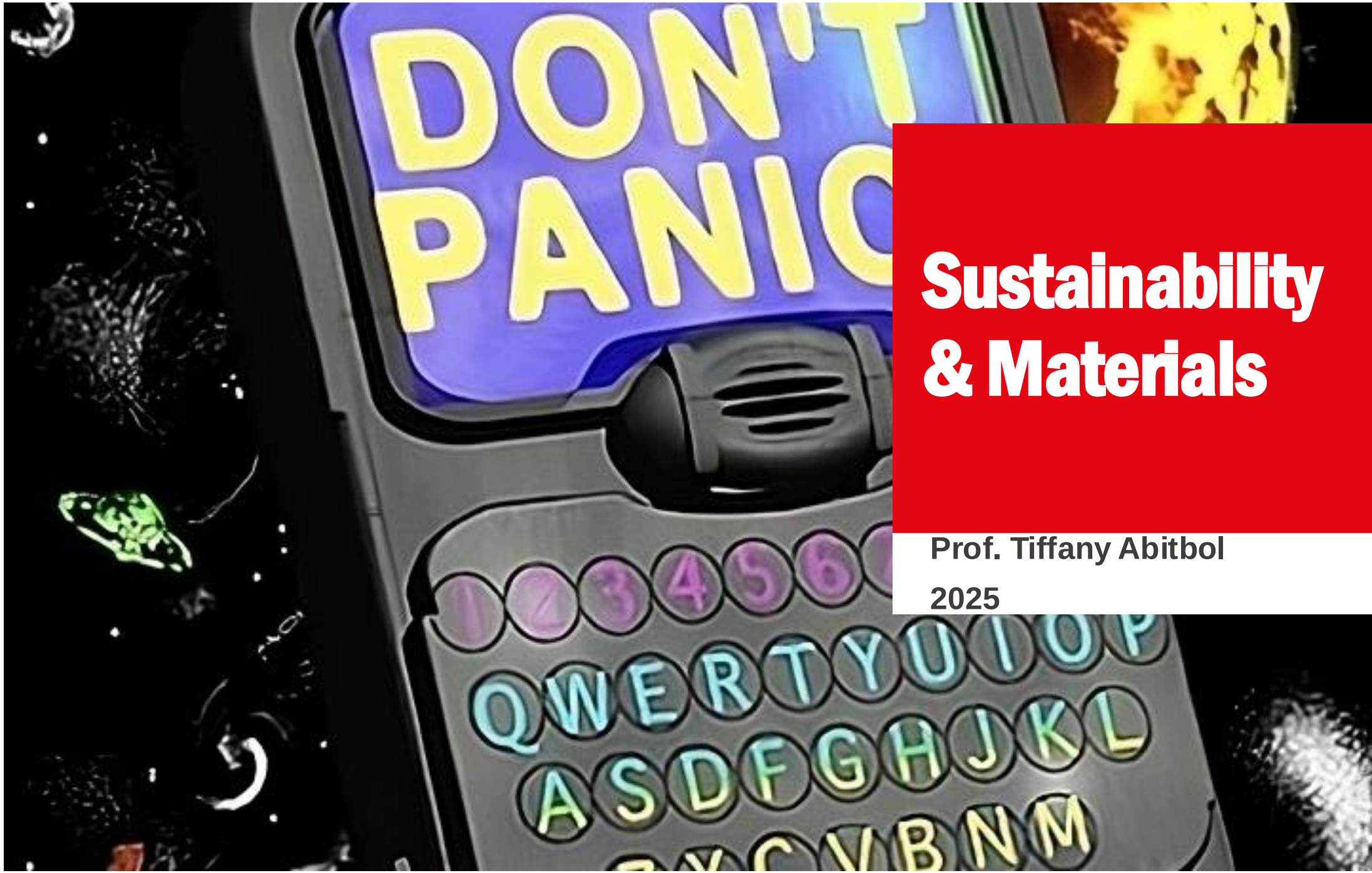


Sustainability & Materials

Prof. Tiffany Abitbol

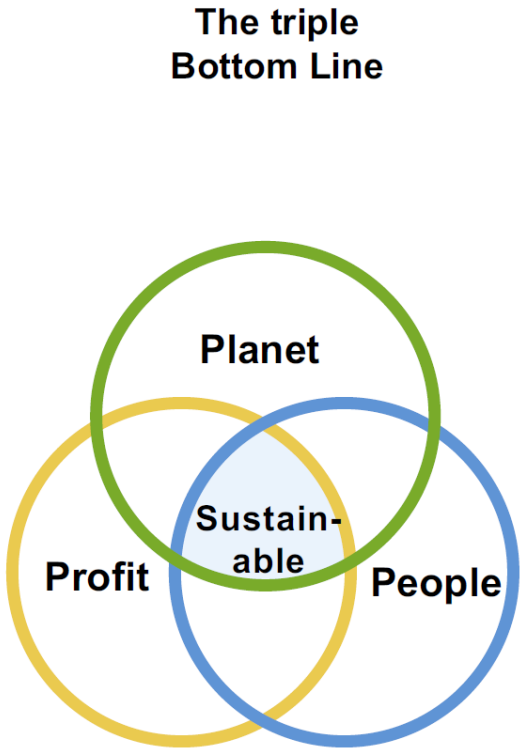
2025

Sustainable development

- According to the Brundtland Report, sustainable development "**is development that meets the needs of today without compromising the ability of future generations to meet their own needs**."

http://netzwerk-n.org/wp-content/uploads/2017/04/0_Brundtland_Report-1987-Our_Common_Future.pdf.

