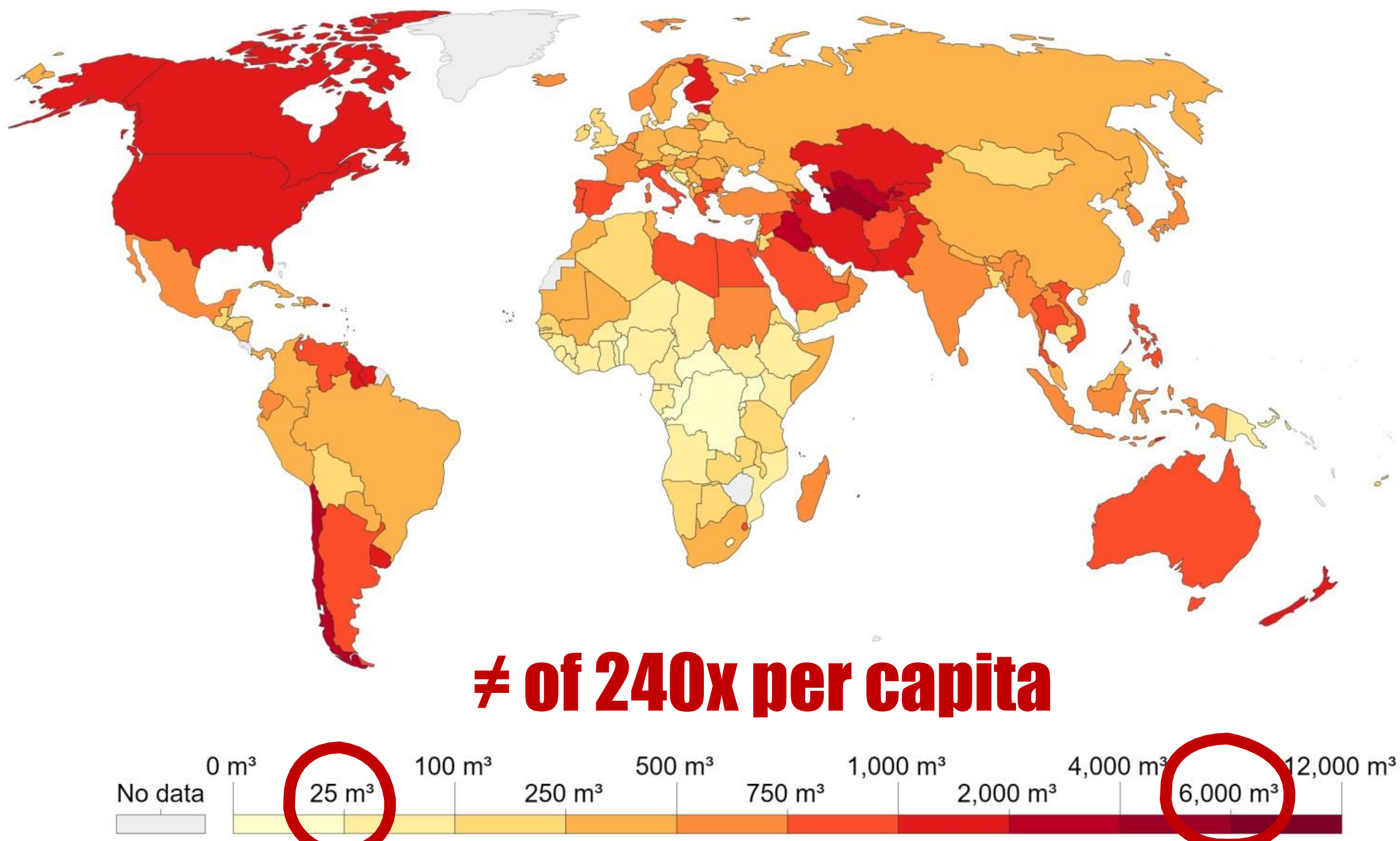
Source: https://ourworldindata.org/water-use-stress

A global development overview – water

Water withdrawals per capita, 2005

Our World in Data

Total water withdrawals from agricultural, industrial and municipal purposes per capita, measured in cubic metres (m³) per year.

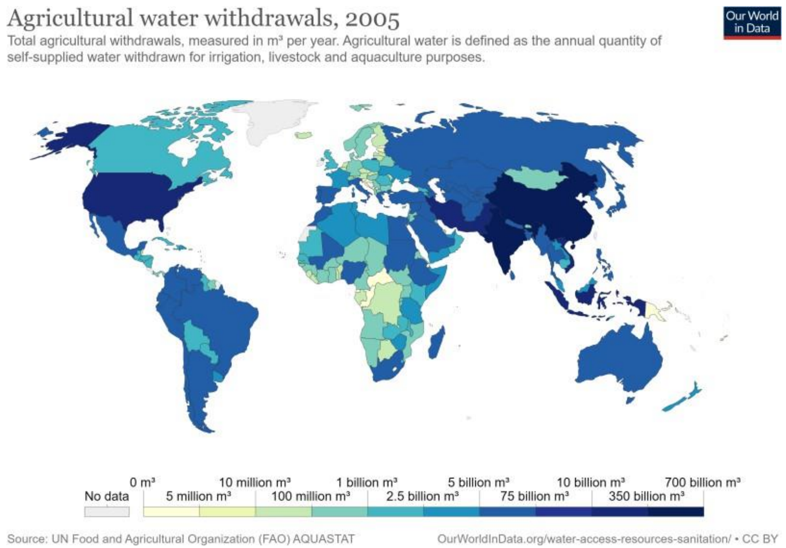


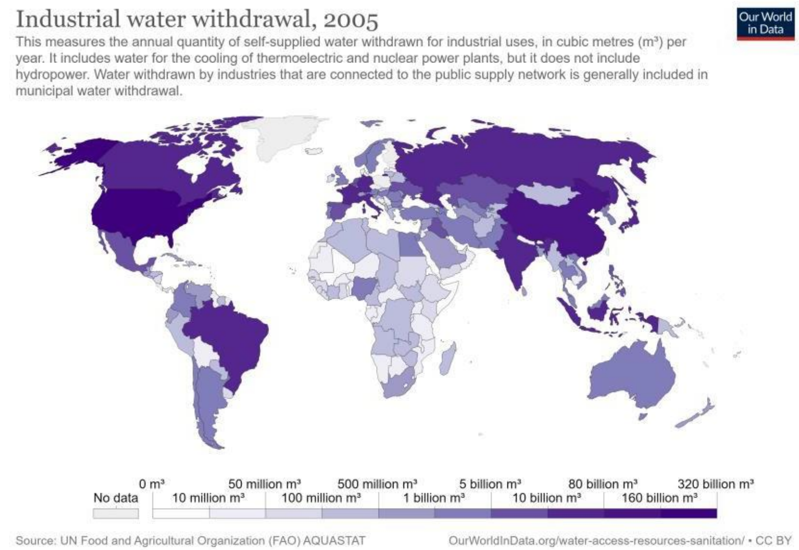
Source: UN Food and Agricultural Organization (FAO) AQUASTAT

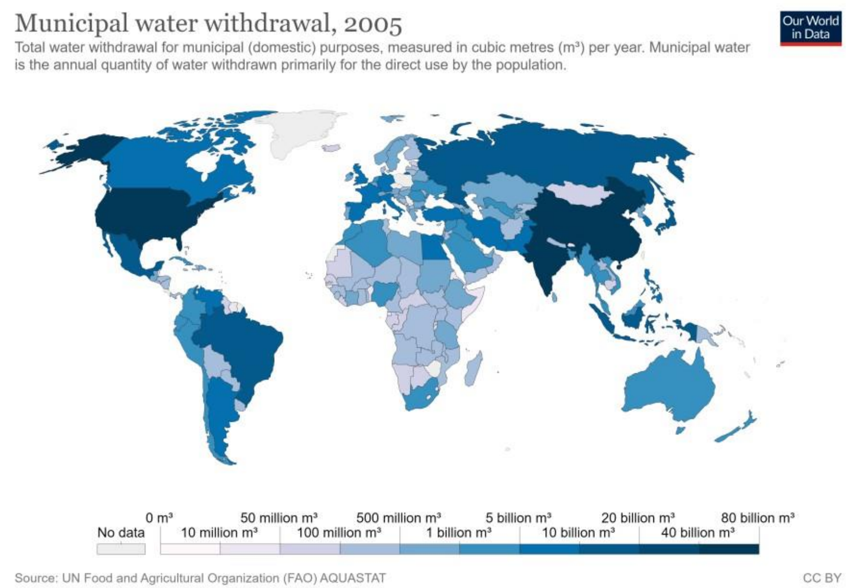
OurWorldInData.org/water-access-resources-sanitation/ • CC BY

Source: https://ourworldindata.org/water-use-stress

A global development overview – water main uses



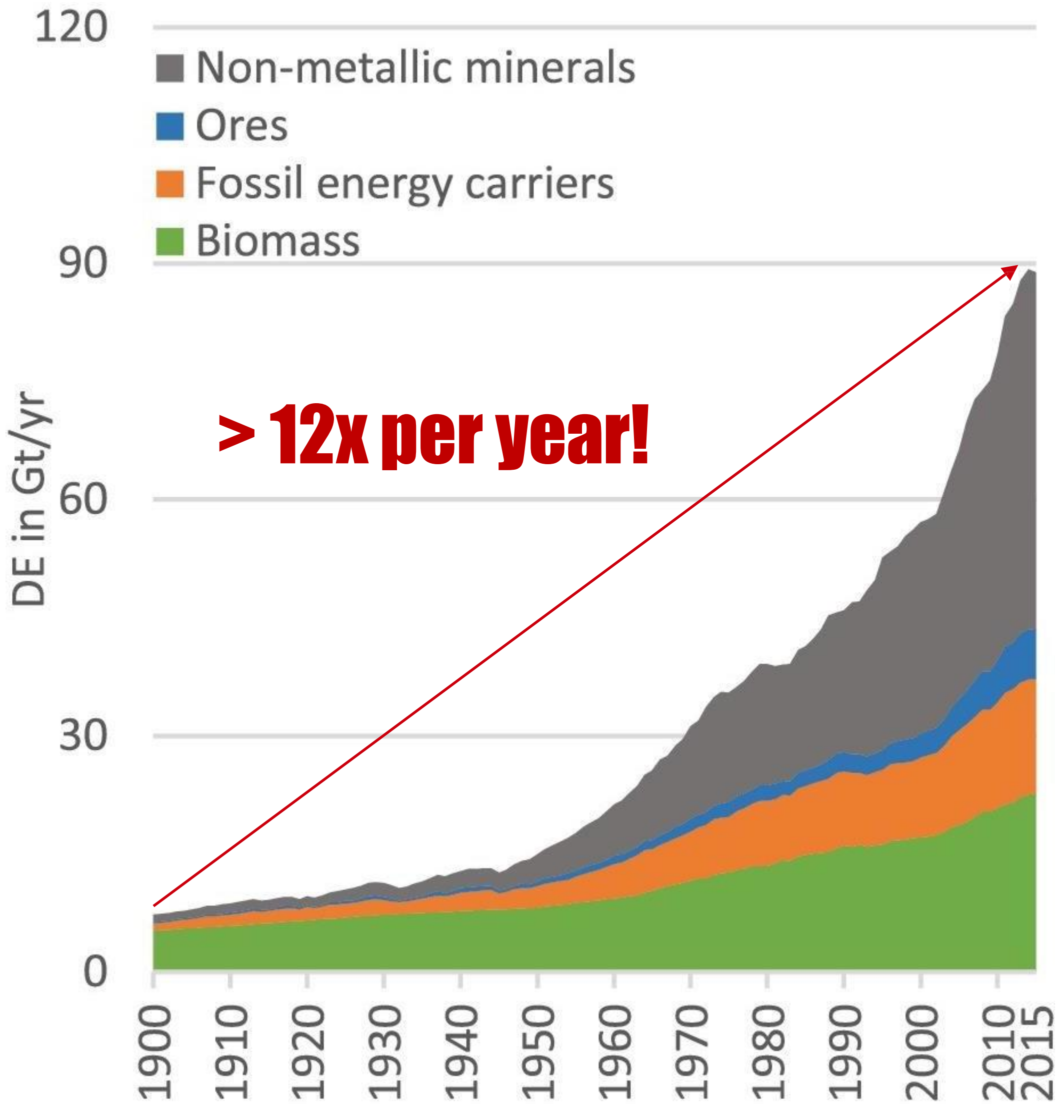




Agriculture >> Industrial
Industrial >> Households

Source: https://ourworldindata.org/water-use-stress

A global development overview – material extraction



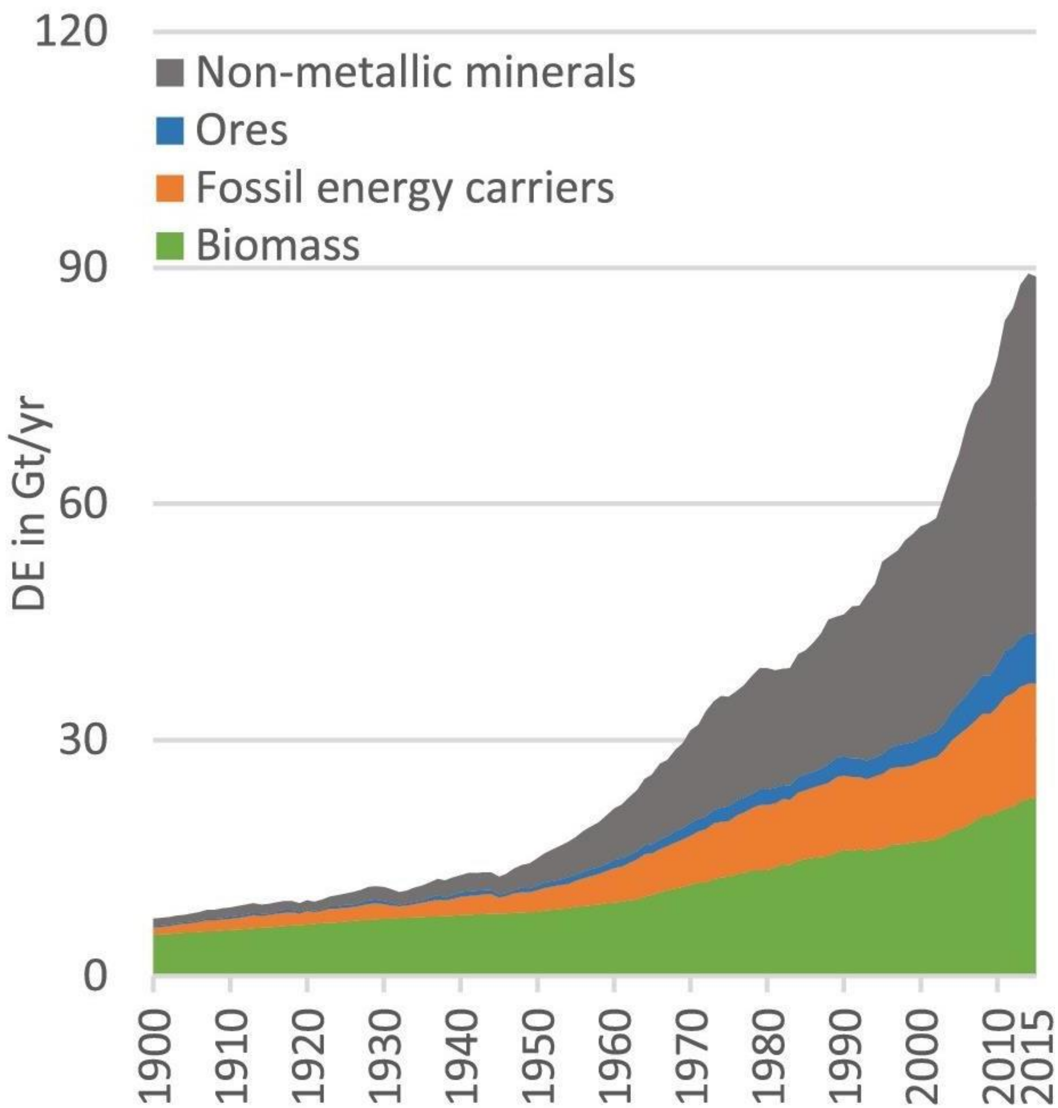
Krausmann, F., Lauk, C., Haas, W., & Wiedenhofer, D. (2018). From resource extraction to outflows of wastes and emissions: The socioeconomic metabolism of the global economy, 1900–2015. *Global Environmental Change*, 52, 131-140.

From 1900 to 2015,
3400 billion tons of materials were extracted, half of these materials were extracted since 1988

From 1900 to 2015,
the amount of materials which was extracted globally went from 7.2 Gt/yr to 82 Gt/yr (an incease of **12 times**) while global population increased by 4.5 times.

Today 100Gt/yr

A global development overview - material extraction



Krausmann, F., Lauk, C., Haas, W., & Wiedenhofer, D. (2018). From resource extraction to outflows of wastes and emissions: The socioeconomic metabolism of the global economy, 1900–2015. *Global Environmental Change*, 52, 131-140.

From 1900 to 2015,

the amount of biomass which was extracted globally went from 5.5 Gt/yr to 22.7 Gt/yr (**an increase of 4.3 times**) while global population increased by 4.5 times.

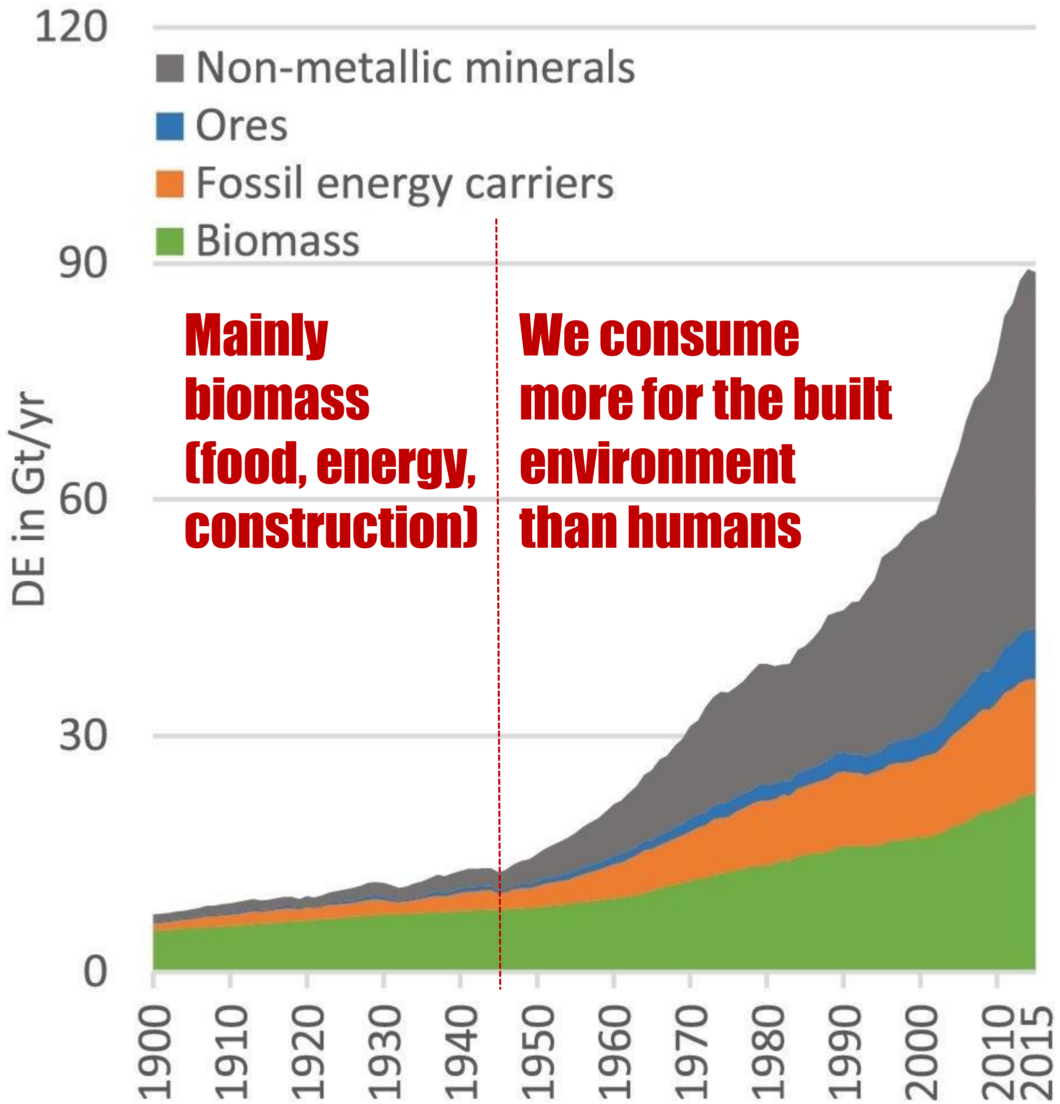
the amount of fossil energy carriers which was extracted globally went from 1 Gt/yr to 14.5 Gt/yr (an increase of **14.5 times**)

the amount of ores which was extracted globally went from 0.2 Gt/yr to 6.5 Gt/yr (an increase of **33 times**)

the amount of non-metallic minerals which was extracted globally went from 0.9 Gt/yr to 45.3 Gt/yr (an increase of **50 times**).

A global development overview - material extraction

Krausmann, F., Lauk, C., Haas, W., & Wiedenhofer, D. (2018). From resource extraction to outflows of wastes and emissions: The socioeconomic metabolism of the global economy, 1900–2015. *Global Environmental Change*, 52, 131-140.



