Lecture 01
Course introduction, the climate crisis, and civil engineering

Andrew Sonta

CIVIL-239: Engineering a sustainable built environment

10 September 2024

Andrew Sonta

Tenure-Track Assistant Professor
September 2022 – present

EPFL Fribourg

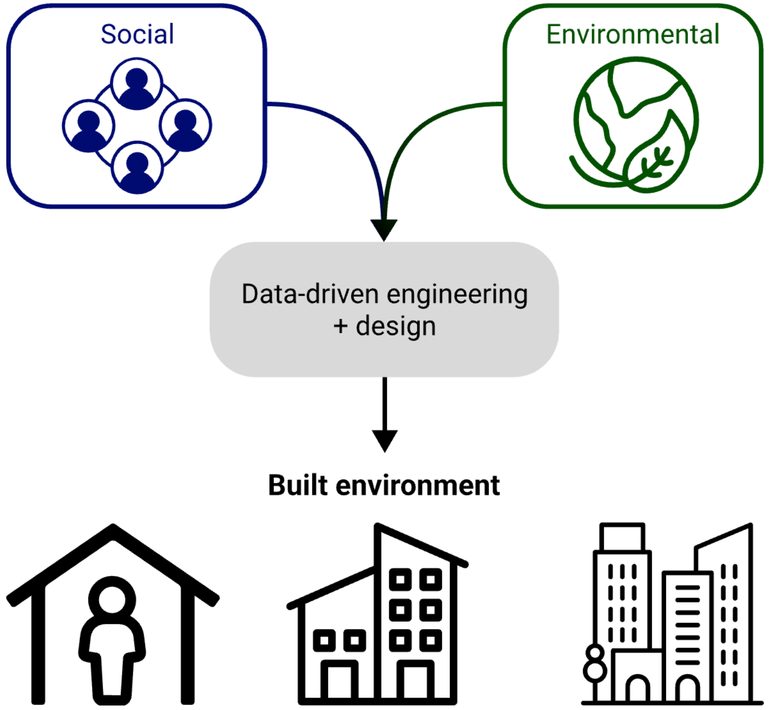
smart living lab

Previously:

- Postdoc, Columbia University, Data Science Institute
- PhD, Stanford University, Civil and Environmental Engineering

ETHOS Lab

Engineering and Technology for Human Oriented Sustainability



Research vision

Using **data**, **engineering**, and **design** to create interventions in the built environment that integrate our **social** and **environmental** goals.

Some current projects

- Occupant-centric building design and management
- Socio-environmental analysis of urban form

Course information (also in PDF on Moodle)

- Lectures: 10:15-12:00, GC B330
- Exercises: 12:15-13:00, GC B330
  - This is time for you to work on the course assignments
  - Course assistants will be present
- Course assistants:
  - Emilie Rausis, civil engineering master student
  - Axel Cebille, civil engineering master student

Course content

- Sustainability in the built environment
  - Sustainability and energy landscape
- Engineering lens
  - Approaches to sustainability in civil engineering
  - Specific **tools** for enacting sustainability in civil engineering
- Topics
  - Energy supply and demand
  - Mobility and sustainability
  - Materials and structures
  - Natural systems
  - Sustainability in the civil engineering profession

Course assessment

- Graded exercises (20%)
  - On your own time, but you may also work on these during the exercise hour (12:15-13:00 on Tuesdays) when course assistants are present
  - The work must be done individually, but you may discuss with your fellow students
  - Write down on your submission who you discussed with
- Midterm exam (30%)
- Final exam, during exam session (50%)

Week	Date	Course Content	Engineering knowledge and tools	Due
	Course introduction			
1	10-Sep	The climate crisis What is sustainability? Sustainability in civil engineering	The role of the built environment in sustainability	
2	17-Sep	Sustainability indicators New economic thinking	The importance of data	
	Buildings and energy			
3	24-Sep	Energy demand: buildings and infrastructure	How design impacts energy demand; Energy and load calcs	Assignment 1
4	1-Oct	Energy supply: Renewables, the grid, and grid integration	Interface between the built environment and energy systems; time-series data analysis	
	Mobility and sustainability			
5	8-Oct	Transportation systems Autonomous vehicles	Link between transportation, energy, and health; systems thinking	Assignment 2
6	15-Oct	Sustainable urban design and active mobility Social systems	System dynamics	
7	22-Oct	No Class - Fall Break		
8	29-Oct	***Midterm exam***		Assignment 3

	Materials, structures, and life-cycle assessment			
9	5-Nov	**Guest lecture**: Embodied carbon emissions and materials	The phases of infrastructure life cycles	
10	12-Nov	Life-cycle assessment	Environmental LCA; Safety factors	
	Natural systems and sustainability economics			
11	19-Nov	**Guest lecture**: Assigning value to natural systems	Sustainability in natural systems; Engineering and sustainability economics	Assignment 4
12	26-Nov	Geo-mechanics, carbon storage, and geo-engineering	Risks of geo-engineering	
	Sustainability in the civil engineering profession			
13	3-Dec	Civil engineering and the intersection of built, natural, and social systems	Complexity in civil engineering systems; engineering decision-making	Assignment 5
14	10-Dec	**Guest lecture**: Sustainable engineering in the industry	Practical issues	
15	17-Dec	Course wrap up Thinking in systems Tentative: class debate		
16	XX-Jan	***Final Written exam***		

Today’s outline

- The climate crisis
- Definitions of sustainability
- Intersections:
  - Environmental, social, economic
  - Human, natural, built
- Sustainability in civil engineering: overview of the topics in the course
- Why civil and environmental engineering is uniquely concerned with sustainability

Our visual understanding of Earth

Landscapes
since ~start
of civilization

City panoramas
(e.g. view from Tour Eiffel)
since ~1800-1900

Views from airplanes
since ~1920

Earthrise

- Photo taken December 24, 1968, during Apollo 8 mission to the Moon
- First color picture of the entire Earth
- Widely credited with propelling the environmental movement

The Blue Marble

- Photo taken December 7, 1972, during Apollo 17 mission to the Moon

Image credit: NASA

THE THIN BLUE LINE

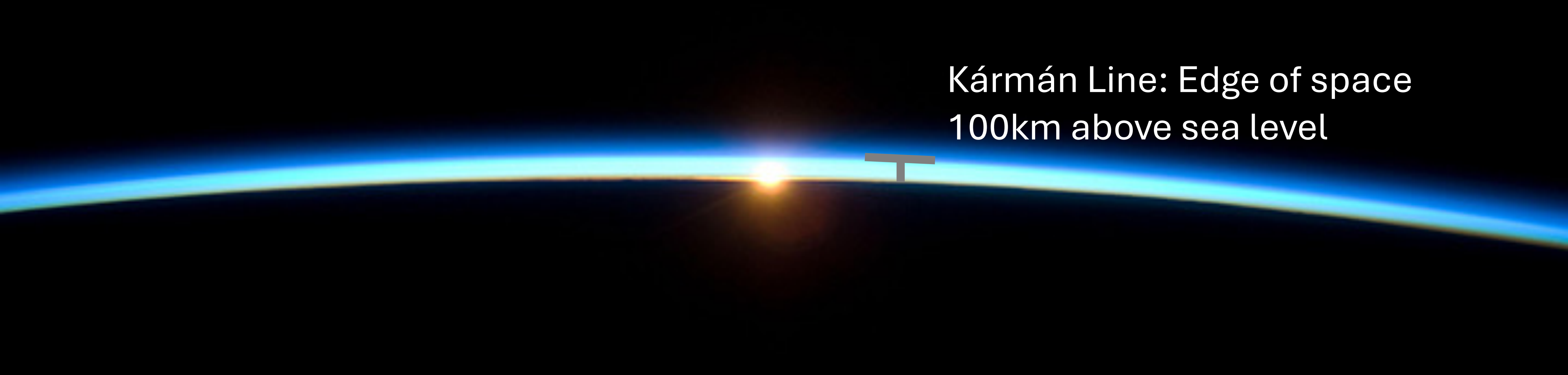
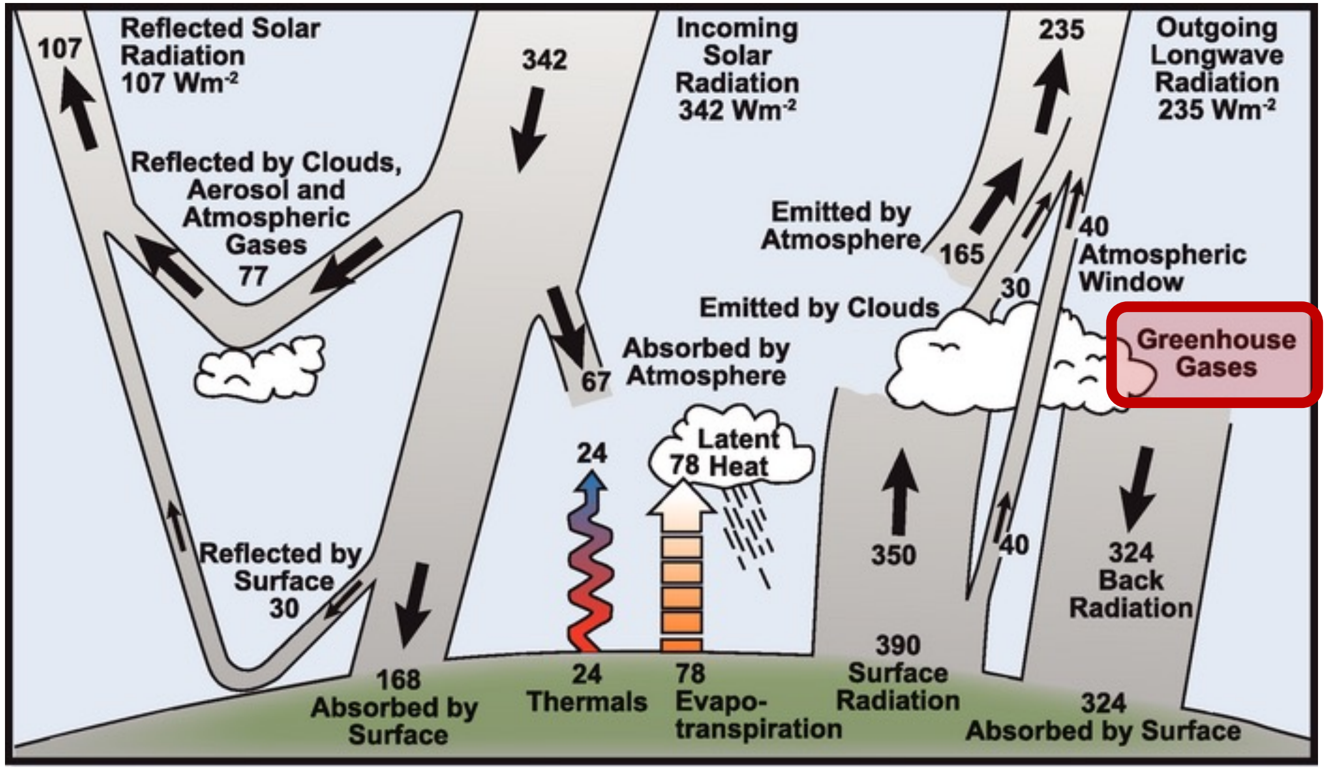


Image credit: NASA

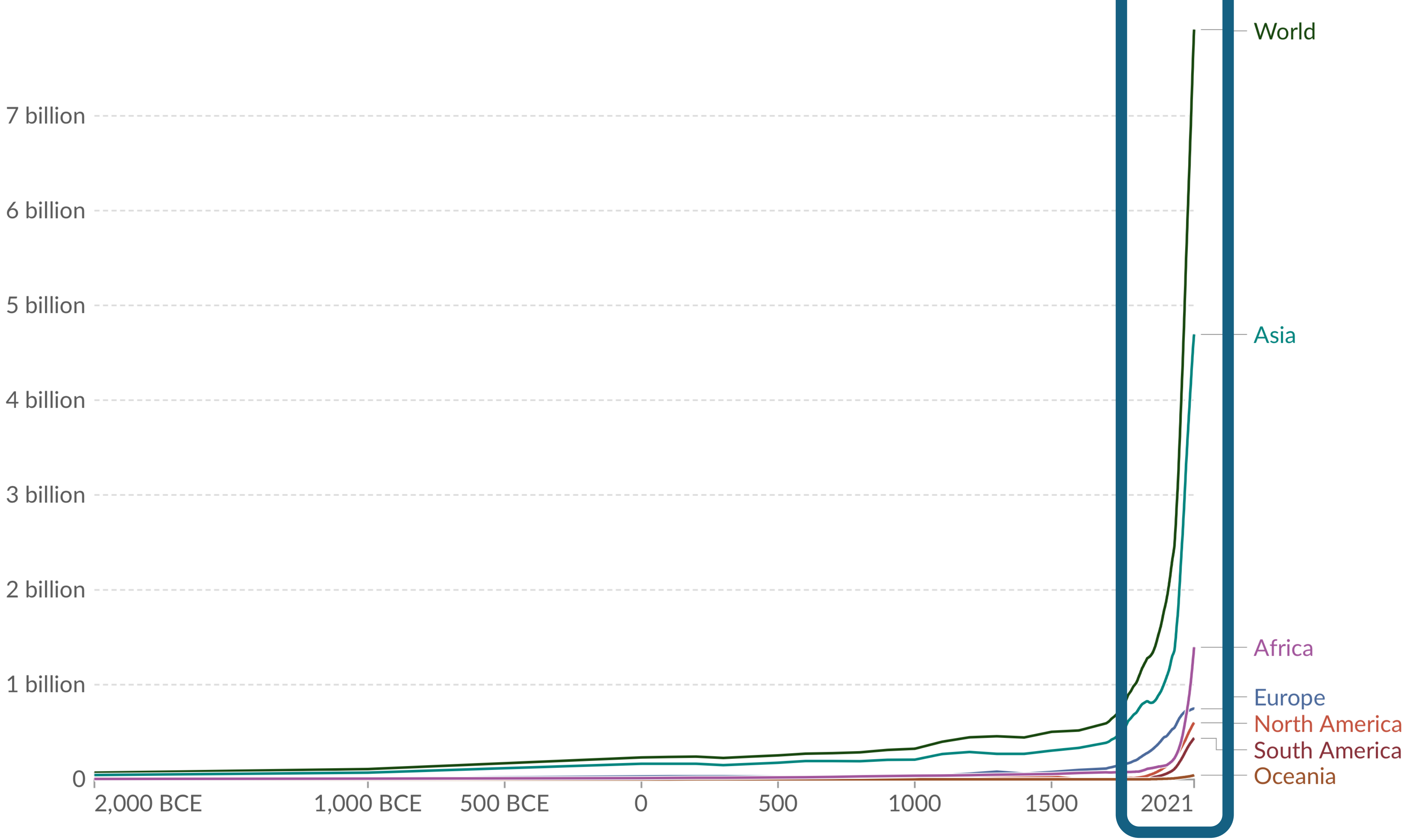
A delicate balance

- The Earth's temperature is the result of radiative balance
- The sun emits 3.9 x 10^{26} W, and the Earth receives ~340 W/m^2 on average
- The Earth emits radiation in the infrared spectrum
- Without the greenhouse effect, the surface of the Earth would be –18ºC on average, instead of the observed 15ºC



Source: IPCC

Population, 2,000 BCE to 2021



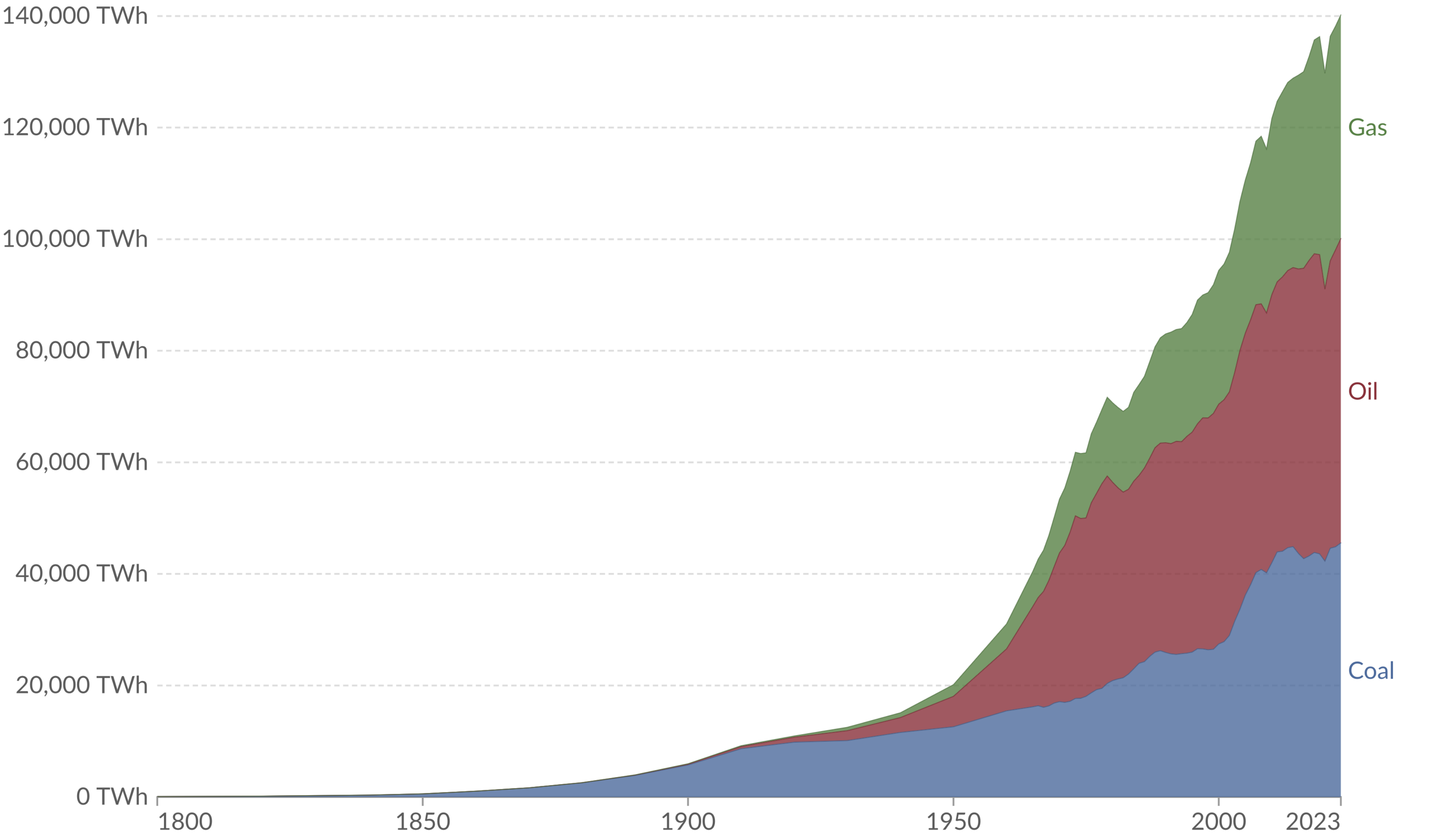
Data source: HYDE (2017); Gapminder (2022); UN (2022)

OurWorldInData.org/population-growth | CC BY

Note: Historical country data is shown based on today's geographical borders.

Global fossil fuel consumption

Measured in terawatt-hours[1] of primary energy[2] consumption.