Intersection of 3 pillars

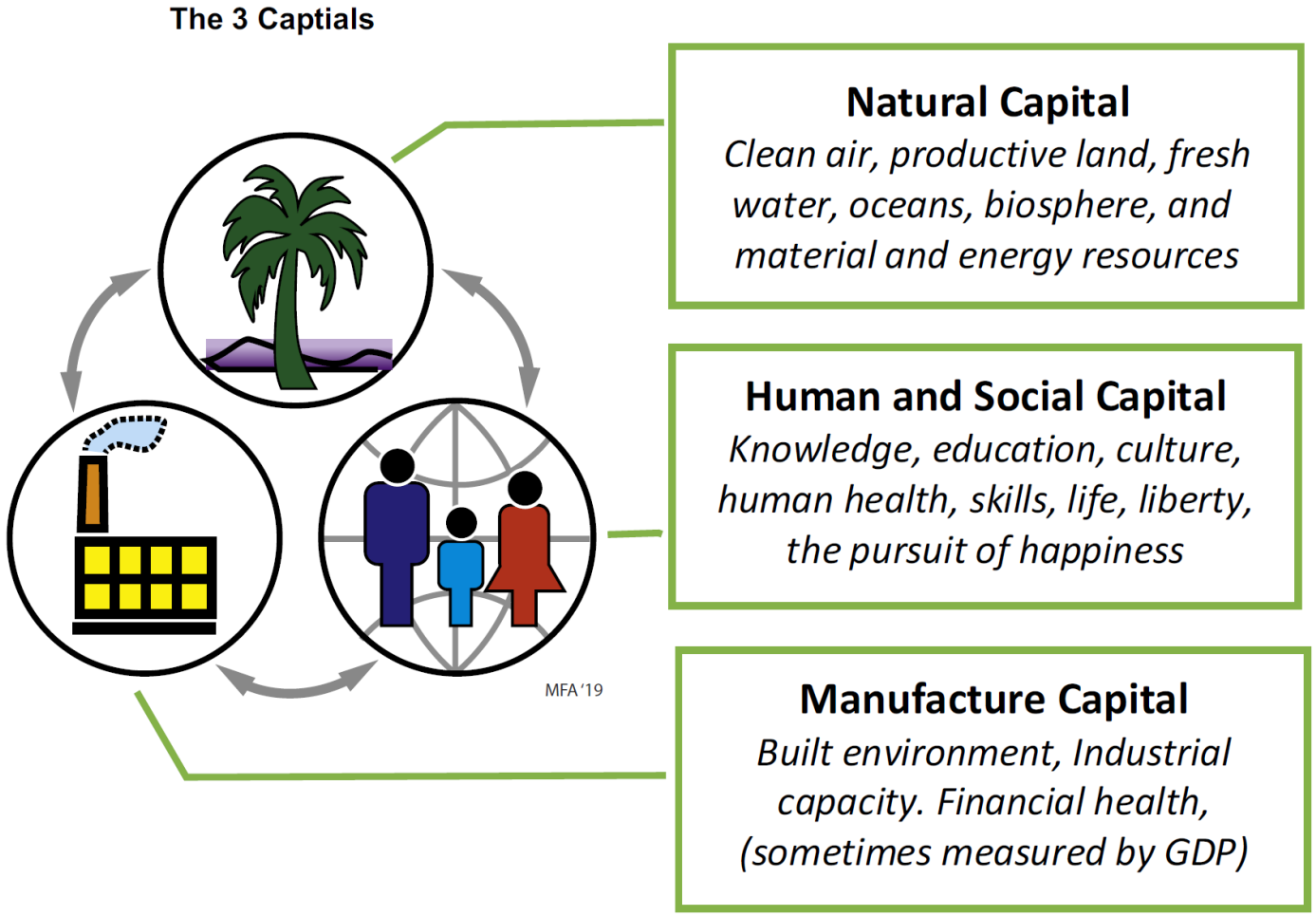


- If planet & people – *bearable* living conditions until money runs out
- If people & profit – *equitable* until environment degrades
- If planet & profit – *viable* until social unrest

- Intersection of *3 pillars* required for sustainable living conditions – need all 3!

From: Materials and the Environment by Michael F. Ashby, 2020, Chapter 14, p. 344 + 345.