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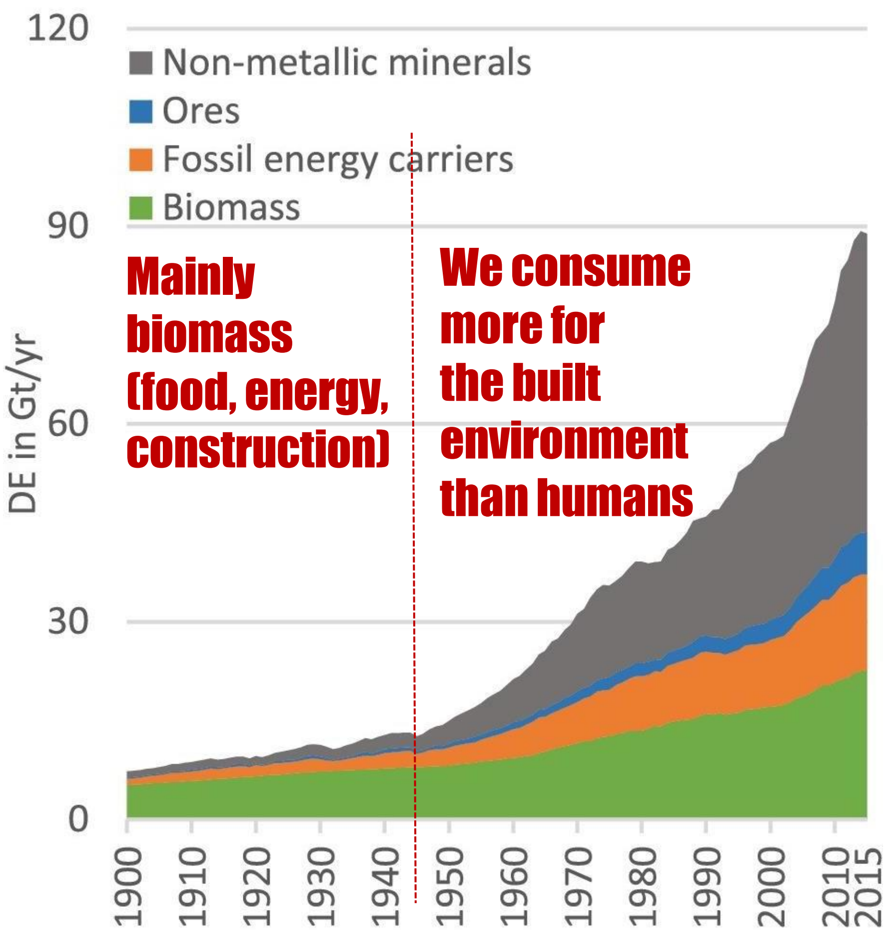
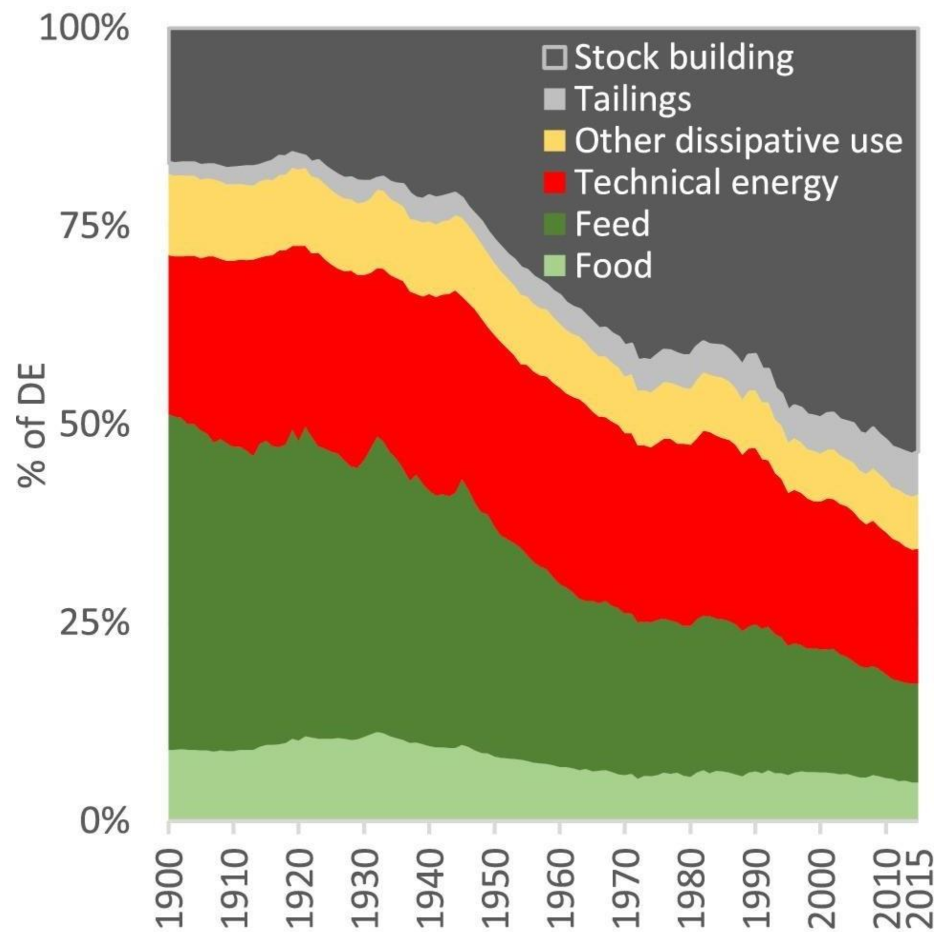
A global development overview - material extraction





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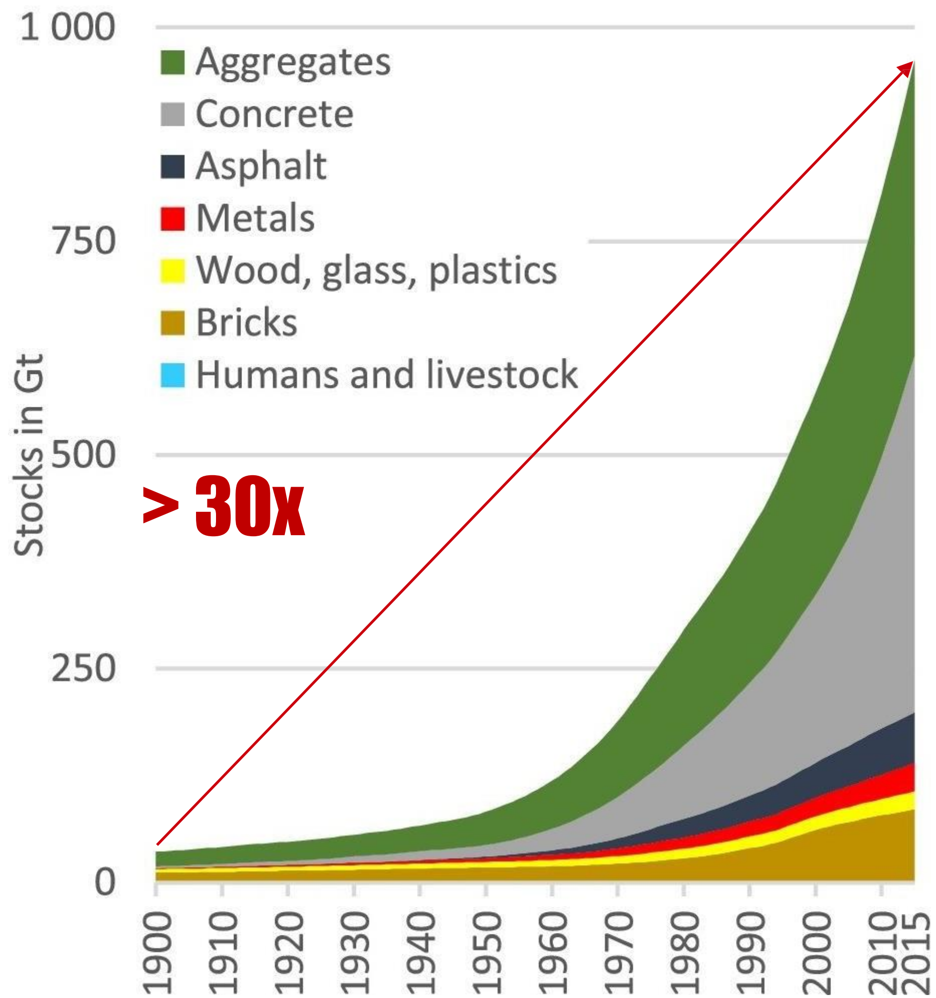
A global development overview - material extraction

STOCK = 1000 GT
EXTRACTION = 100 GT/YR



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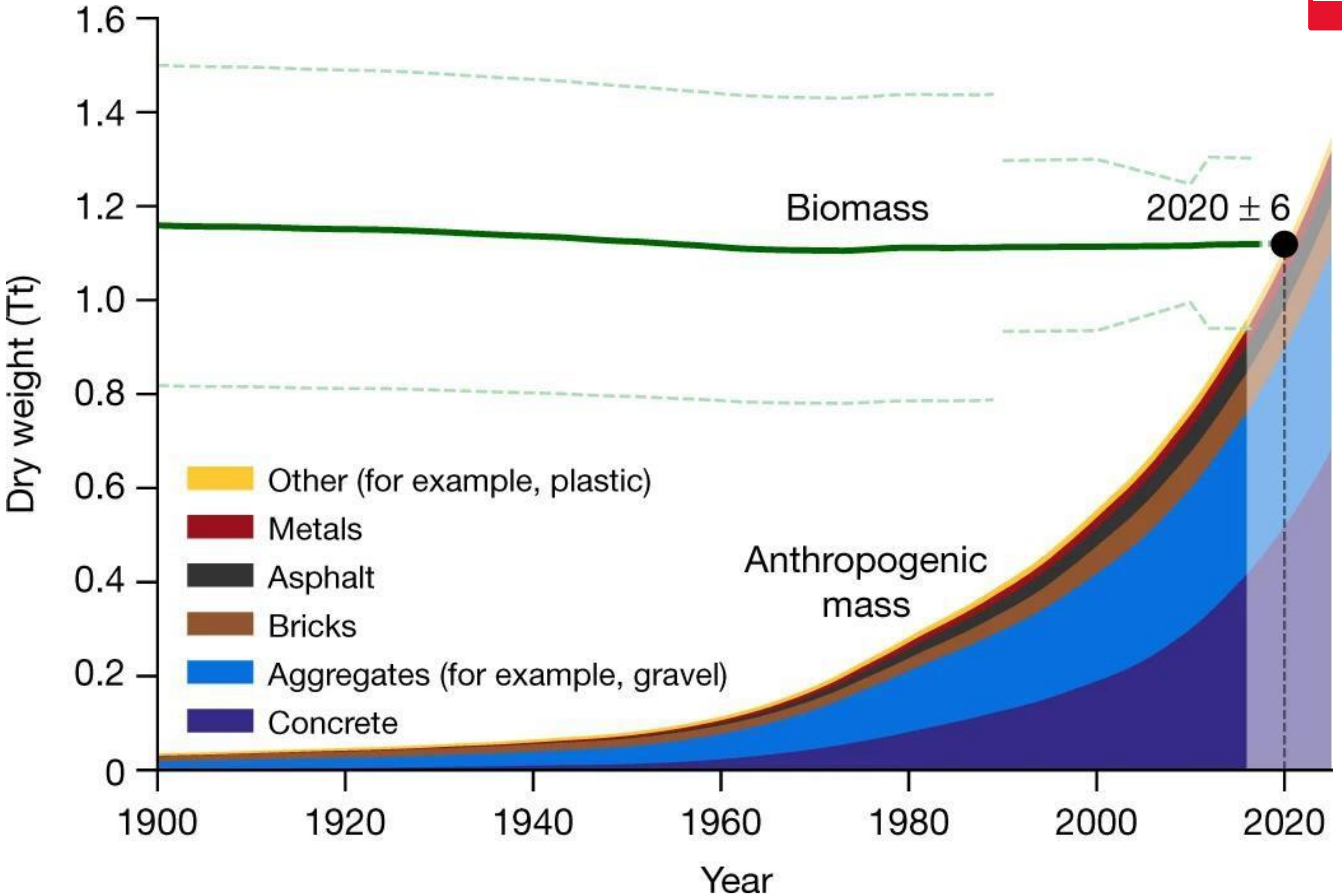
A global development overview - material stocks



Elhacham, E., Ben-Uri, L., Grozovski, J., Bar-On, Y. M., & Milo, R. (2020). Global human-made mass exceeds all living biomass. *Nature*, *588*(7838), 442-444.

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A global development overview - material stocks

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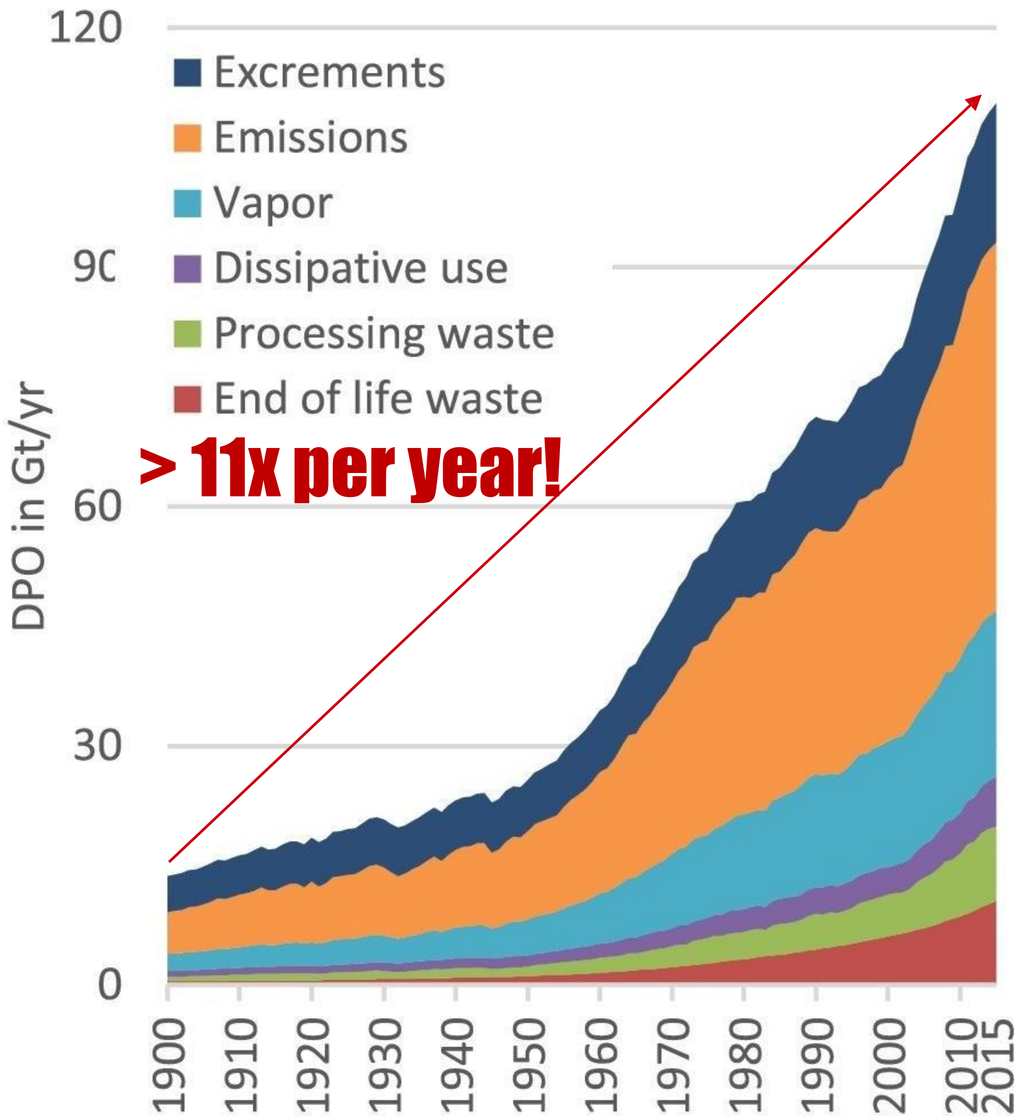
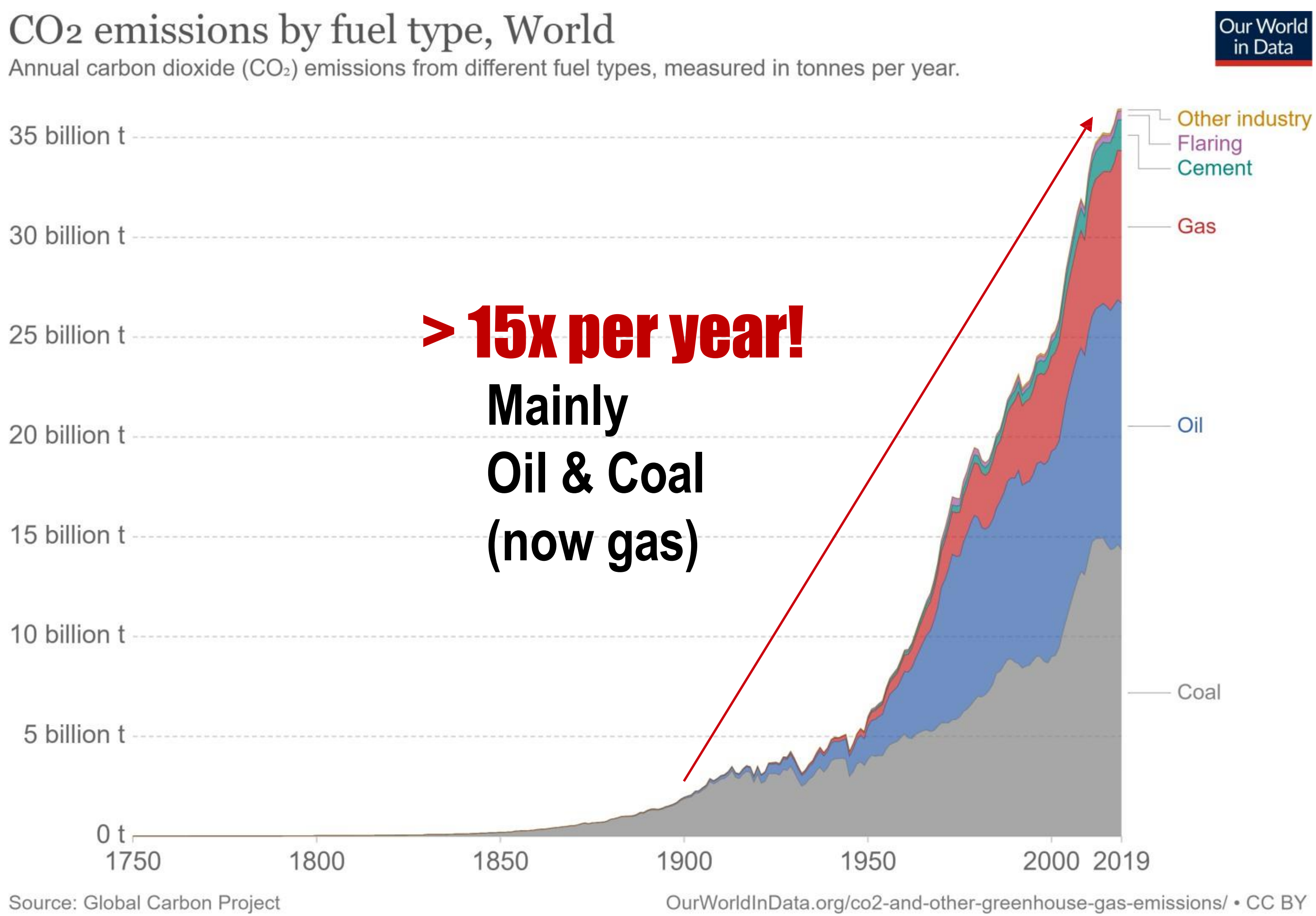
A global development overview – outflows/waste



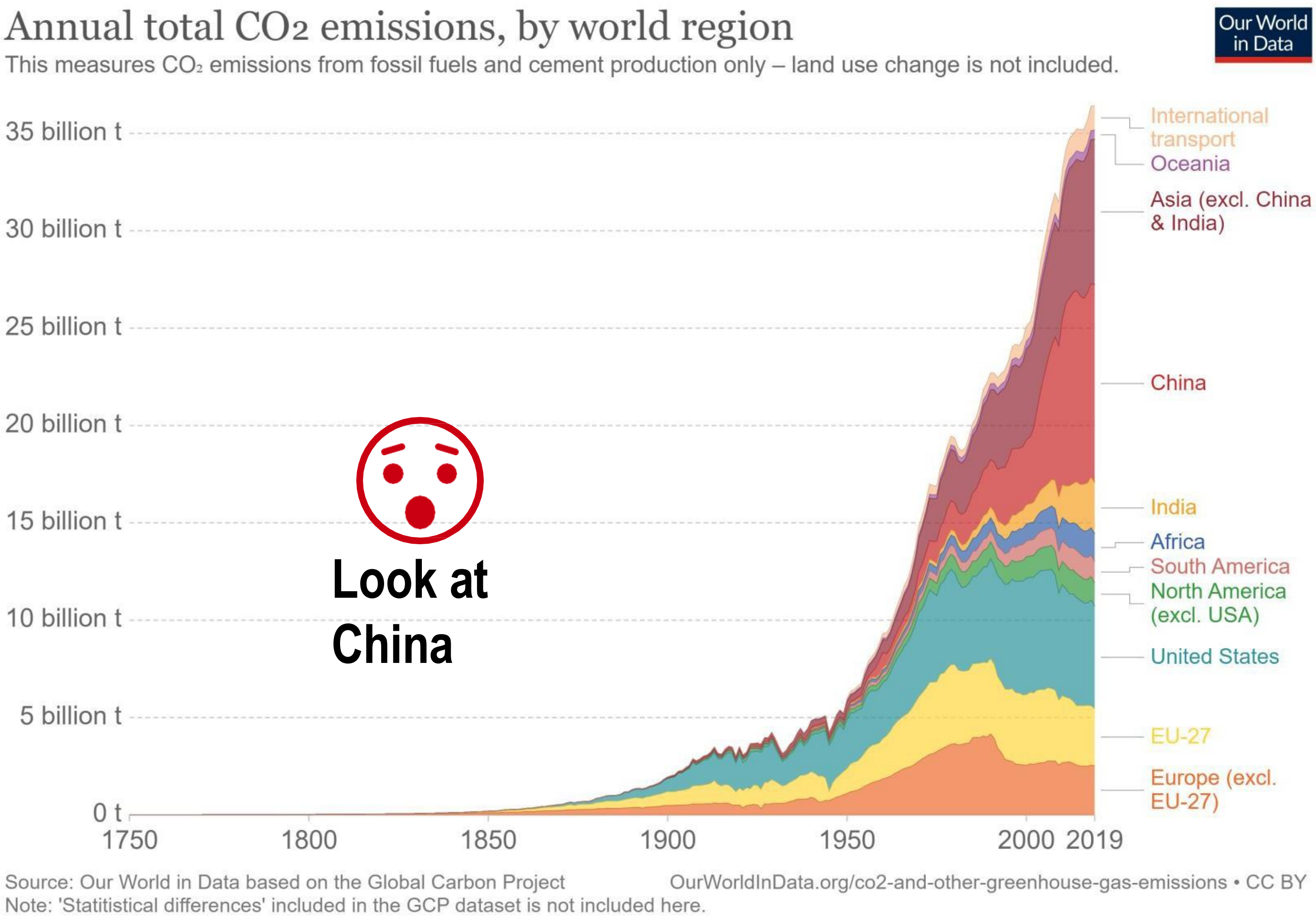
Krausmann, F., Lauk, C., Haas, W., & Wiedenhofer, D. (2018). From resource extraction to outflows of wastes and emissions: The socioeconomic metabolism of the global economy, 1900–2015. *Global Environmental Change*, *52*, 131-140.

A global development overview – CO_2 emissions



Source: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

A global development overview – CO_2 emissions



Source: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

Recap – what number surprised you the most?

From 1900-2015

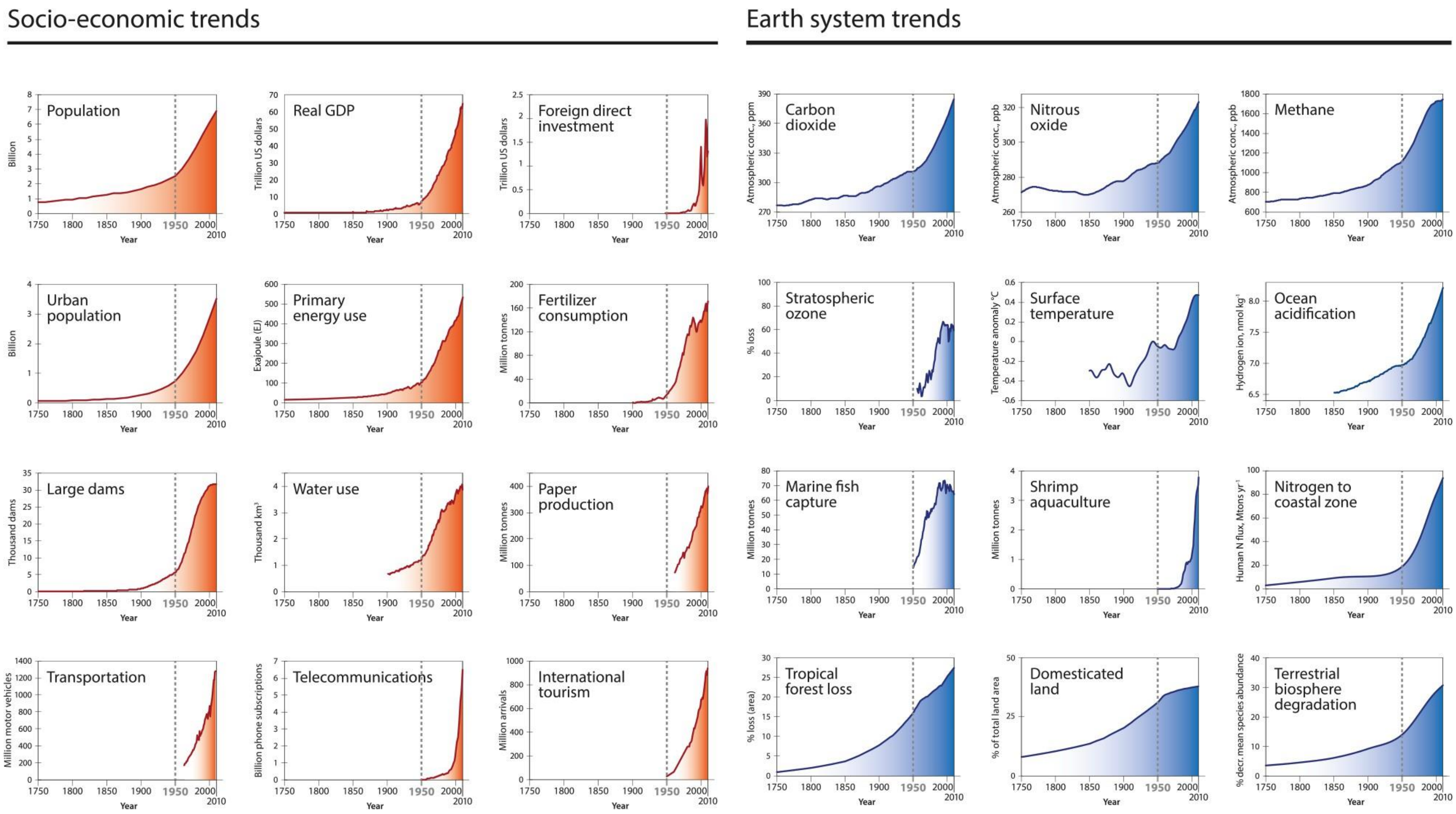
- Population: 4.6x
- Rural Population: 2.6x
- **Urban Population: 14x**
- Global primary energy consumption: 15x/year
- Global freshwater use: 6x/year
- Global material extraction: 12x/year
- Material stocks: 30x
- Waste/Outflows: 11x/year
- CO_2 emissions: 15x/year
- Global GDP: 30x

So what? Why should we care?

