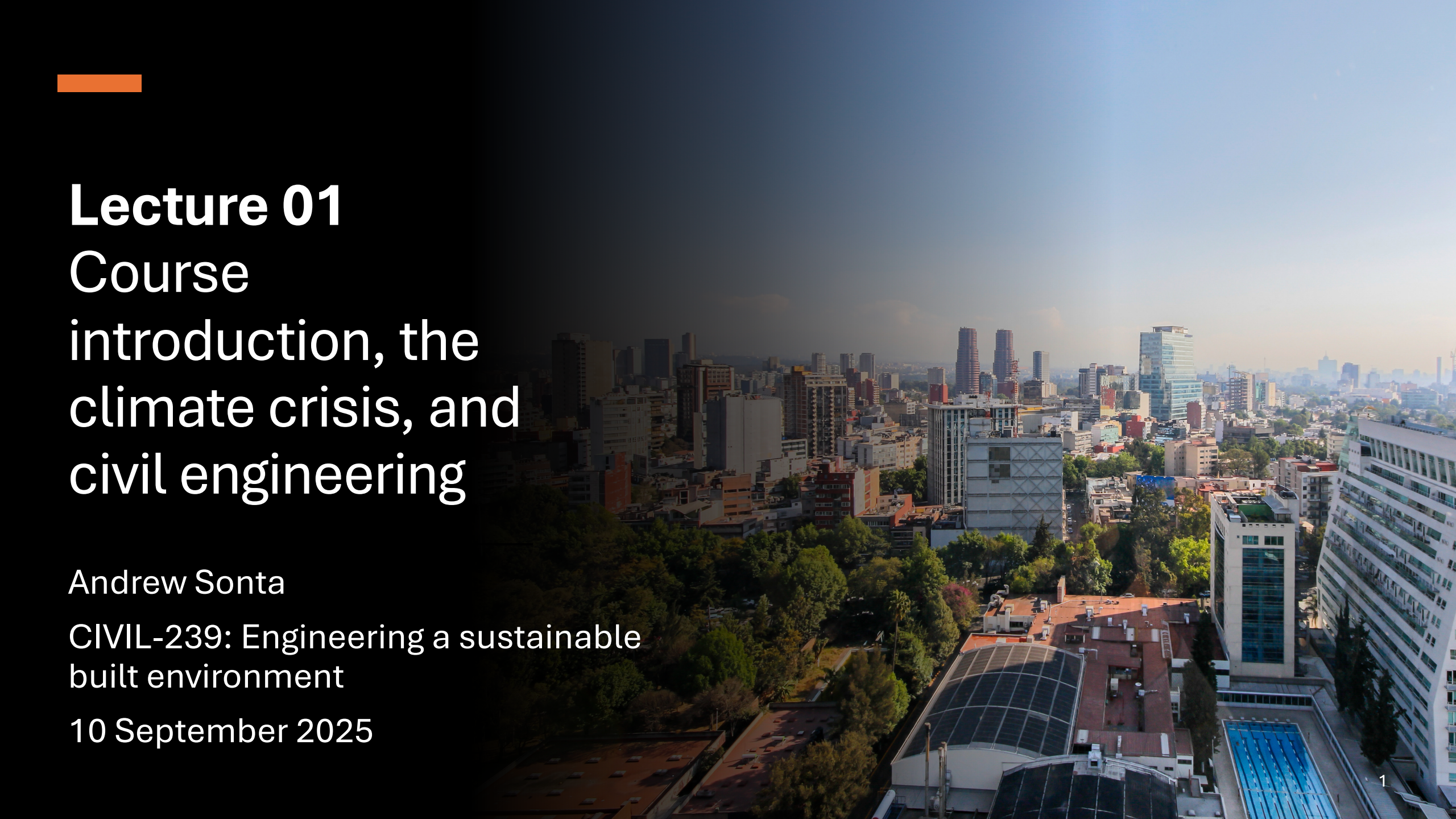
# Lecture 01
# Course introduction, the climate crisis, and civil engineering