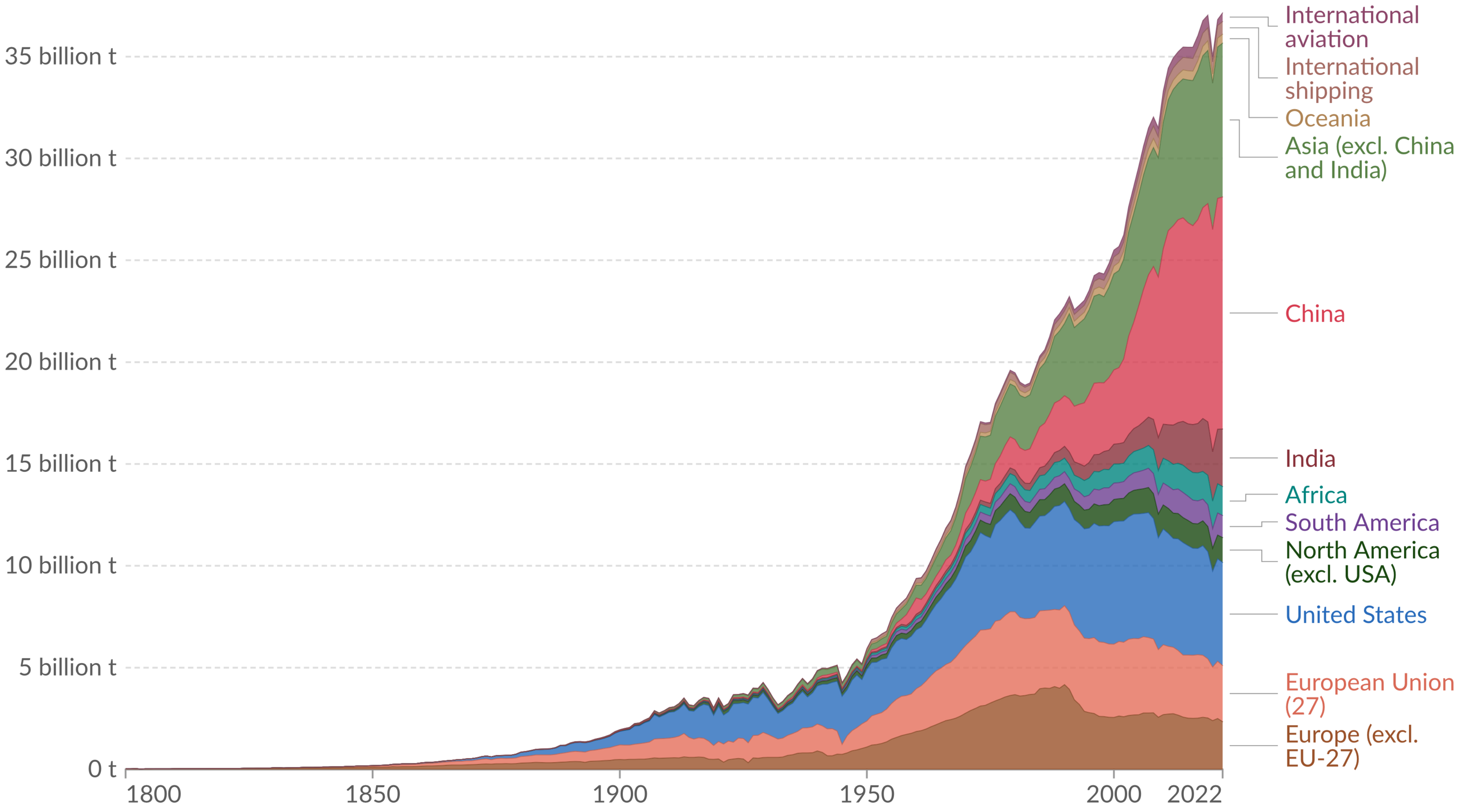


Data source: Energy Institute - Statistical Review of World Energy (2024); Smil (2017)

OurWorldInData.org/fossil-fuels | CC BY

Annual CO_2 emissions by world region

Emissions from fossil fuels and industry[1] are included, but not land-use change emissions. International aviation and shipping are included as separate entities, as they are not included in any country's emissions.

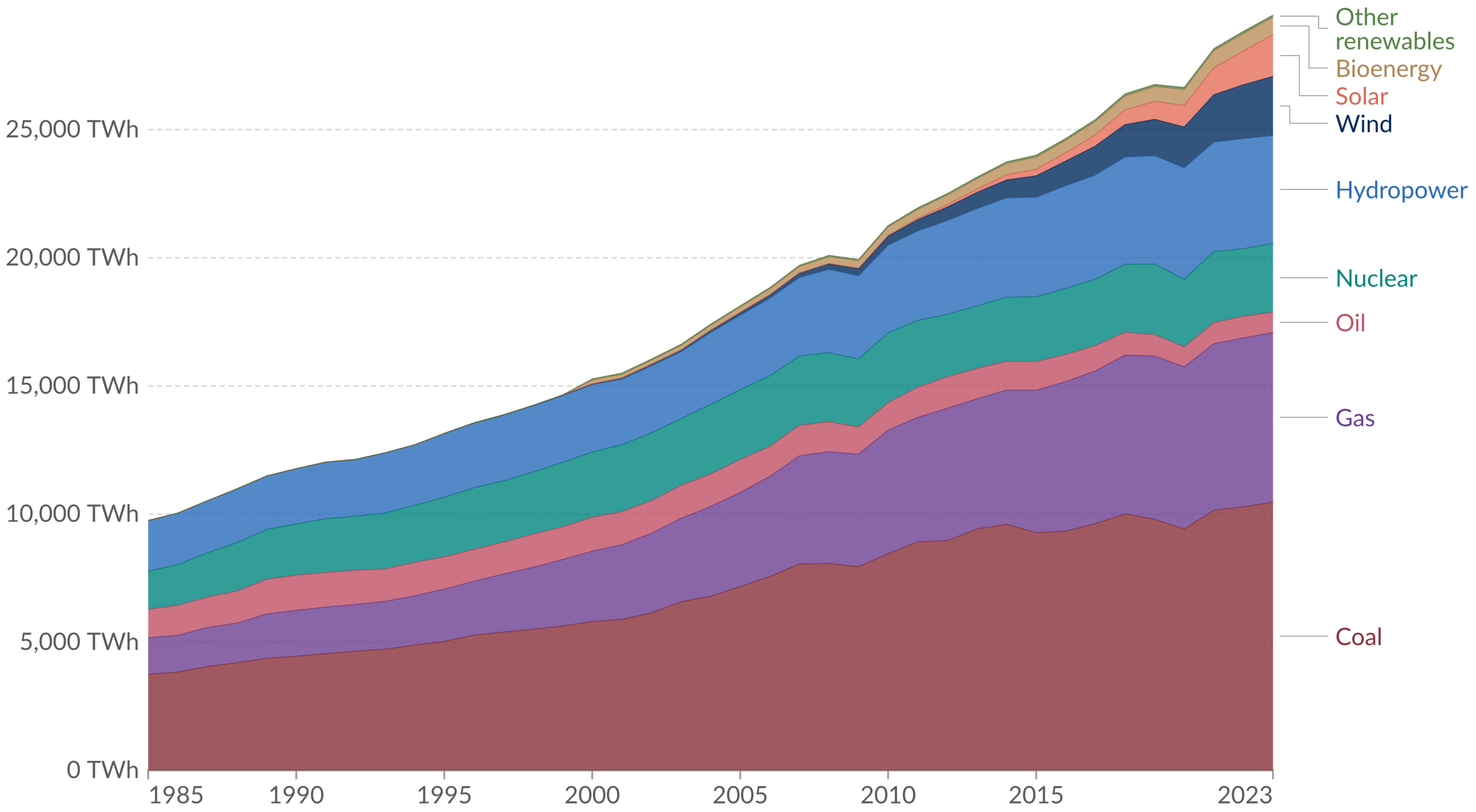


Data source: Global Carbon Budget (2023)

OurWorldInData.org/co2-and-greenhouse-gas-emissions | CC BY

Electricity production by source, World

Measured in terawatt-hours[1].



Data source: Ember (2024); Energy Institute - Statistical Review of World Energy (2024)

OurWorldInData.org/energy | CC BY

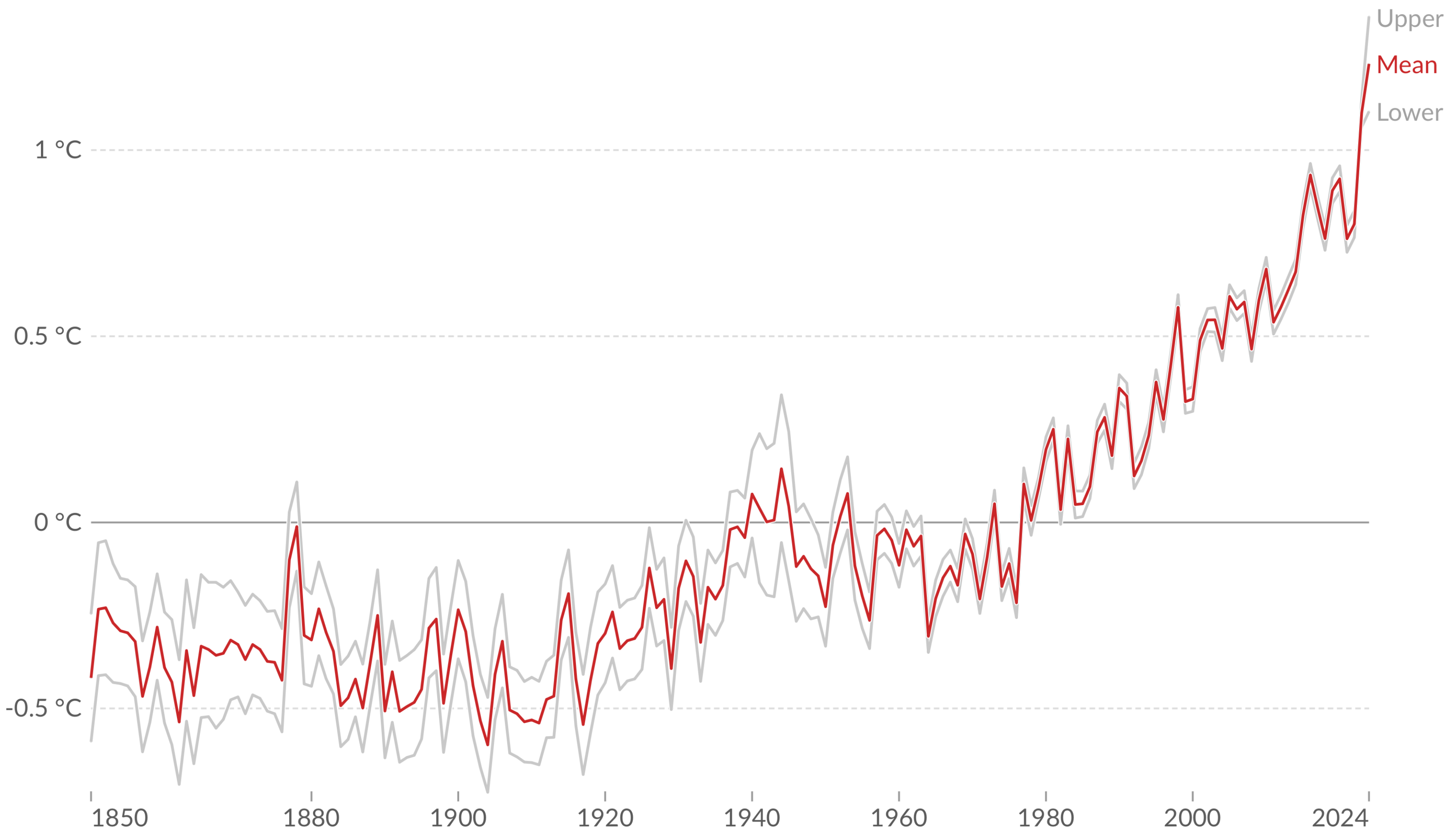
Note: "Other renewables" include waste, geothermal, wave, and tidal.


AIR TRANSPORT
THAWING PERMAFROST
COAL MINING
OIL PRODUCTION
COAL PLANTS
FERTILIZATION
INDUSTRIAL PROCESSES
LAND TRANSPORT
LANDFILLS
Illustration © Don Foley

Average temperature anomaly, Global

Global average land-sea temperature anomaly relative to the 1961-1990 average temperature.

Our World in Data



Data source: Met Office Hadley Centre (2024) OurWorldInData.org/co2-and-greenhouse-gas-emissions | CC BY

Note: The gray lines represent the upper and lower bounds of the 95% confidence intervals.

But Andrew, there are natural cycles that cause Earth's CO_2 concentrations to vary over time. How do we know this is an urgent issue?

Carbon dioxide concentrations in the atmosphere

Atmospheric carbon dioxide (CO_2) concentration is measured in parts per million (ppm). Long-term trends in CO_2 concentrations can be measured at high-resolution using preserved air samples from ice cores.

Data source: NOAA Global Monitoring Laboratory - Trends in Atmospheric Carbon Dioxide (2024); EPA based on various sources (2022)

OurWorldInData.org/climate-change | CC BY

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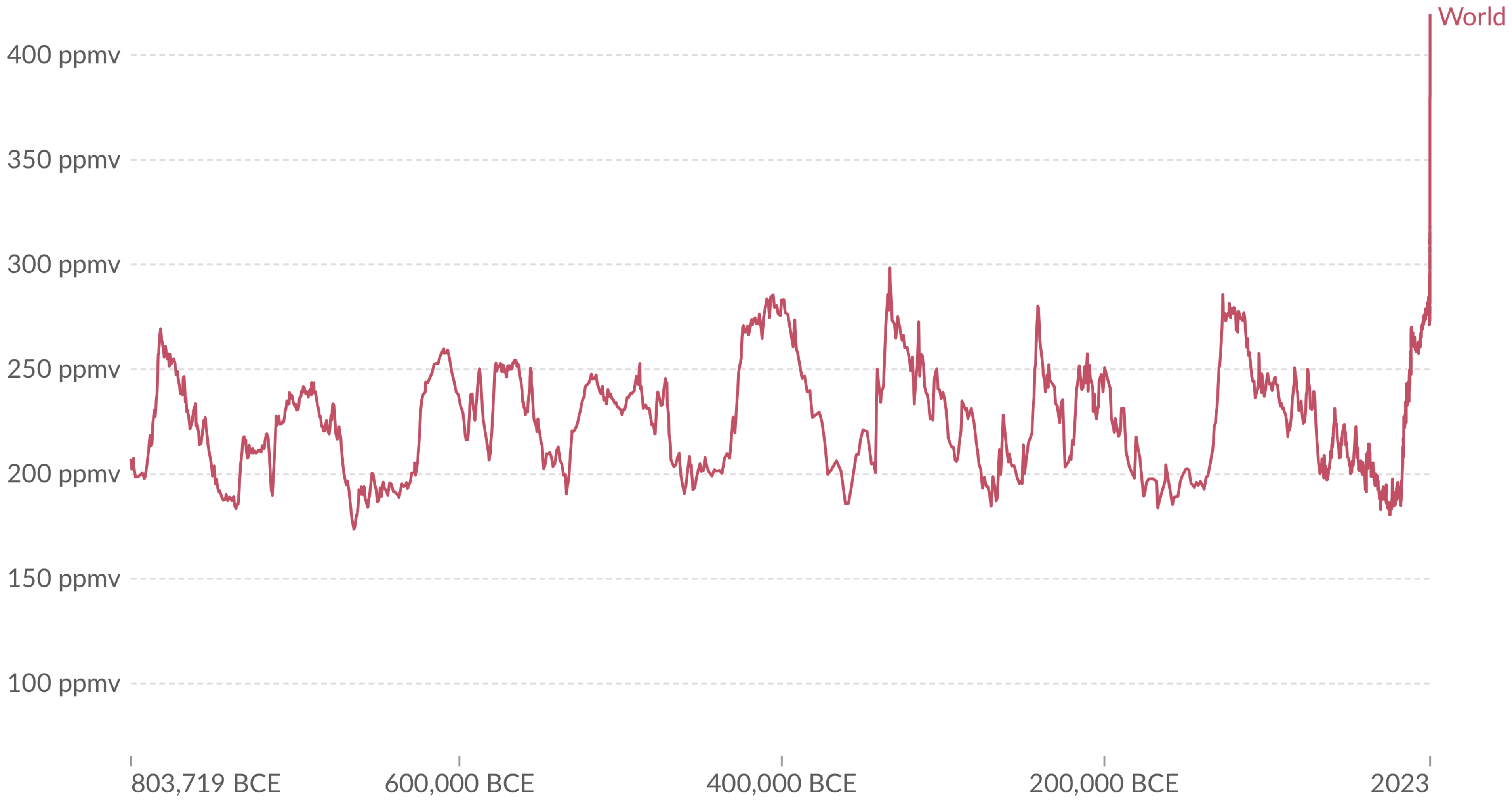

Data source: NOAA Global Monitoring Laboratory - Trends in Atmospheric Carbon Dioxide (2024); EPA based on various sources (2022)
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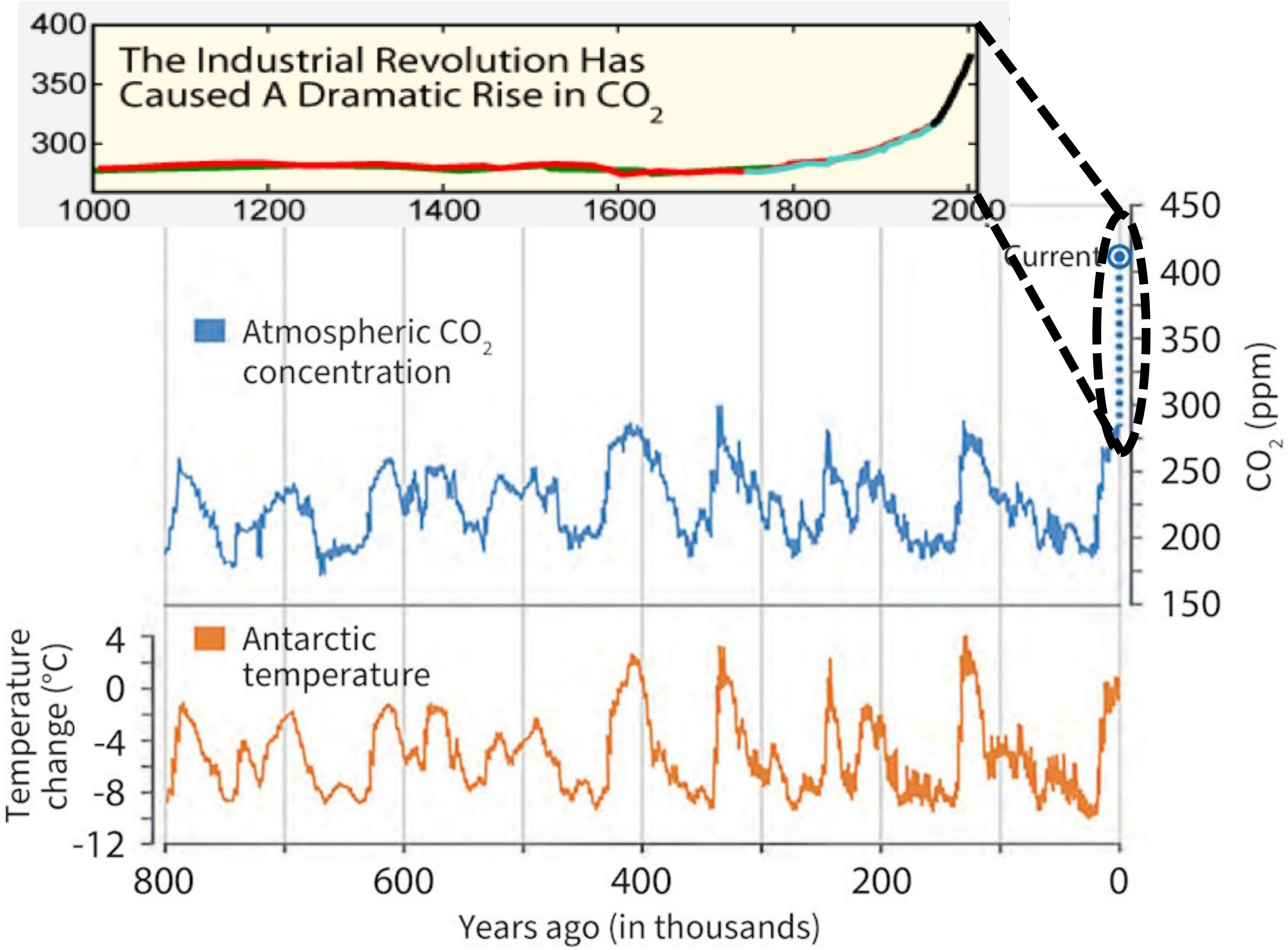
Unprecedented impact of human activity

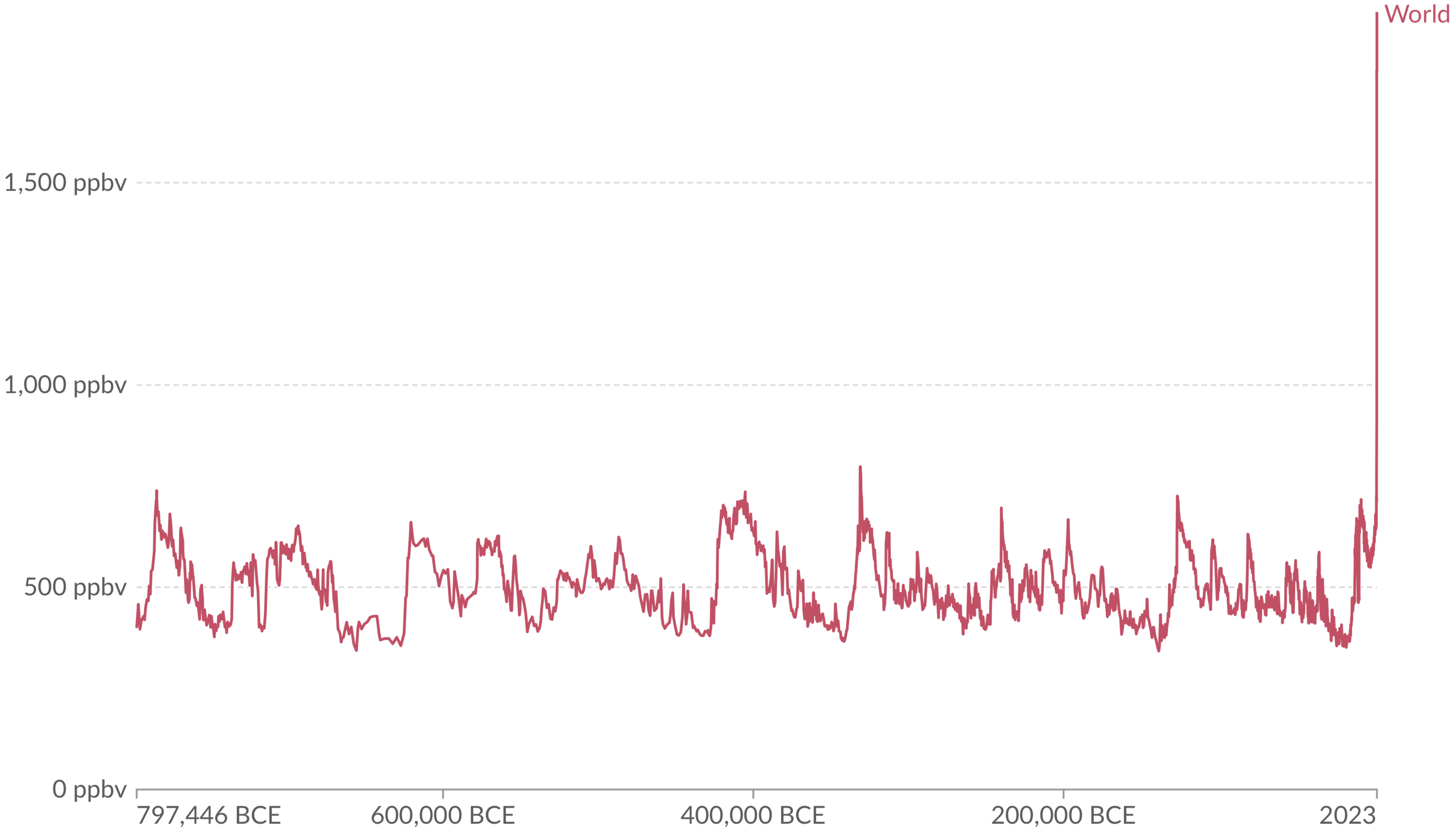
- “The cyclical pattern of temperature variations constitutes the ice age/interglacial cycles…
- During these cycles, changes in CO2 concentrations (in blue) track closely with changes in temperature (in orange)…
- As the record shows, the recent increase in atmospheric CO2 concentration is unprecedented in the past 800,000 years.”