Three capitals

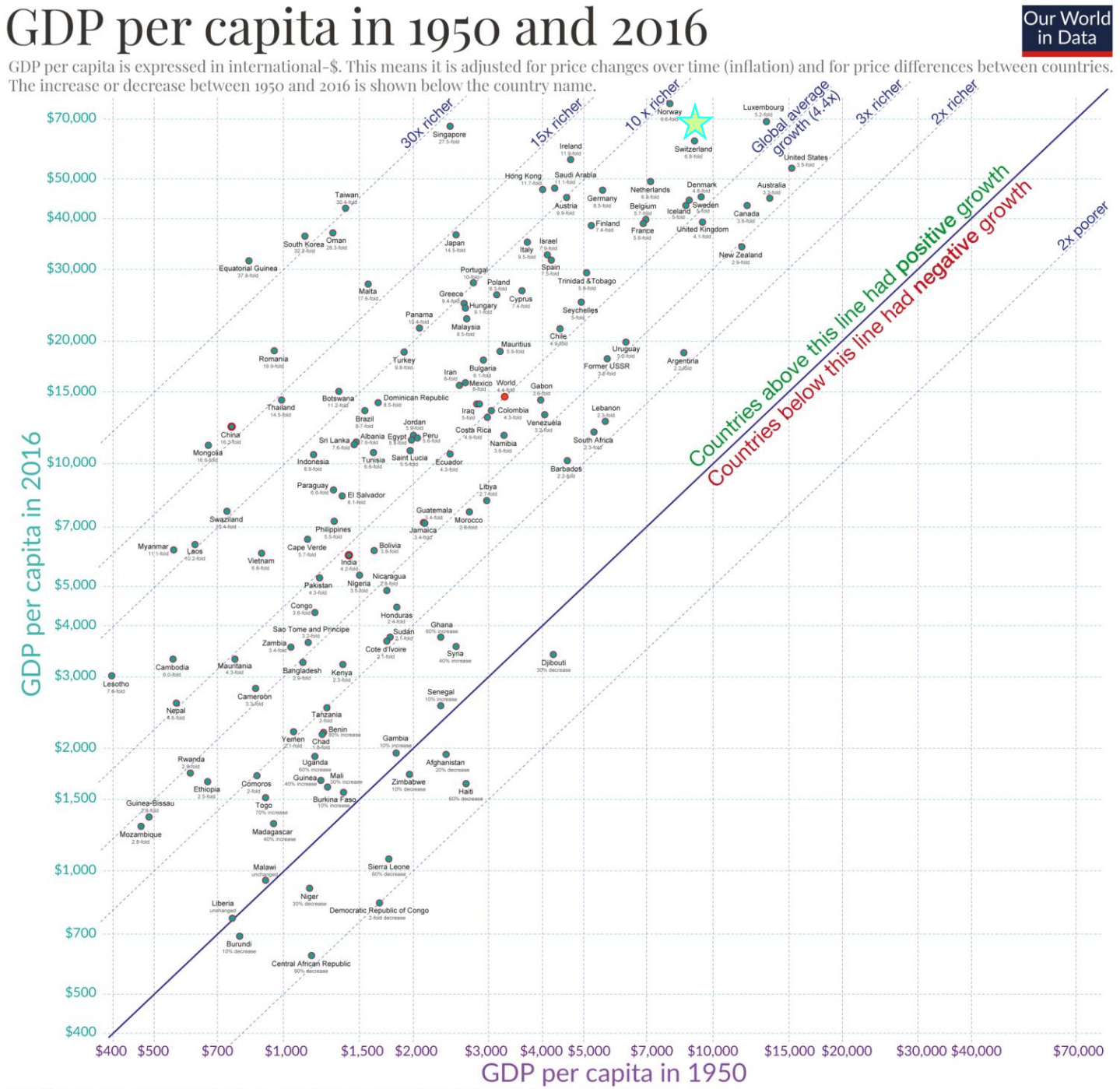


- Sustainability through an economic lens
- Global or national "wealth" as the sum of capitals
- A capital is a finite asset that can be built up, conserved, or exchanged for other goods and services

From: Materials and the Environment by Michael F. Ashby, 2020, Chapter 14, p. 344 + 345.

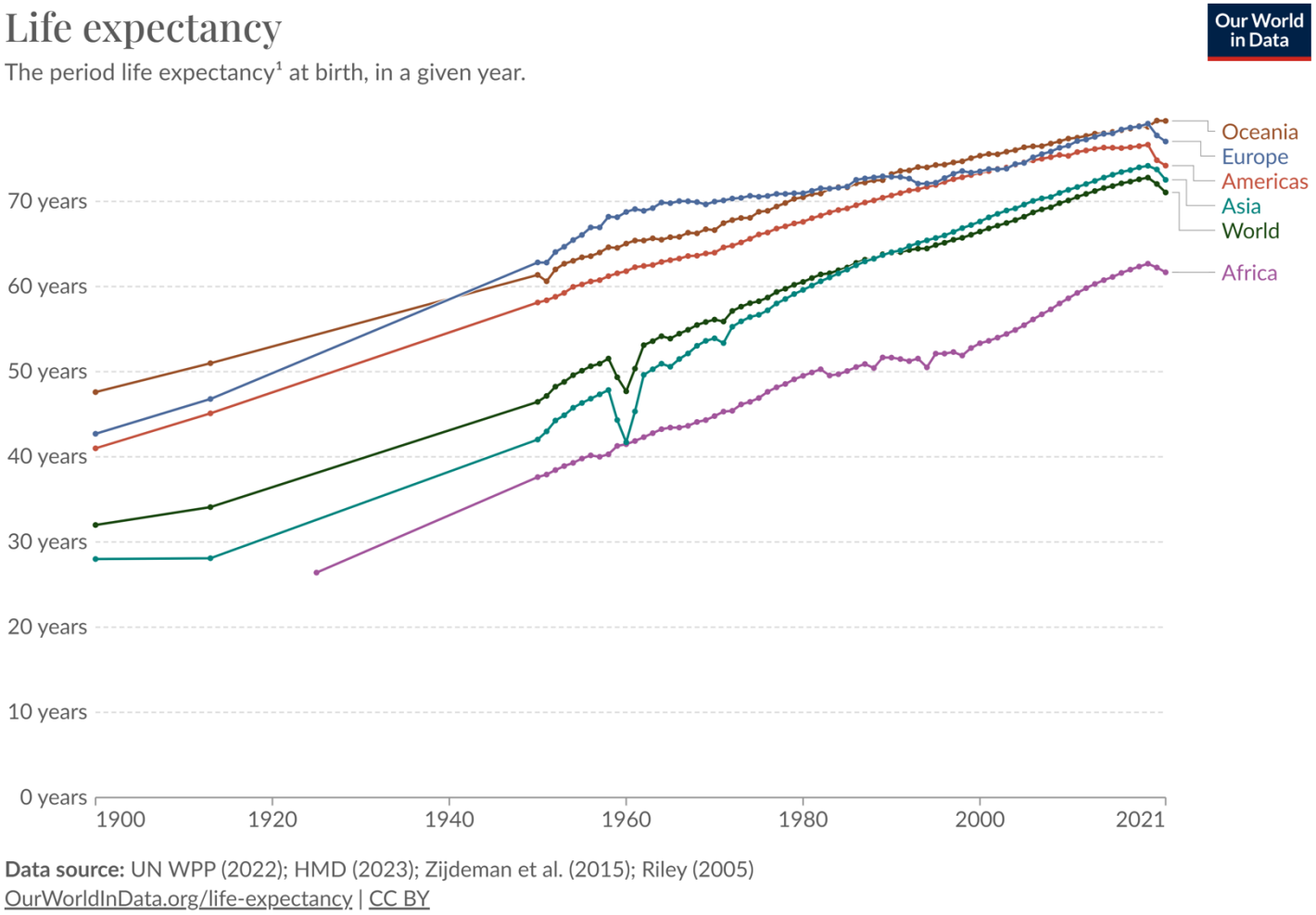
Manufactured capital

- A common index of economic growth is the gross domestic product (GDP) of a country
- GDP measures the total production of an economy (monetary value of all goods and services) over a specific timeframe (1 year)
- Average person in the world is 4.4× richer now than in 1950, while at same time population increased 3×