Andrew Sonta

CIVIL-239: Engineering a sustainable built environment

10 September 2025

# Andrew Sonta

Tenure-Track Assistant Professor
September 2022 – present

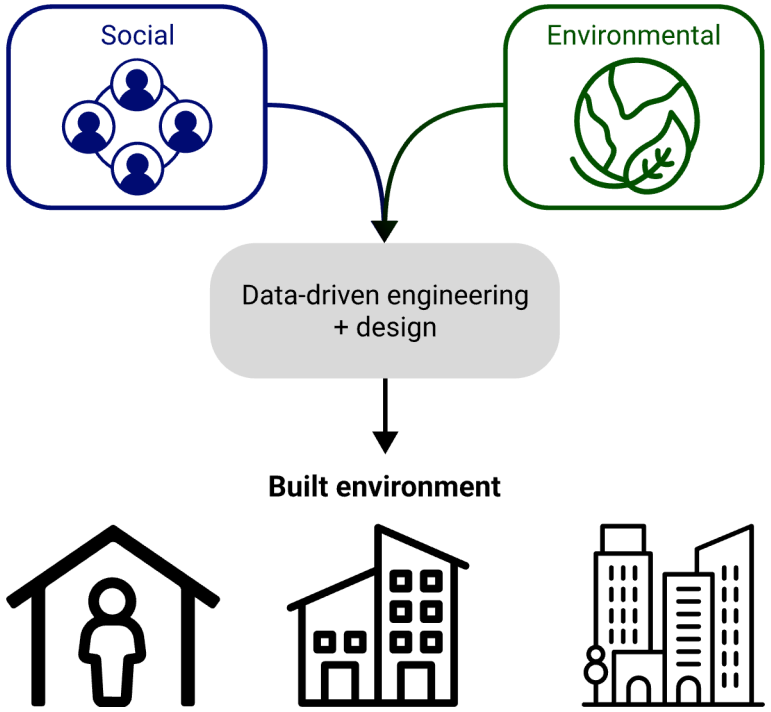
EPFL Fribourg

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

# Respect and Diversity at ENAC

# What is harassment?

**Psychological harassment or mobbing**

- Mobbing is an **unethical** et **destructive** behaviour in a situation or toward a person

**Sexual harassment**

- Sexual or sexist harassment **any comment or act of a sexual nature** or based on sexual identification toward a person **who does not want it** and **which affects their dignity**

**At EPFL: Zero tolerance!**

# What to do in these situations


@ EPFL

- If you witness inappropriate behaviours, **show you don't approve**! Also, inform your coach, class representative of section

- If you are a victim, **only if you feel comfortable doing it**, **clarify the situation** and communicate to the person the behaviour that make you feel **harassed**