What is the most preoccupying figure? Report back to the group

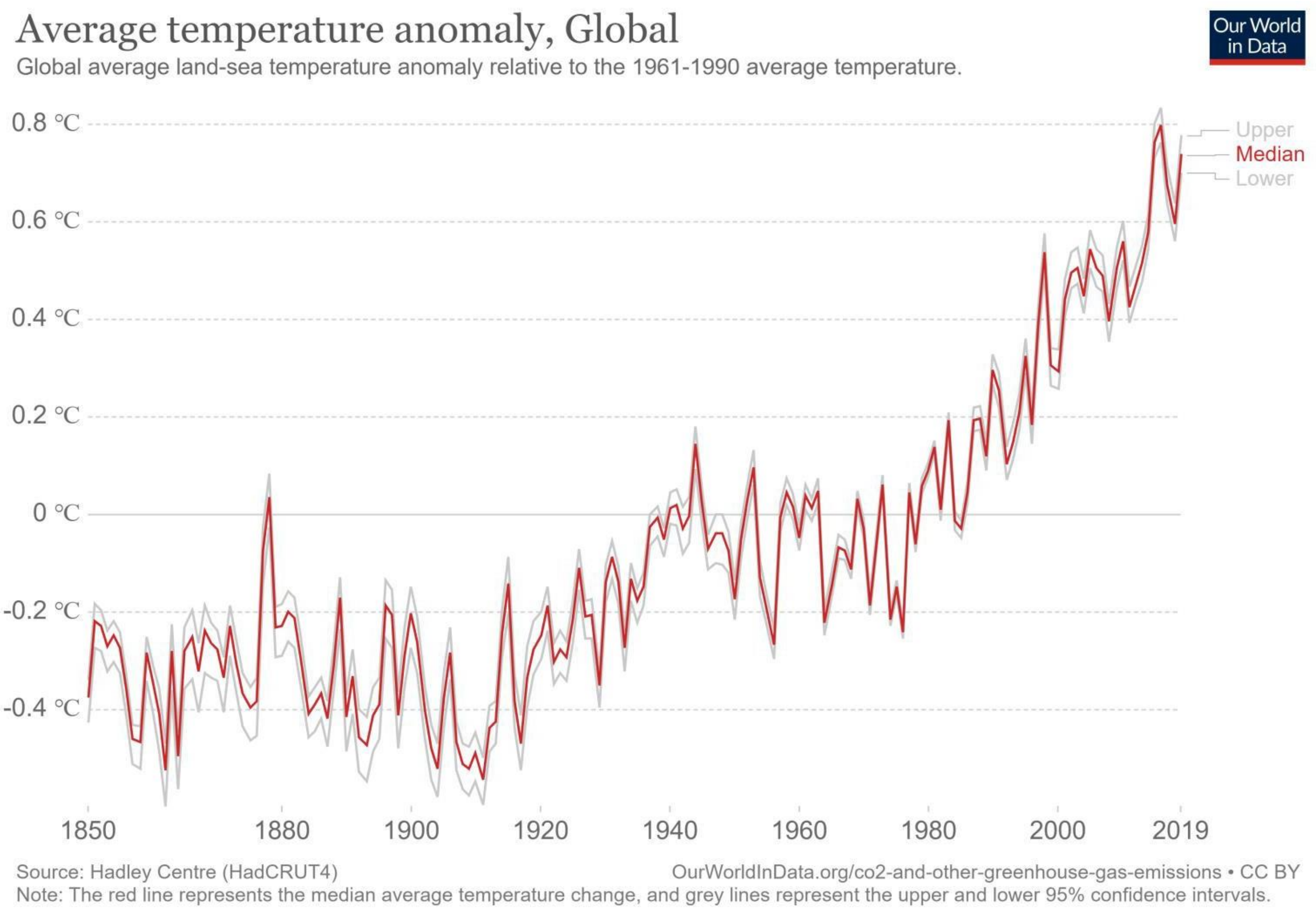
The impact(s) of global growth - Welcome to the Anthropocene

The Great Acceleration – to recap



Steffen, W., Broadgate, W., Deutsch, L., Gaffney, O., & Ludwig, C. (2015). The trajectory of the Anthropocene: the great acceleration. *The Anthropocene Review*, 2(1), 81-98.

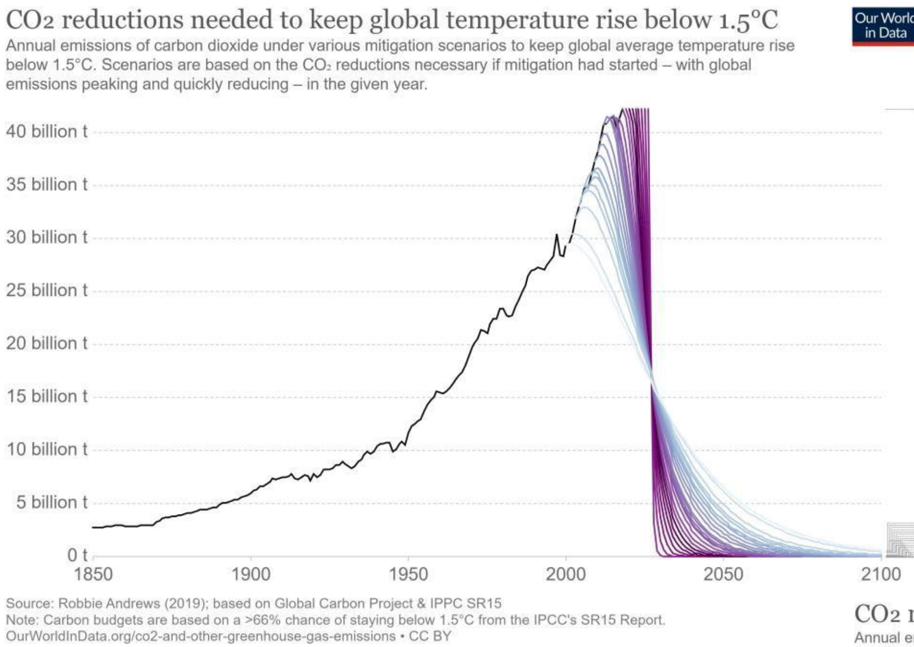
Impacts of global development – global warming

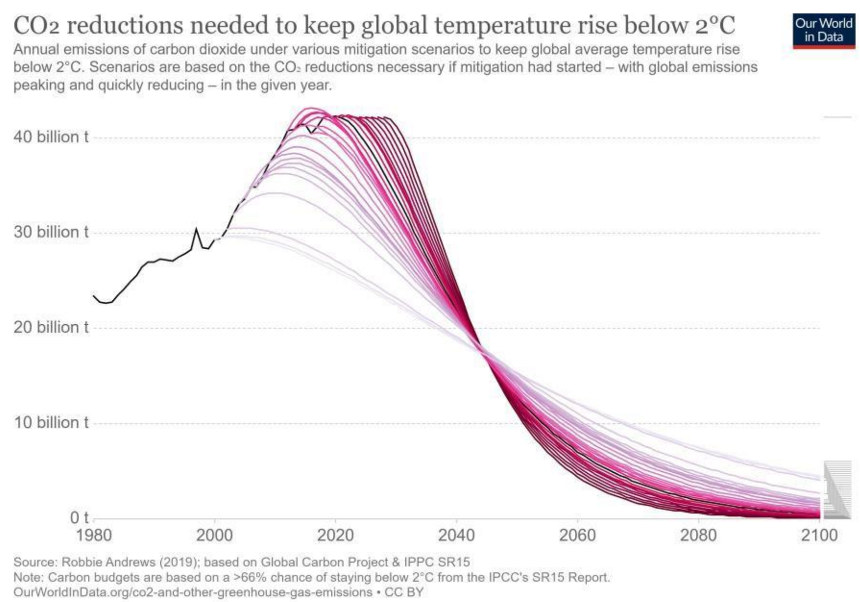


Source: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

We see that over the last few decades, global temperatures have risen sharply — to approximately 0.7°C higher than our 1961-1990 baseline. When extended back to 1850, we see that temperatures then were a further 0.4°C colder than they were in our baseline. Overall, this would amount to an average temperature rise of 1.1°C.

Impacts of global development – global warming





Source: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

Impacts of global development – biodiversity loss

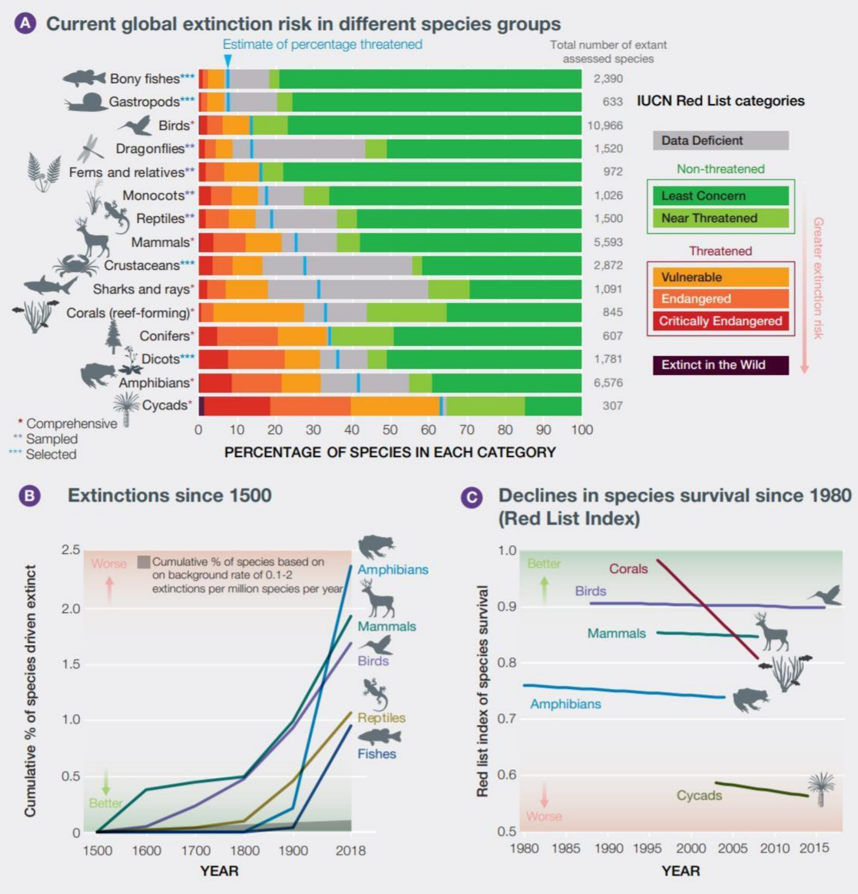


Figure SPM 3 **A substantial proportion of assessed species are threatened with extinction and overall trends are deteriorating, with extinction rates increasing sharply in the past century.**

A Percentage of species threatened with extinction in taxonomic groups that have been assessed comprehensively, or through a 'sampled' approach, or for which selected subsets have been assessed, by the International Union for Conservation of Nature (IUCN) Red List of Threatened Species. Groups are ordered according to the best estimate for the percentage of extant species considered threatened (shown by the vertical blue lines), assuming that data deficient species are as threatened as non-data deficient species. B Extinctions since 1500 for vertebrate groups. Rates for reptiles and fishes have not been assessed for all species. C Red List Index of species survival for taxonomic groups that have been assessed for the IUCN Red List at least twice. A value of 1 is equivalent to all species being categorized as Least Concern; a value of zero is equivalent to all species being classified as Extinct. Data for all panels derive from www.iucnredlist.org (see Chapter 3 Figure 3.4 and Chapter 2 Figure 2.7).

https://ipbes.net/sites/default/files/2020-02/ipbes_global_assessment_report_summary_for_policymakers_en.pdf

EPFL

A global development overview – global inequalities

Source: http://www.astro4dev.org/wp-content/uploads/2020/08/South-Africa-drone_inequality.png

Global inequalities

In 2015, a**round half the emissions of the** **richest 10 percent** **- people with net income over** **$38,000** - are linked to citizens in the US and the EU and around a fifth with citizens of China and India. **Over a third of the emissions of the richest one percent – people with net income over** **$109,000 -** are linked to citizens in the US, with the next biggest contributions from citizens of the Middle East and China.

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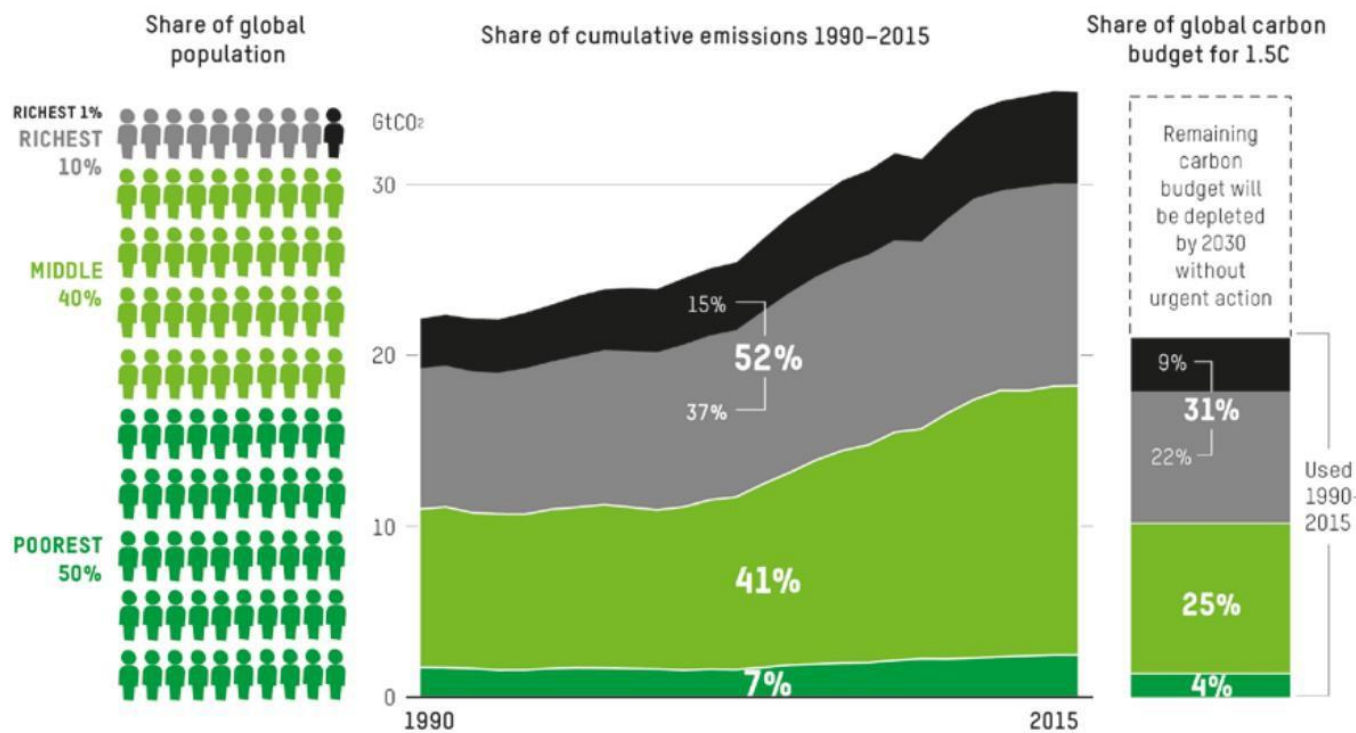
Carbon emissions of richest 1 percent more than double the emissions of the poorest half of humanity

Published: 21st September 2020

Figure 1: Share of cumulative emissions from 1990 to 2015 and use of the global carbon budget for 1.5C linked to consumption by different global income groups



Per capita income threshold [$PPP2011] of richest 1%: $109k; richest 10%: $38k; middle 40%: $6k; and bottom 50%: less than $6k.
Global carbon budget from 1990 for 33% risk of exceeding 1.5C: 1,205Gt.

https://www.oxfam.org/en/press-releases/carbon-emissions-richest-1-percent-more-double-emissions-poorest-half-humanity

Global inequalities over use

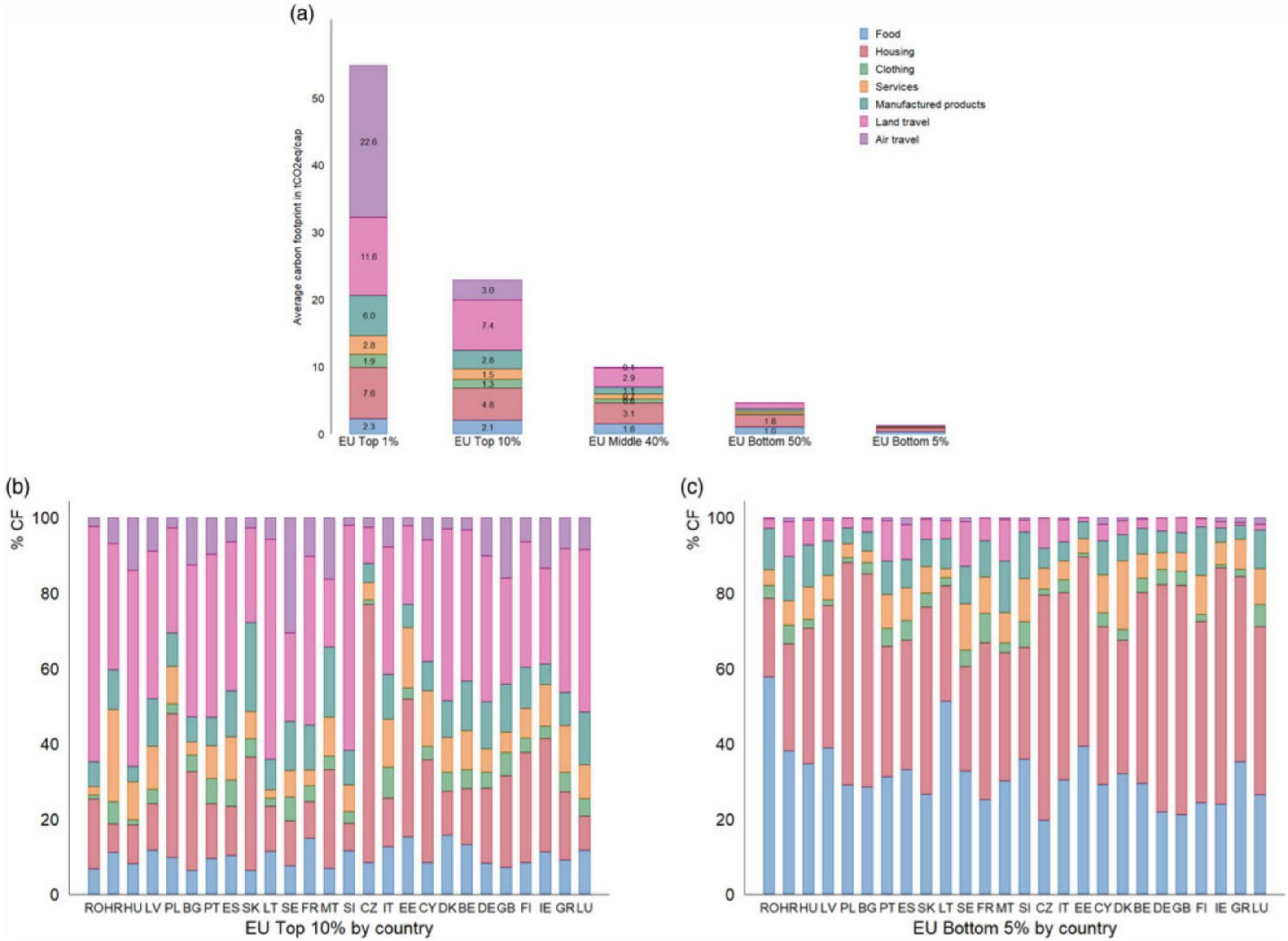
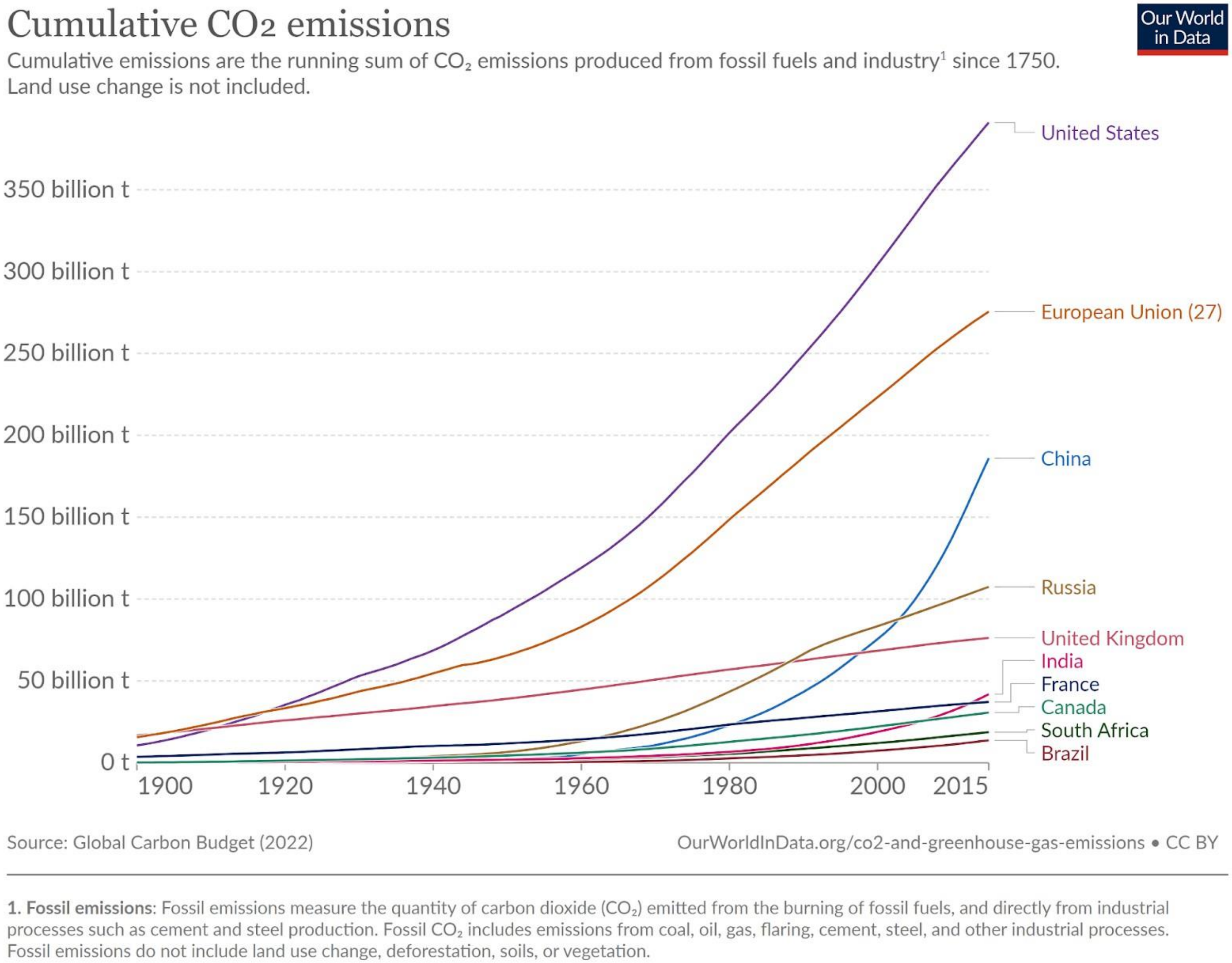


Fig. 3. Average carbon footprint (CF) distribution by consumption category in the European Union (EU) (top). The bottom graph depicts the average CF shares by consumption category and countries of EU top 10% emitters on the left (with CF >15 tCO_2eq/cap) and EU bottom 5% of emitters on the right (with CF <2.5 tCO_2eq/cap). See SI4 for country averages. EU household weights applied. See Section 2 for country codes.