Economic growth

Human & social capital – life expectancy

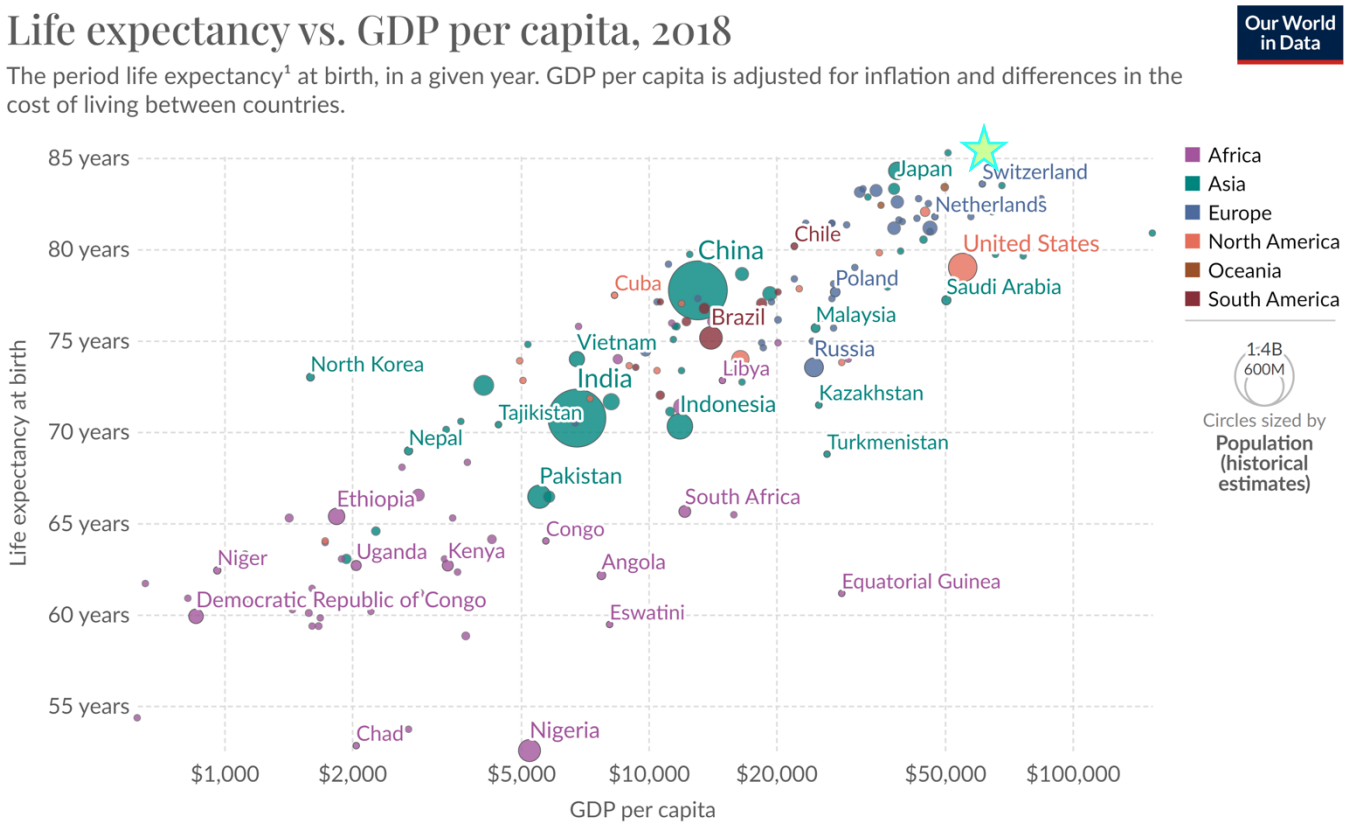


1. **Period life expectancy**: Period life expectancy is a metric that summarizes death rates across all age groups in one particular year. For a given year, it represents the average lifespan for a hypothetical group of people, if they experienced the same age-specific death rates throughout their whole lives as the age-specific death rates seen in that particular year. Learn more in our article: "Life expectancy" – What does this actually mean?

- Average life expectancy in 1900 was 32
- Average life expectancy in 2021 was 71
- Advances medicine, public health, and living standards
- So many good things!

Life expectancy

Life expectancy vs. GDP



Data source: UN WPP (2022); HMD (2023); Zijdeman et al. (2015); Riley (2005); Maddison Project Database (2020)
Note: GDP per capita is expressed in international-$[2] at 2011 prices.
OurWorldInData.org/life-expectancy | CC BY

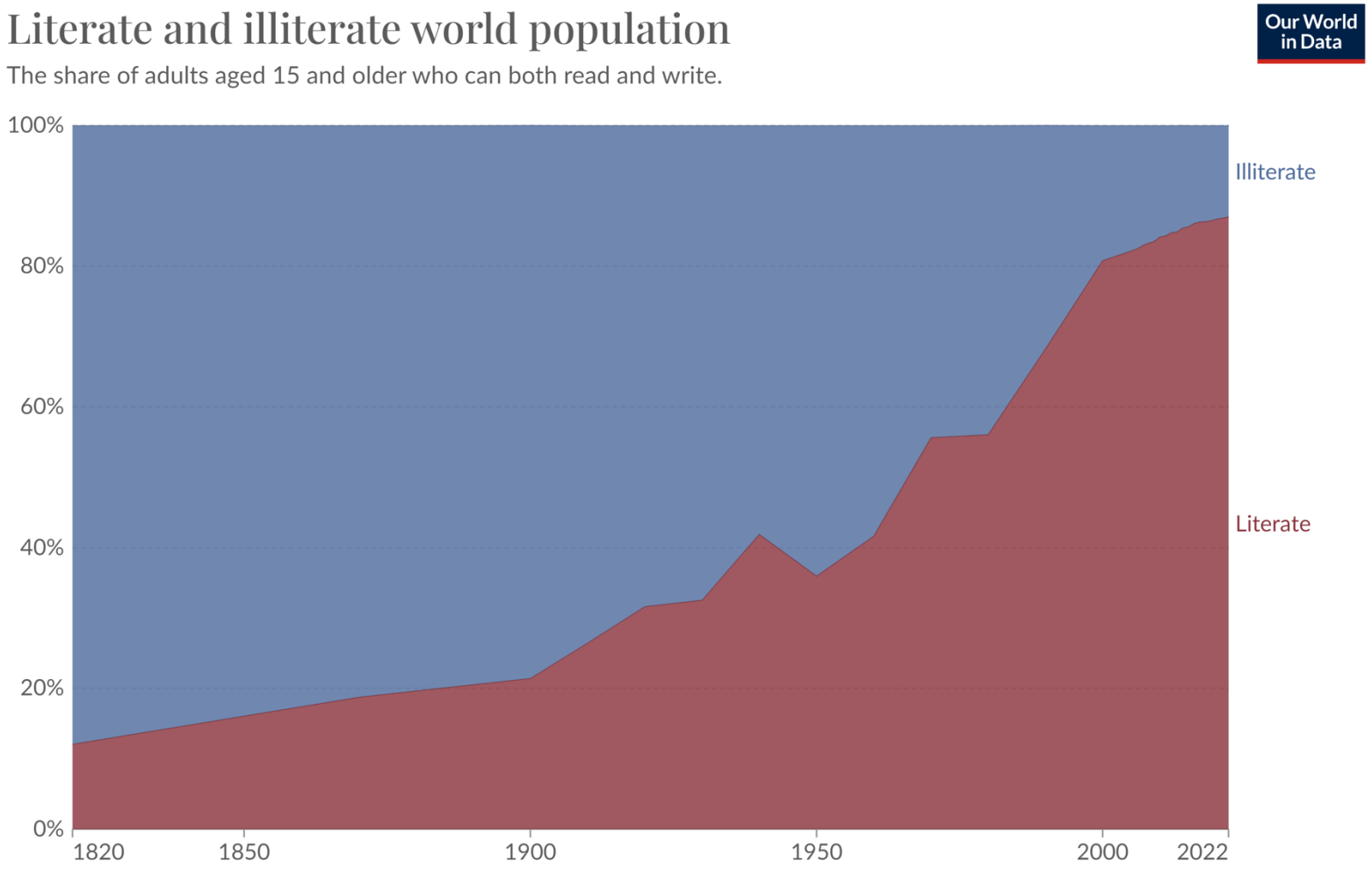
1. Period life expectancy: Period life expectancy is a metric that summarizes death rates across all age groups in one particular year. For a given year, it represents the average lifespan for a hypothetical group of people, if they experienced the same age-specific death rates throughout their whole lives as the age-specific death rates seen in that particular year. Learn more in our article: "Life expectancy" – What does this actually mean?