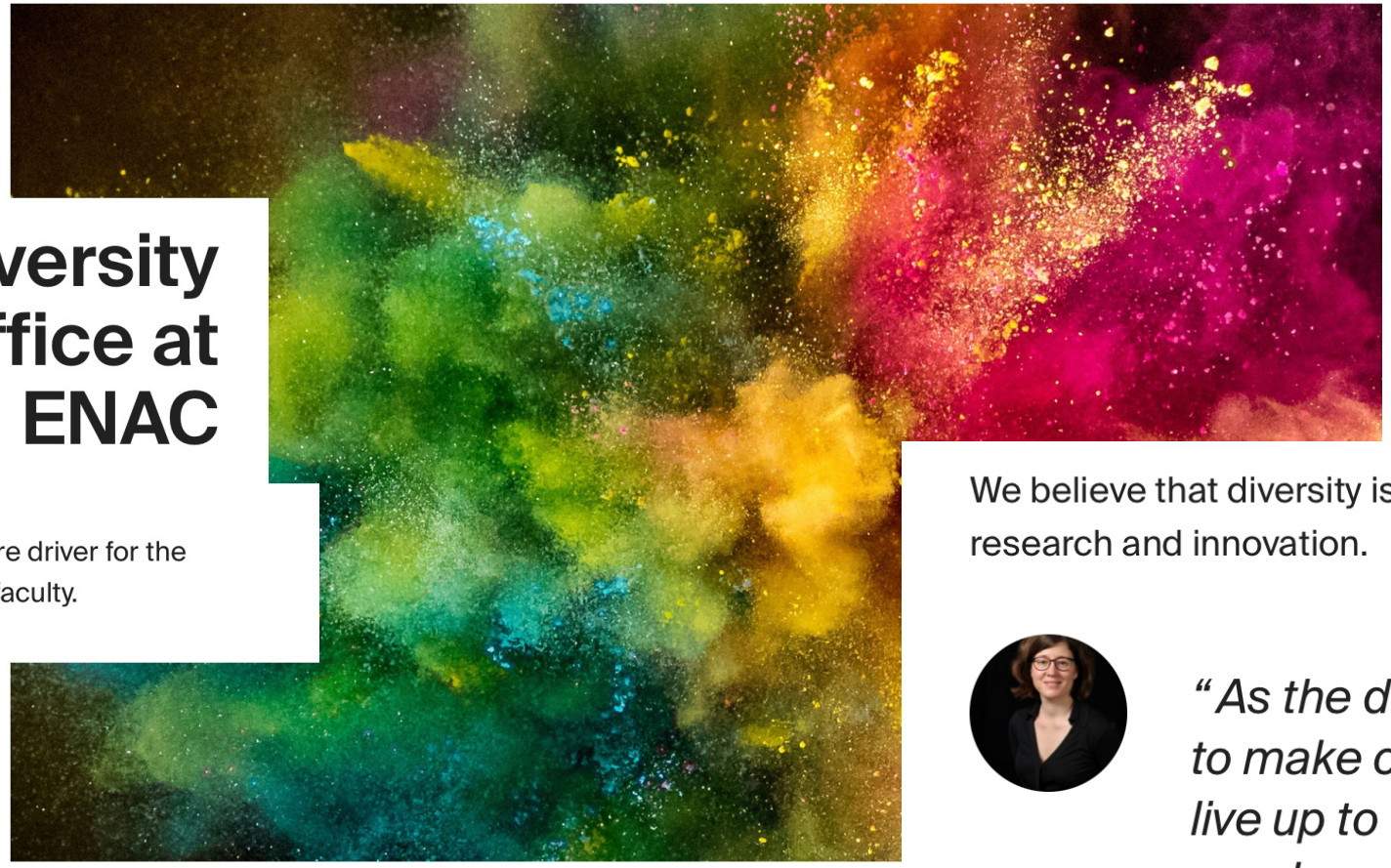
- **Rapidly communicate** to a person of trust or contact the support network (Trust and Support Network): https://www.epfl.ch/campus/community/trust-and-support-network/

- Feel free to contact me or anyone at the Diversity Office at ENAC (https://www.epfl.ch/schools/enac/about/diversity-office/)

# What is the ENAC Diversity Office?

- Group that gathers representatives of all ENAC components:
  - Students
  - Researchers
  - Administrative, scientific and technical staff
  - Professors and teachers

- Work together to develop proactive measures to:
  - Identify and eliminate bias and other barriers to inclusion
  - Raise awareness and promote responsible behaviour



# Diversity Office at ENAC

Diversity is a core driver for the success of our faculty.

We believe that diversity is essential to achieving excellence in education, research and innovation.