Source: The Royal Society

Methane concentration in the atmosphere

Measured in parts per billion.



Data source: NOAA Global Monitoring Laboratory - Trends in Atmospheric Methane (2024); EPA based on various sources (2022)
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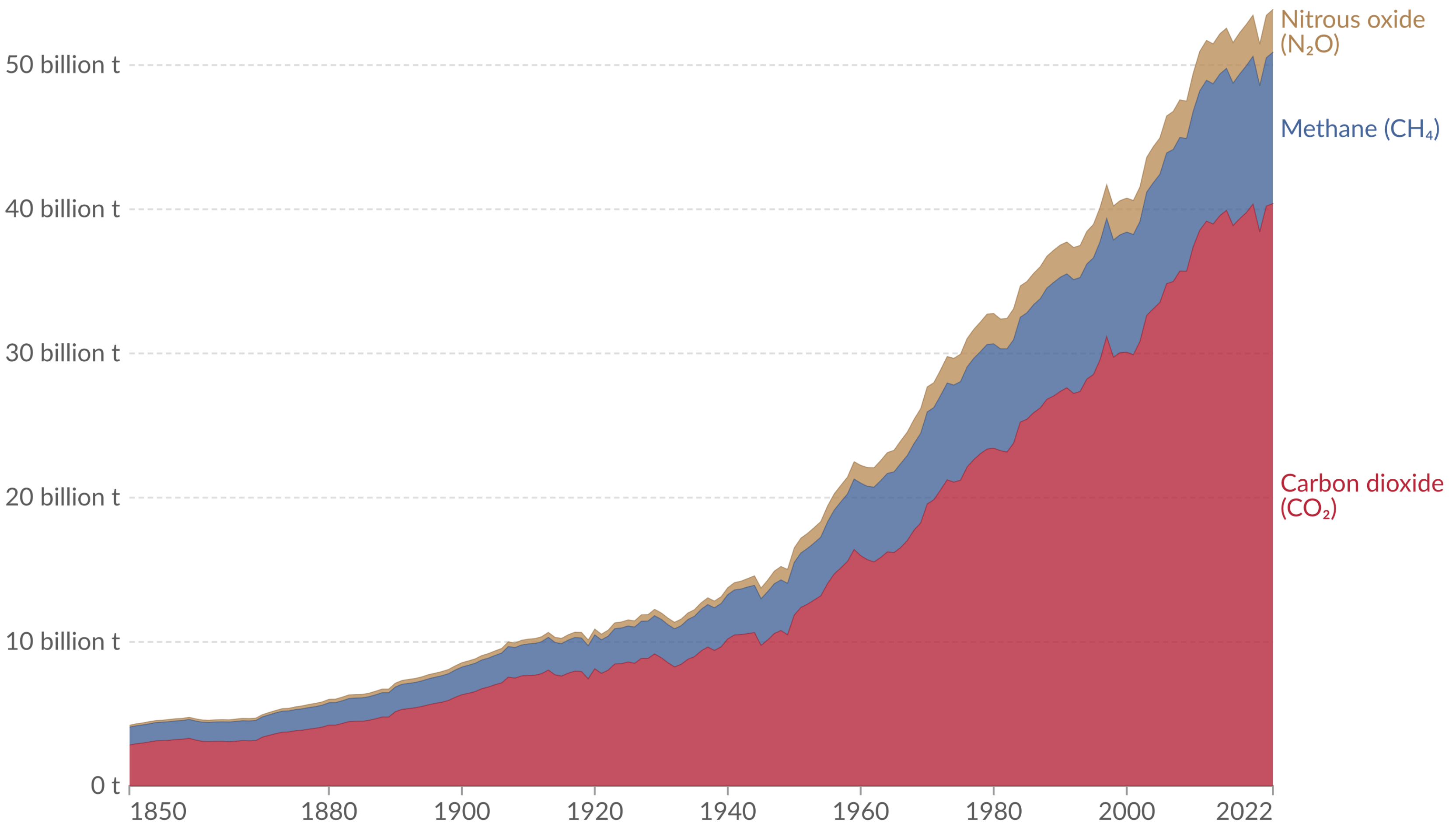
Measured in CO_2e (carboned dioxide equivalents)

Example: Methane is ~27x more effective in trapping heat compared to carbon dioxide, so the raw amount of methane emitted is ~1/27 of what is shown.

Greenhouse gas emissions by gas, World, 1850 to 2022

Greenhouse gas emissions[1] from all sources, including agriculture and land-use change. They are measured in tonnes of carbon dioxide-equivalents[2] over a 100-year timescale.



Data source: Jones et al. (2024)

OurWorldInData.org/co2-and-greenhouse-gas-emissions | CC BY

Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years

Changes in global surface temperature relative to 1850–1900

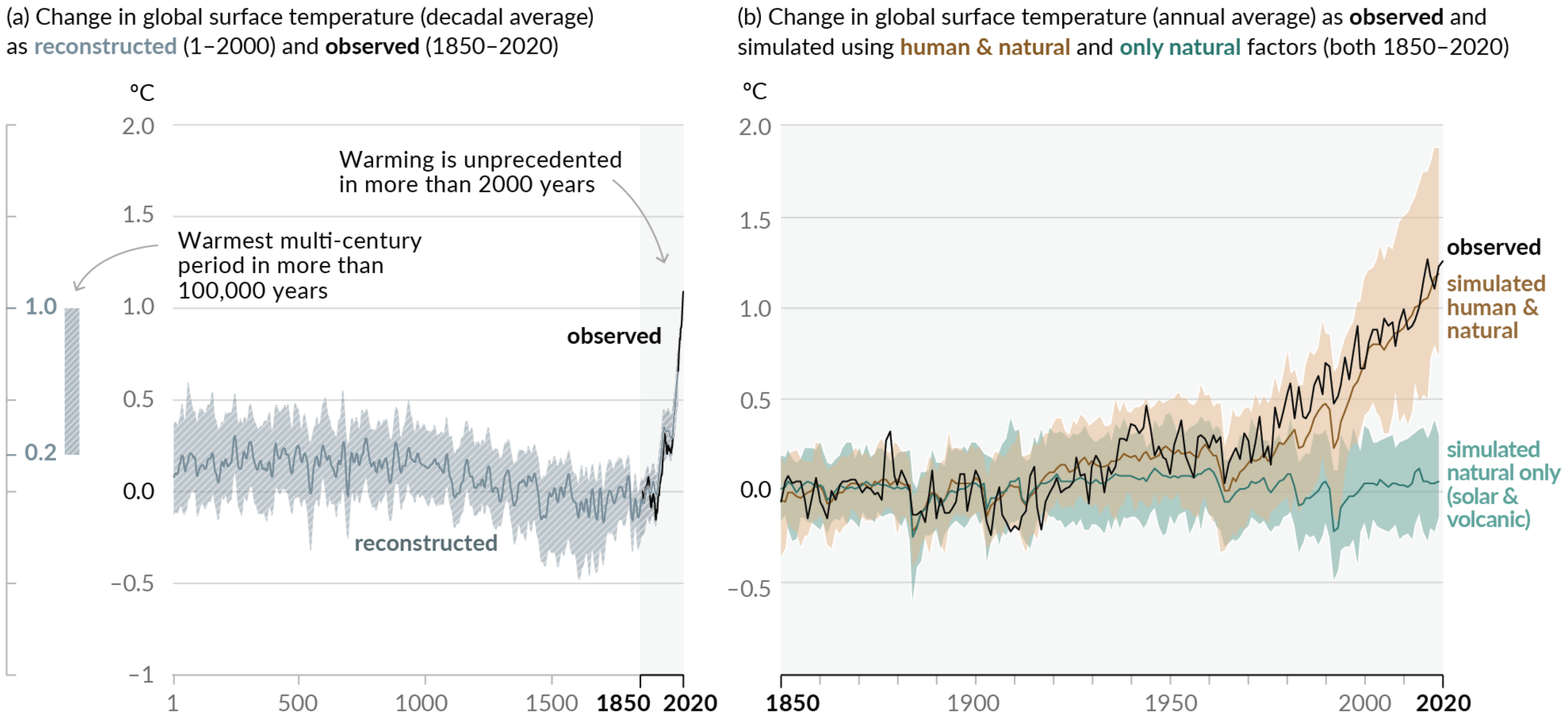
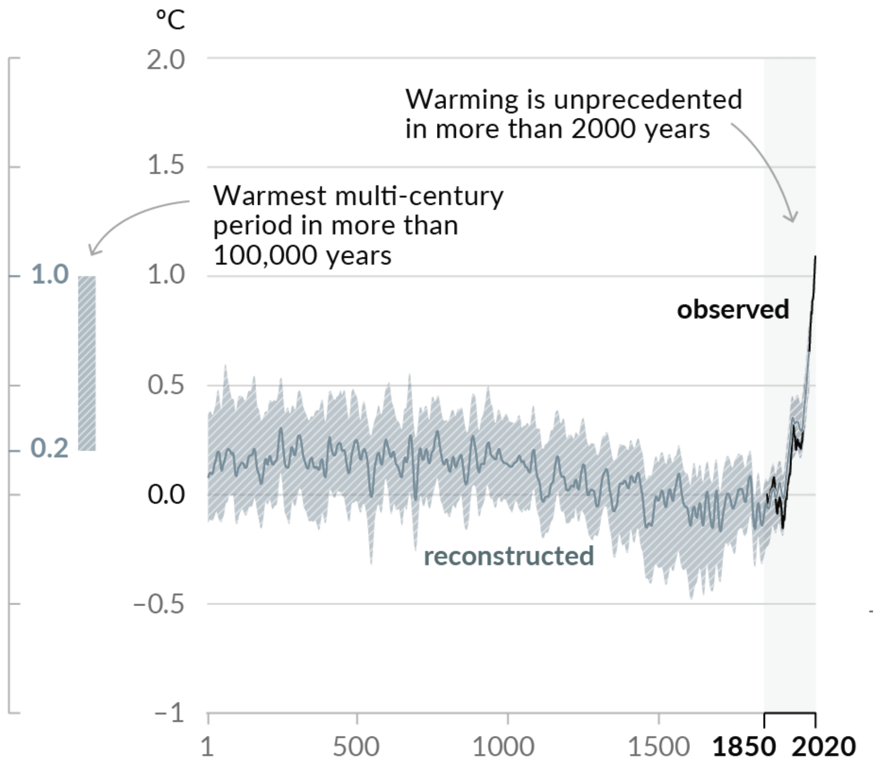


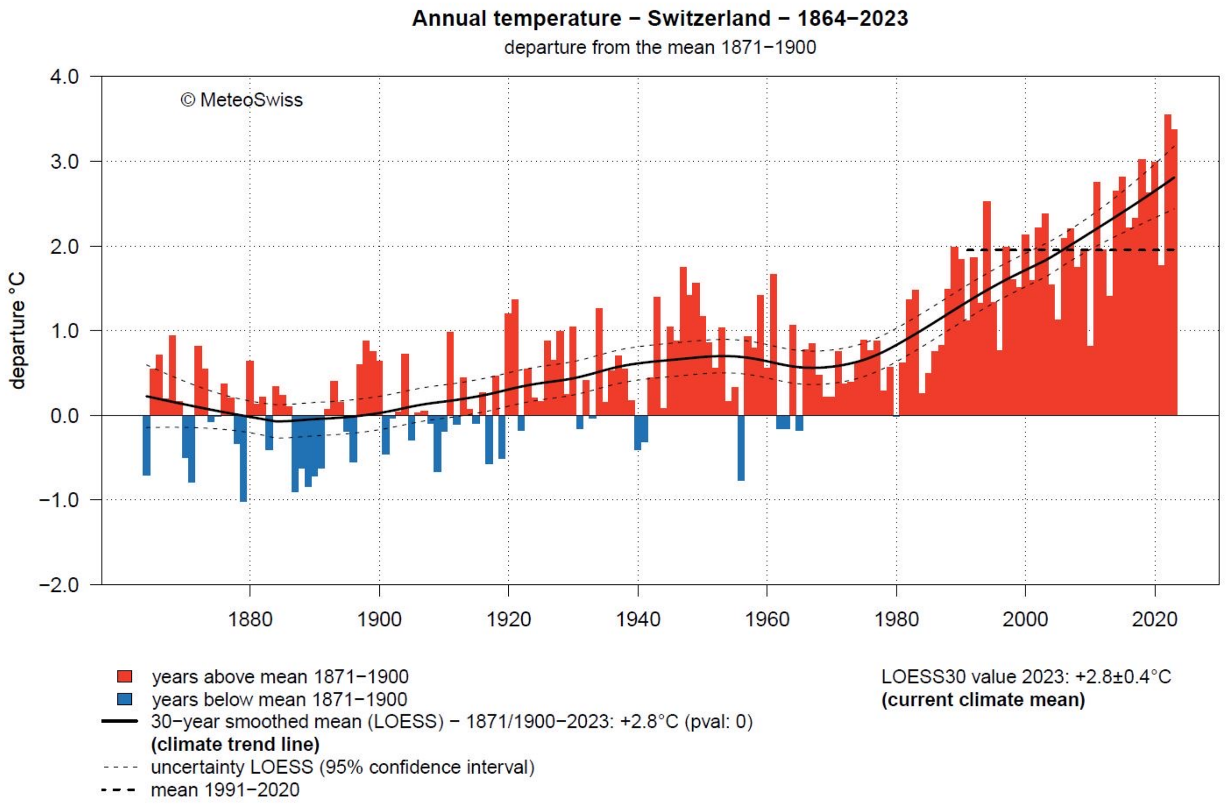
Figure SPM.1 in IPCC, 2021: Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., et al. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY,USA, pp. 3−32, doi: 10.1017/9781009157896.001 .]

Warming is about 2x faster in Switzerland

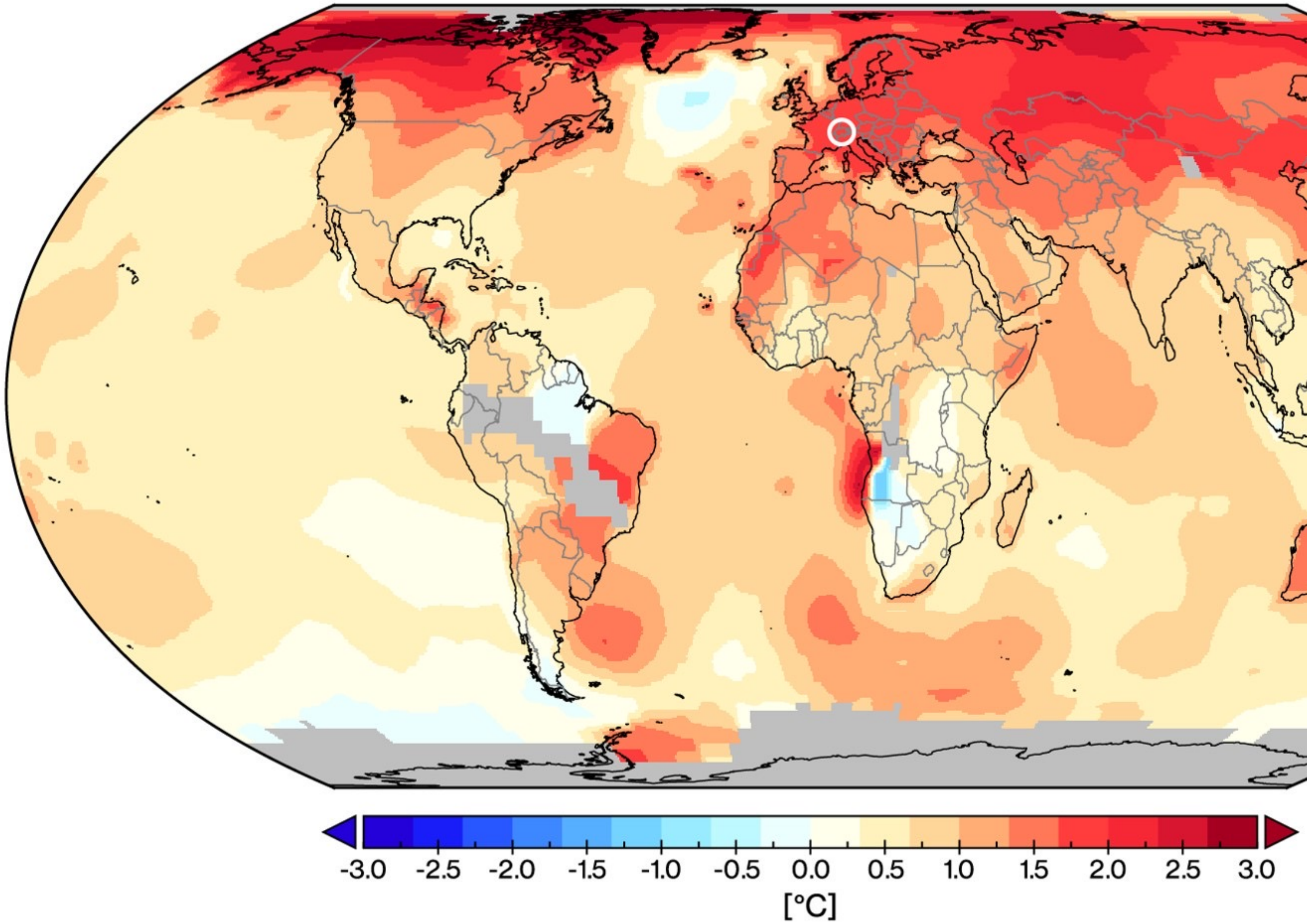
Changes in global surface temperature relative to 1850–1900

(a) Change in global surface temperature (decadal average) as reconstructed (1–2000) and **observed** (1850–2020)





Observed warming of the earth. Difference between 30-year mean values from 1881-1910 and 1991-2020. Data: GISTEMP, NASA



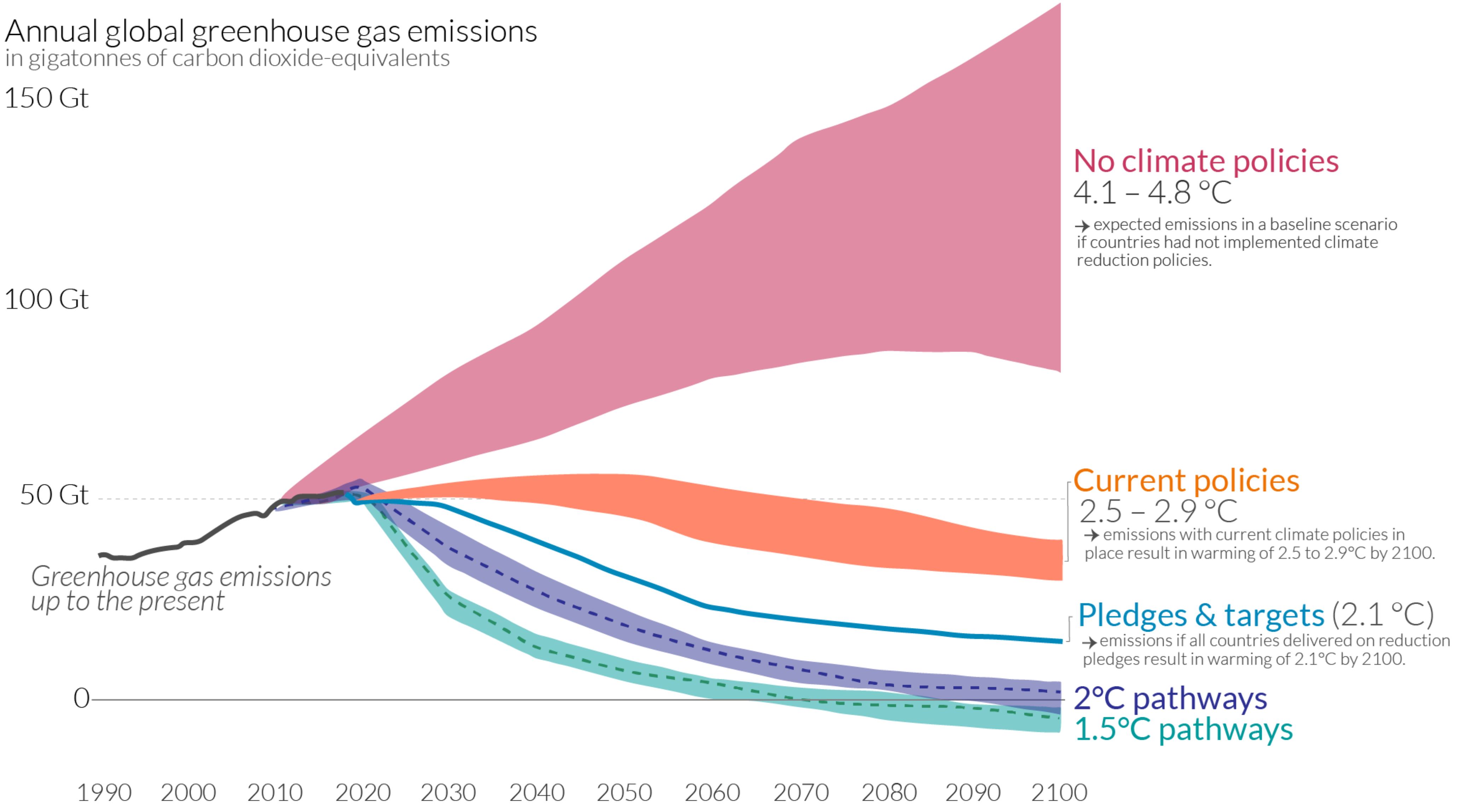
Source: MeteoSwiss

Climate crisis summary

- All scientists agree that human activities and greenhouse gas emissions (primarily CO_2) are responsible for the current temperature increases
- Climate models agree about the effects, trends, and causes of climate change
- Global average temperatures have risen by 1.2ºC compared to the pre-industrial average
- Current atmospheric CO_2 concentrations (>420 ppm) are the highest in 800,000 years
- With current policies, expected warming will be in the range of 2.5-2.9ºC (best case), or 3-5ºC (worst case)

Global greenhouse gas emissions and warming scenarios

– Each pathway comes with uncertainty, marked by the shading from low to high emissions under each scenario.
– Warming refers to the expected global temperature rise by 2100, relative to pre-industrial temperatures.