Source: . Ivanova D, Wood R (2020). The unequal distribution of household carbon footprints in Europe and its link to sustainability. Global Sustainability 3, e18, 1–12. https://doi.org/10.1017/sus.2020.12

Global inequalities over time

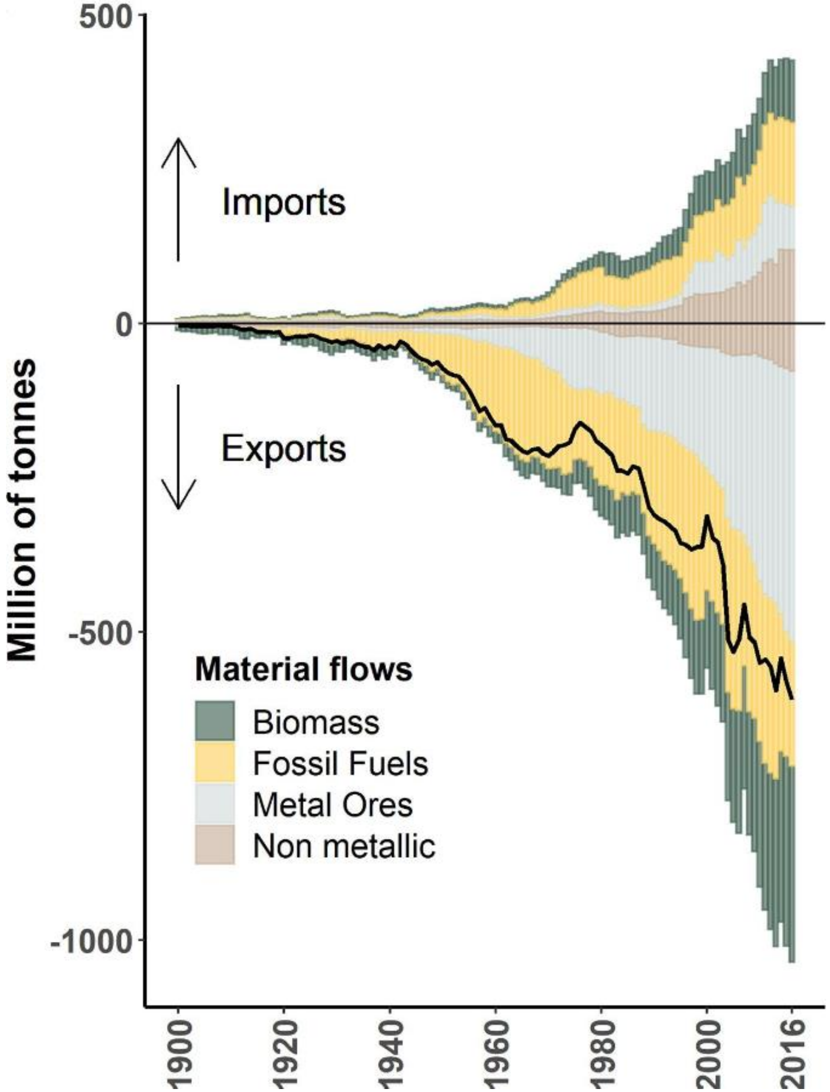


https://ourworldindata.org/co2-emissions#cumulative-co2-emissions

Impacts of Global Development – Resource Drain

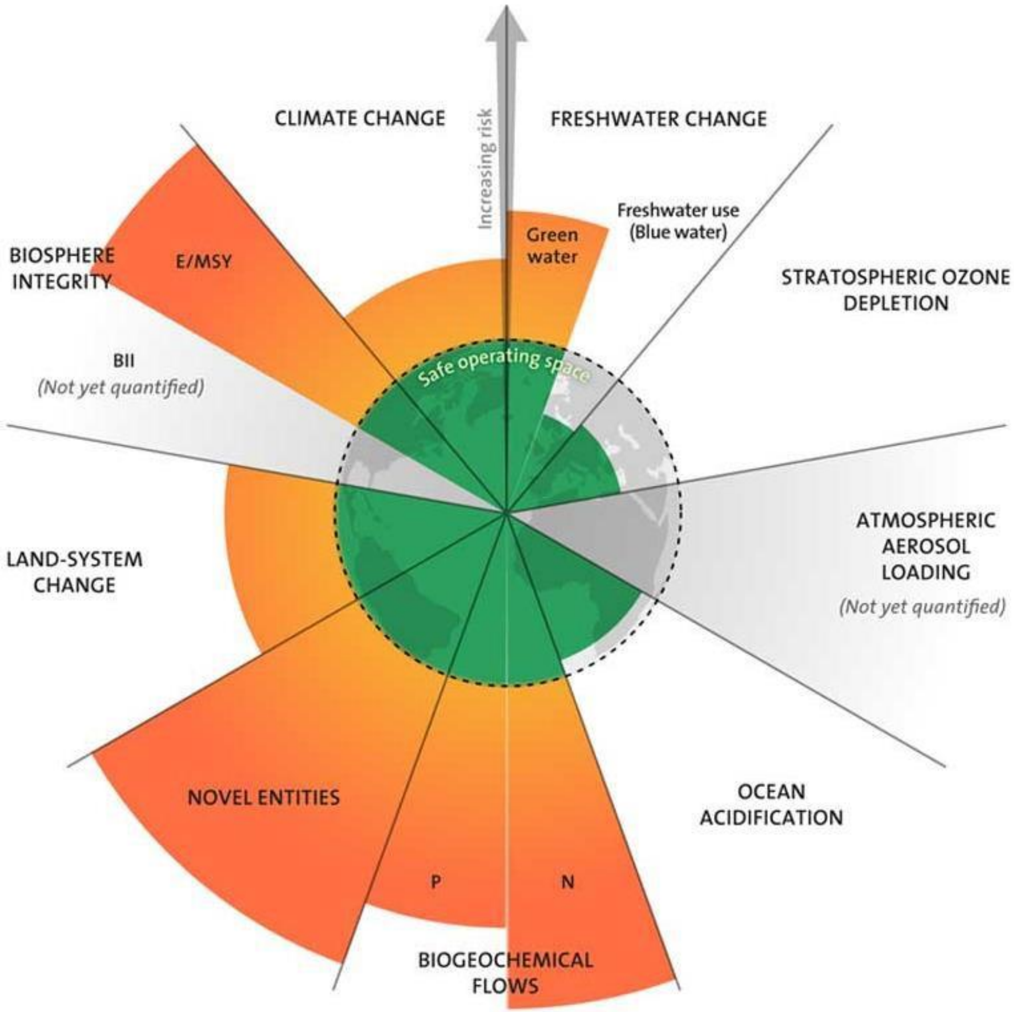
Hickel, J., Dorninger, C., Wieland, H., & Suwandi, I. (2022). Imperialist appropriation in the world economy: Drain from the global South through unequal exchange, 1990–2015. *Global Environmental Change*, *73*, 102467.

Impacts of Global Development – Resource Drain



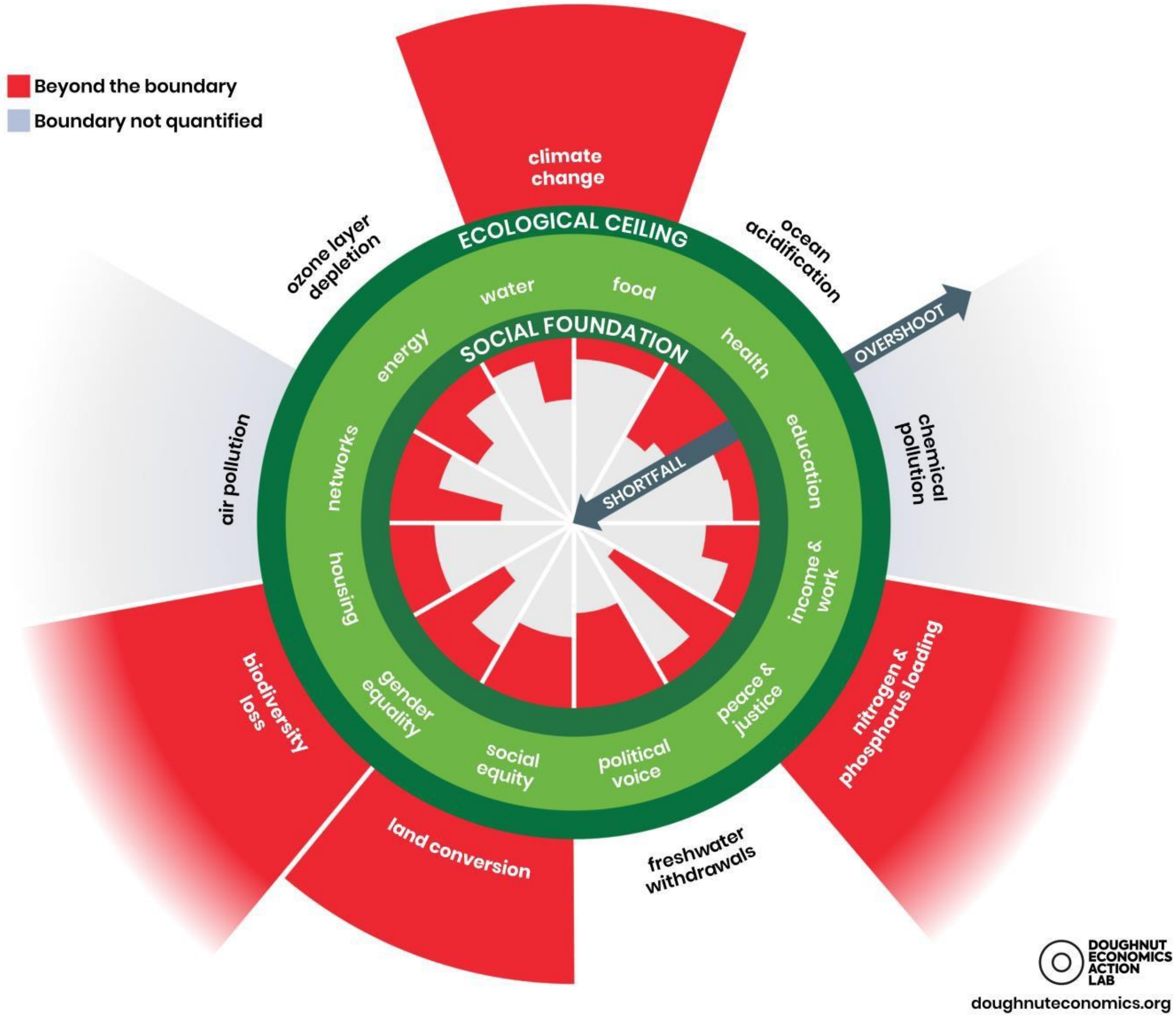
Infante-Amate, J., Urrego-Mesa, A., Pinero, P., & Tello, E. (2022). The open veins of Latin America: Long-term physical trade flows (1900–2016). Global Environmental Change, 76, 102579.

Planetary boundaries



Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F. S., Lambin, E., ... & Foley, J. (2009). Planetary boundaries: exploring the safe operating space for humanity. *Ecology and society*, *14*(2).

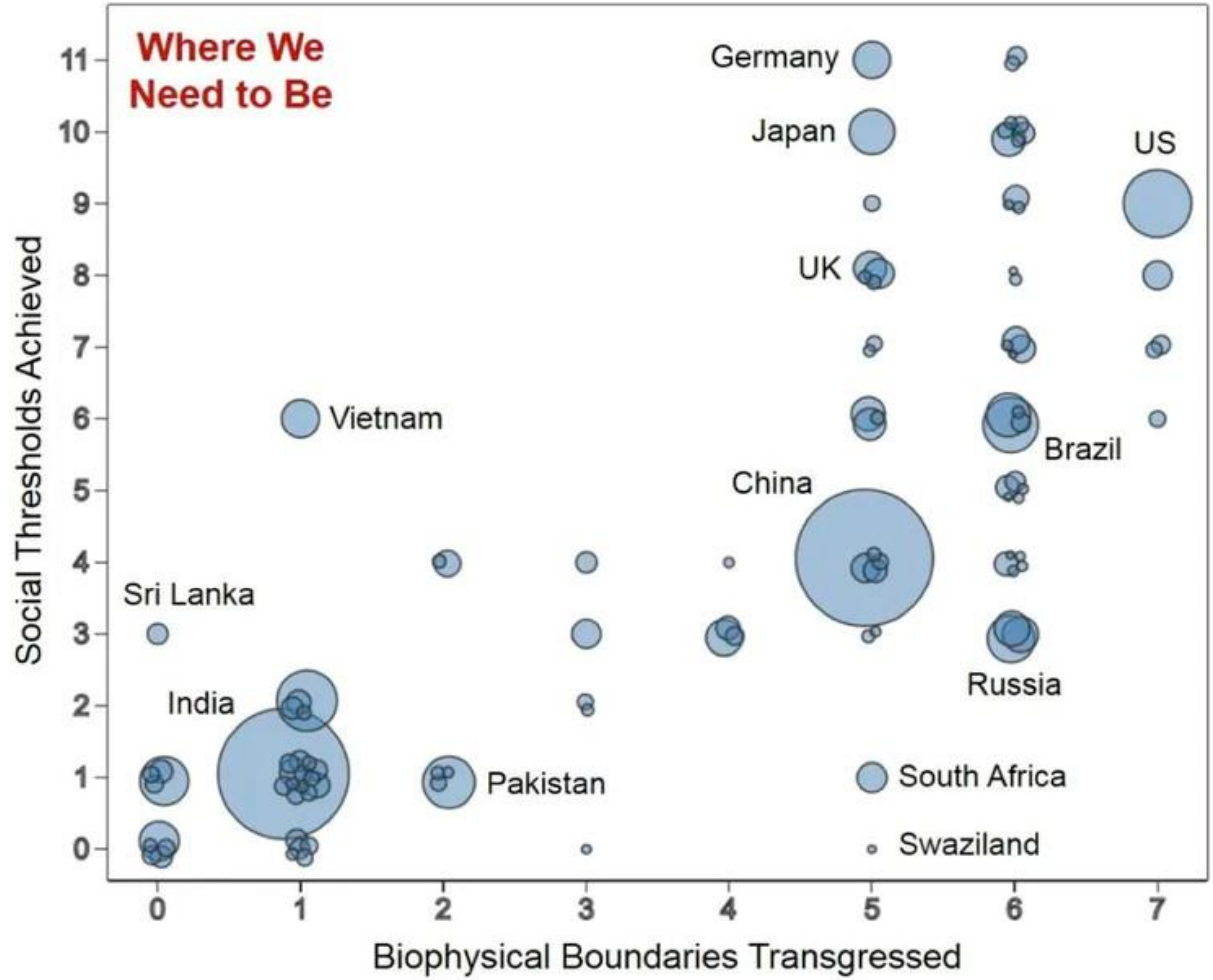
Doughnut Economics



https://doughnuteconomics.org/

EPFL

A Good Life For All Within Planetary Boundaries



Measures of a 'good life' vs overuse of resources for different countries (scaled by population). Ideally, countries would be located in the top-left corner.
O'Neill et al, Author provided

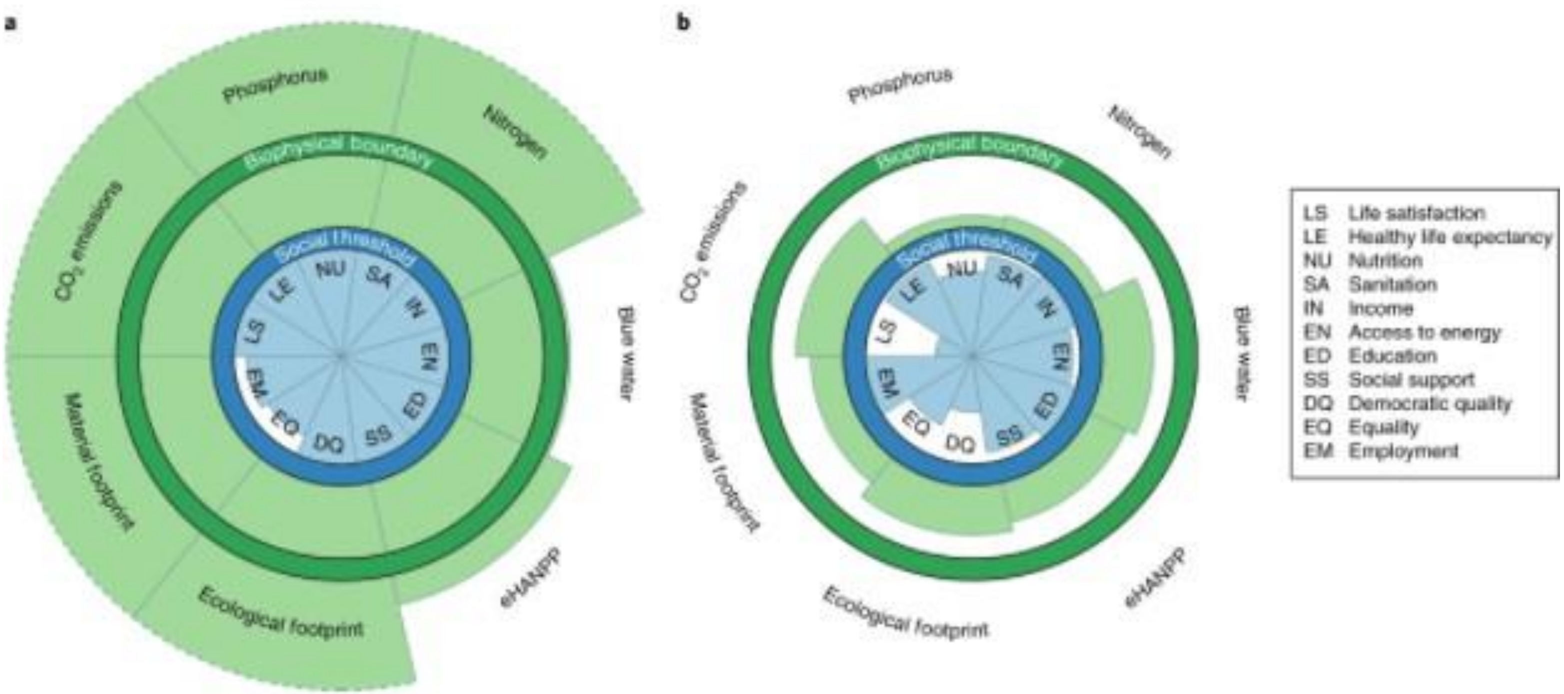
https://theconversation.com/is-it-possible-for-everyone-to-live-a-good-life-within-our-planets-limits-91421

O'Neill, D.W., Fanning, A.L., Lamb, W.F. *et al.* A good life for all within planetary boundaries. *Nat Sustain* **1**, 88–95 (2018). https://doi.org/10.1038/s41893-018-0021-4

A Good Life For All Within Planetary Boundaries

Fig. 3: National performance relative to a 'safe and just space' for two countries.

From: A good life for all within planetary boundaries



a, The United States. **b**, Sri Lanka. Blue wedges show social performance relative to the social threshold (blue circle), whereas green wedges show resource use relative to the biophysical boundary (green circle). The blue wedges start at the centre of the plot (which represents the worst score achieved by any country), whereas the green wedges start at the outer edge of the blue circle (which represents zero resource use). Both the social thresholds and biophysical boundaries incorporate a range of uncertainties, and should be interpreted as fuzzy lines. Wedges with a dashed edge extend beyond the chart area. Ideally, a country would have blue wedges that reach the social threshold and green wedges within the biophysical boundary. See Supplementary Data for data for all countries and https://goodlife.leeds.ac.uk for an interactive website that produces plots for all countries.

O'Neill, D.W., Fanning, A.L., Lamb, W.F. *et al.* A good life for all within planetary boundaries. *Nat Sustain* **1**, 88–95 (2018). https://doi.org/10.1038/s41893-018-0021-4

EPFL


Where to now?

What about Energy Transition ?

National **4+ categories** material flows

National **13+ categories** material flows

National material **totals and ratios**

Filter countries | Clear filter | World ×

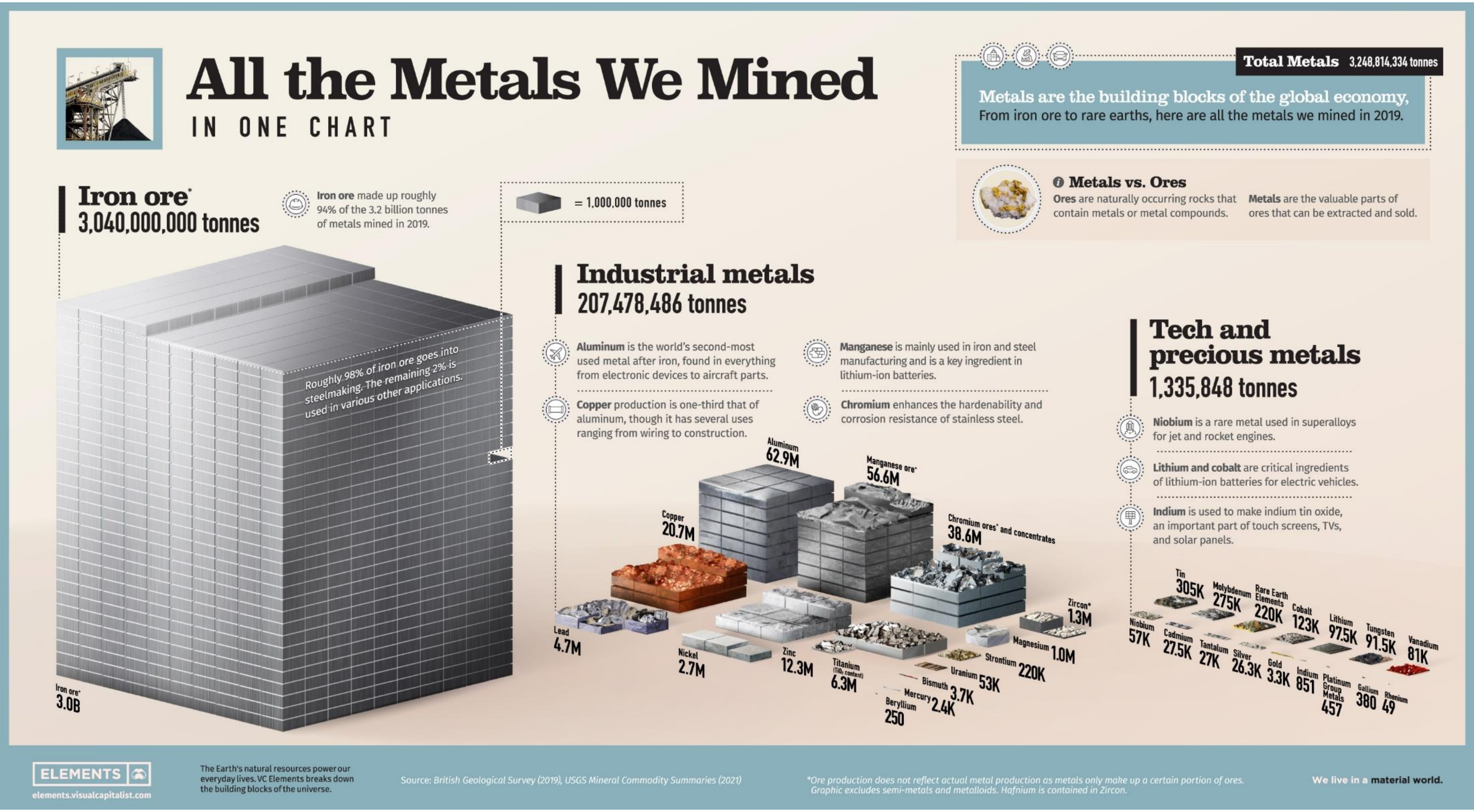
Filter categories | Clear filter | Fossil fuels × | Metal ores ×