*“As the dean of ENAC, one of my top priorities is to make our school a place where everyone can live up to their full potential, regardless of their gender, nationality, ethnic origin, sexual orientation, religion, disability or any other distinguishing feature. I want ENAC to be a vibrant, welcoming community where diversity is a key engine not just for learning and studying, but also creating, inventing, building and developing talent and know-how.”*

— Katrin Beyer, Dean of ENAC

# Course information (also in PDF on Moodle)

- Lectures: 10:15-12:00, INR 219
- Exercises: 12:15-13:00, INR 219
  - This is time for you to work on the course assignments
  - Course assistants will be present
  - Note: we will not be using GC B330 as indicated on ISA
- Course assistants:
  - Axel Cebille, civil engineering master student
  - Pedro Savini, civil engineering master student

# Course content

- Sustainability in the built environment
  - Sustainability, energy, carbon emissions, social and economic aspects
- 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 should 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
  - See course information sheet for policy on Generative AI!
- Midterm exam (30%)
- Final exam, during exam session (50%)

# Generative AI policy

- Generative AI tools (such as ChatGPT) can be valuable aids for reflection, studying, and generating ideas
- They also carry limitations and risks, so their use in this course is restricted to specific, responsible practices:
  - **Study aid only** — do not generate content for assignments
  - Only use with **proper citation** and acknowledgement
  - You are **responsible** for the output, no one else
  - ChatGPT can be a good resource, but it can also **limit learning**
- **See course information sheet for full policy**

# ChatGPT

What is one third of a decade?

A decade is **10 years**.

One third of 10 years = **10 ÷ 3 = 3.333... years**,
which is **3 years and 4 months** (approximately).

What is half a decade?

Half a decade is **5 years ÷ 2 = 2.5 years**.

So half a decade is two and a half years.

So half a decade is shorter than one third of a decade?

No — it's the other way around.

- **Half a decade** = 2.5 years
- **One third of a decade** ≈ 3.33 years

So **one third of a decade is longer than half a decade**.

Credit: Phillip Schwaller

| Week | Date | Course Content | Engineering knowledge and tools | Due |
|---|---|---|---|---|
| | **Course introduction** | | | |
| 1 | 10-Sep | The climate crisis<br>What is sustainability?<br>Sustainability in civil engineering | The role of the built environment in sustainability | |
| 2 | 17-Sep | Sustainability indicators<br>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 | Link between transportation and energy; systems thinking | Assignment 2 |
| 6 | 15-Oct | Sustainable urban design and active mobility<br>Social systems | System dynamics | |
| 7 | 22-Oct | No Class - Fall Break | | |
| 8 | 29-Oct | ***Midterm exam – CE 1 1*** | | Assignment 3 |

| | | | | |
|---|---|---|---|---|
| | **Materials, structures, and life-cycle assessment** | | | |
| 9 | 5-Nov | Life-cycle assessment | Environmental LCA | |
| 10 | 12-Nov | **Guest lecture**: Embodied carbon emissions and materials | The phases of infrastructure life cycles | |
| | **Civil engineering and natural systems** | | | |
| 11 | 19-Nov | **Guest lecture**: Assigning value to natural systems | Sustainability in natural systems; Engineering and sustainability economics | |
| 12 | 26-Nov | Engineering with natural systems; geotechnical engineering, water resources engineering | Multi-criteria decision-making, resilience, sensitivity analysis, nature-based solutions | Assignment 4 |
| | **Sustainability in the civil engineering profession** | | | |
| 13 | 3-Dec | Safety and reliability in civil engineering | Load combinations, safety and reliability, safety factors | |
| 14 | 10-Dec | **Guest lecture**: Sustainable engineering in the industry | Practical issues | |
| 15 | 17-Dec | Course wrap up<br>Class debate | | Assignment 5 |
| - | TBD | ***Final written exam*** | | |