2. International dollars: International dollars are a hypothetical currency that is used to make meaningful comparisons of monetary indicators of living standards. Figures expressed in international dollars are adjusted for inflation within countries over time, and for differences in the cost of living between countries. The goal of such adjustments is to provide a unit whose purchasing power is held fixed over time and across countries, such that one international dollar can buy the same quantity and quality of goods and services no matter where or when it is spent. Read more in our article: What are Purchasing Power Parity adjustments and why do we need them?

- The details of how long you live really depends on where you live
- Still, everyone is living longer on average

Life expectancy vs GDP per capita

Human & social capital - literacy



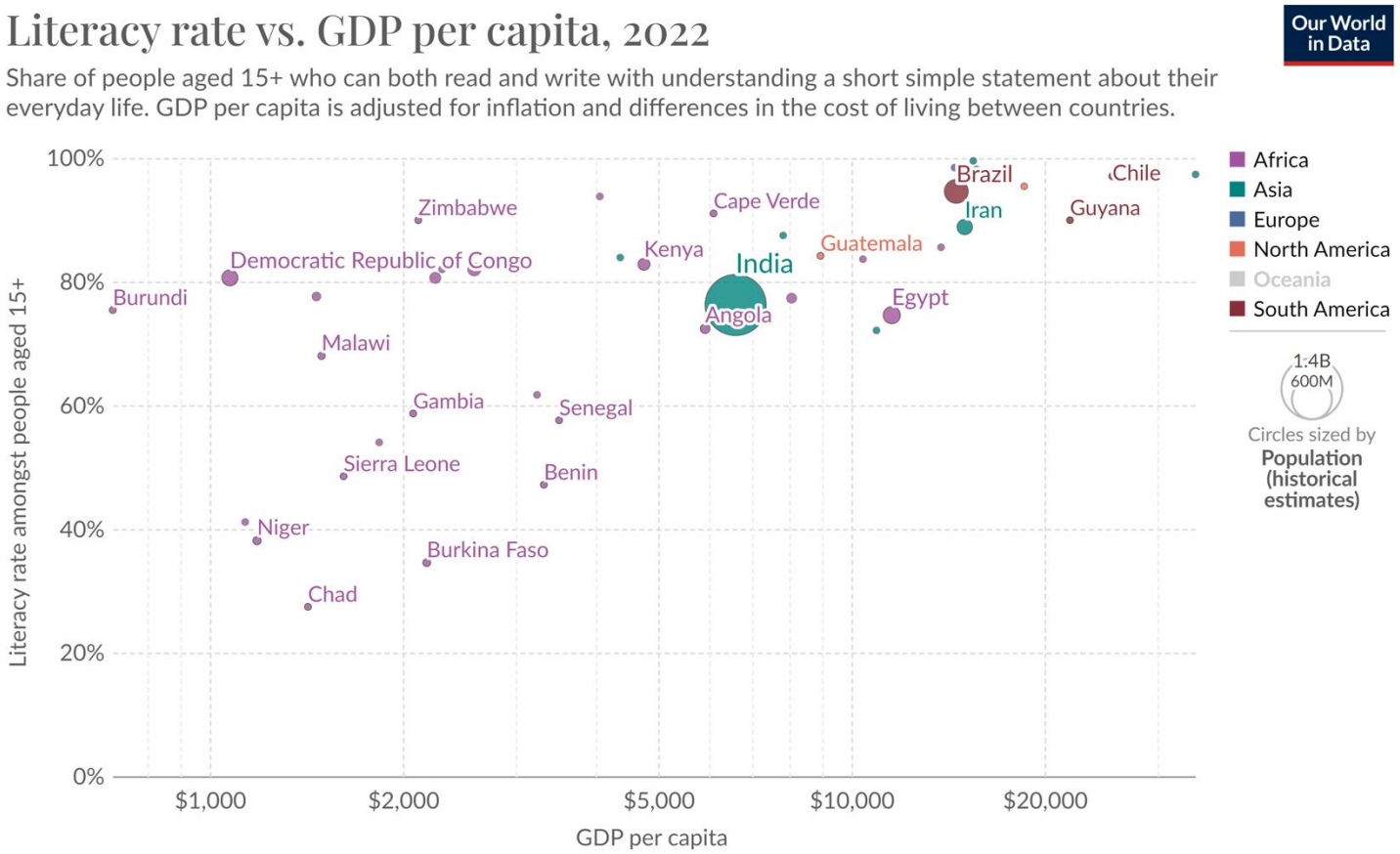
Data source: Our World in Data based on Zanden, J. et al. (2014) via OECD and UNESCO via World Bank
OurWorldInData.org/literacy | CC BY

Data can be broken down in many ways; old vs. young, by gender, by country

In 1820, only 12% of people in the world were literate, now only 14% are illiterate!