Filter flow types | Clear filter | DE (Domestic Extraction,... ×

Country	Category	Flow	2020	2021	2022	2023	2024
World	Fossil fuels	DE	,362,033,658	15,823,307,613	15,915,740,174	15,998,218,386	16,102,490,158
World	Metal ores	DE	405,077,100	9,830,519,158	10,070,051,181	10,321,586,529	10,619,770,397

https://www.resourcepanel.org/global-material-flows-database

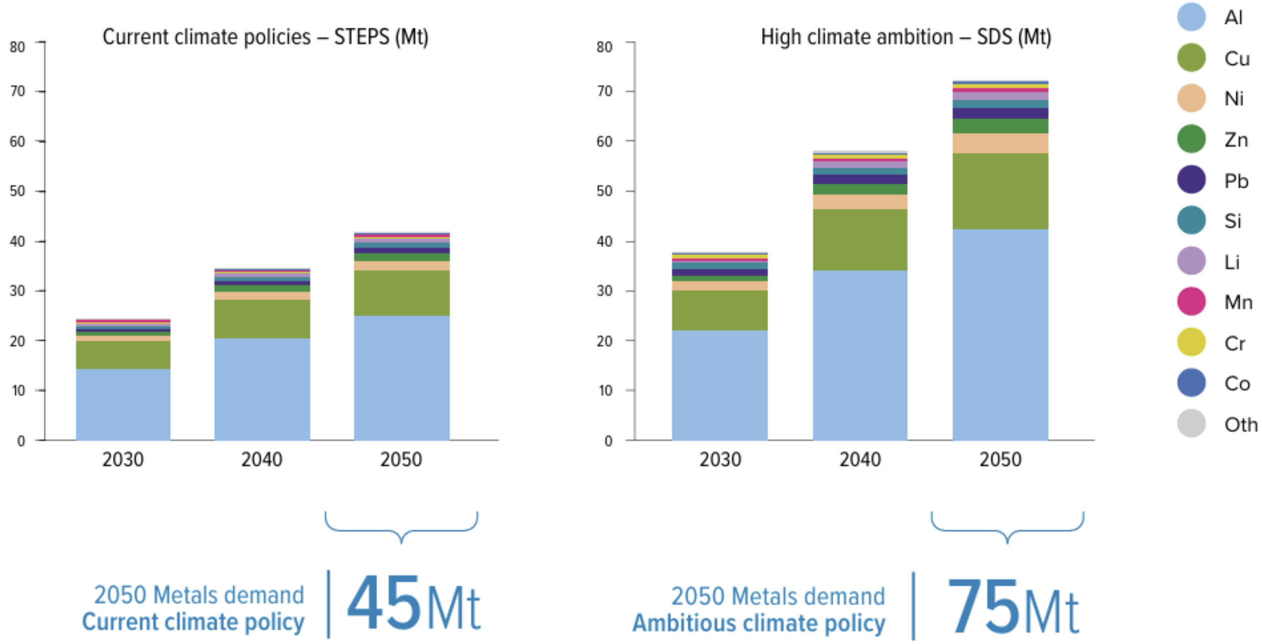
What about Energy Transition ?



https://www.visualcapitalist.com/all-the-metals-we-mined-in-one-visualization/

What about Energy Transition ? Metal needs

Global metal demand by commodity for clean energy technologies in a STEPS and SDS scenario respectively (Mt*)



% metal required in 2050 for clean energy technologies vs. 2020 overall use (Global SDS ambitious climate scenario).** †

Lithium	2,109%	Silicon	62%
Dysprosium	433%	Terbium	62%
Cobalt	403%	Copper	51%
Tellurium	277%	Aluminium	43%
Scandium	204%	Tin	28%
Nickel	168%	Germanium	24%
Praseodymium	110%	Molybdenum	22%
Gallium	77%	Lead	22%
Neodymium	66%	Indium	17%
Platinum	64%	Zinc	14%
Iridium	63%	Silver	10%

**Mt = million tonnes, annual (including lithium expressed as metal equivalent)*

https://www.eurometaux.eu/media/hr2ftbp3/2022-policymaker-summary-report-final-13-5-22.pdf

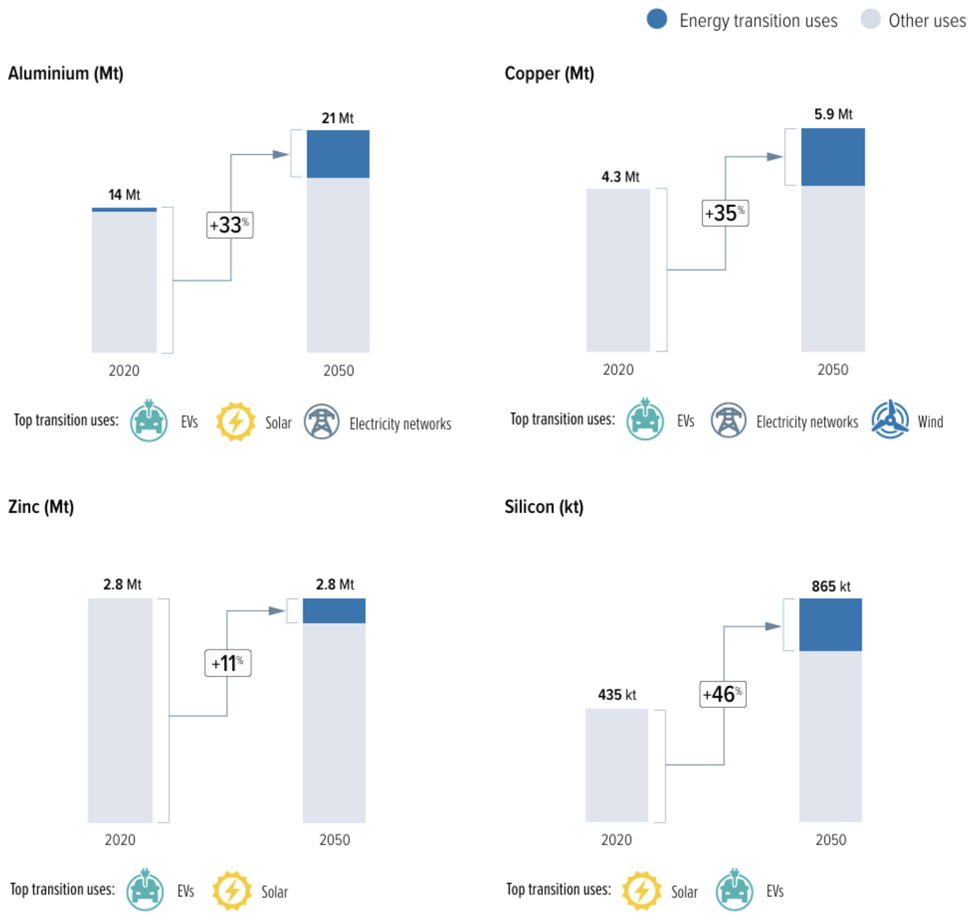
What about Energy Transition ? (Lithium need in EU x35)

World Mine Production and Reserves: Reserves for Argentina, Australia, Brazil, China, the United States, and "Other countries" were revised based on company and Government reports.

	Mine production 2022	Mine production 2023[e]	Reserves[4]
United States	W	W	1,100,000
Argentina	6,590	9,600	3,600,000
Australia	74,700	86,000	[5]6,200,000
Brazil	[e]2,630	4,900	390,000
Canada	[e]520	3,400	930,000
Chile	38,000	44,000	9,300,000
China	[e]22,600	33,000	3,000,000
Portugal	[e]380	380	60,000
Zimbabwe	[e]1,030	3,400	310,000
Other countries[6]	—	—	2,800,000
World total (rounded)	[7]146,000	[7]180,000	28,000,000

https://www.usgs.gov/centers/national-minerals-information-center/lithium-statistics-and-information

What about Energy Transition ? In Eu ? Opening of new Mines ?

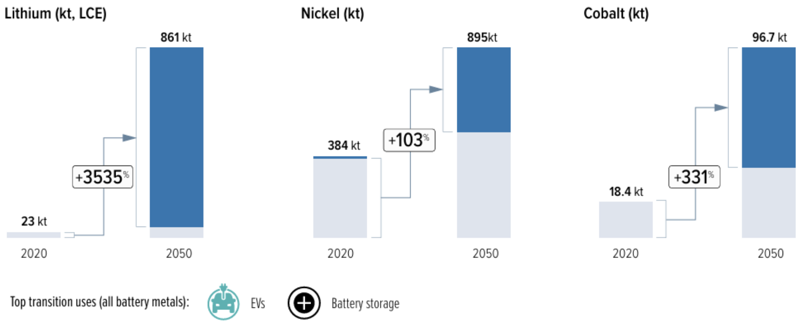


BATTERY METALS

Europe will require significant new supplies of nickel, lithium, and cobalt for its domestic battery cathode manufacturing plans. Of these metals, Europe only has a significant existing market for nickel, which is mainly used in stainless steel.

By 2050, batteries will be Europe's major use for lithium, nickel, and cobalt under all the study's scenarios, with new demand reaching up to 3500% of Europe's lithium consumption today, 330% of cobalt, and more than 100% of nickel.

Uncertain technology developments after 2030 will likely impact these long-term projections. Regular attention is required to the battery market and potential breakthrough technologies.

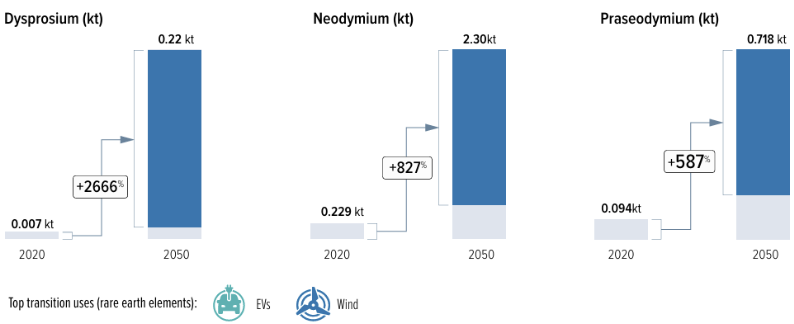


RARE EARTH METALS

Significant volumes of rare earth elements in permanent magnets will be required in Europe's electric vehicles and wind turbines.

But Europe will only require new supplies of rare earth metals if it is successful in building up domestic permanent magnets production – competing against China's near monopoly of the rare earths/permanent magnets market.

Even a moderate level of European domestic magnets production would transform the European rare earths market, requiring between 600% and 2700% extra compared with Europe's consumption today.



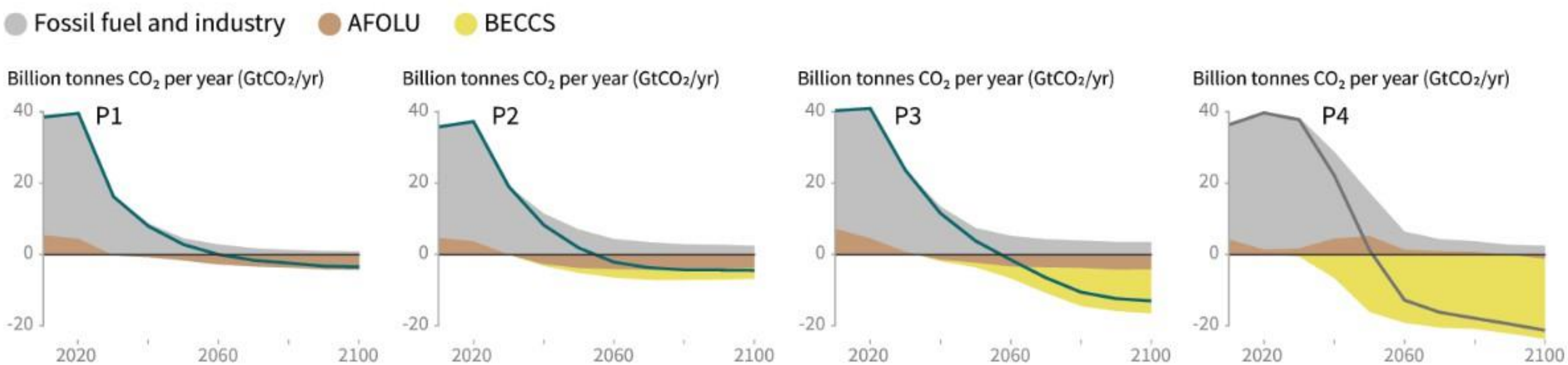
https://www.eurometaux.eu/media/hr2ftbp3/2022-policymaker-summary-report-final-13-5-22.pdf

IPCC Pathways that stay under 1,5 C

Characteristics of four illustrative model pathways

Different mitigation strategies can achieve the net emissions reductions that would be required to follow a pathway that limits global warming to 1.5°C with no or limited overshoot. All pathways use Carbon Dioxide Removal (CDR), but the amount varies across pathways, as do the relative contributions of Bioenergy with Carbon Capture and Storage (BECCS) and removals in the Agriculture, Forestry and Other Land Use (AFOLU) sector. This has implications for emissions and several other pathway characteristics.

Breakdown of contributions to global net CO_2 emissions in four illustrative model pathways



P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

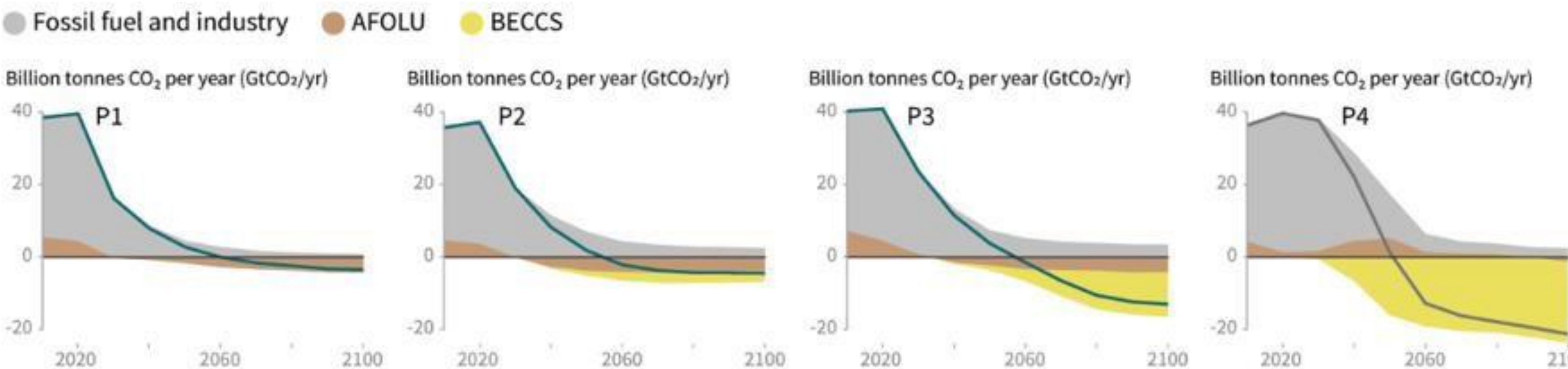
P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource- and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

Source: IPCC, 2018: Summary for Policymakers. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3-24, doi:10.1017/9781009157940.001.

What Scenario is most desirable ?



P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

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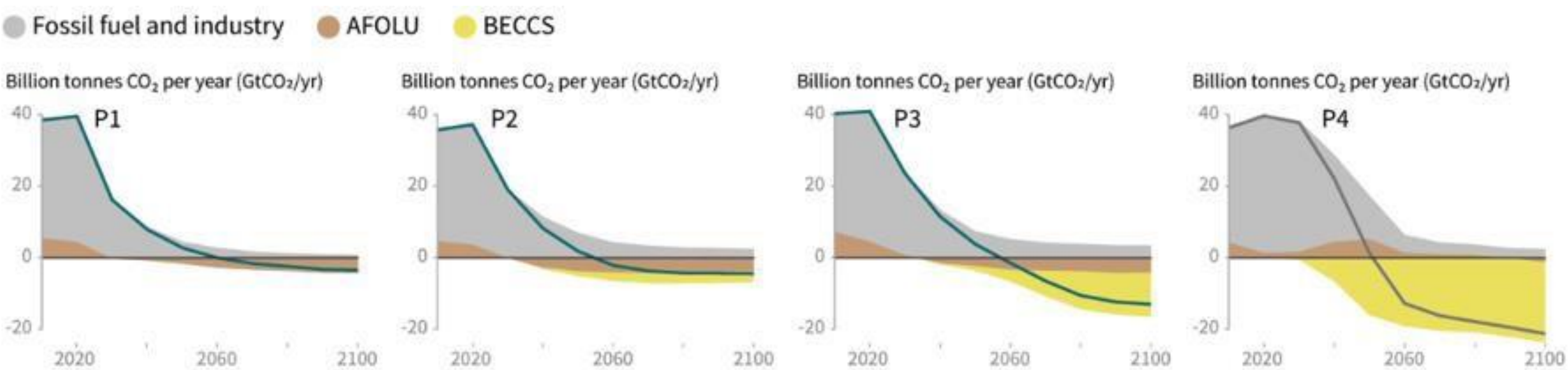
What Scenario is most likely ?



P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

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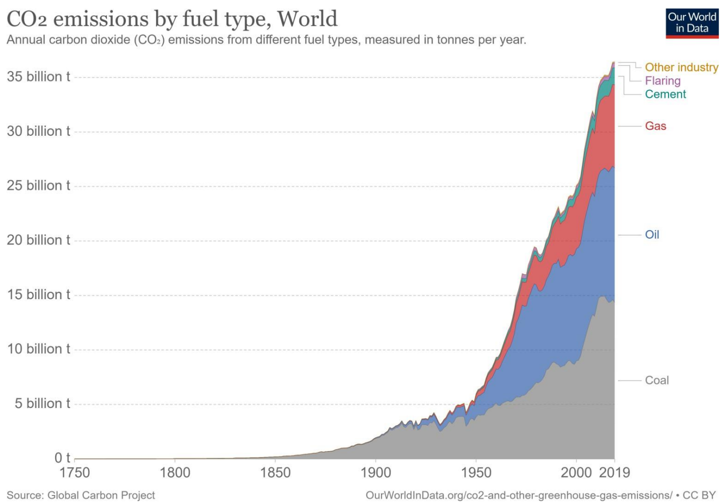
Source: IPCC, 2018: Summary for Policymakers. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3-24, doi:10.1017/9781009157940.001.

What solutions do we have ? Technologies



Many options available now in all sectors are estimated to offer substantial potential to reduce net emissions by 2030. Relative potentials and costs will vary across countries and in the longer term compared to 2030.

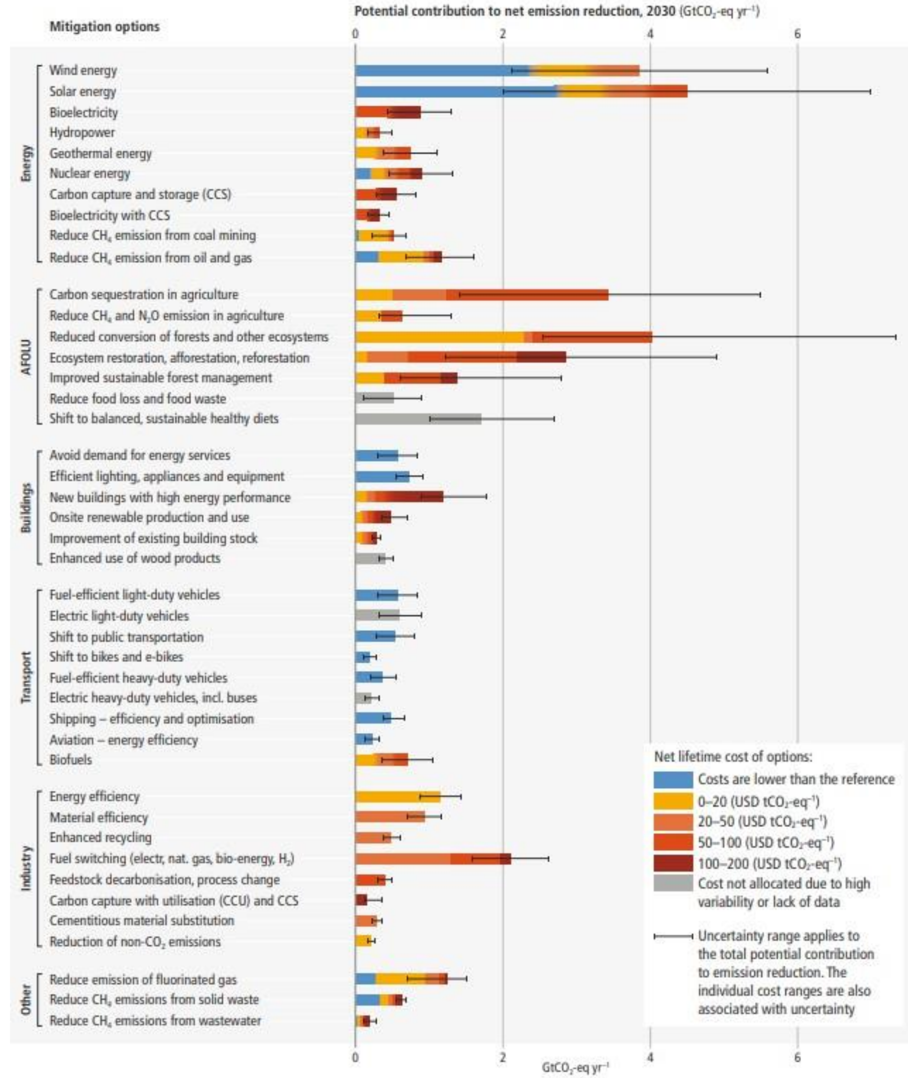


Figure SPM.7 | Overview of mitigation options and their estimated ranges of costs and potentials in 2030.

Source: IPCC, 2022: Summary for Policymakers. In: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.001.

What solutions do we have ? - Sufficiency

Sufficiency policies are a set of measures and daily practices that avoid demand for energy, materials, land and water while delivering human well-being for all within planetary boundaries.

ELSEVIER

Global Environmental Change
Volume 65, November 2020, 102168

Providing decent living with minimum energy: A global scenario

Joel Millward-Hopkins [a], Julia K. Steinberger [a b], Narasimha D. Rao [c d], Yannick Oswald [a]

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Highlights

- Providing Decent Living with Minimum Energy: A Global Scenario.
- As ecological breakdown looms, the basic material needs of billions remain unmet.
- We estimate the minimal energy for providing decent living globally & universally.
- Despite population growth, 2050 global energy use could be reduced to 1960 levels.
- This requires advanced technologies & reductions in demand to sufficiency levels.
- But 'sufficiency' is far more materially generous than many opponents often assume.

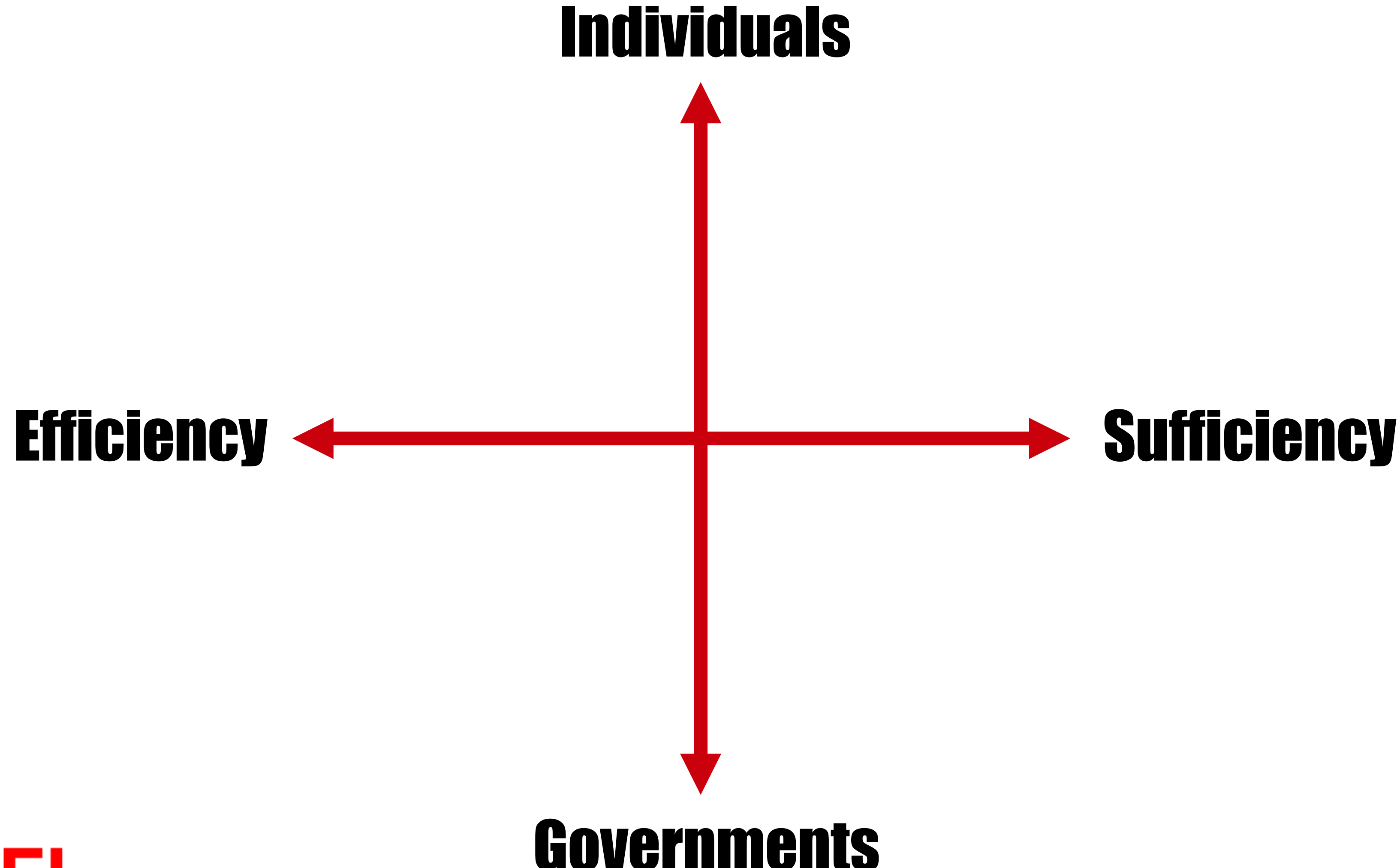
Table 1. . Inventory of the prerequisites for *Decent Living Standards* (DLS) (Rao and Min, 2018a) broken-down into key material requirements and services. The final column indicates where we implement regional variations in the model, and gives a brief explanation; the Supplementary Materials give full details.