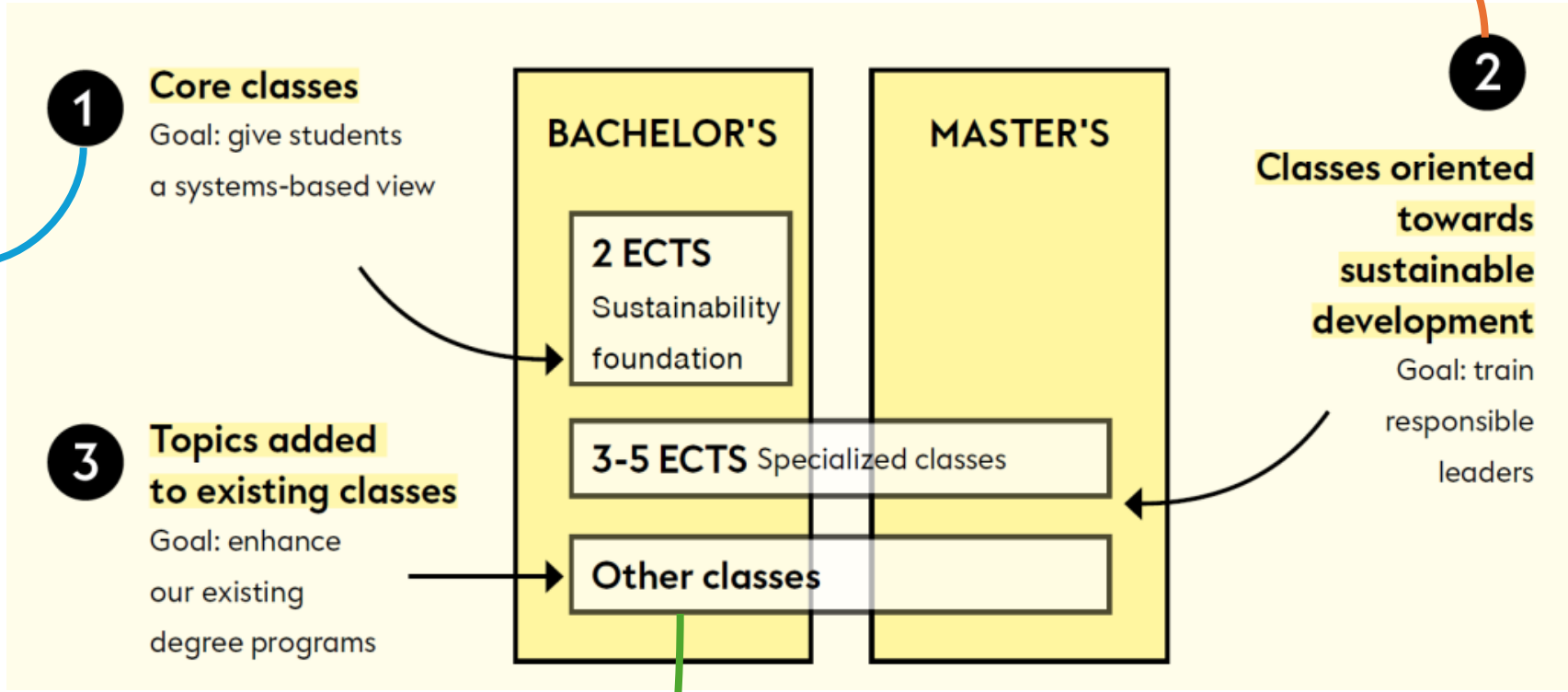
# Today’s outline

- Sustainability in the curriculum at EPFL
- Sustainability in civil engineering: overview of the topics in the course
- The climate crisis
- Definitions of sustainability
- Why civil and environmental engineering is uniquely concerned with sustainability

# Teach4Sustainability

This is the purpose of CIVIL-239

ENV-101:
- Climate crisis
- Planetary boundaries
- Definitions of sustainability
- Technological aspects
- Social and political aspects
- Systems thinking