Literacy

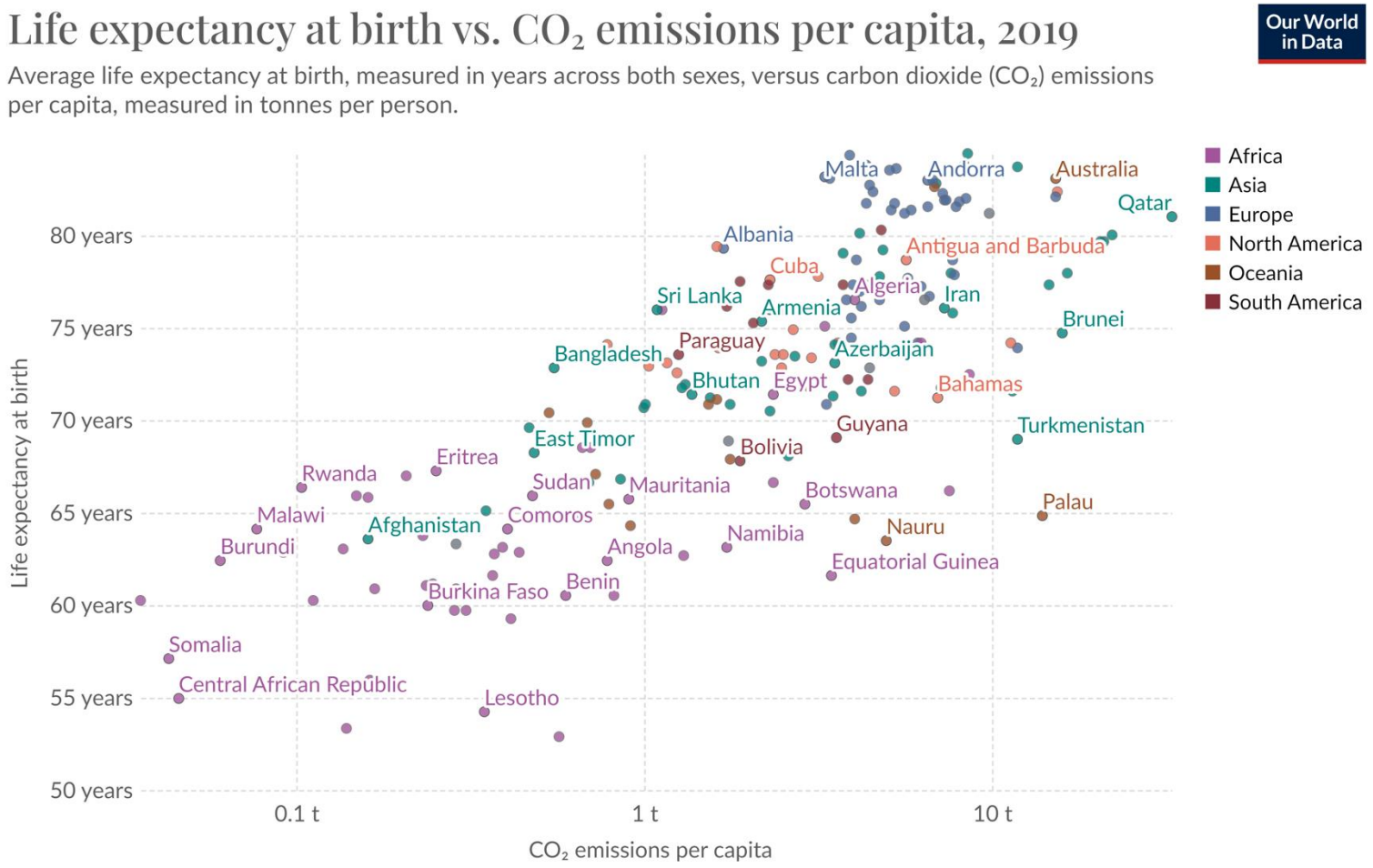
Literacy vs. GDP



- The details of whether you are literate or not depend on where you live
- Still, more and more people are literate

Literacy

It's complicated...



Data source: UN WPP (2022); Data compiled from multiple sources by World Bank
OurWorldInData.org/co2-and-greenhouse-gas-emissions | CC BY

- More CO_2 emissions can be linked to more pollution (lower life expectancy) and/or a more prosperous economy (higher life expectancy)!

Life expectancy vs. CO2 emissions

Planetary boundaries – metrics for global environmental sustainability

- Set of 9 planetary boundaries; interrelated processes that regulate the stability and resilience of the Earth System
- Framework is based on scientific evidence that human activities are the main drivers of recent global environmental change
- If we live within these boundaries, humanity will be in a safe space to develop and thrive in the future – *stay in Holocene!*
- If we transgress these boundaries, we risk catastrophic consequences – abrupt and irreversible environmental changes – *exit Holocene!*
- The boundaries have been quantified & mark a critical threshold for risks

- Rockström, J., Steffen, W., Noone, K. *et al.* A safe operating space for humanity. *Nature* **461**, 472–475 (2009). https://doi.org/10.1038/461472a
- Steffen, W. et al., Planetary boundaries: Guiding human development on a changing planet. *Science* **347**, (2015). DOI: 10.1126/science.1259855
- Planetary boundaries- Stockholm University

	Planetary boundary	Description
1	Stratospheric ozone depletion	Ozone layer protects the earth from harmful UV radiation
2	Freshwater consumption	Blue and green water; surface reservoirs = blue water, rainfall absorbed by soil and available to plants = green water
3	Biodiversity loss	Extinction rates
4	Land system change	Driven largely by agricultural expansion; framework proposes that no more than 15% of global useable land be cropland
5	Climate change	Measured by atmospheric CO_2 and radiative forcing
6	Biogeochemical flows	Measured by N and P; essential for plant growth - leach into the marine environment
7	Atmospheric aerosol loading	Air pollution; affects health and climate
8	Ocean acidification	Decrease in pH due to CO_2 absorption; threatens marine life
9	Novel entities	Microplastics, pesticides heavy metals, radioactive materials, persistent organic pollutants, etc.,

Circularity Gap Reporting Initiative - Planetary boundaries

9 Planetary Boundaries in data

	Planetary boundary	Boundary value (2023)	Boundary transgressed?	Pre-industrial level
1	Climate Change	< 350 ppm CO_2 in atmosphere	Yes (417 ppm)	280
2	Ocean acidification	carbonate ion (CO_3^{2-}) concentration; 2.8	No (but at margin)	3.44
3	Land system change	% of forest cover remaining 85%/50%/85% boreal/temperate/tropical forests	Yes (60; global)	100
4	Biogeochemical flows (P and N)	P flow from freshwater into ocean (global); 11 Tg/year	Yes (22 Tg/year)	0
		Industrial and intentional fixation of N (global) 62	Yes (190)	0