Data source: Climate Action Tracker (based on national policies and pledges as of November 2021).
OurWorldinData.org – Research and data to make progress against the world's largest problems.

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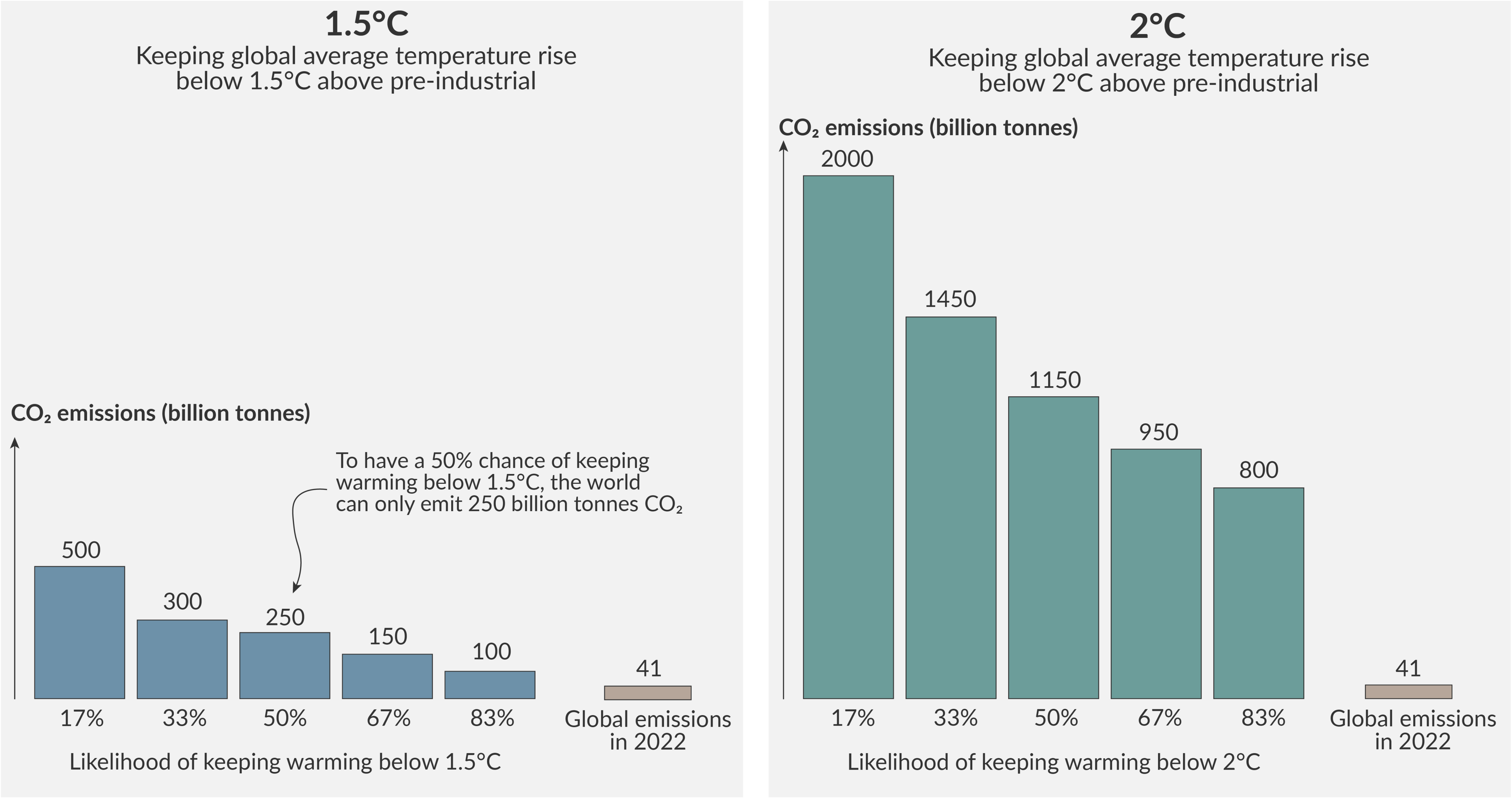
Carbon budget to keep global warming below 1.5°C and 2°C

How much total CO_2 can be emitted to keep global average temperature rise below 1.5C and 2C, compared to pre-industrial temperatures. This is remaining budget from the start of 2023. Current annual emissions from fossil fuels, industry and land use are shown for context.



Data source: Budgets from Forster et al. (2023). Current emissions data from the Global Carbon Project.

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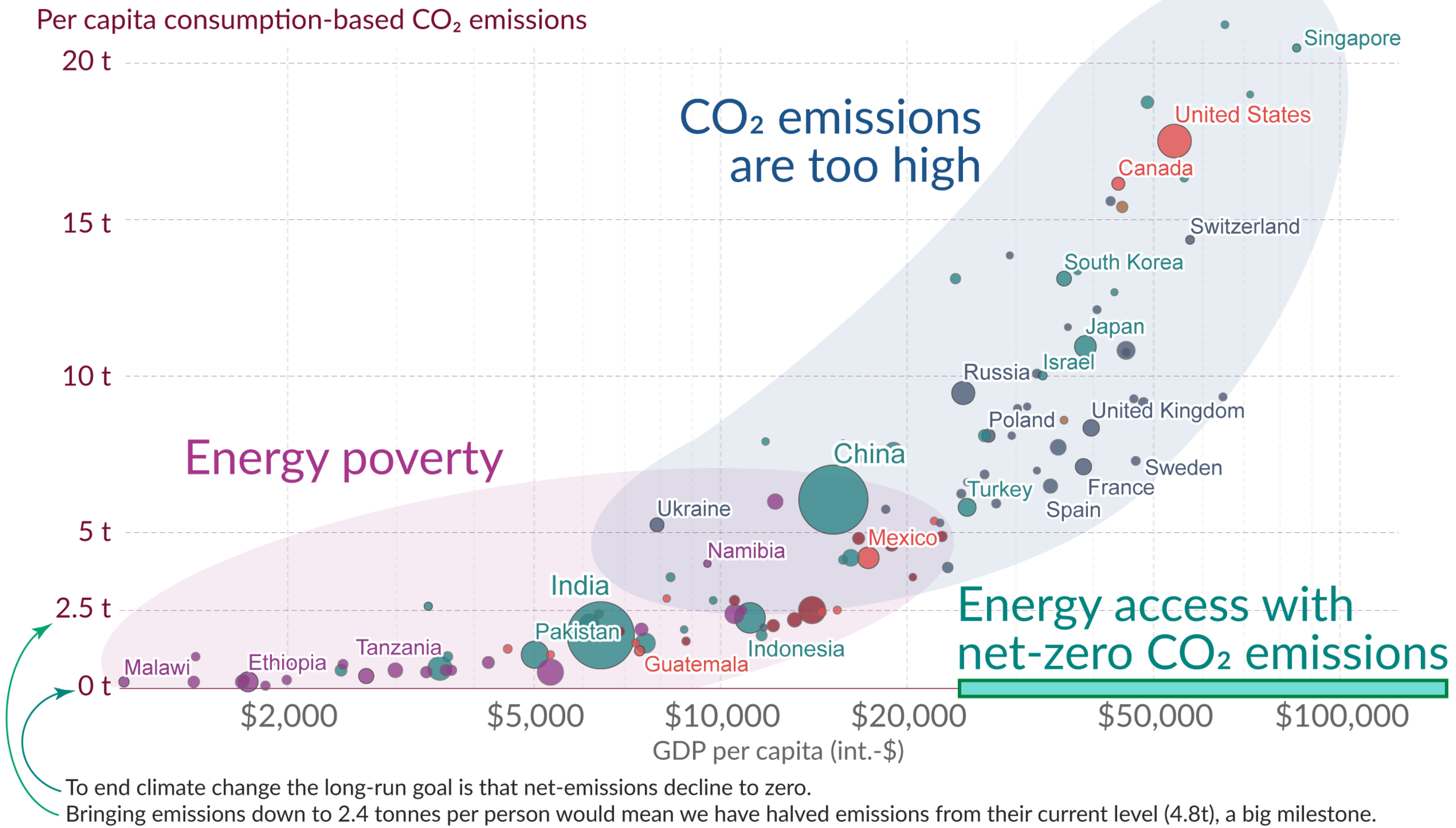
CO_2 emissions per capita vs GDP per capita

Our World in Data



Data: Global Carbon Project, UN Population, and World Bank.

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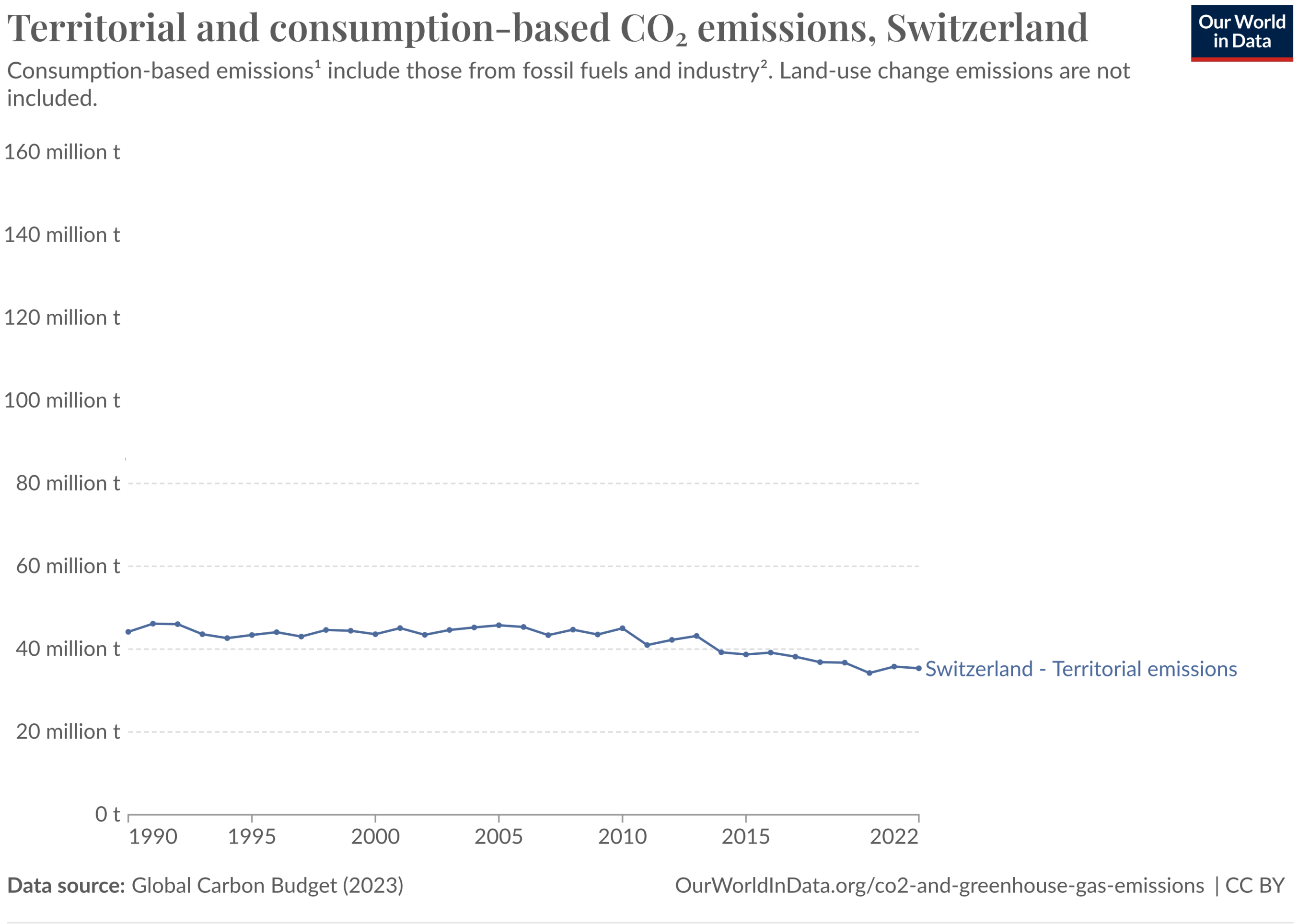
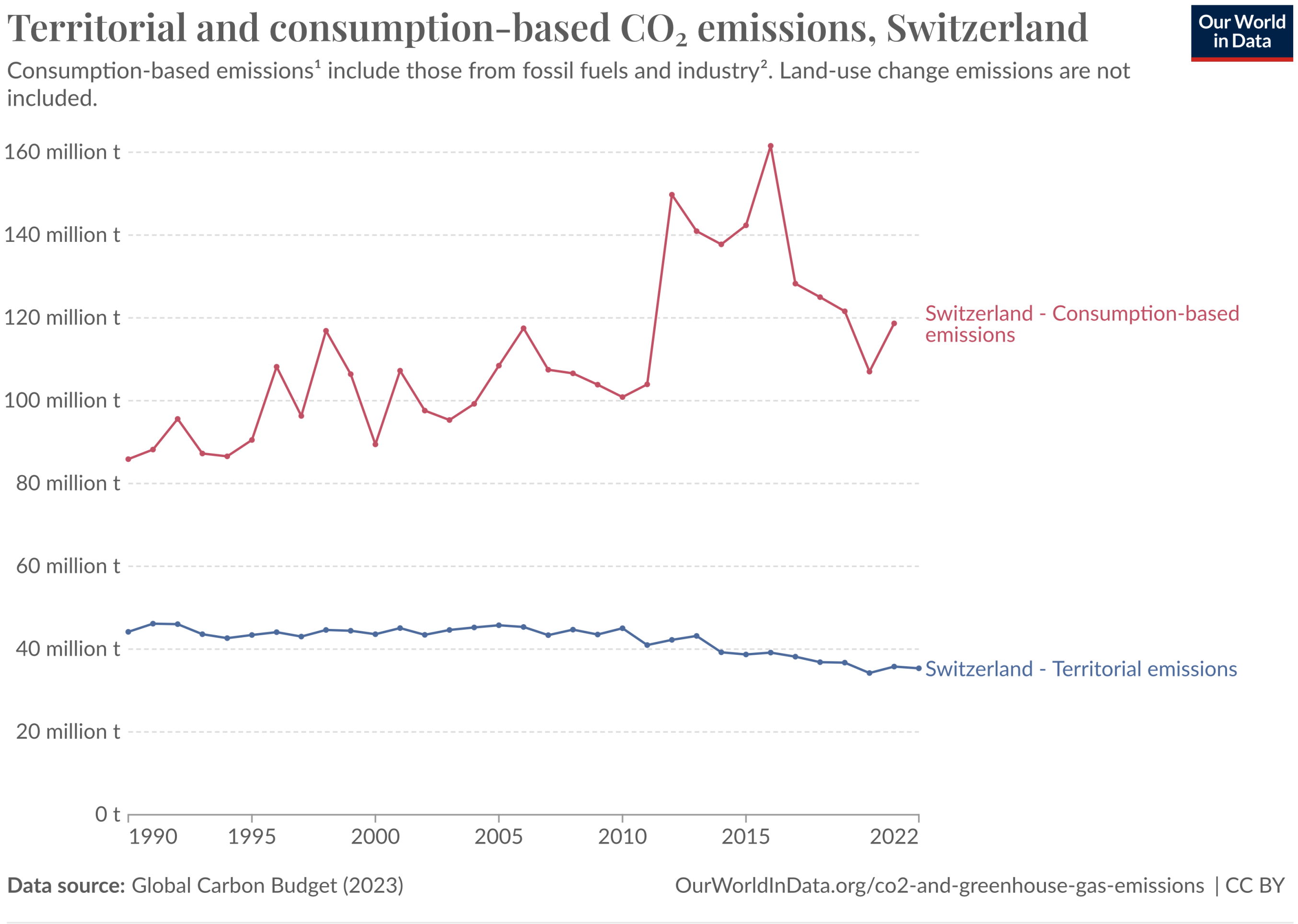
Swiss CO_2 emissions

- 20% reduction in national CO_2 emissions since 1990



Swiss CO_2 emissions

- 20% reduction in national CO_2 emissions since 1990
- But there is growth (with variability) in emissions when trade flows are integrated
- "Imported CO_2" = ~3x CO_2 produced
  - Ex: 3x more air transport than the European average