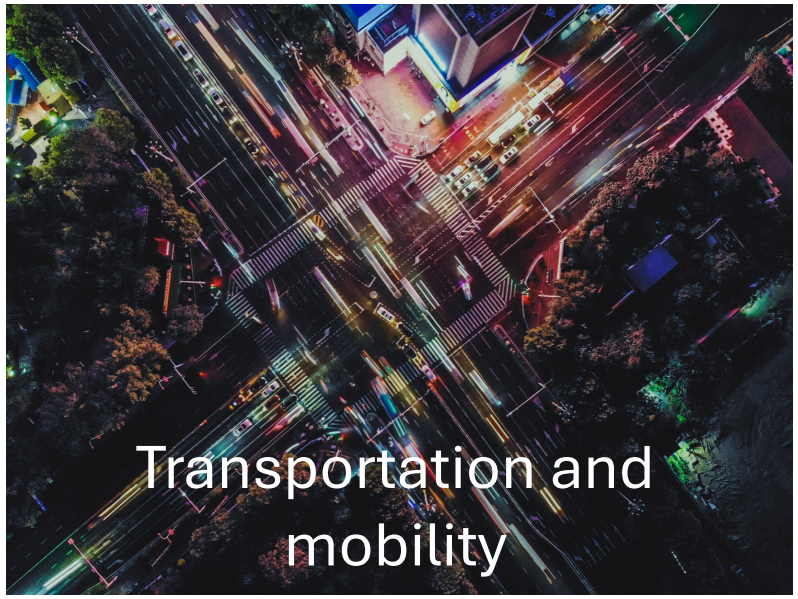

For some of you: Global Issues courses on sustainability
- Energy and innovation
- Climate change
- Food and sustainability
- …