DLS dimension	Material requirements and services	Regional variation
Nutrition	Food	Consumption varies with countries' age structures
	Cooking appliances	*None implemented*
	Cold Storage	*None implemented*
Shelter and living conditions	Sufficient housing space	*None implemented*
	Thermal comfort	Requirements vary with regional HDDs and CDDs
	Illumination	*None implemented*
Hygiene	Water supply	Intensity varies with water scarcity (higher scarcity→higher intensities)
	Water heating	Intensity varies with countries' average temperatures
	Waste management	*None implemented*
Clothing	Clothes	*None implemented*
	Washing facilities	*None implemented*
Healthcare	Hospitals	*None implemented*
Education	Schools	Requirements vary with age structures (more young people→more schools)
Comms' and information	Phones	Requirements vary with age structures (more children <10yo→less phones)
	Computers	*None implemented*
	Networks+data centres	*None implemented*
Mobility	Vehicle production	Activity levels and mode shares vary with countries' adjusted ('lived') population densities (higher densities→lower activity levels)
	Vehicle's propulsion	
	Transport infrastructure	

EPFL

Source: Millward-Hopkins, J., Steinberger, J. K., Rao, N. D., & Oswald, Y. (2020). Providing decent living with minimum energy: A global scenario. *Global Environmental Change*, *65*, 102168.

Who has to do something about it ?
How to do it ?
Give me some solutions ?



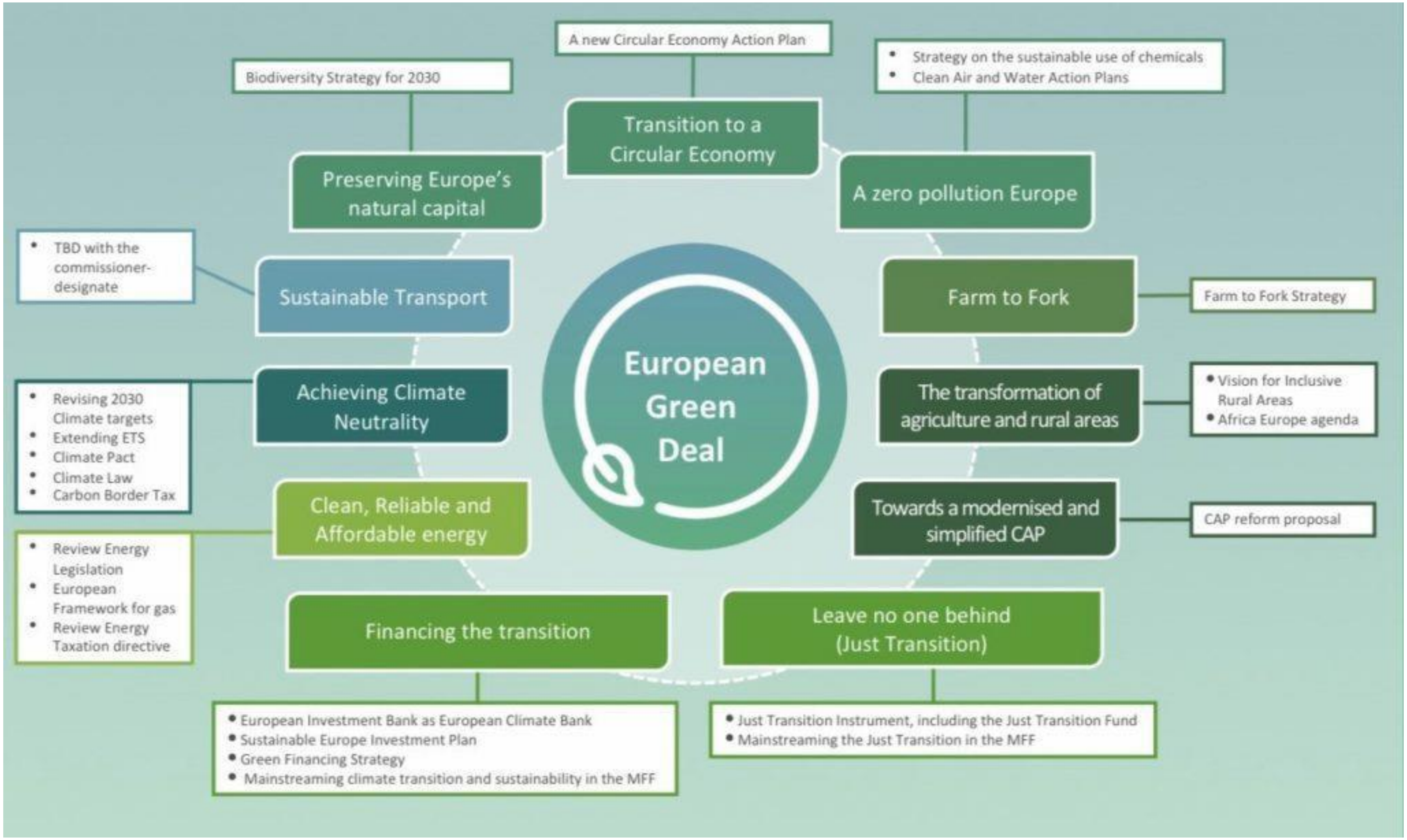
What is happening ? Paris agreement (2015)

SDGs (2030)

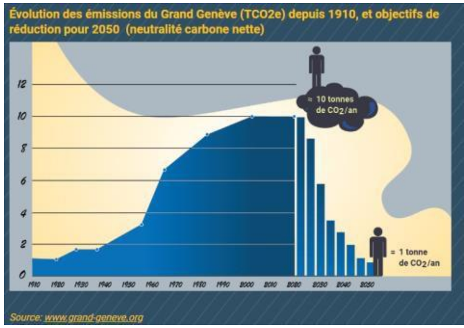

1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS
THE GLOBAL GOALS
For Sustainable Development

Green New Deal

EU Green New Deal



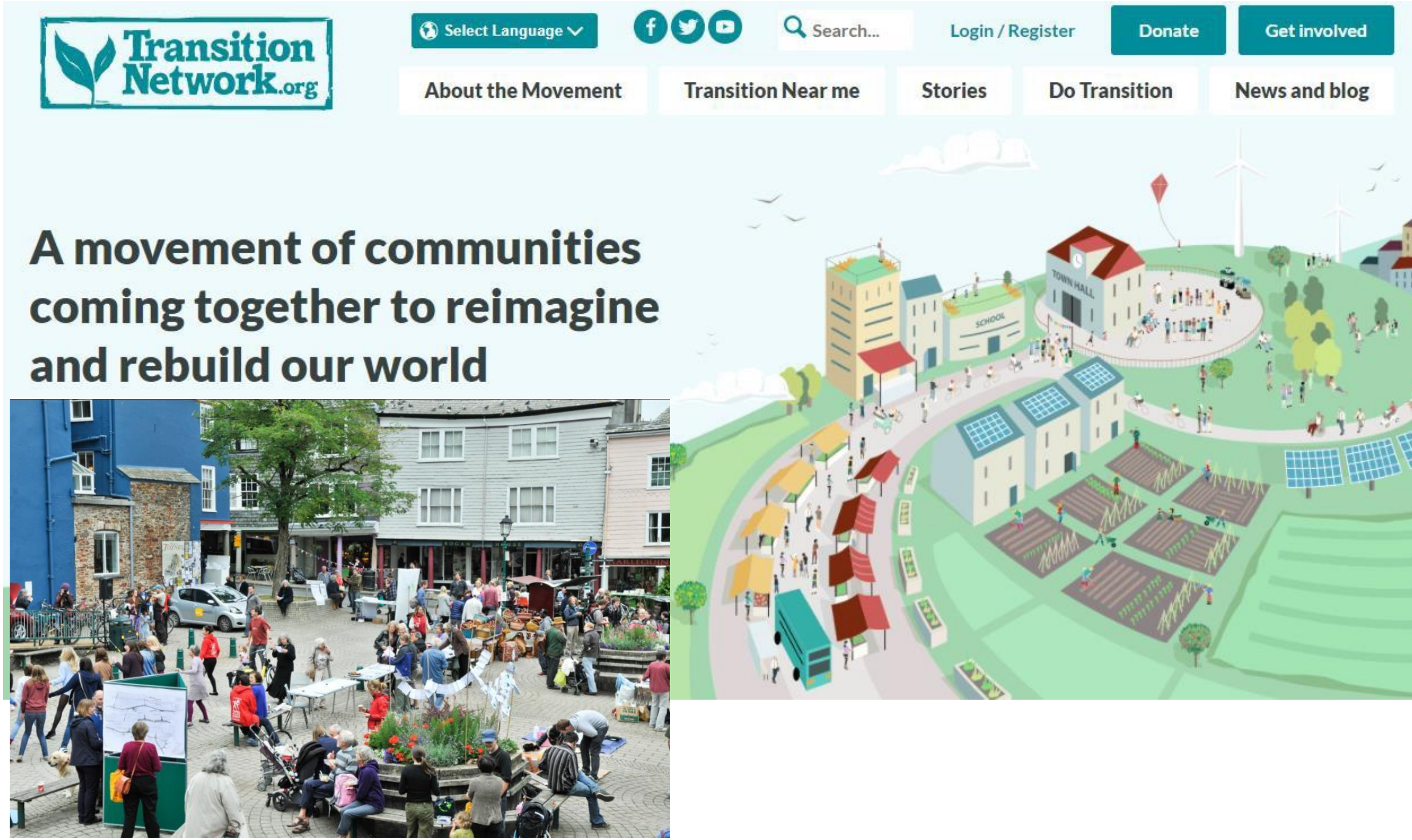
Examples at a city level (Lausanne climat)



Source: https://www.ge.ch/teaser/plan-climat-cantonal-geneve-2030/plan-climat

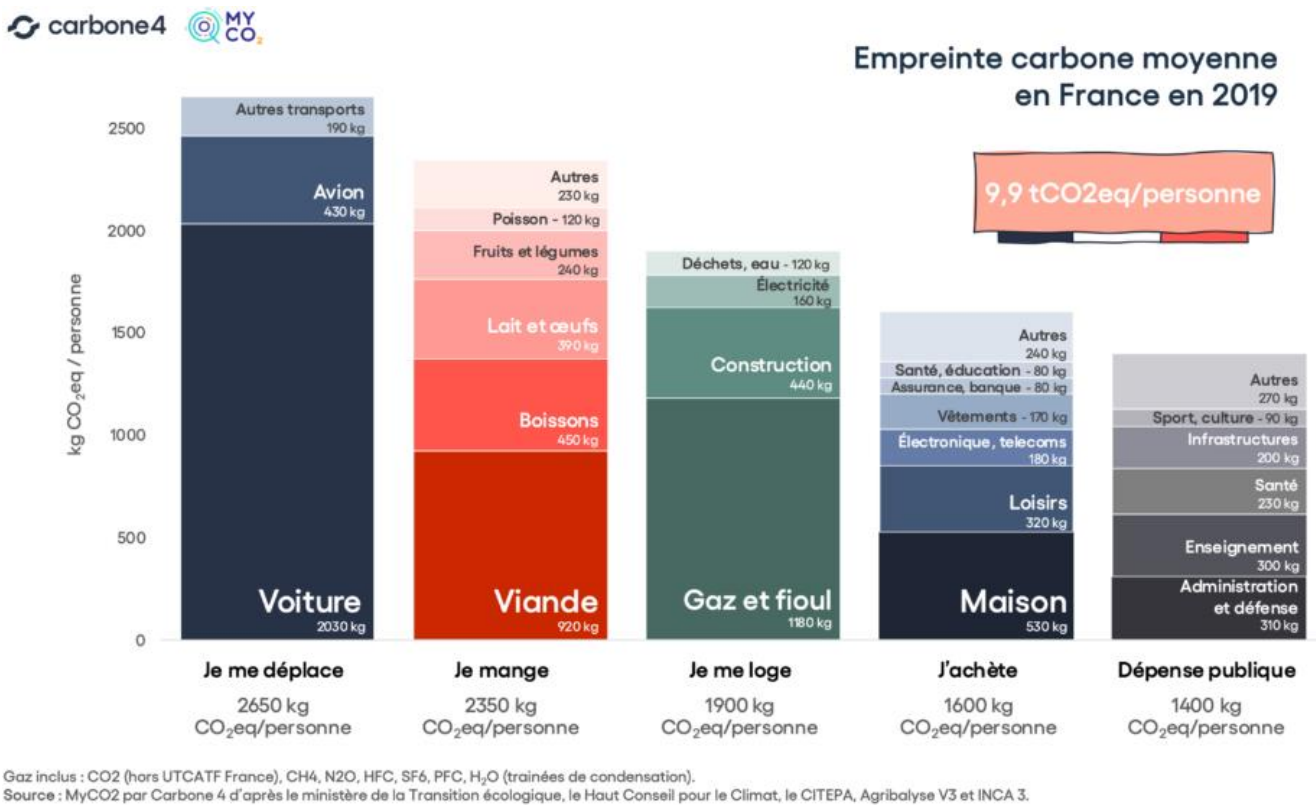
Source: https://www.ge.ch/document/24973/telecharger

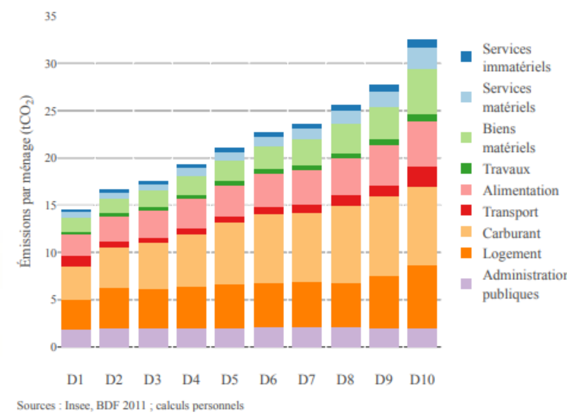
Examples at a city level (Transition Towns)



https://transitionnetwork.org/

Everyday choices – what can you cut off?





Source: https://bonpote.com/comment-calculer-son-empreinte-carbone/

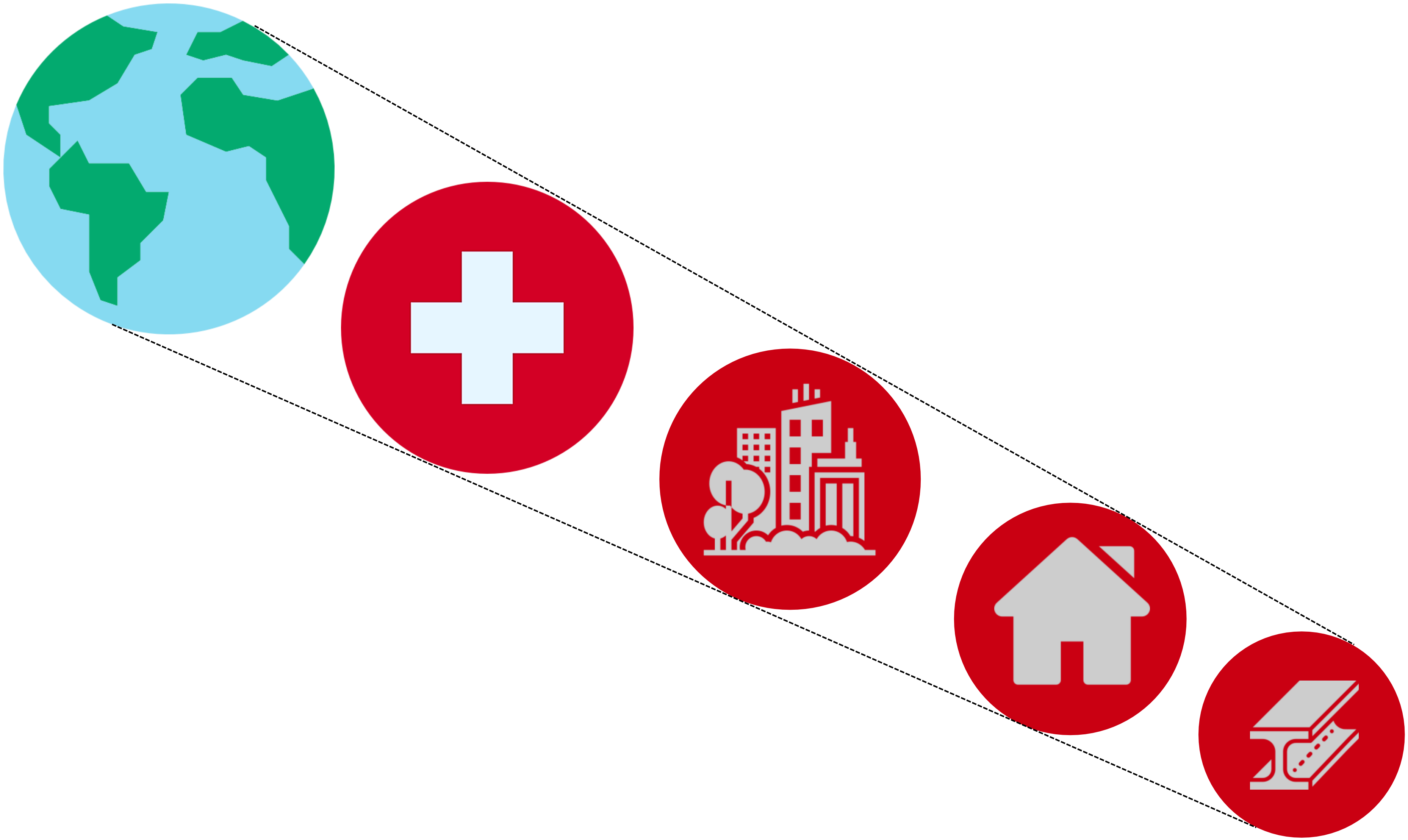
Source: Pottier, A., Combet, E., Cayla, J. M., de Lauretis, S., & Nadaud, F. (2020). Qui émet du CO2? Panorama critique des inégalités écologiques en France. *Revue de l'OFCE*, *169*(5), 73-132.

Where to now? Let's vote

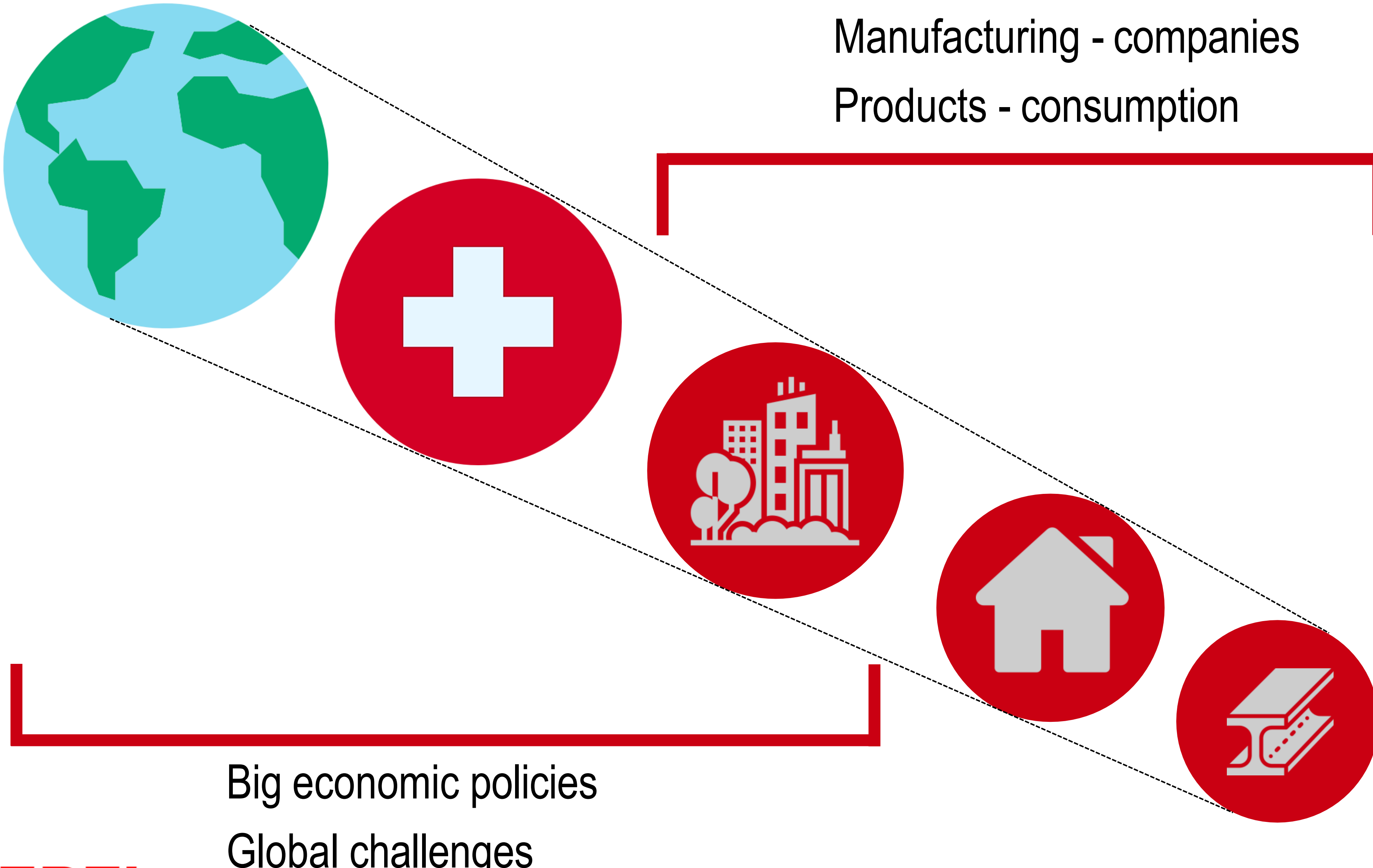
- Degrowth
- Technological fix
- Policy vs everyday choices

	Degrowth	Technofix
Individual	A	B
Policy	C	D

Link from Planet to Product

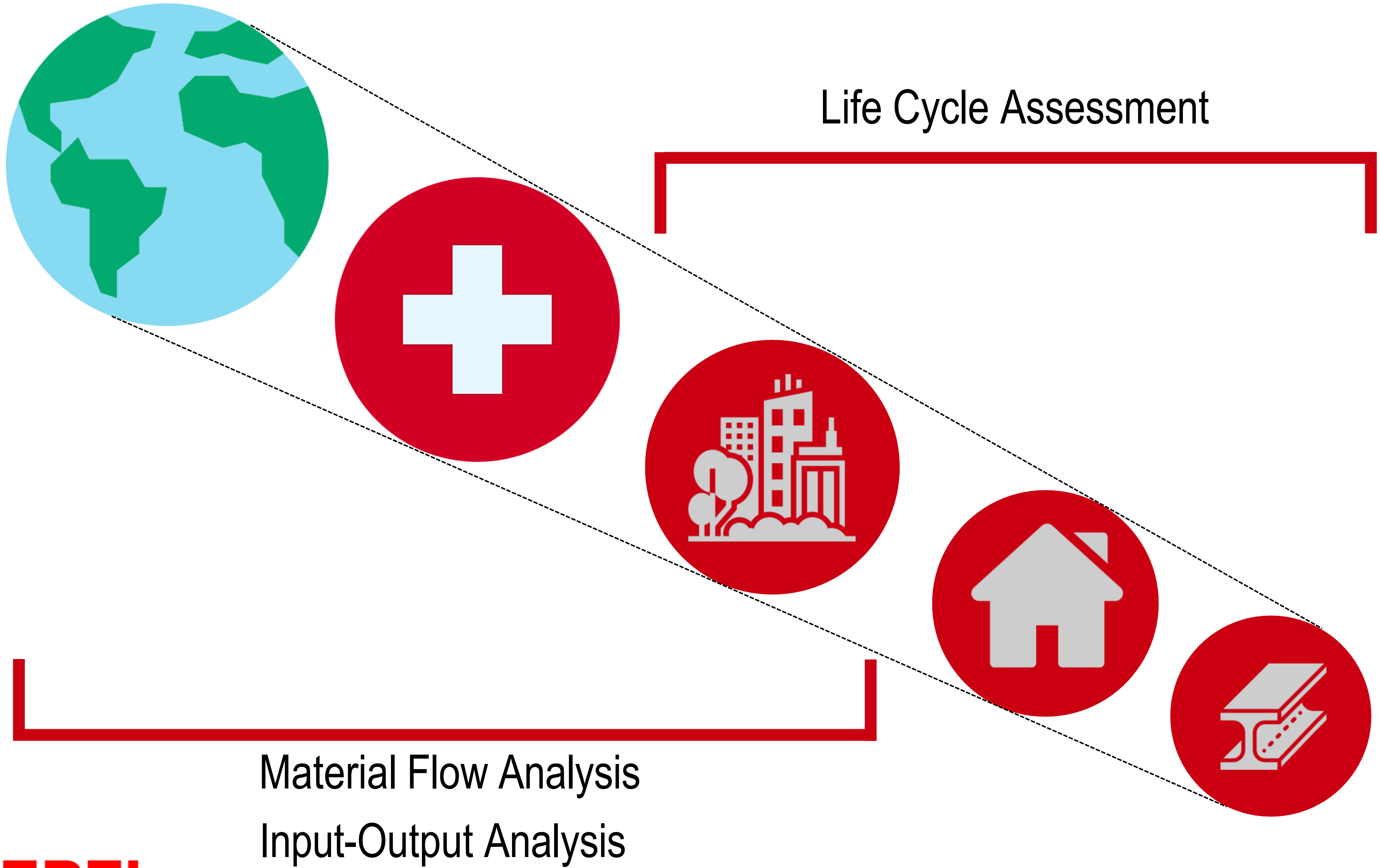


Link from Planet to Product – what systemic vantage point?