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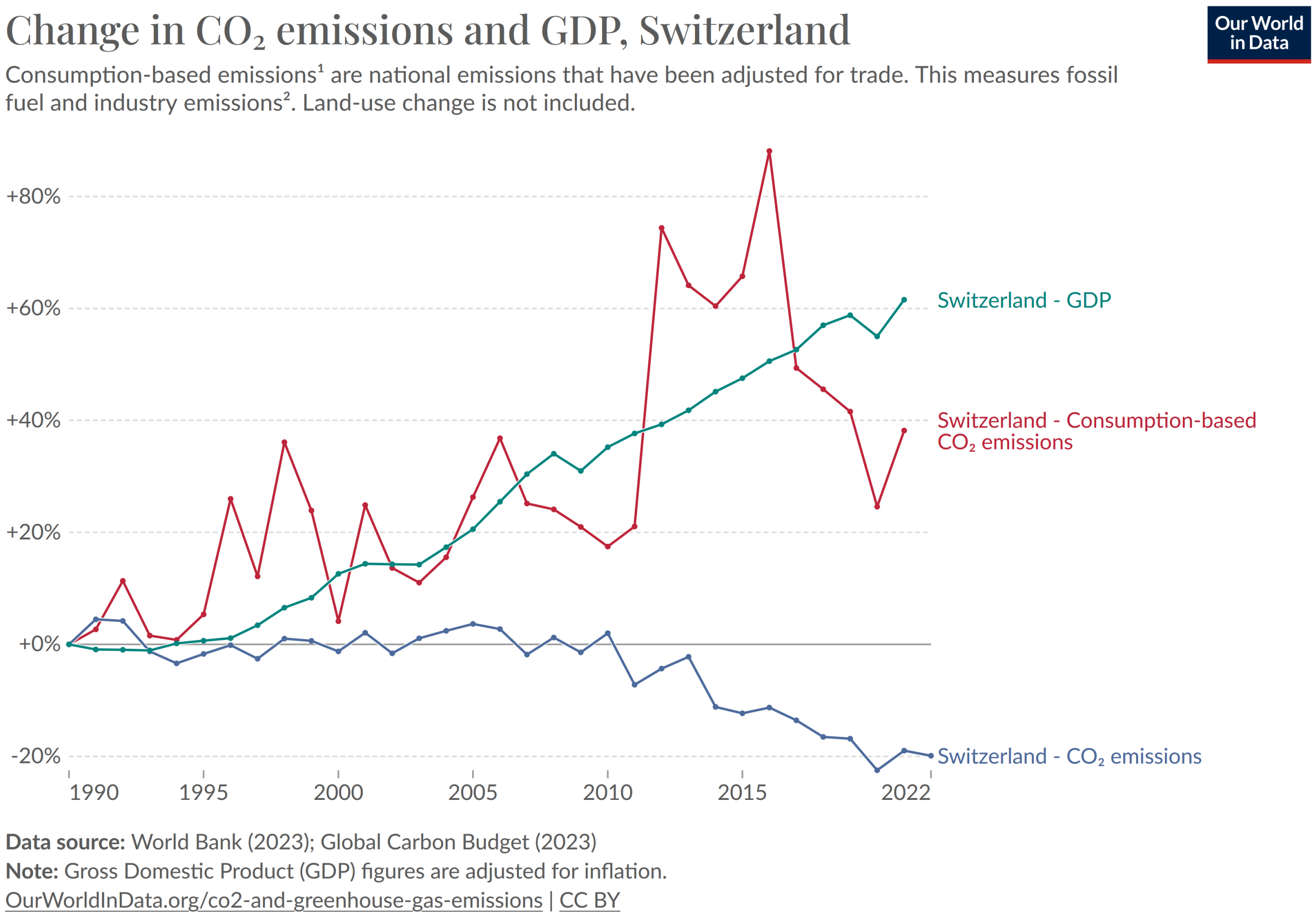
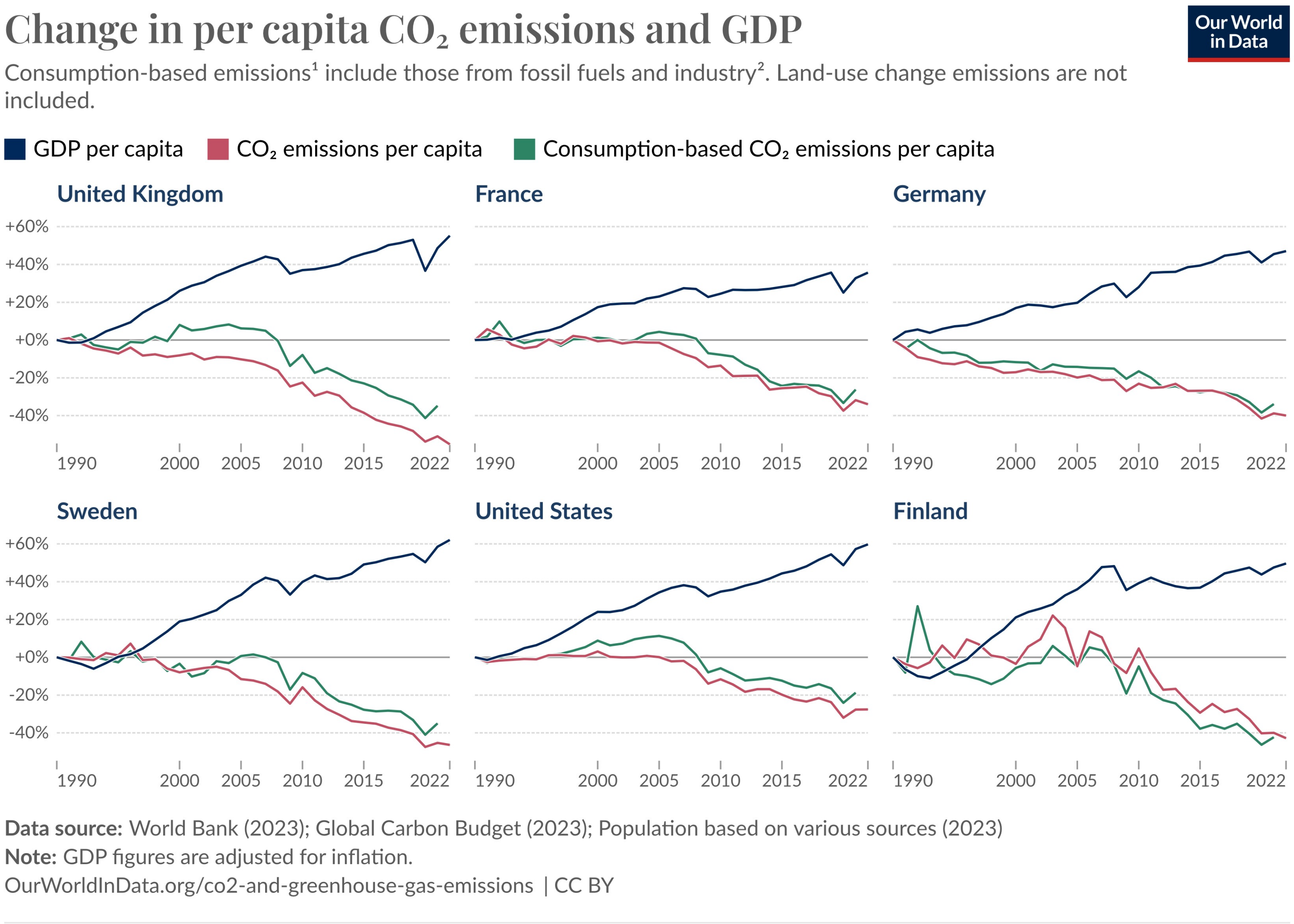


Some countries (not many) have been able to decouple economic growth from both territorial carbon emissions and consumption-based carbon emissions



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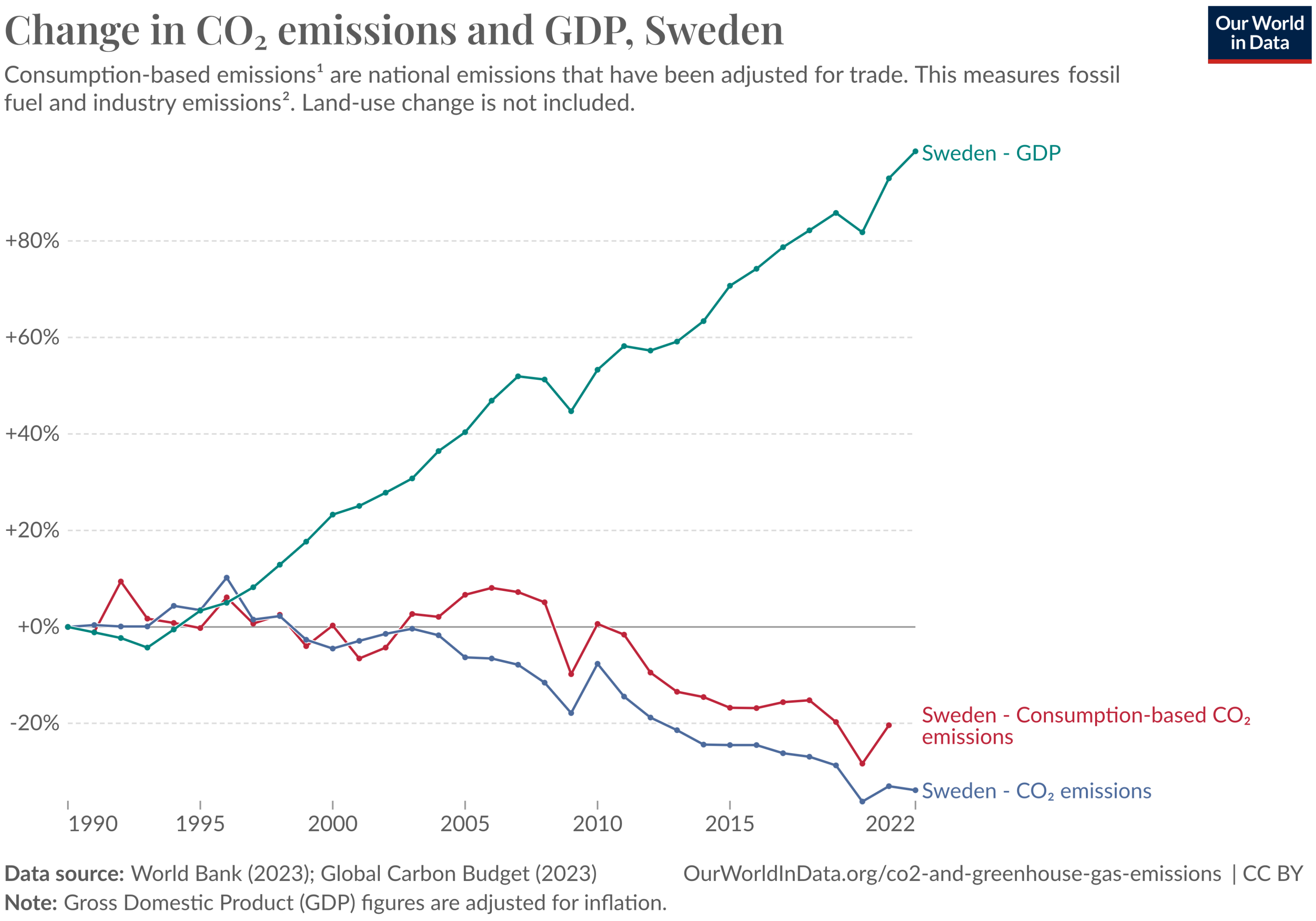
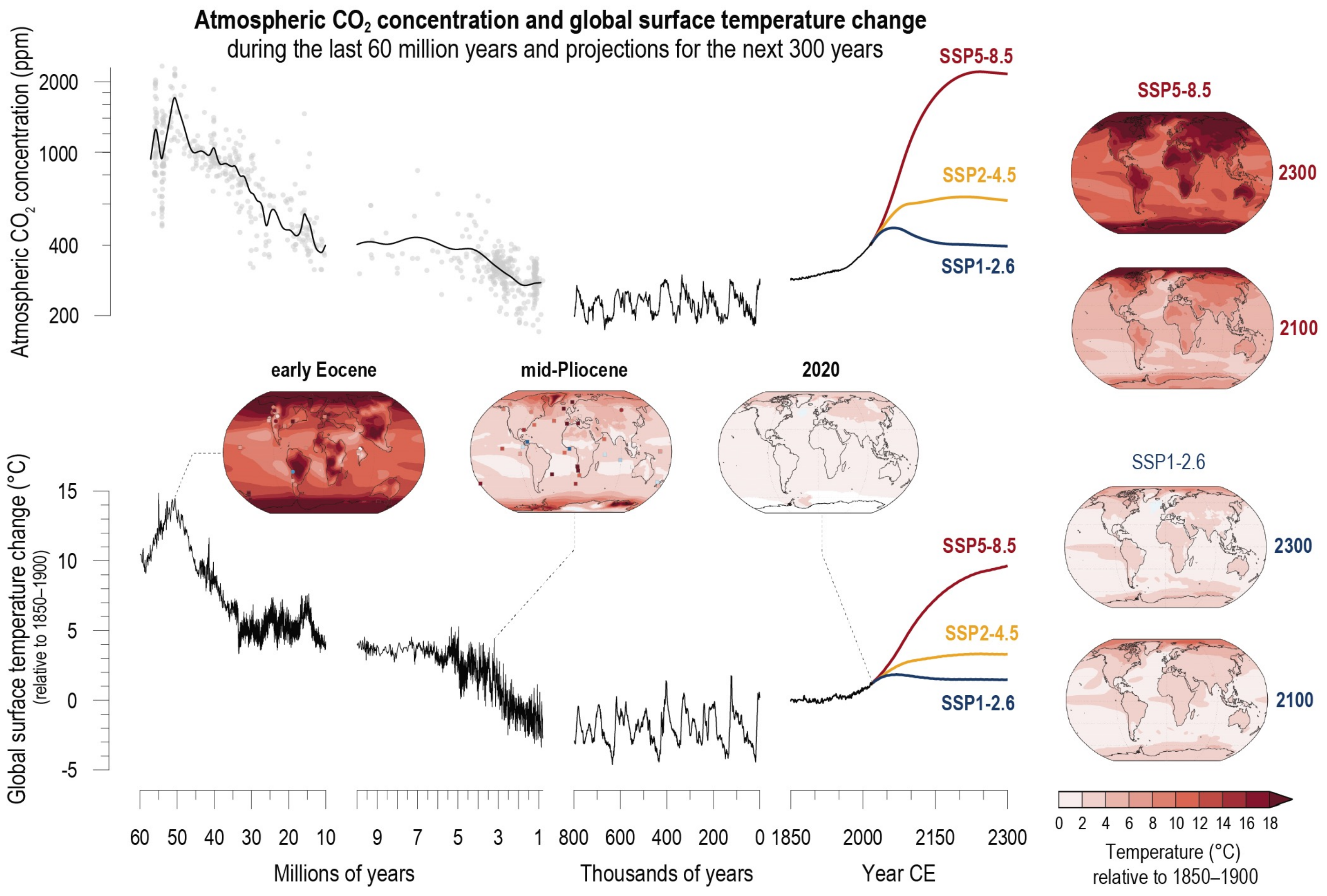
Some elements from Sweden

- Growing carbon tax since 1991
- Increasing renewables production
- Improving energy efficiency
- Promoting sustainable transportation
- Encouraging sustainable production and consumption



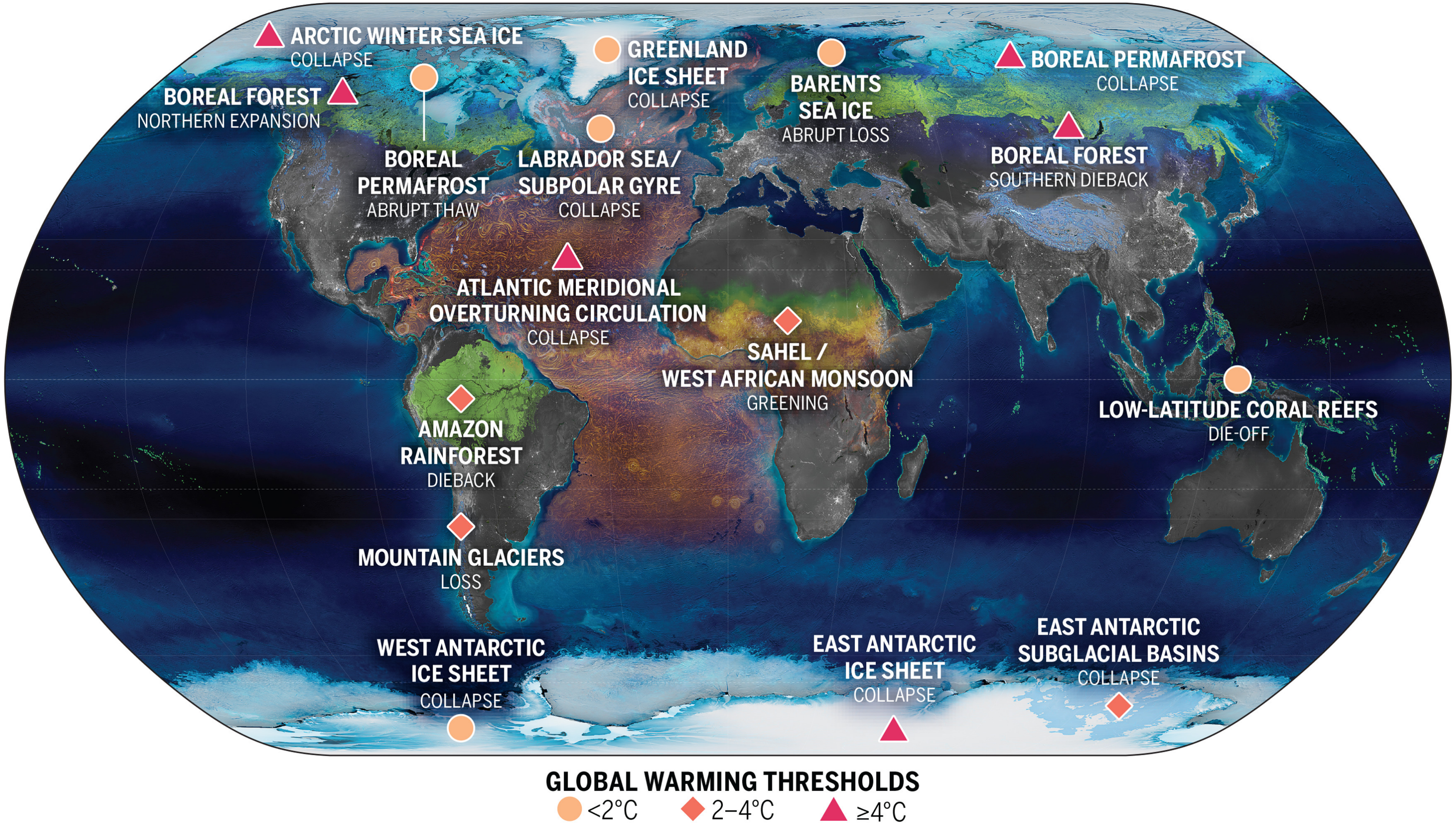
Is it a problem?

- Let's take a 60-million-year perspective compared to future scenarios
- Middle scenario: climate of the mid Pliocene
- High scenario: climate of the early Eocene (50 million years ago)



Source : IPCC AR6 WG1 Figure TS.1, 2021

Ok, so the earth is warming, but 2º doesn’t sound like very much!



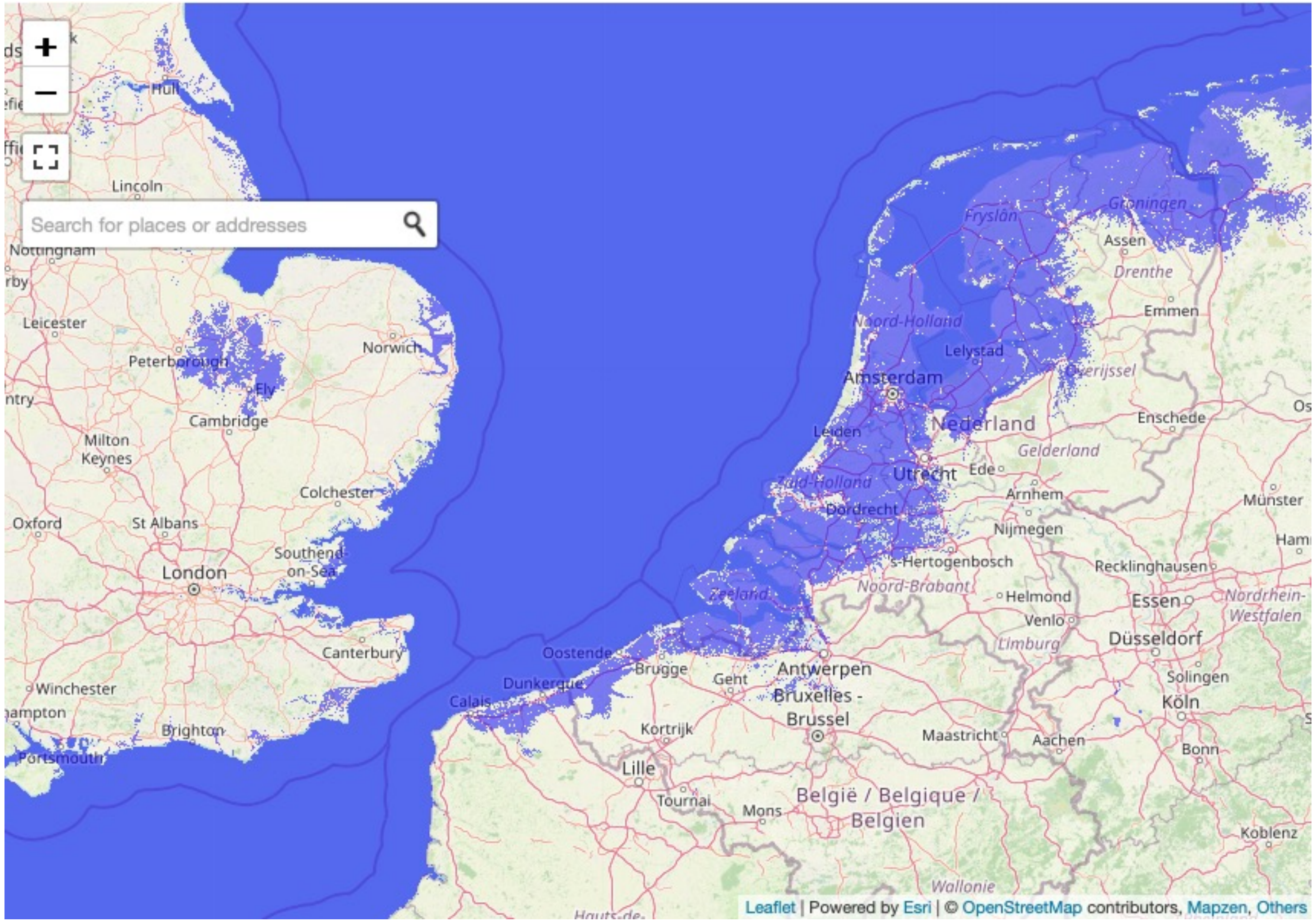
Impacts from climate change

- Sea level rise and coastal erosion
- Extreme weather
  - Heat waves
  - Fires
  - Storms
  - Droughts
- Agricultural impacts
- Loss of biodiversity
- Local pollution
- It is affecting the planet and the people
- Global warming, **climate change**, or **climate crisis**?