# 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.

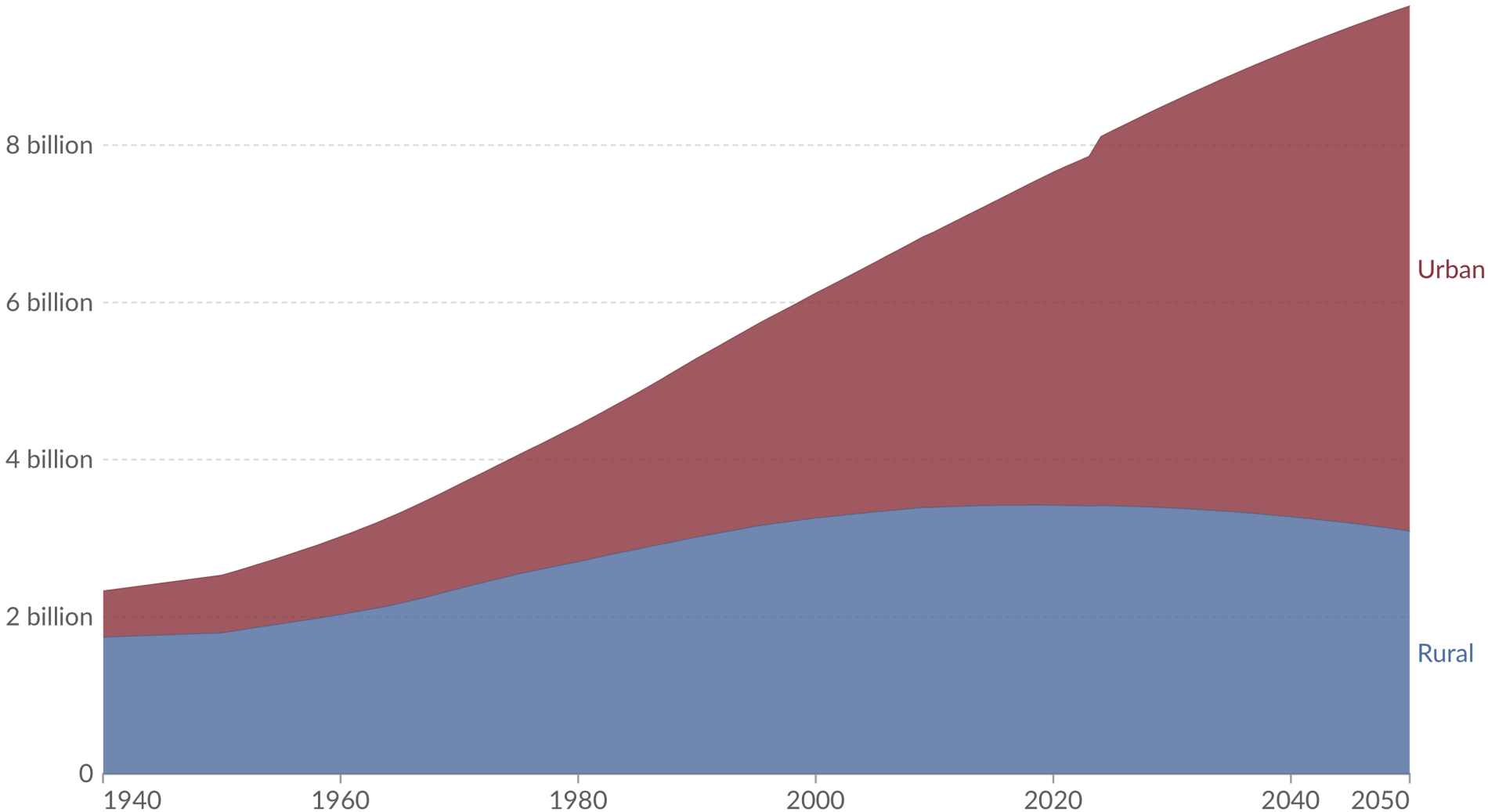
# Subdisciplines of civil engineering




# 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

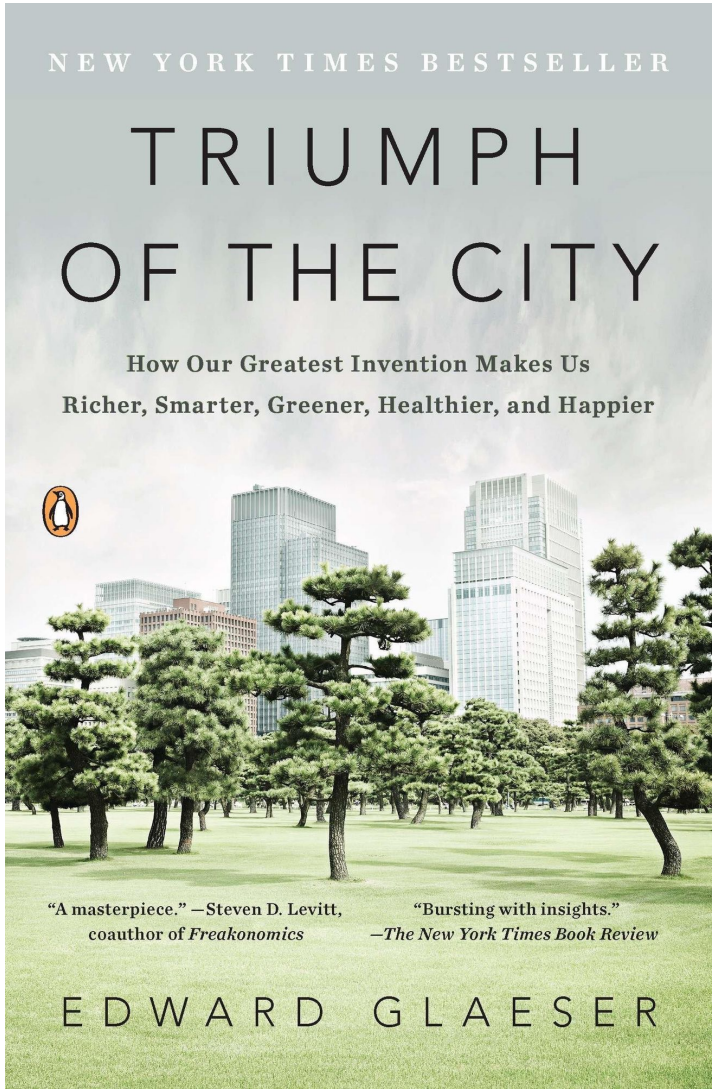
# Why do cities grow?