EPFL

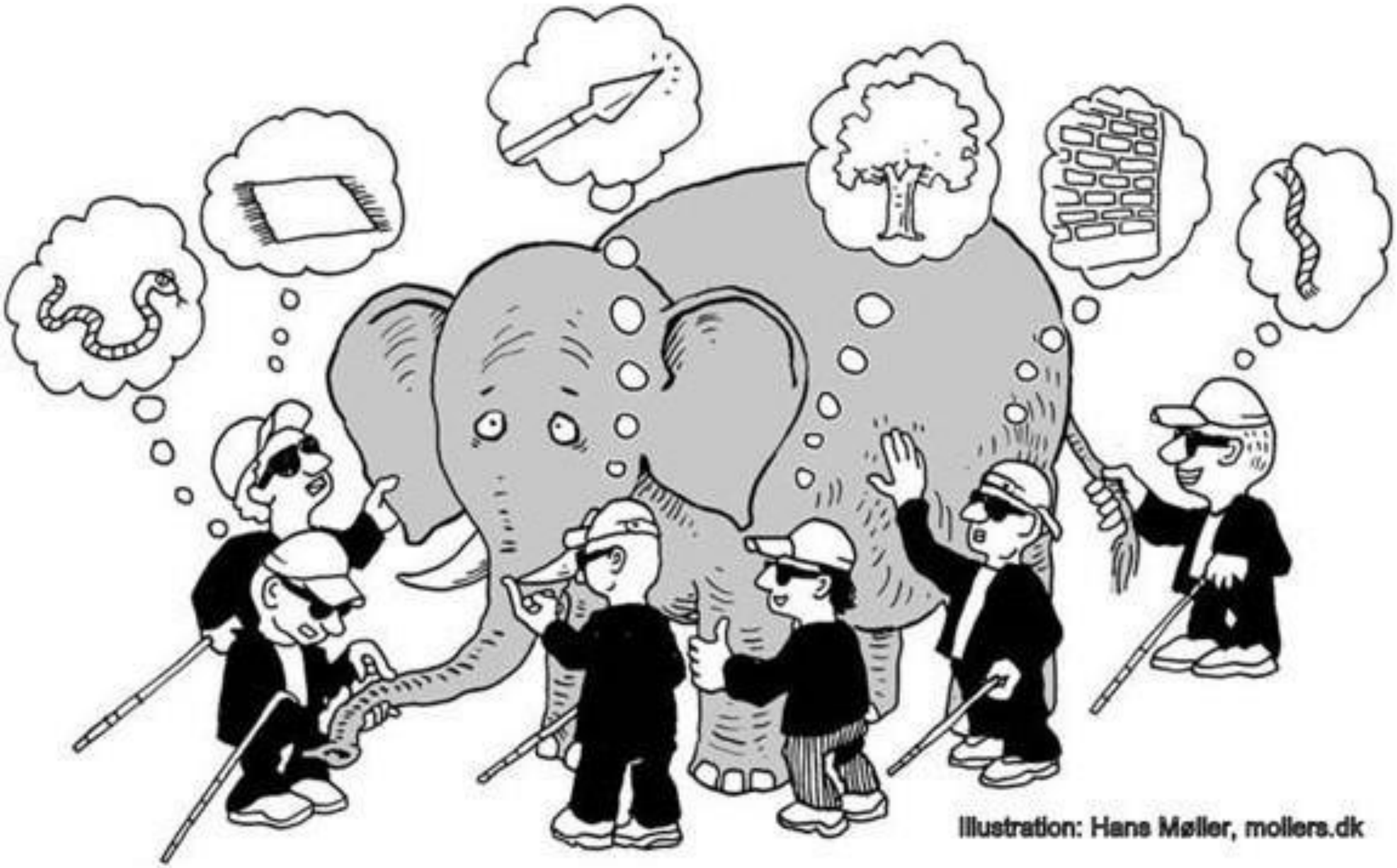
Link from Planet to Product – accounting methods



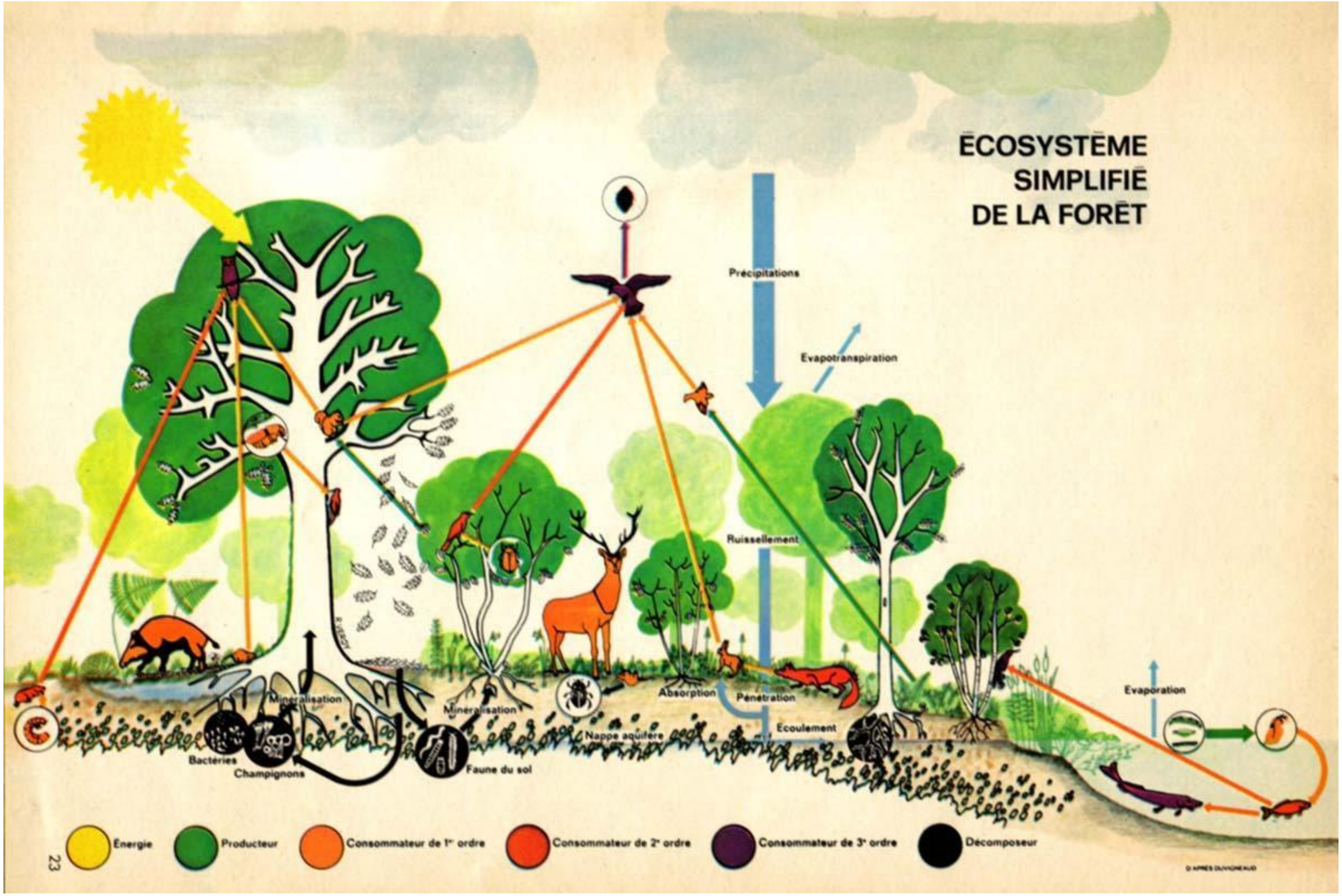
Systems thinking

What is a system?

The elephant and the blind men – what is a system?



What is a system?



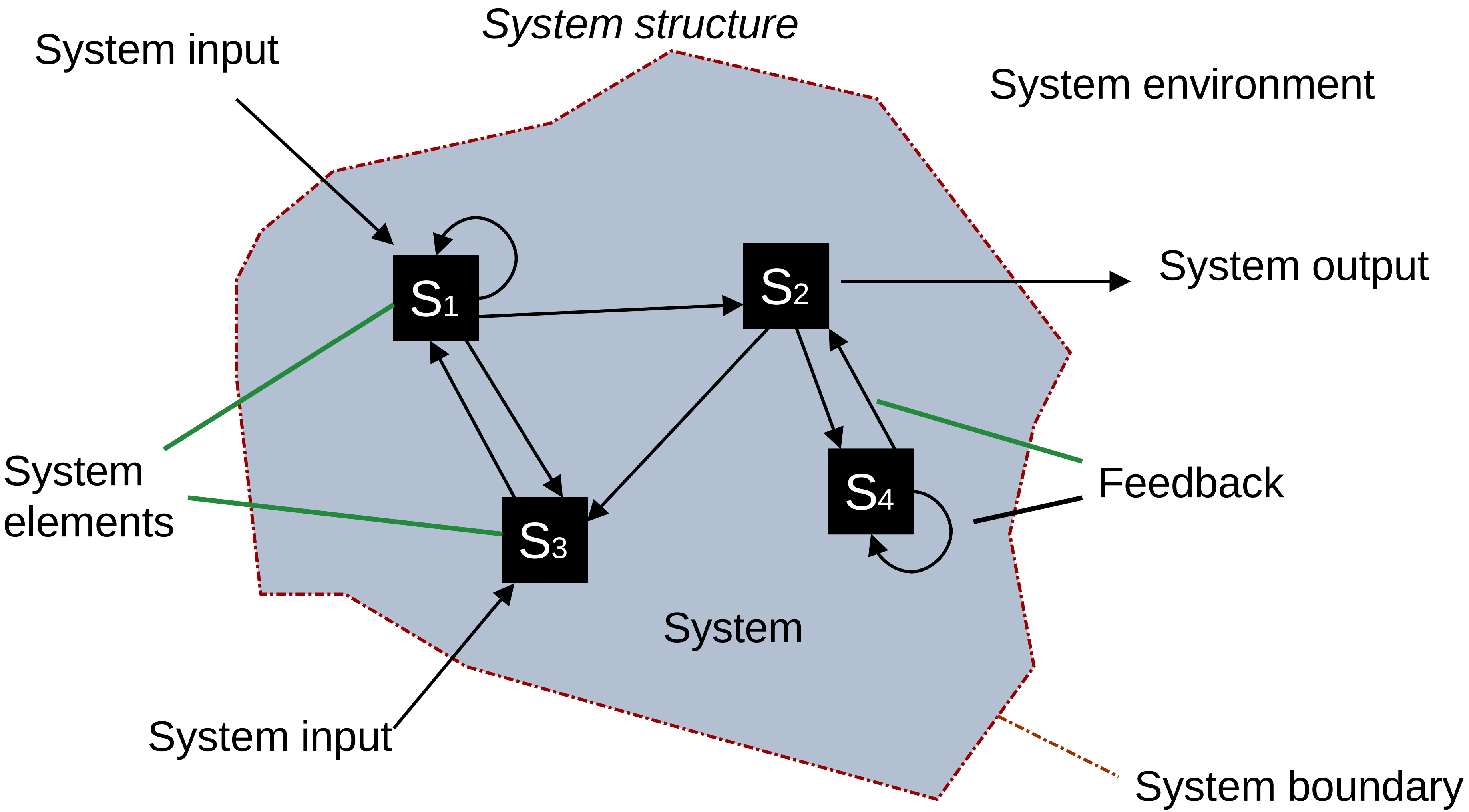
Duvigneaud, P. (1974). *A synthesis of ecology: populations, communities, ecosystems, biosphere and noosphere*. Doin, editeurs..

What is a system?

A ***system*** is anything that is composed of system ***elements*** connected in a characteristic system ***structure***. This configuration of system elements allows it to perform specific system ***functions*** in its system ***environment***.

These functions can be interpreted as serving a distinct system ***purpose***. The system ***boundary*** is permeable for ***inputs*** from and ***outputs*** to the environment. It defines the system's ***identity*** and ***autonomy***. (Bossel, 1999)

What is a system? Elements, interrelations, system boundaries



After Bossel, 2004; Mrotzek, 2009

What is a system? System boundary

- Defines what is inside of the system to be analysed and what belongs to the system context
- Defines inputs and outputs of the system
- Elements of a system boundary: space and time.

What is a system? The role of system boundaries

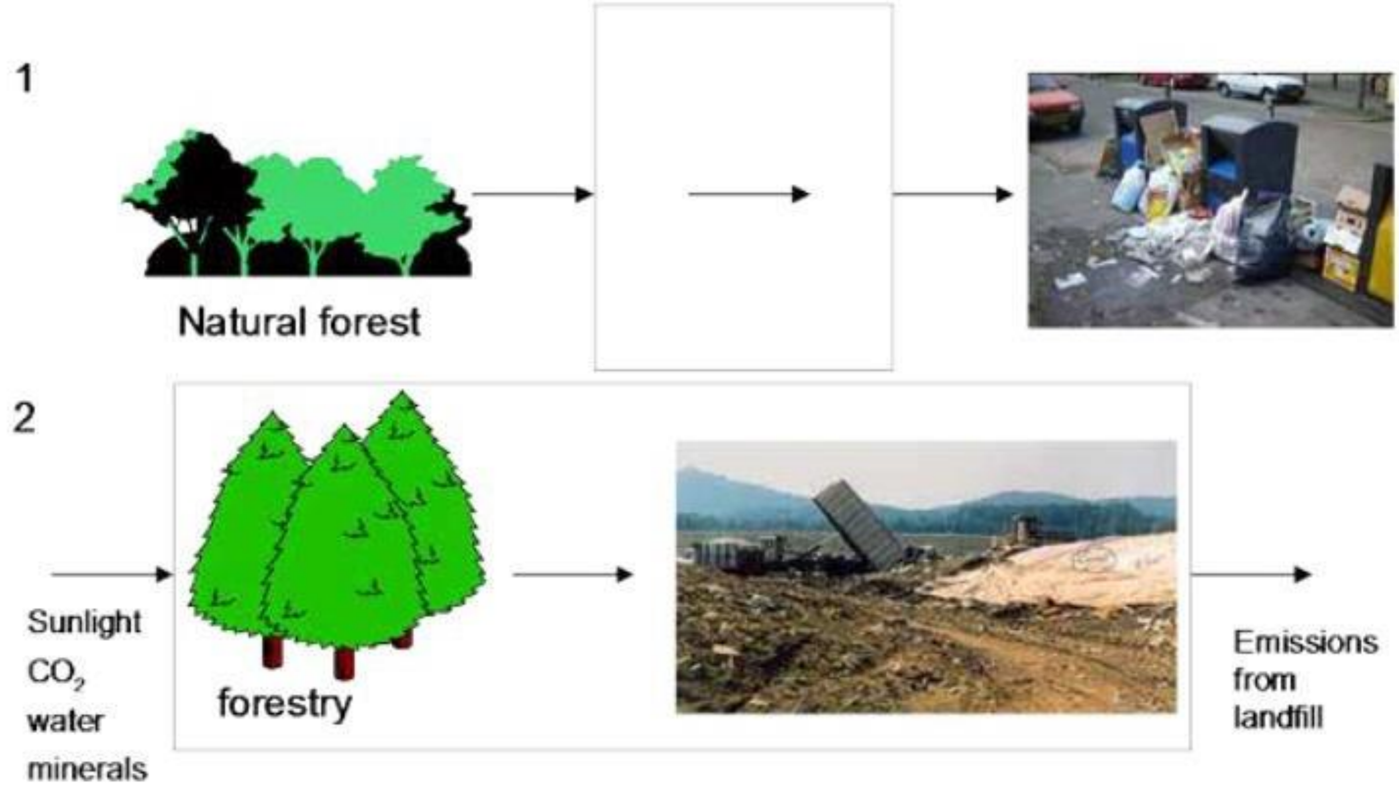
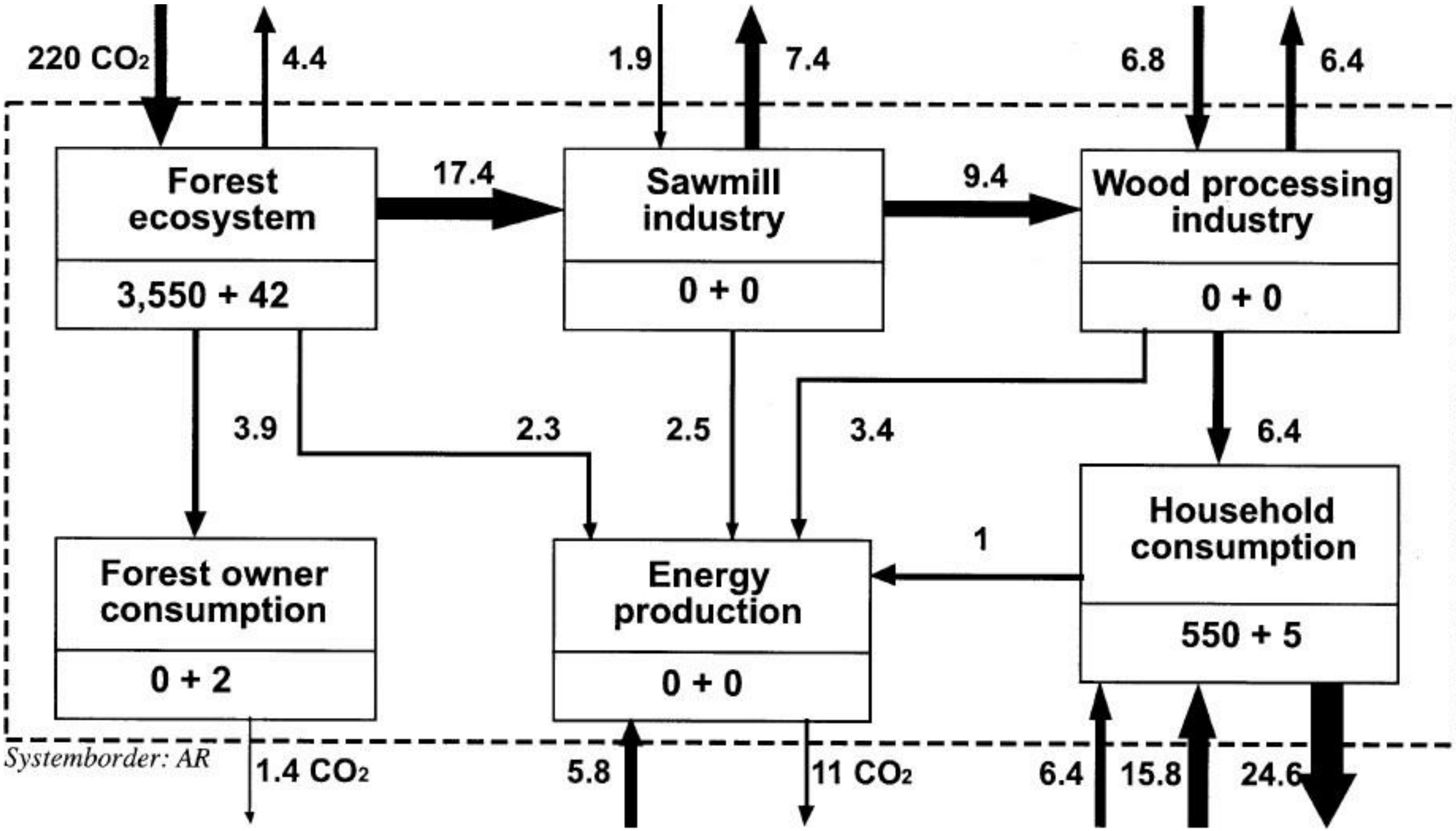


Figure 2 : Two ways of defining system boundaries between physical economy and environment in LCA; a) with narrow system boundaries, b) with extended boundaries.

Jeroen B. Guinée, 2001

Example – The wood flow in Appenzell Ausserhoden

Stock in 1000 m_3; wood flow in 1000 m_3 wood/year; CO_2 flow in 1000 t CO_2



Binder et al., 2004

System purpose – Function of systems

What are some functions of systems ?

System purpose – Function of systems

- Self-preservation (biological and social systems)
- Conservation of a stable state (body temperature)
- Reproduction and multiplication (biol. und social systems)
- Security and shelter (ABS, airbag)
- Production (brewery ➔ beer)
- Provision of housing
- Provision of services (health, communication, transport, etc.)

System structure – elements / interrelations

- **Structure:** Internal composition and interrelations within a system
  - subsystems and their hierarchy;
  - specific system elements and their characteristics (types, diversity, parsimony, sufficiency);
  - the relation or interaction between the system elements (connectivity, feedbacks).

- **Dynamics:** Development over time

The dynamics of a system are determined primarily by its (static) structure.

„Structure determines dynamics“

Examples: „arguing couple“, arms race

System dynamics – Causal loops (i)

Conceptual representation by means of **Causal Loop Diagrams (CLD)**

- CLDs are used to depict **causal relations** in systems
- CLDs help **revealing feedback** in systems
- The CLD notation is a tool to **communicate** complex system structures.
- A CLD may be **drawn before model implementation** to get acquainted with the system.
- The CLD can be **derived from a Stock and Flow model** to reveal feedback not apparent from the Stock and Flow structure.

System dynamics – Causal loops (ii)

- The arrows in a causal loop diagram are label + or – depending on whether the causal influence is positive or negative!