Sea level rise

- Due to melting ice on land and expanding water
- Even more impactful with storm surges
- IPCC estimates 0.29-0.59m for a low emissions scenario, 0.61-1.10m for a high emissions scenario

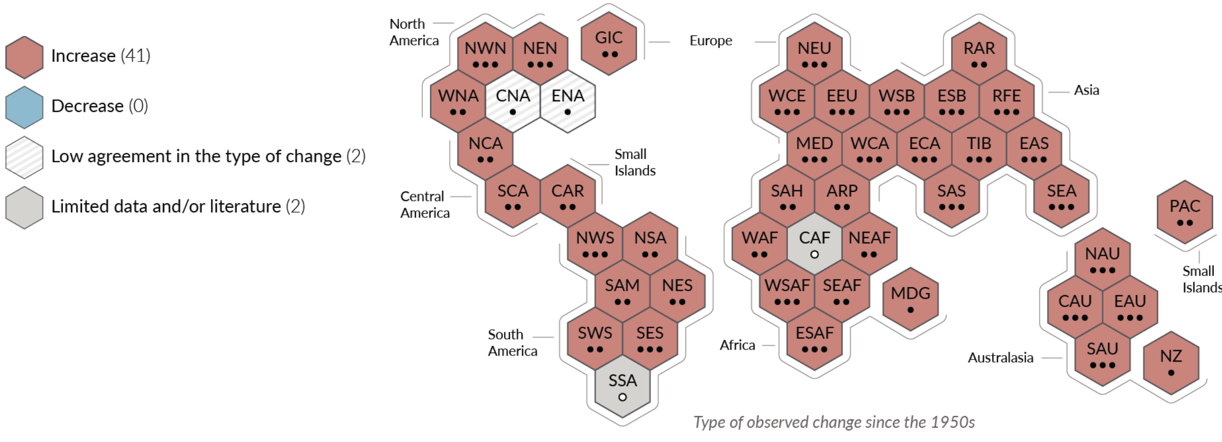
1m of sea level rise



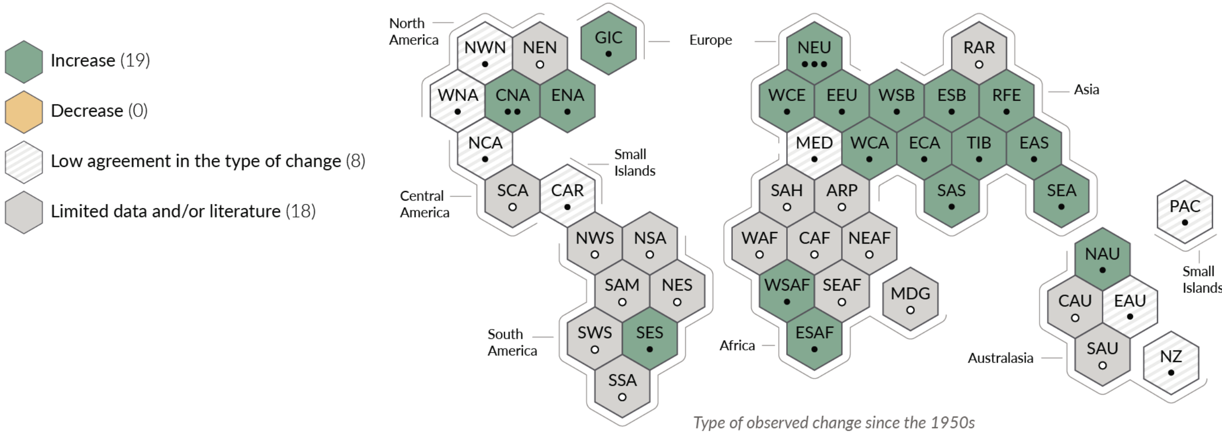
Acute weather impacts

- The frequency and strength of heat waves, extreme (acute) rainstorms, and droughts are all increasing

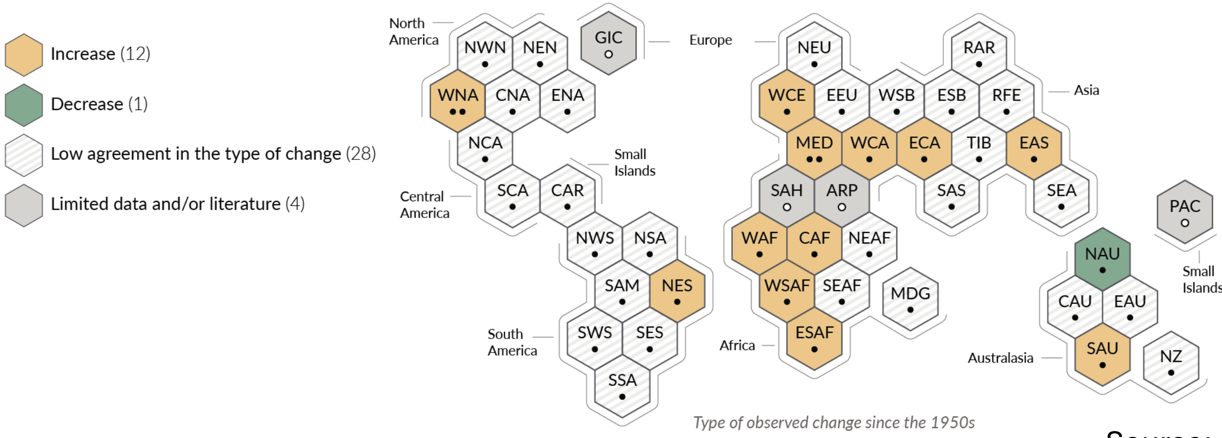
Extreme heat



Extreme rain



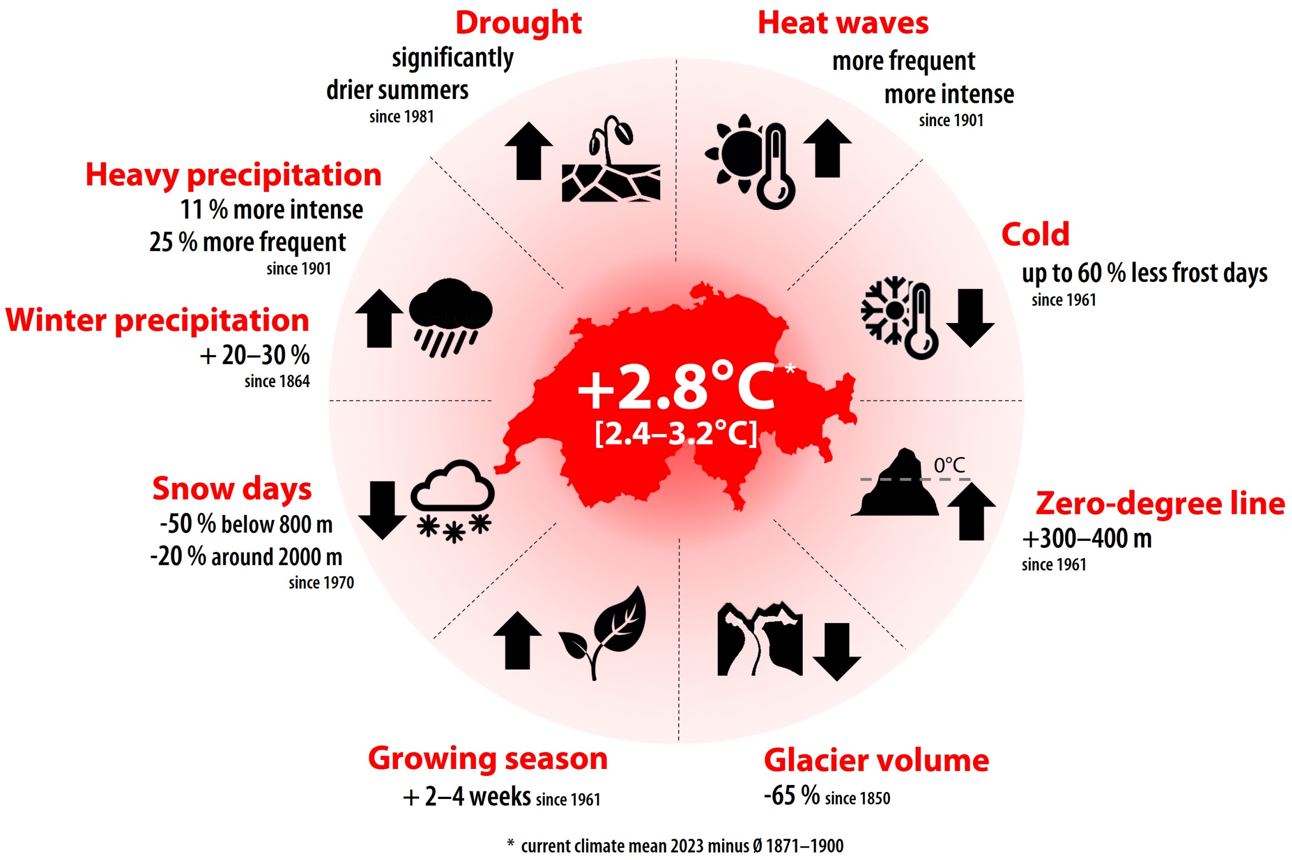
Drought



Source: IPCC

Impacts from climate change in Switzerland

- Some very specific impacts in alpine regions



Source: MeteoSwiss

A summary of CO_2 emission mitigation strategies

- Switching to renewable energies – a huge number of solar panels, wind turbines, and batteries are required
- Reducing energy demand – e.g., in buildings, transportation
- Electrification – shifting away from fossil fuels in heating and transportation
- Less emissions from agriculture – especially eating less meat
- Carbon capture and storage? – lots of debate here
- **For first assignment: explore En-ROADS Climate Solutions Simulator from MIT**

What is **sustainability**?

- We have seen the stark realities of human activity on the climate
- How can we conceptualize solving the problem?
- How do we consider the various systems at play?
  - Earth and environment
  - Human society and our well-being

Early definition of sustainability

- The World Commission on Environment and Development, now known as the **Brundtland Commission**, was founded as a sub-organization of the United Nations in 1983 and published an influential report in 1987

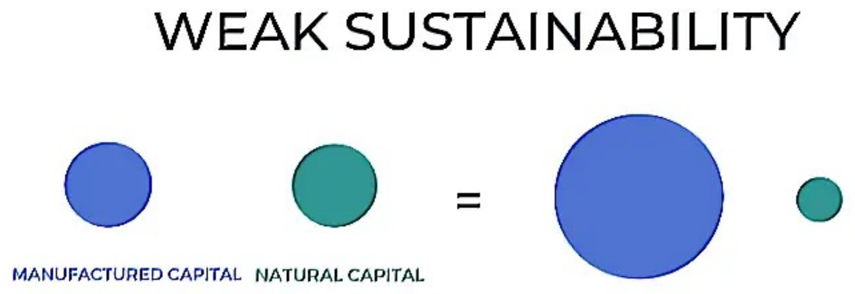
- "**Sustainable development** is development
- that **meets the needs of the present**
- without compromising the ability
- of **future generations** to meet their own needs"

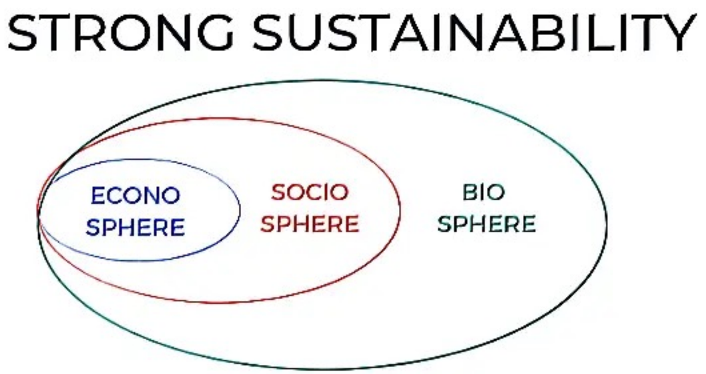
Gro Harlem Brundtland, first head of the commission

Weak and strong sustainability

- Weak sustainability
  - Claims that human and manufactured capital can replace natural capital
  - If we degrade the natural environment, we can make up for lost capital through technological innovation
  - Based on the work of Robert Solow, MIT economist and Nobel Prize winner, who argued that sustainability does not required saving specific natural resources

- Strong sustainability:
  - Claims that human and manufactured capital are not interchangeable with natural capital
  - Destruction of natural capital cannot be reversed
  - We derive human/manufactured capital from natural capital
  - It is critical to preserve our natural resources

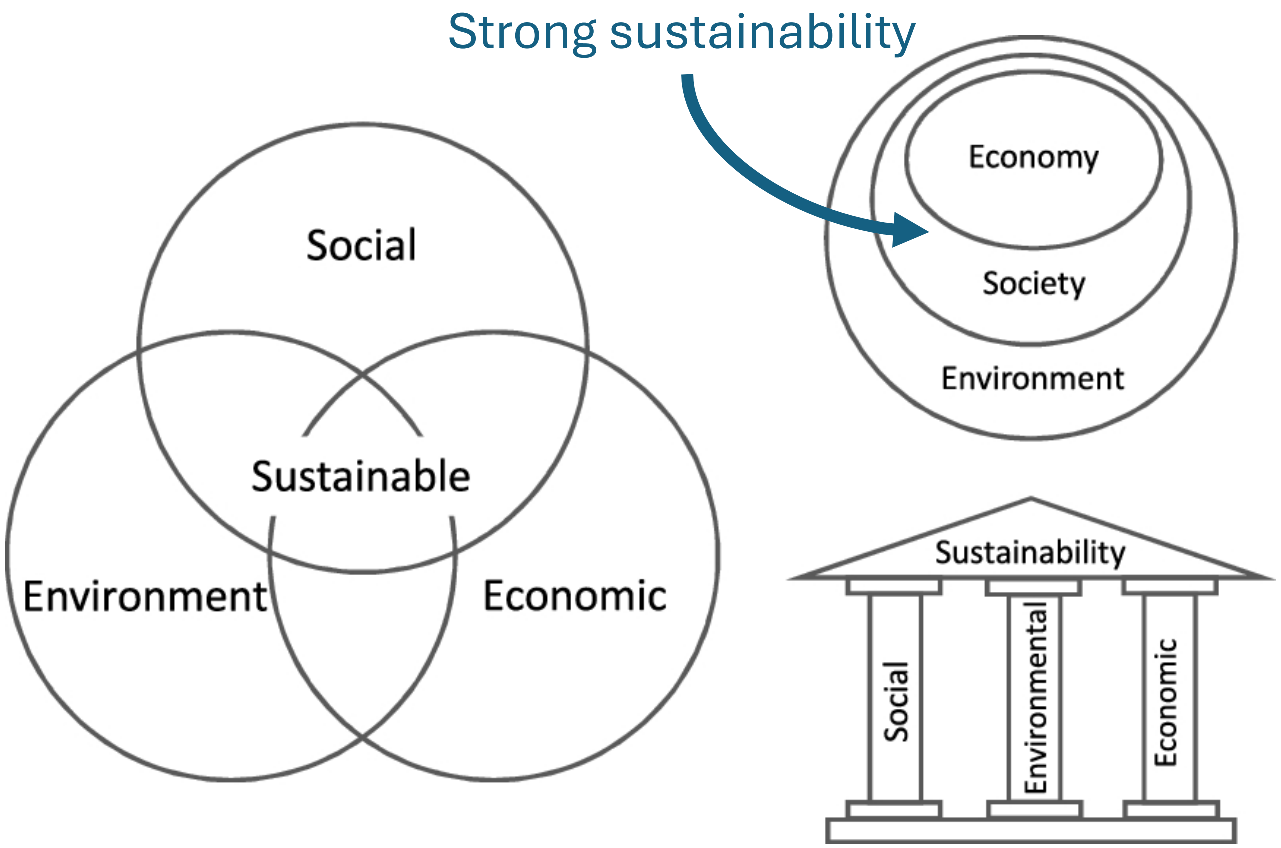




Source: UN

The three-pillar conception of sustainability

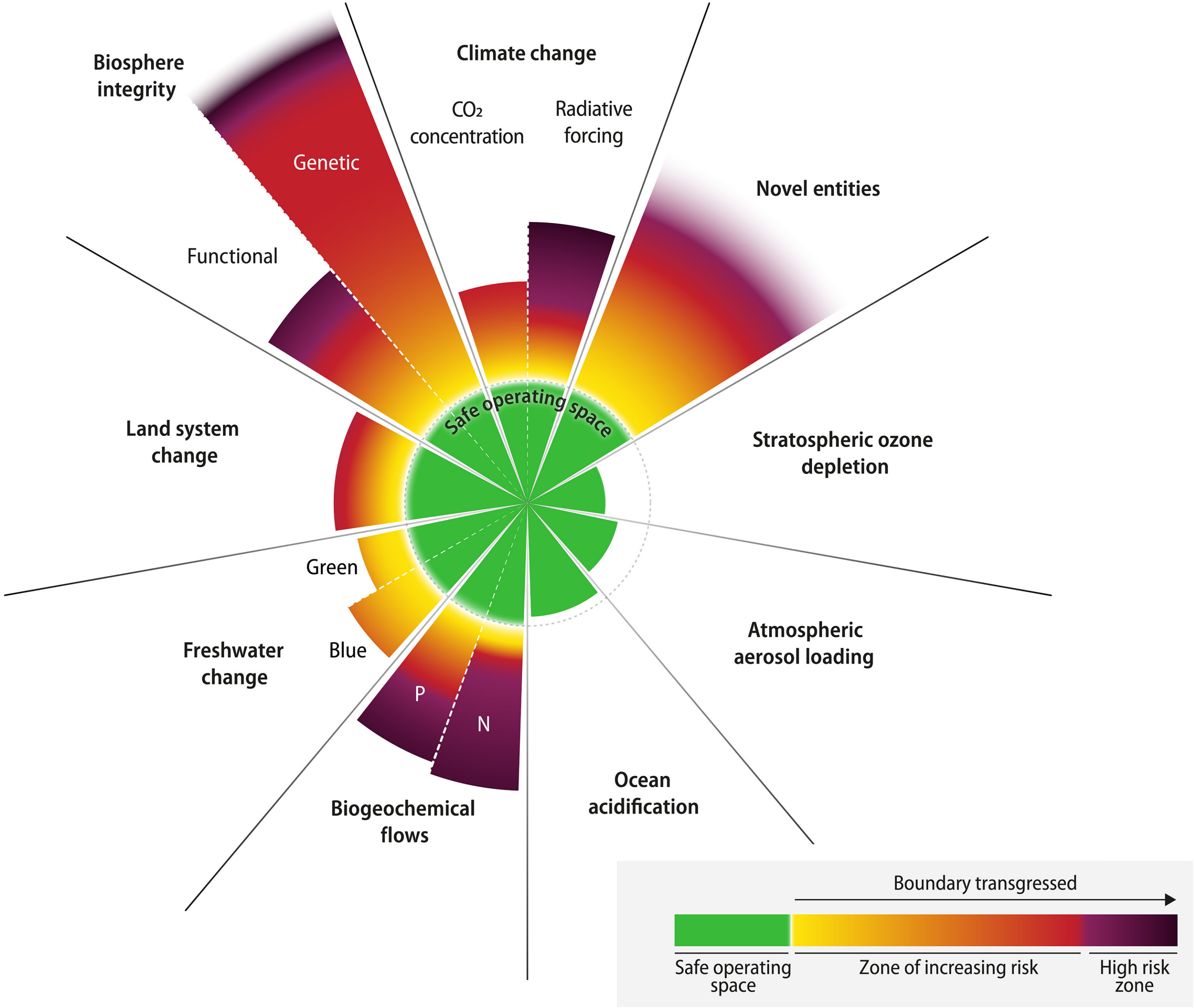
- Three pillars:
  - Environment
  - Social
  - Economic
- Ubiquitous definition of "sustainability," though the origin has been difficult to identify precisely



Source: Purvis, B., Mao, Y. & Robinson, D. Three pillars of sustainability: in search of conceptual origins. Sustain Sci 14, 681–695 (2019). https://doi.org/10.1007/s11625-018-0627-5

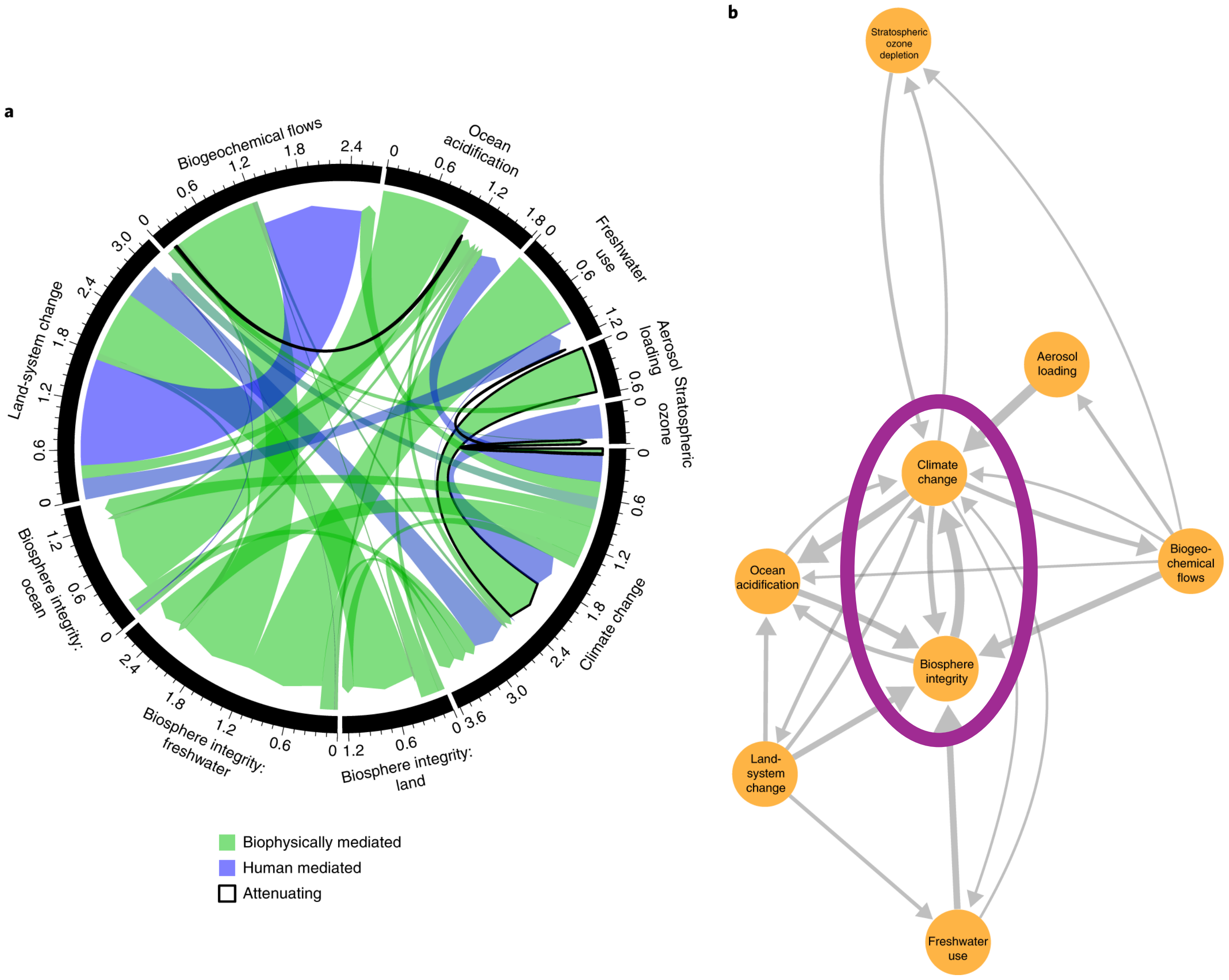
The Planetary Boundaries

- The framework identifies nine processes that are critical for maintaining the stability and resilience of Earth system as a whole
- All are presently heavily perturbed by human activities
- 2023 update: We have transgressed 6 of 9.