Earth beyond six of nine planetary boundaries_Science_2023

9 Planetary Boundaries in data

	Planetary boundary	Boundary value (2023)	Boundary transgressed?	Pre-industrial level
5	Change in biosphere integrity	< 10 E/MSY (extinctions per million species-year)	Yes (>100 E/MSE)	1 E/MSY
6	Stratospheric ozone depletion	276 DU (stratospheric ozone concentration in Dobson Units)	No (284)	290
7	Freshwater change (Blue/green)	Blue water: Human-induced disturbances to blue water flow (rivers, lakes, groundwater, ice); 10.2%	Yes (18.2%); overshot in 2022	9.4%
		Green water: Human-induced disturbance of water available to plants; 11.1%	Yes	9.8%

Earth beyond six of nine planetary boundaries_Science_2023

9 Planetary Boundaries in data

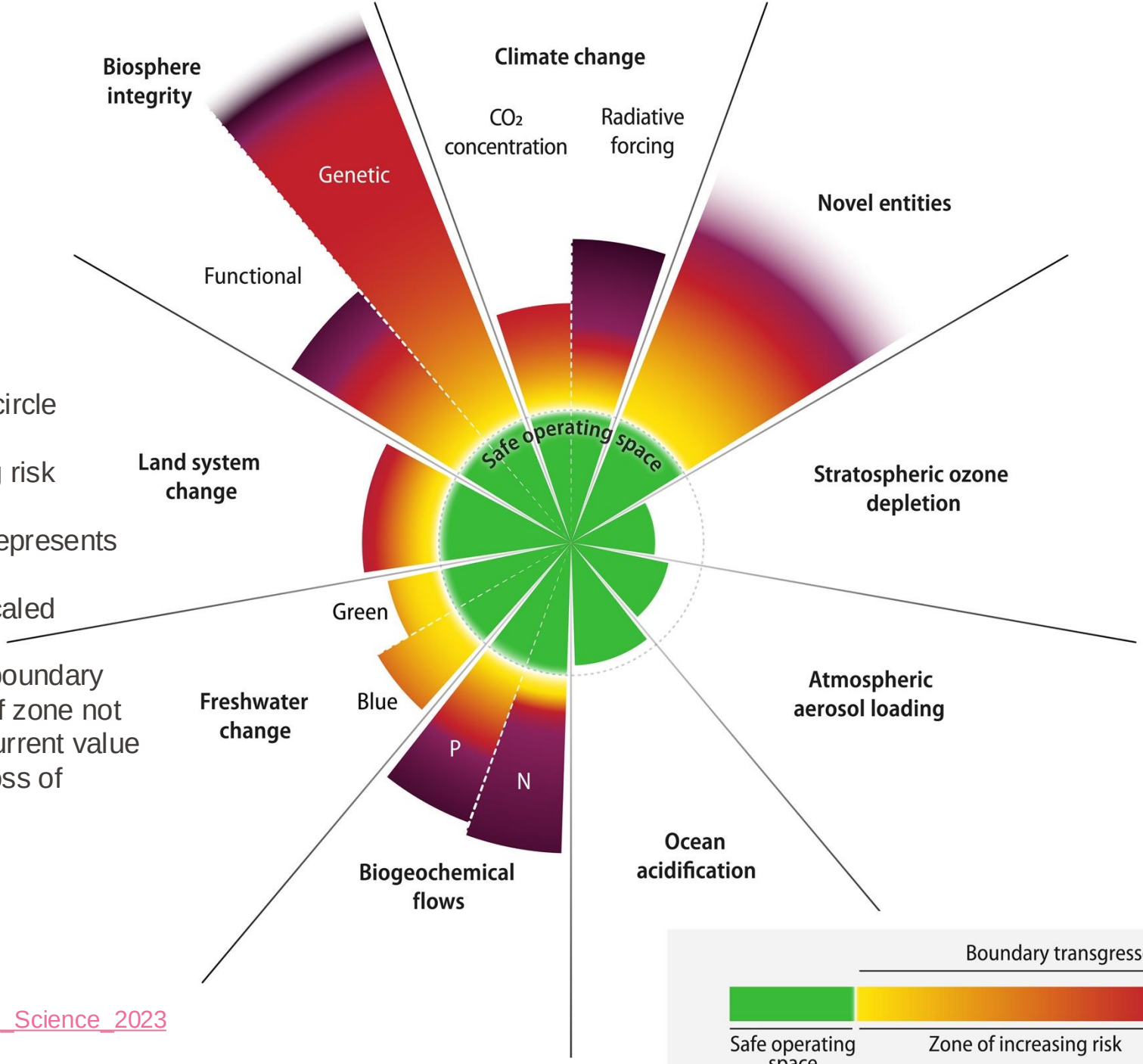
	Planetary boundary	Boundary value (2023)	Boundary transgressed?	Pre-industrial level
8	Atmospheric aerosols	Interhemispheric difference in AOD (aerosol optical depth); AOD measures the reduction in sunlight reaching the earth's surface due to scattering and absorption effects; 0.1 (mean annual interhemispheric difference)	No (0.076)	0.03
9	Novel entities	Anthropogenic origins; geological markers of Anthropocene; 0*	Yes	0

"The percentage of untested synthetics released globally is **unknown**. However, Persson *et al.* (*43*) report that for the chemicals currently registered under the EU Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulation (a small subset of the chemical universe), **~80% of these chemicals had been in use for at least 10 years without yet having undergone a safety assessment**. Likewise, few safety studies consider potential Earth system effects. With such an enormous percentage of untested chemicals being released to the environment, a novel entities boundary defined in this manner is **clearly breached**. Persson *et al.* (*43*) did not identify or quantify a singular planetary boundary for novel entities but, nevertheless, also concluded that the safe operating space is currently overstepped."