- Two variables change in the **same direction** – positive polarity

Number of Births —(+)→ Population

- Two variables change in the **opposite direction** – negative polarity

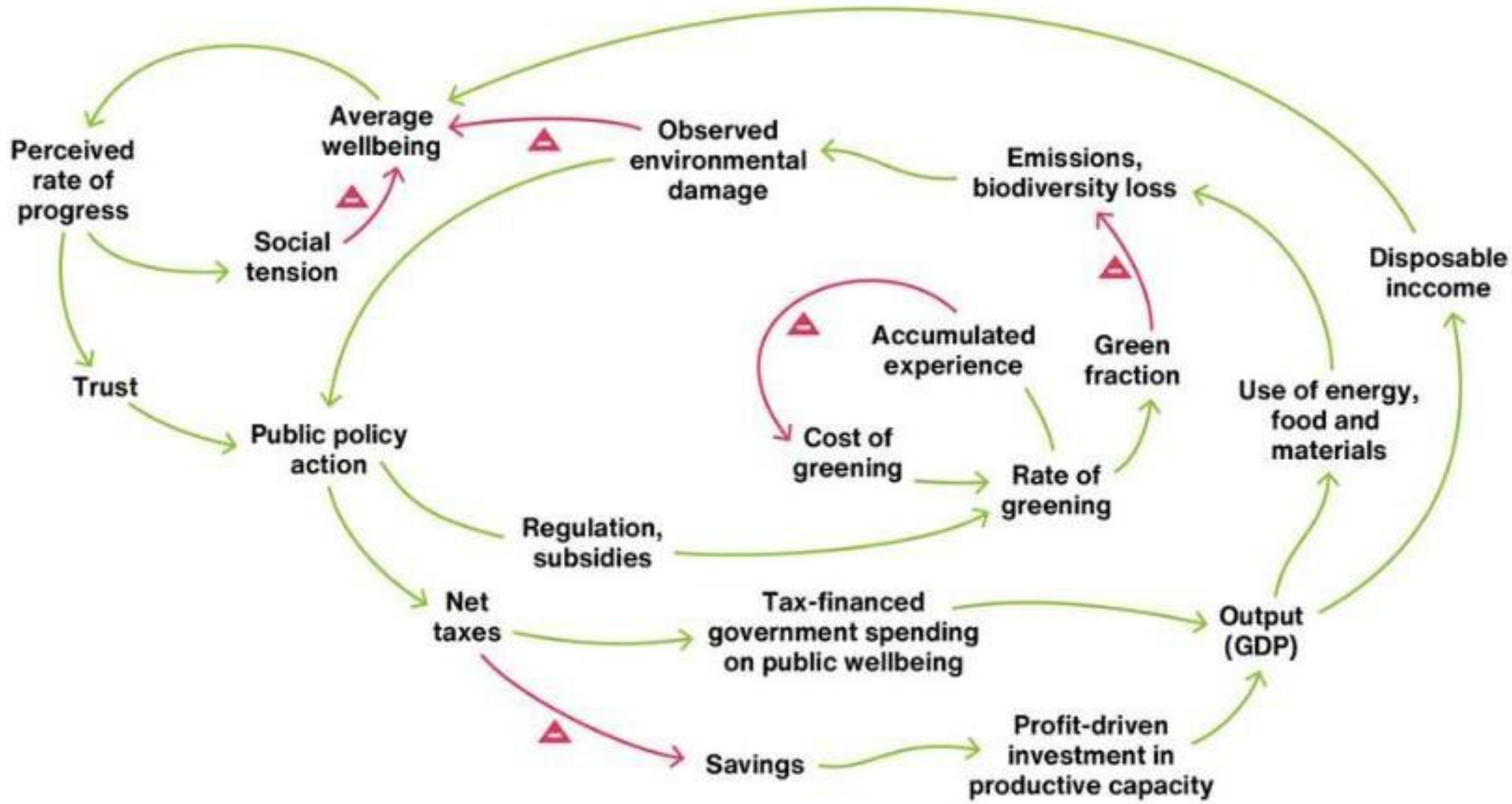
Number of fatalities —(-)→ Population

System dynamics – Causal loops (iii)

Positive Feedback (enforcing feedback):
Feedback is positive, if a loop consists of causalities with positive polarity only or an even number of negative polarities

Negative Feedback (balancing feedback):
Feedback is negative, if a loop consist of an uneven number of negative causal relations.

System dynamics – Causal loops diagram example



Source: Pagani et al., 2020

Source: https://www.earth4all.life/the-science

Systems science

Systems science

System sciences focus on interrelations and feedbacks within systems

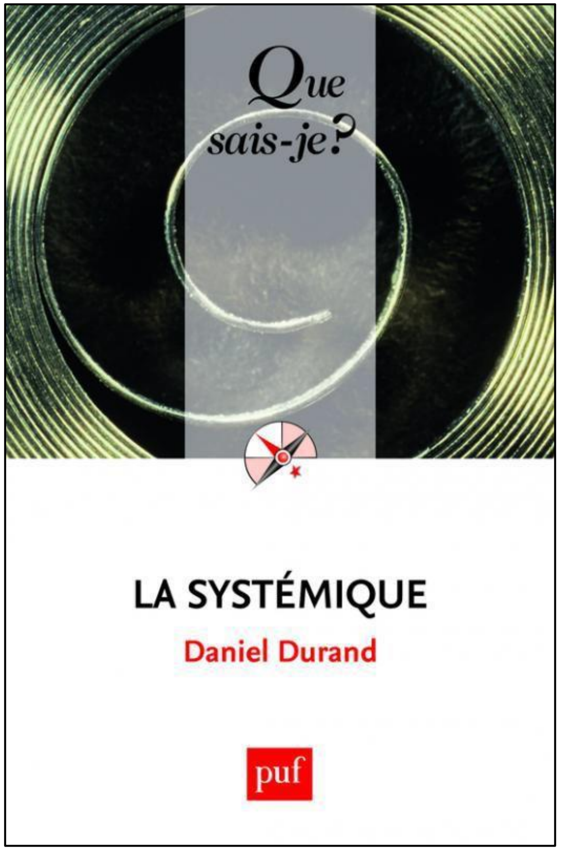
Goals:

- Understanding the dynamics of systems
- Insights into future developments / simulations
- Management approaches

Principle:

„The whole is more than the sum of its parts.“

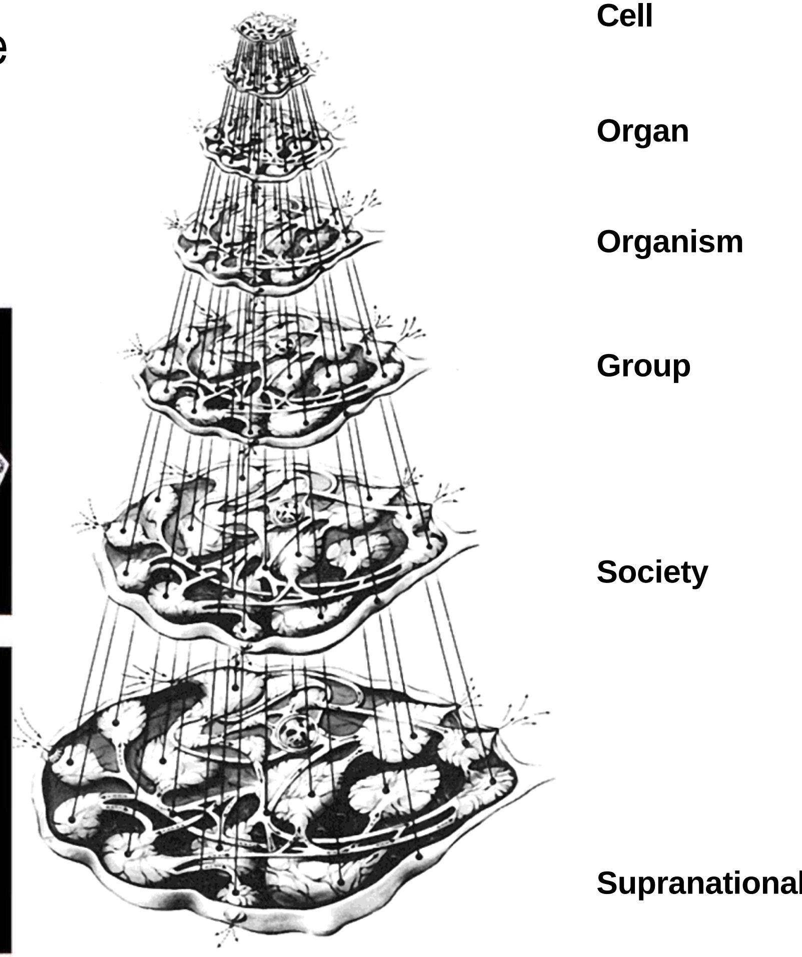
Aristoteles (384-322 v. Chr.)



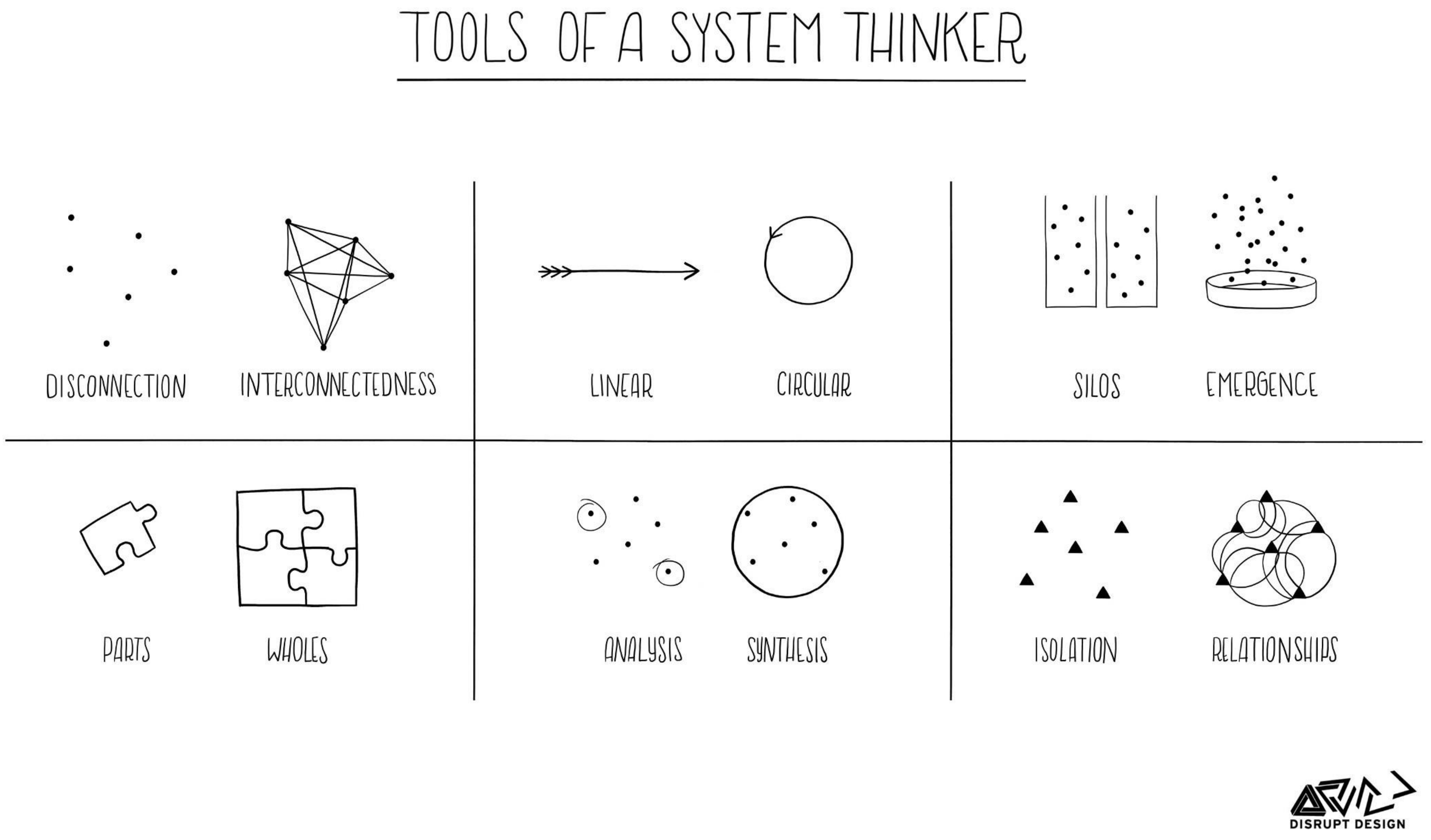
Systems science : Emergence

In philosophy, systems theory, science, and art, **emergence** occurs when an entity is observed to have **properties its parts do not have on their own**, properties or behaviors which emerge only when the parts interact in a wider whole (Wikipedia, 2021).

https://en.wikipedia.org/wiki/Emergence#/media/File:SnowflakesWilsonBentley.jpg

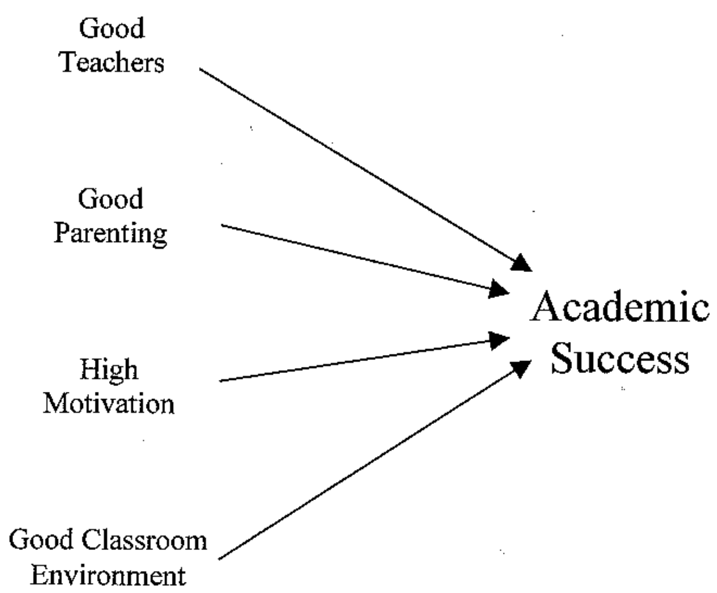


Systems science: analytical vs systems thinking

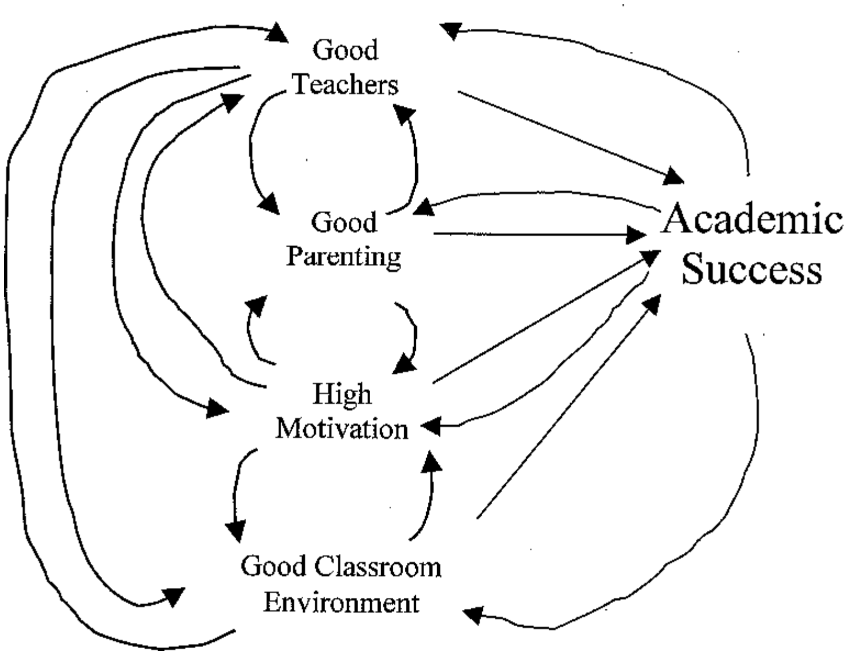


Why is systems view useful?

Systems thinking



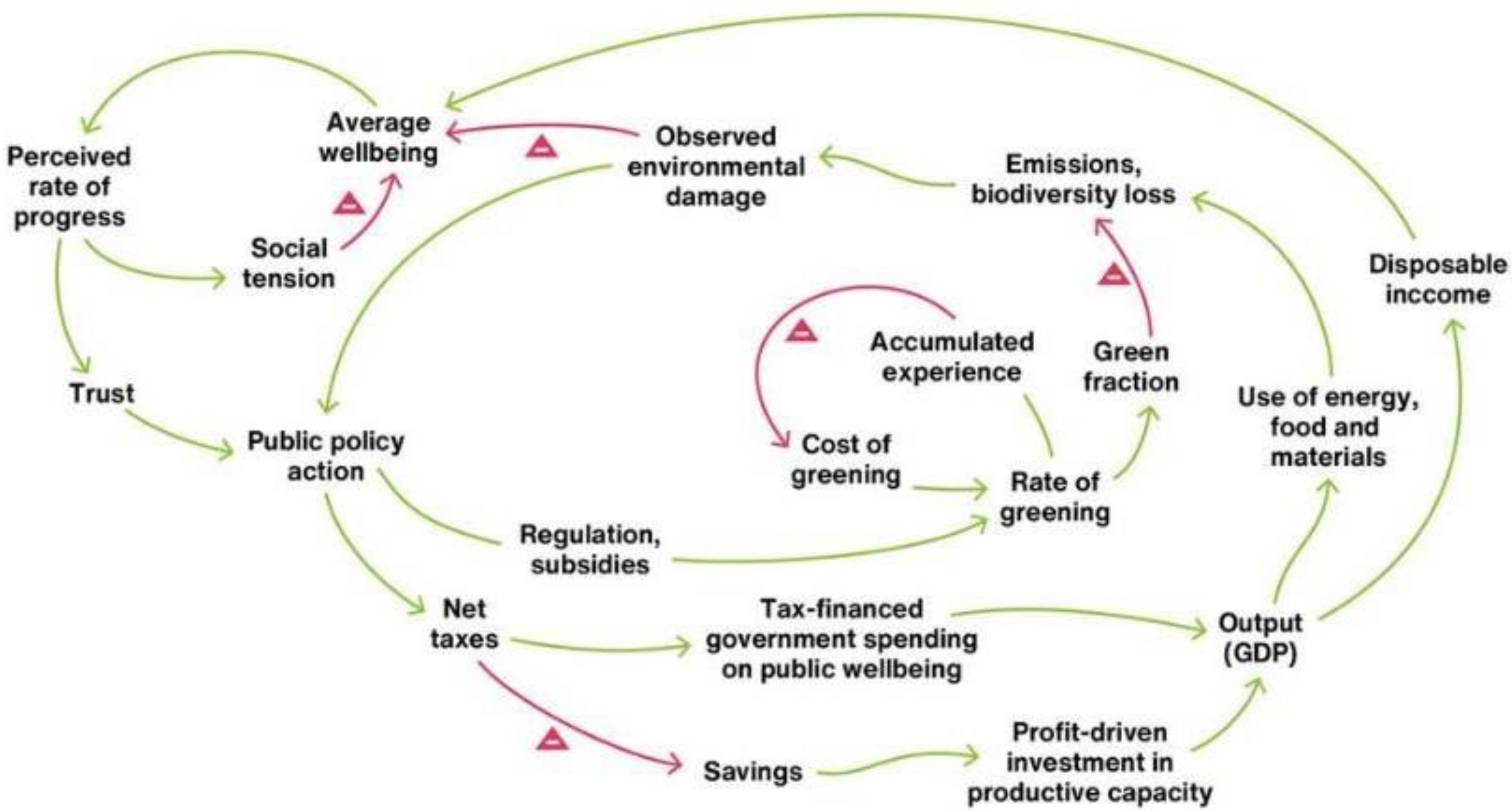
Descriptive View



Explanatory System View

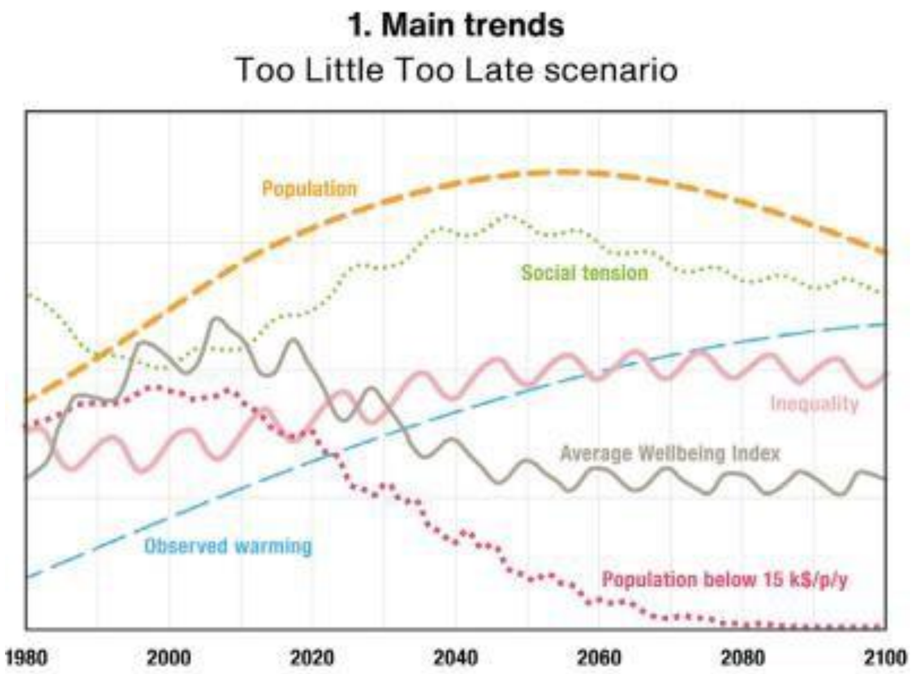
Source: Richmond, 2001

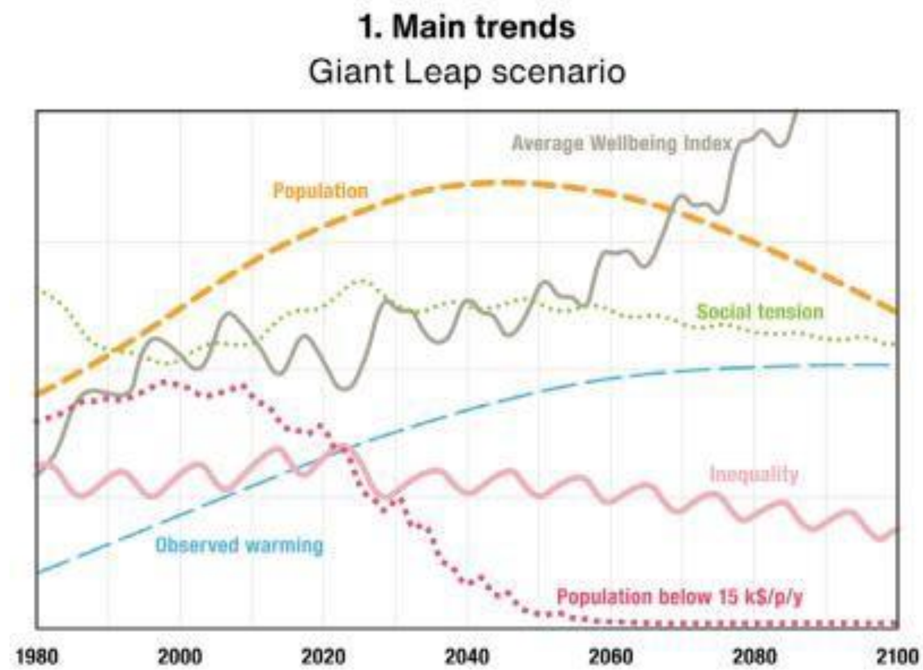
From Causal Loop Diagram …



Source: https://www.earth4all.life/the-science

... to Scenario making





- **Too Little Too Late** – a scenario that explores what if economic policy continues in the same track it has for the last forty years.
- **Giant Leap** – a scenario that explores what if societies make extraordinary decisions and invest in building more resilient societies? What will valuing our collective future look like? Can societies enhance social cohesion and strengthen democracies to reduce vulnerability to shocks and provide wellbeing for the majority on a planet under enormous pressure?

Course organisation

Aim of the course (I)

- Analyser un produit ou nu service avec l'ACV
- Calculer les impacts environnementaux d'un produit
- Anticiper les évolutions réglementaires en environnement
- Optimiser les performances environnementales des produits
- Critiquer une étude existante
- Elaborer des stratégies holistiques pour boucler les flux de matière
- Critiquer les stratégies et plans environnementaux des villes et pays
- Analyser les flux de ressources et de déchets

Aim of the course (II)

- Planifier des actions et les mener à bien de façon à faire un usage optimal du temps et des ressources à disposition.
- Recevoir du feedback (une critique) et y répondre de manière appropriée.
- Ecrire un rapport scientifique ou technique.
- Utiliser les outils informatiques courants ainsi que ceux spécifiques à leur discipline.
- Etre responsable des impacts environnementaux de ses actions et décisions.

Course evaluation

- Projet (examen écrit) – 60% de la note
  - System analysis : 1h
  - ACV : 1h – 15 à 18 questions rapides sur des points clés de l'ACV

- Evaluation projet ACV– 40% de la note

Projet à 2 ou 3 étudiants : Evaluation ACV d'un système photovoltaïque intégré à des bâtiments. Evaluation avec un rapport (15 pages maximum hors annexes) + Pitch 3 min

Partie Analyse du Cycle de Vie

Cours théorique et mise en application pratique

ACV d'un système photovoltaïque intégré à des bâtiments (BIPV)

- Etudiants par groupe de 2 ou 3
- Choix d'un système photovoltaïque (libre)
- Collecte des données
- Réaliser l'ACV simplifiée de ce système
- Rapport d'ACV (15 pages maximum hors annexes) + 1pitch (3 minutes) présentant le produit BIPV, la méthode et les résultats obtenus
- Evaluation 40% note totale (moitié rapport et moitié pitch)

Course references

- Analyse du cycle de vie - Comprendre et réaliser un écobilan O. Jolliet, M. Saadé, P. Crettaz, Presses Polytechniques et Universitaires Romandes, 2005
- Brunner P. H., Rechberger, H. 2016, Practical handbook of material flow analysis, Lewis Publishers
- Baccini, P. and P. H. Brunner 2012, Metabolism of the Anthroposphere: Analysis, Evaluation, Design, MIT Press
- Ferrão, P. and J. E. Fernández, 2013. Sustainable urban metabolism, Cambridge (MA): MIT Press.
- Circular Metabolism Podcast (iTunes, Youtube, Spotify, Stitcher)