Source: Katherine Richardson *et al.*, Earth beyond six of nine planetary boundaries. *Sci. Adv.* **9**, eadh2458 (2023). DOI:10.1126/sciadv.adh2458

Planetary boundary interactions

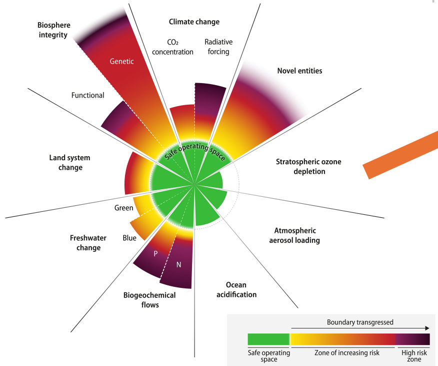


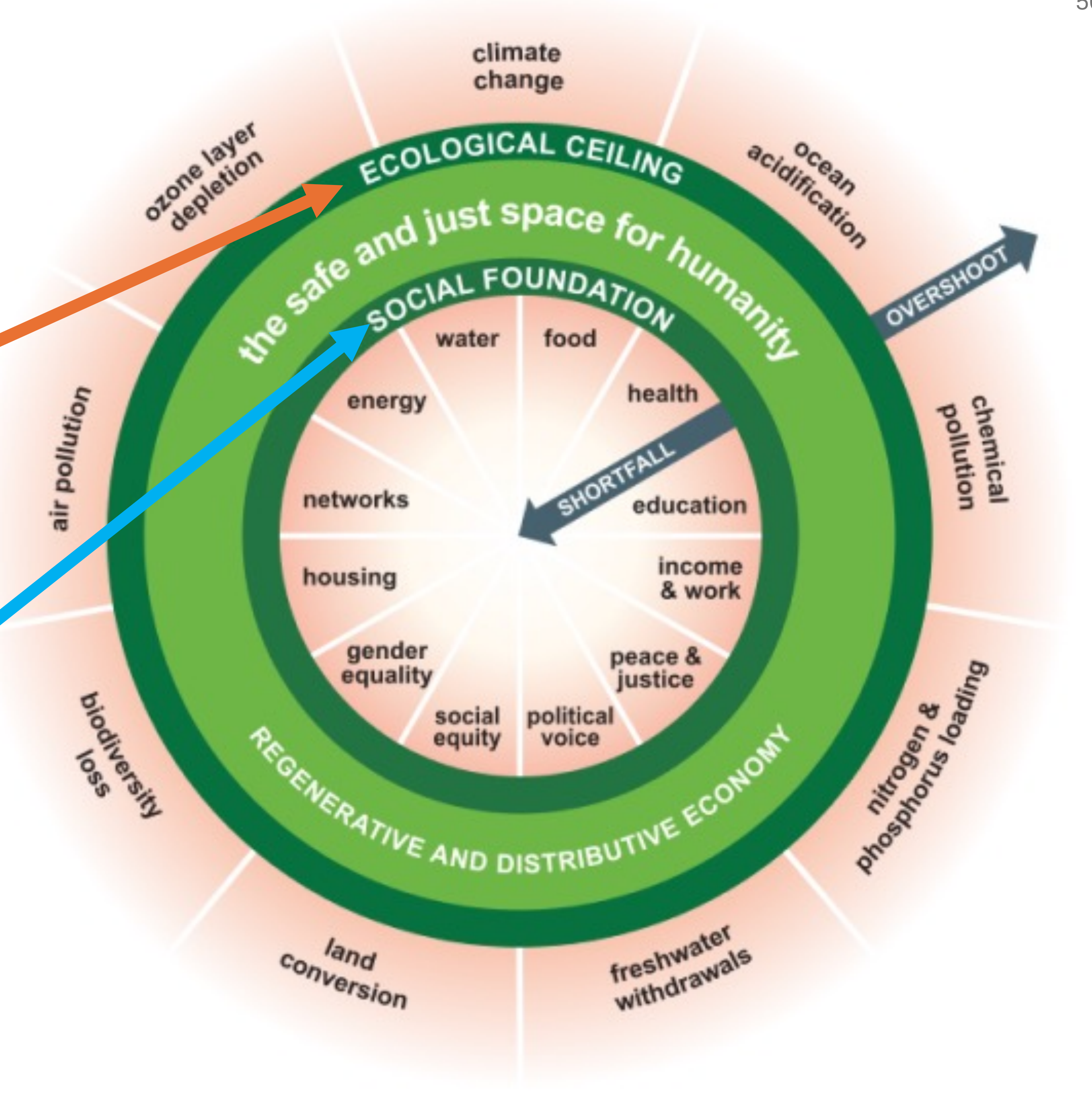
- Planetary boundaries can impact each other
- Climate change and Biosphere integrity are central

Lade, S. J., et al. (2020). Human impacts on planetary boundaries amplified by Earth system interactions. Nature Sustainability, 3(2), Article 2.

The Doughnut Model

- PBs define the ecological ceiling
- Sustainable development goals define social foundations

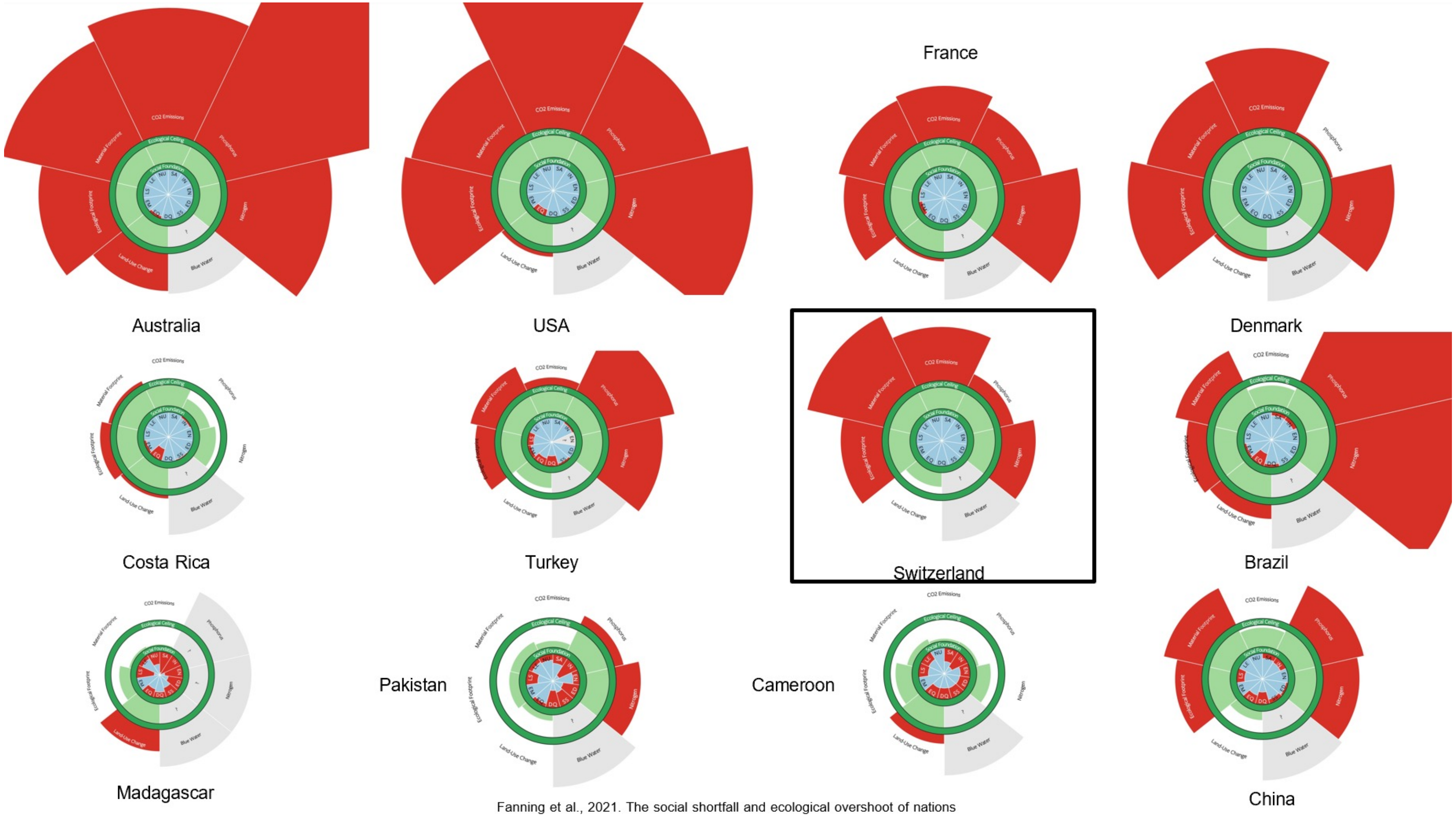




Source: Doughnut Economics Action Lab

The Doughnut Model

- Current status of different countries



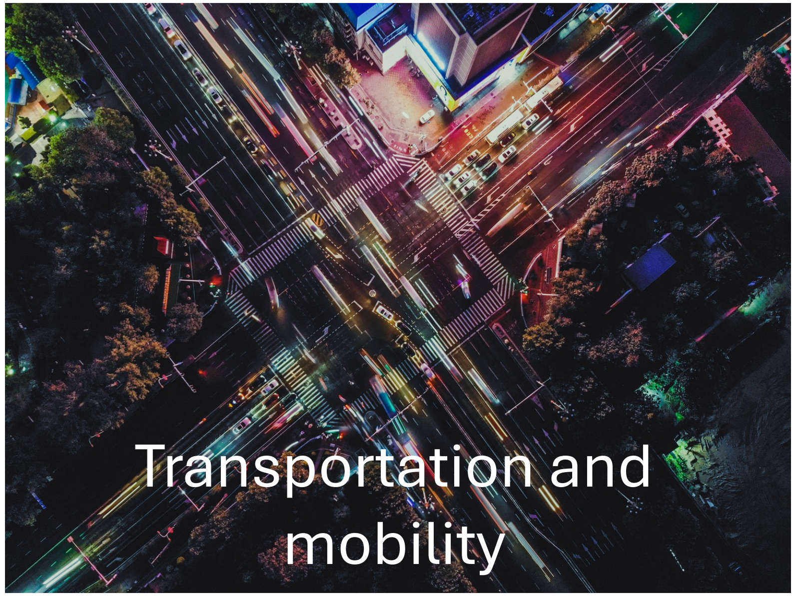
Fanning, A. L., et al. (2021). The social shortfall and ecological overshoot of nations. Nature Sustainability, 1-16. Supplementary material.

Sustainability in civil engineering

What is civil engineering at its core?

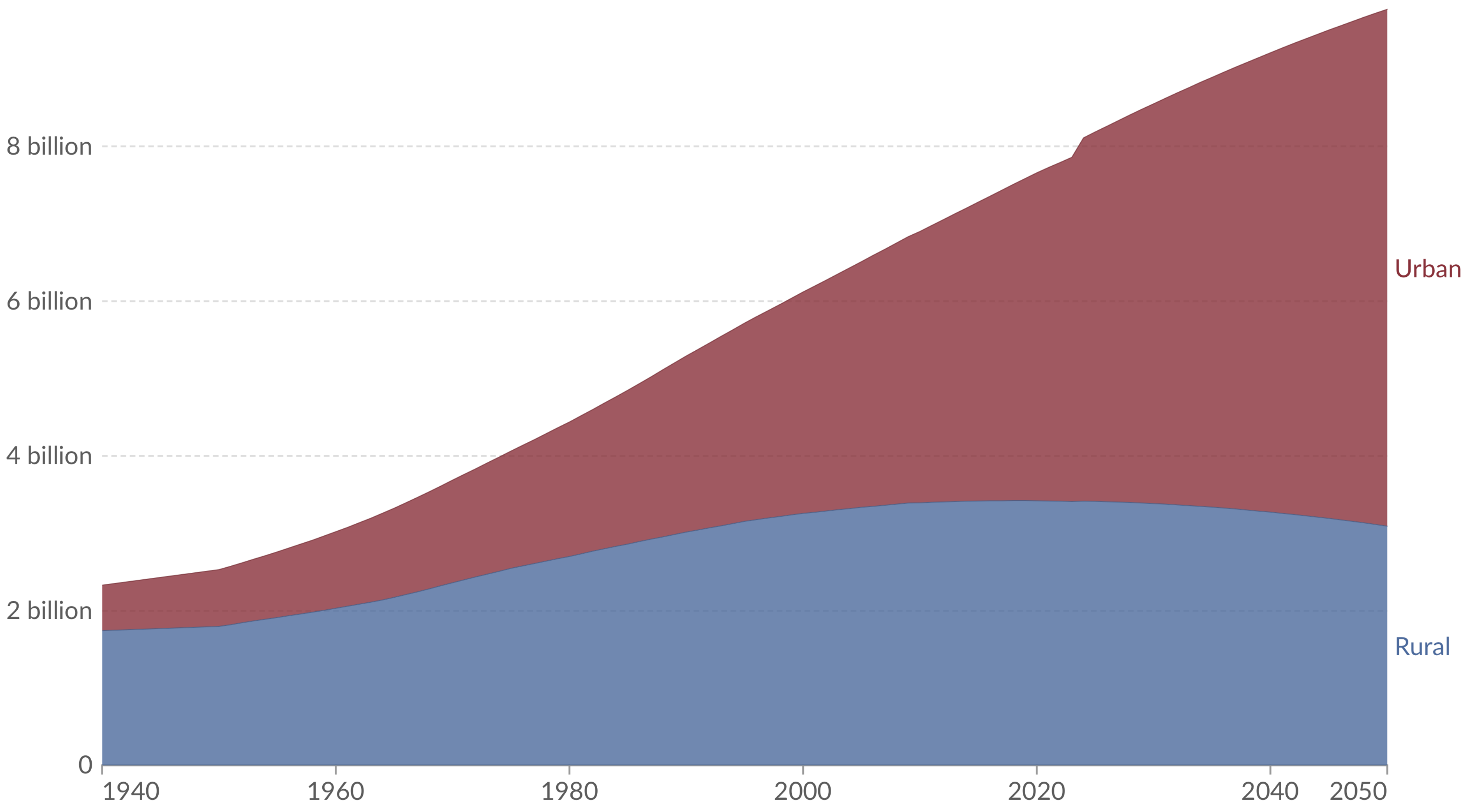
- American Society of Civil Engineers definition: Civil engineers **design, build, and maintain** the foundation for our modern **society** – our buildings, roads and bridges, drinking water and energy systems, sea ports and airports, and the infrastructure for a cleaner environment, to name just a few.

Subdisciplines of civil engineering



Urban and rural population projected to 2050, World, 1940 to 2050

Total urban and rural population, given as estimates to 2023, and UN projections to 2050. Projections are based on the UN World Urbanization Prospects and its median fertility scenario.



Data source: United Nations, Department of Economic and Social Affairs, Population Division (2018); HYDE (2023)
OurWorldInData.org/urbanization | CC BY

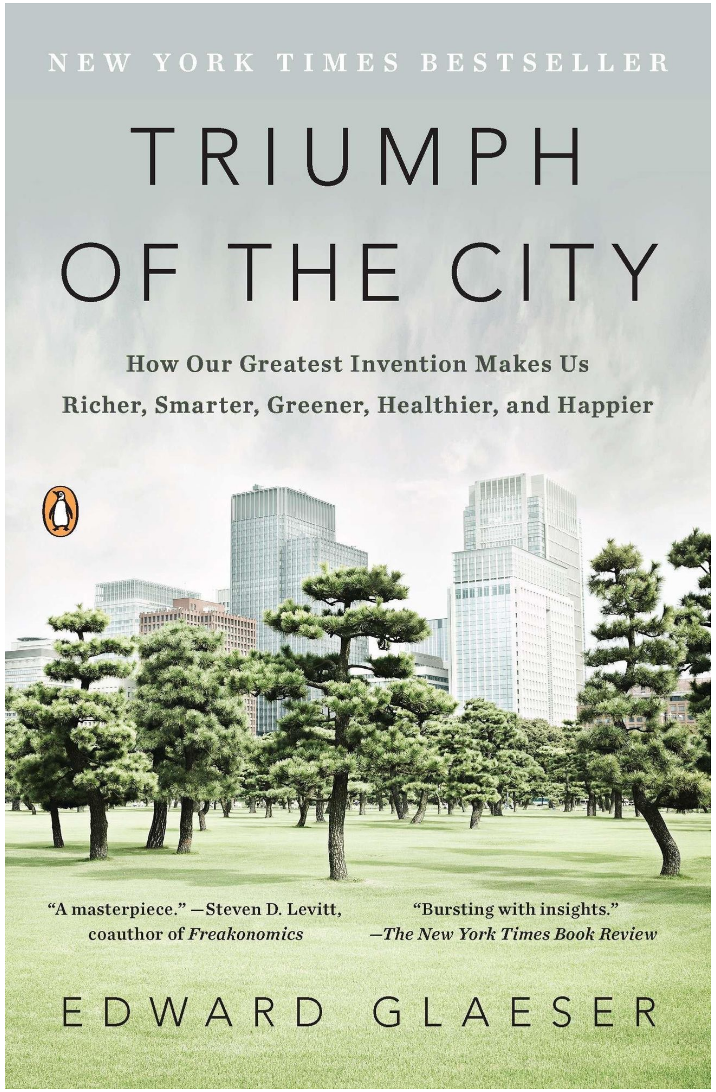
Why do cities grow?