Earth beyond six of nine planetary boundaries_Science_2023

Current View (2023)

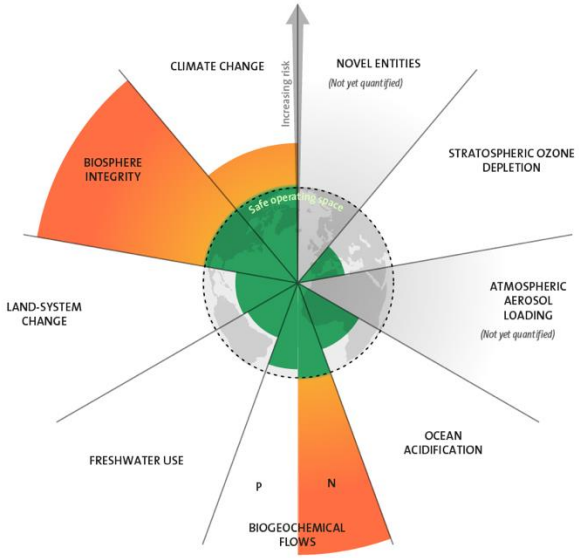
- Planetary boundary is the dotted circle
- Green is safe operating space
- Yellow to red is zone of increasing risk
- Purple is high risk zone
- Values normalized so that origin represents Holocene conditions
- Wedge length is logarithmically scaled
- 6/9 transgressed
- Ocean acidification approaching boundary
- Blurred edges: either upper end of zone not yet quantified (novel entities) or current value is known with great uncertainty (loss of genetic diversity)



Earth beyond six of nine planetary boundaries_Science_2023

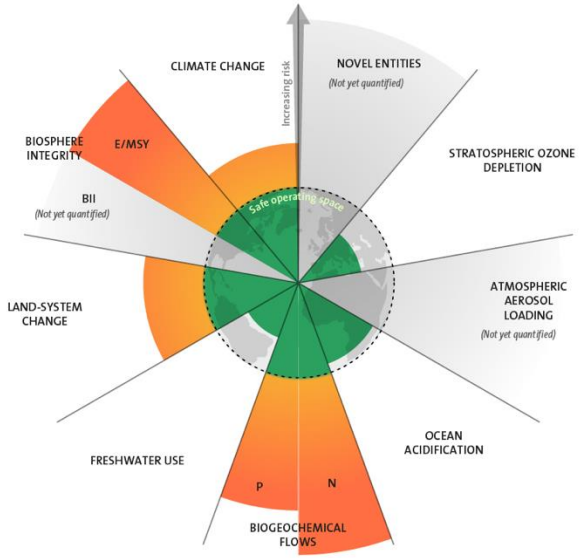
Planetary boundaries over time

2009



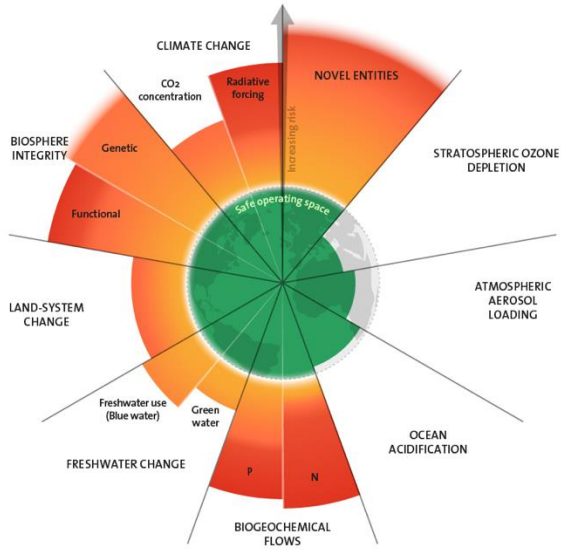
7 boundaries assessed,
3 crossed

2015



7 boundaries assessed,
4 crossed

2023



9 boundaries assessed,
6 crossed

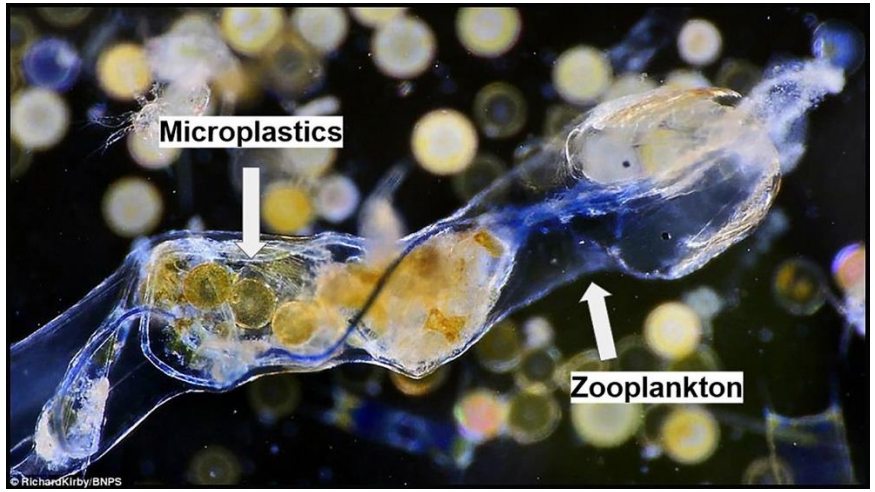
[Planetary boundaries- Stockholm University]

Deep dive on a selection planetary boundaries

- Biodiversity loss
- Novel entities
- Ocean acidification (C cycle)
- Climate change (via anthropogenic disturbances to the C cycle)
- Biogeochemical flows (P and N cycles)

Novel entities, e.g., microplastics, nanoplastics

- Since the 1950s, plastic use has skyrocketed
- Plastic debris (< 20 µm) – cut-off variable
- Waste mismanagement, tire abrasion, textile washing, paints and coatings, etc.,
- Carried by air, water
- 14 million tonnes of microplastics on the ocean floor
- Abundance increases as particles get smaller, as does the number of species ingesting them
- Under investigation; effects on feeding, behavior, metabolism, reproduction (*link to biodiversity loss!*)
- Scientific challenges in sampling and characterizing; long-term data is needed



A global perspective on microsplastics_JGR_2020

Zooplankton image

Ocean image

14 million tonnes estimate_2020

Take aways

- Different models of sustainability: 3 pillars, 3 capitals, doughnut
- Different metrics for economic, social, and environmental sustainability (also many more than were discussed)
- It’s complicated – economic growth has gone hand in hand with social prosperity but sometimes at the cost of planetary sustainability (eventually, if the ecosystem no longer sustains this growth…)
- Planetary boundaries – quantified limits of a safe planet
- Special focus on: novel entities