"Cities magnify humanity's strengths"

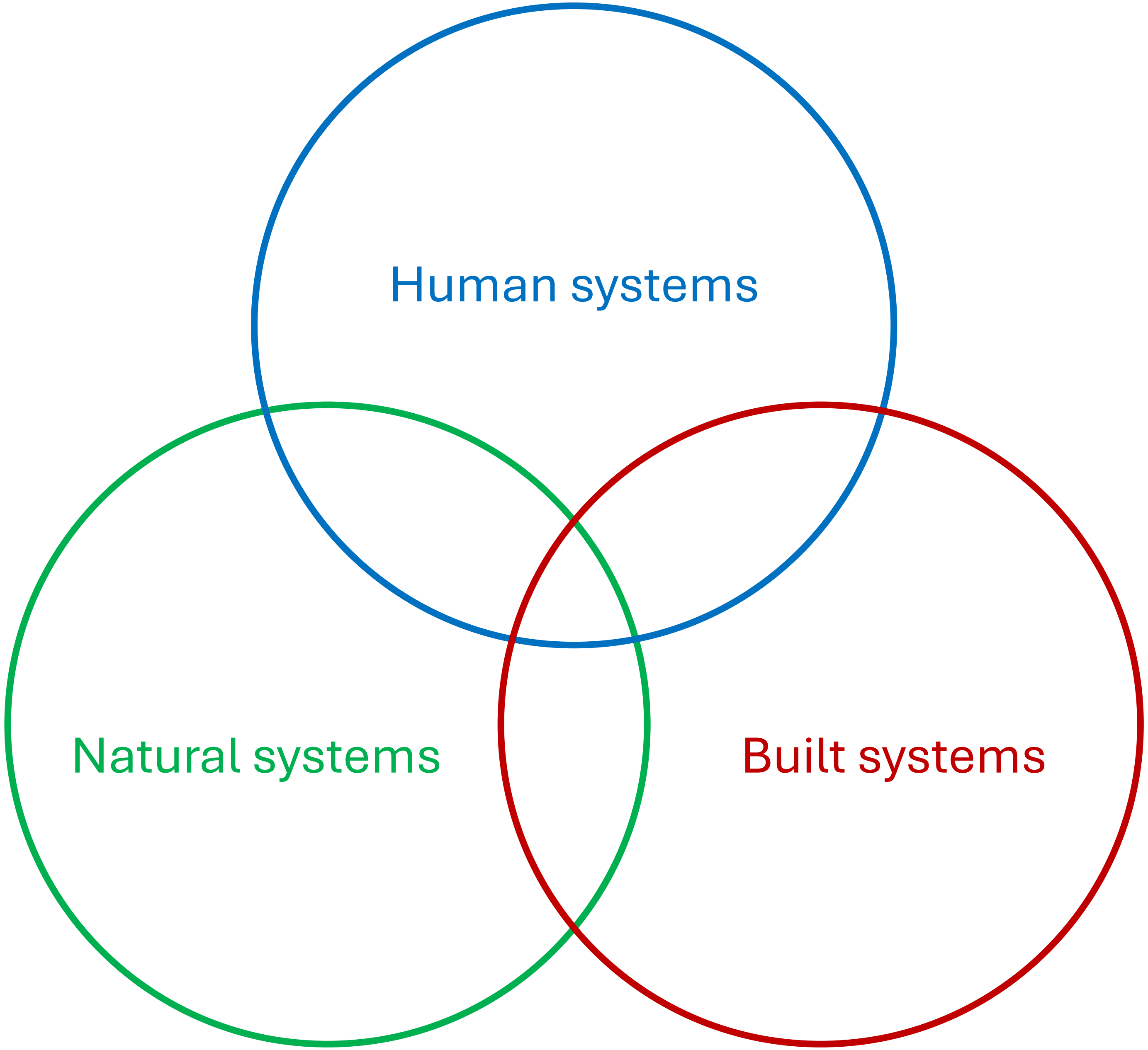
-Edward Glaeser, Professor of Economics, Harvard

*"They spur **innovation** by facilitating face-to-face interaction, they attract talent and sharpen it through competition, they encourage entrepreneurship, and they allow for social and economic mobility."*

-Diana Silver, Asst. Professor of Public Health, NYU (review of Triumph of a City in NY-Times)



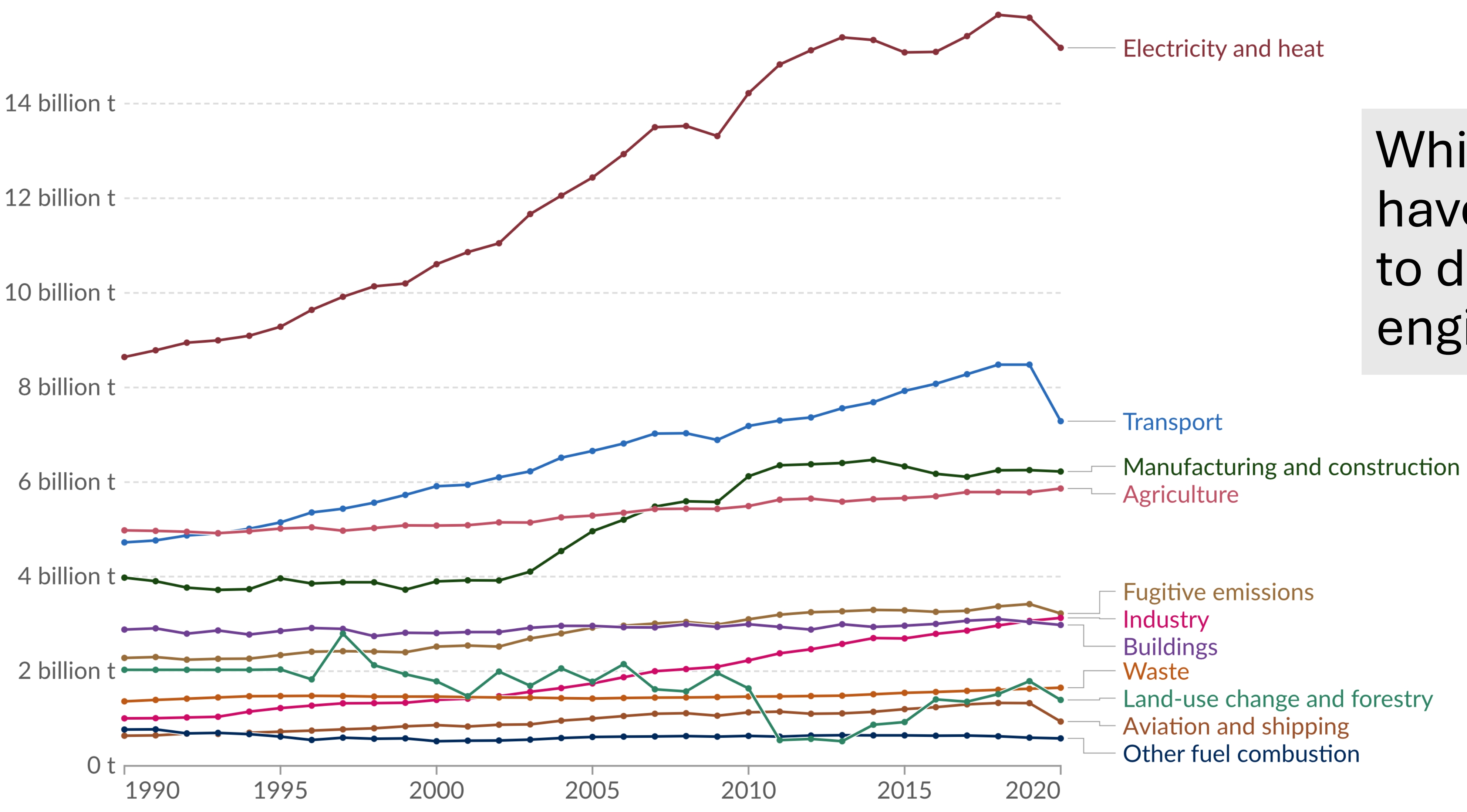
What systems exist in cities?



Greenhouse gas emissions by sector, World

Our World in Data

Greenhouse gas emissions[1] are measured in tonnes of carbon dioxide-equivalents[2] over a 100-year timescale.



Data source: Climate Watch (2023)

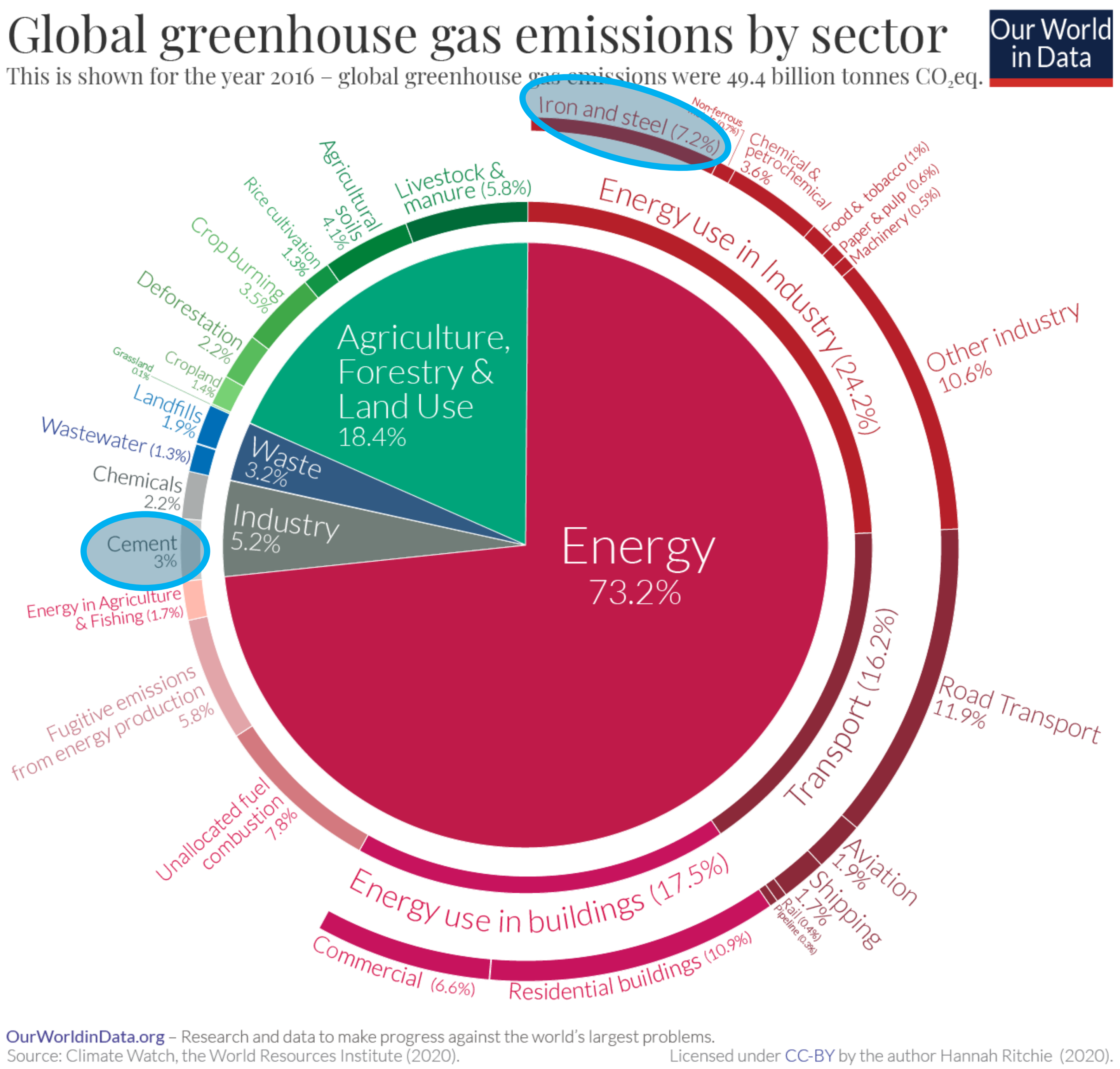
OurWorldInData.org/co2-and-greenhouse-gas-emissions | CC BY

Note: Land-use change emissions can be negative.

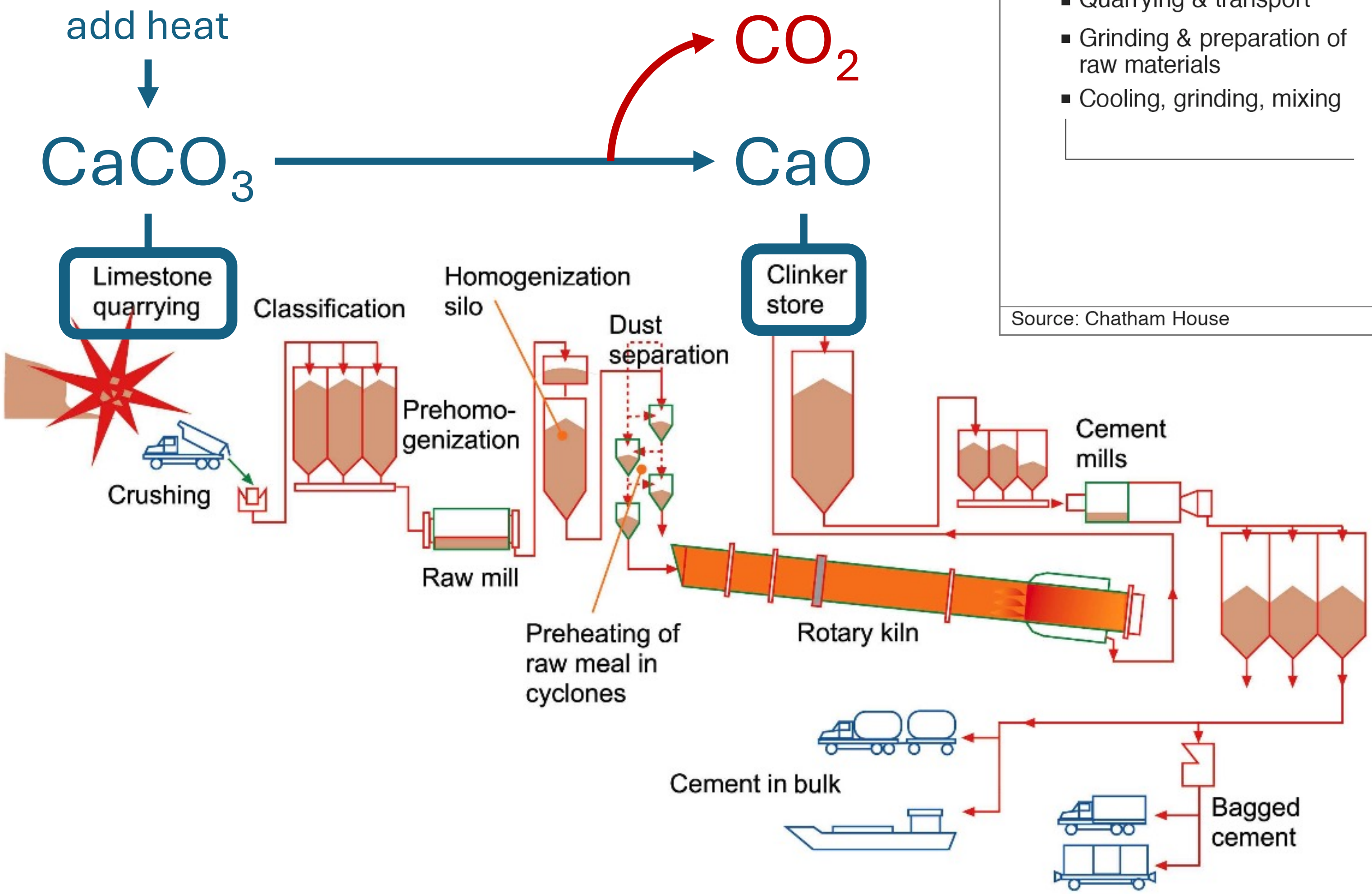
Which of these have something to do with civil engineering?

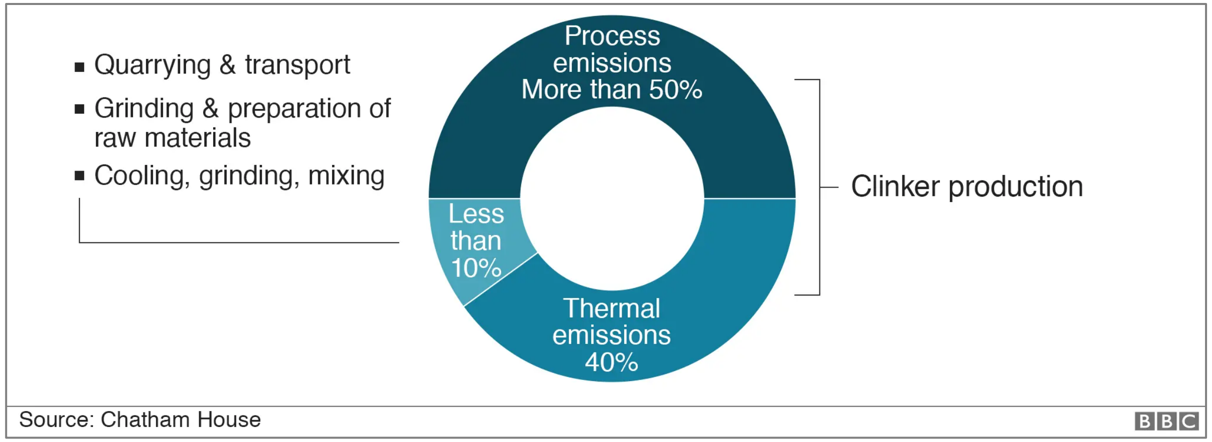
Another way to visualize (but note data is from 2015)

- Direct CO2 emissions from electricity production ~40% of total
- Cement and steel production



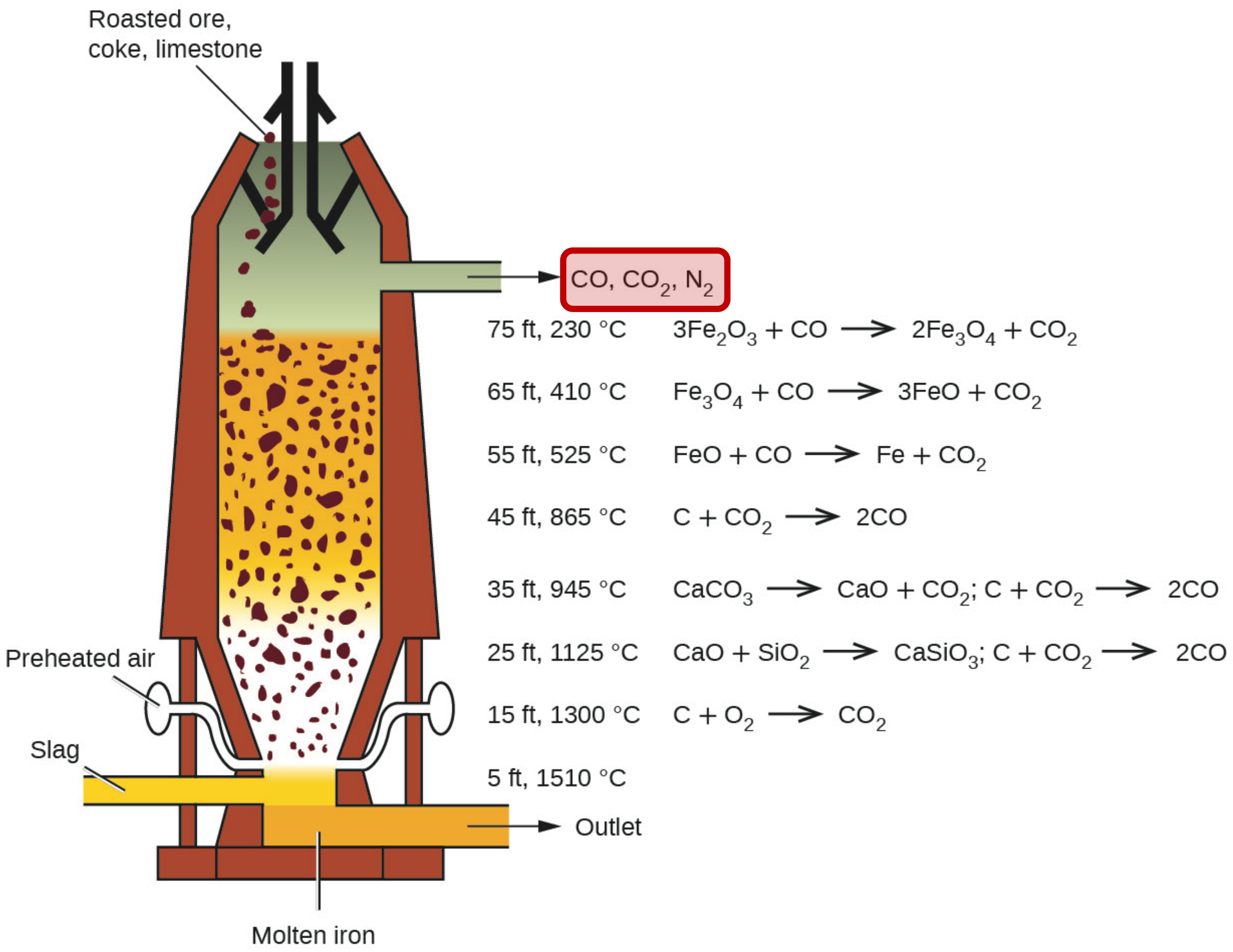
Cement production





Steel productio

- Production of steel also involves chemical processes that produce CO_2



Source: Wikimedia commons

UN Sustainable Development Goals (SDGs)

SUSTAINABLE DEVELOPMENT GOALS

Directly related to civil engineering

Overview of the topics in this course

- Part 1 – Course introduction, the climate crisis, setting the scene
- Part 2 – Buildings, energy demand, and energy supply
- Part 3 – Mobility and sustainability
- Part 4 – Materials, structures, and life-cycle assessment
- Part 5 – Natural systems and natural capital
- Part 6 – Sustainability in practice (guest lecture from industry)