"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)



# 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

Image credit: NASA

# Earthrise

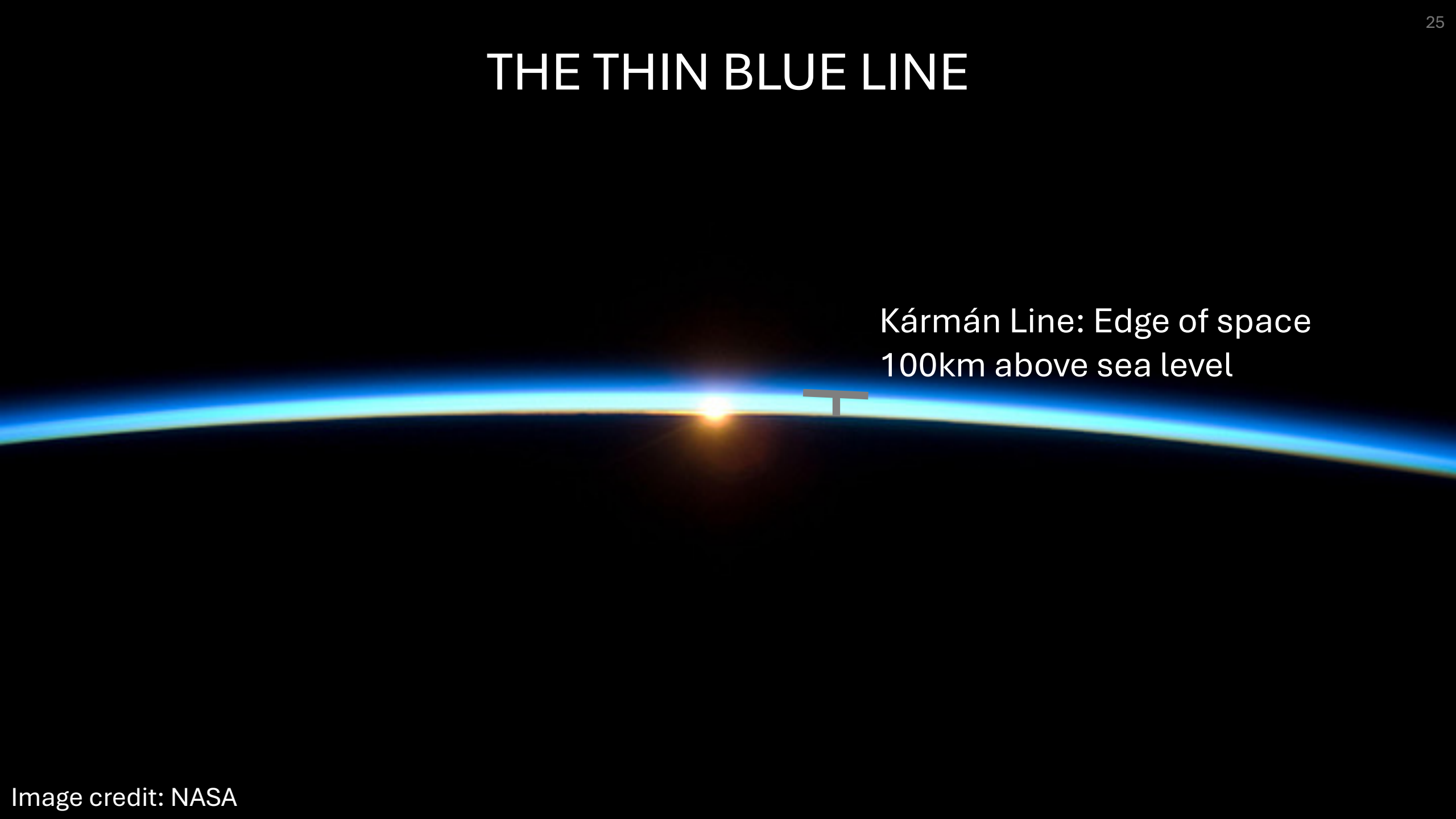
- Photo taken December 24, 1968, during Apollo 8 mission to the Moon
- First color picture of the entire Earth
- Widely credited with propelling the environmental movement

# The Blue Marble

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

Image credit: NASA

# THE THIN BLUE LINE

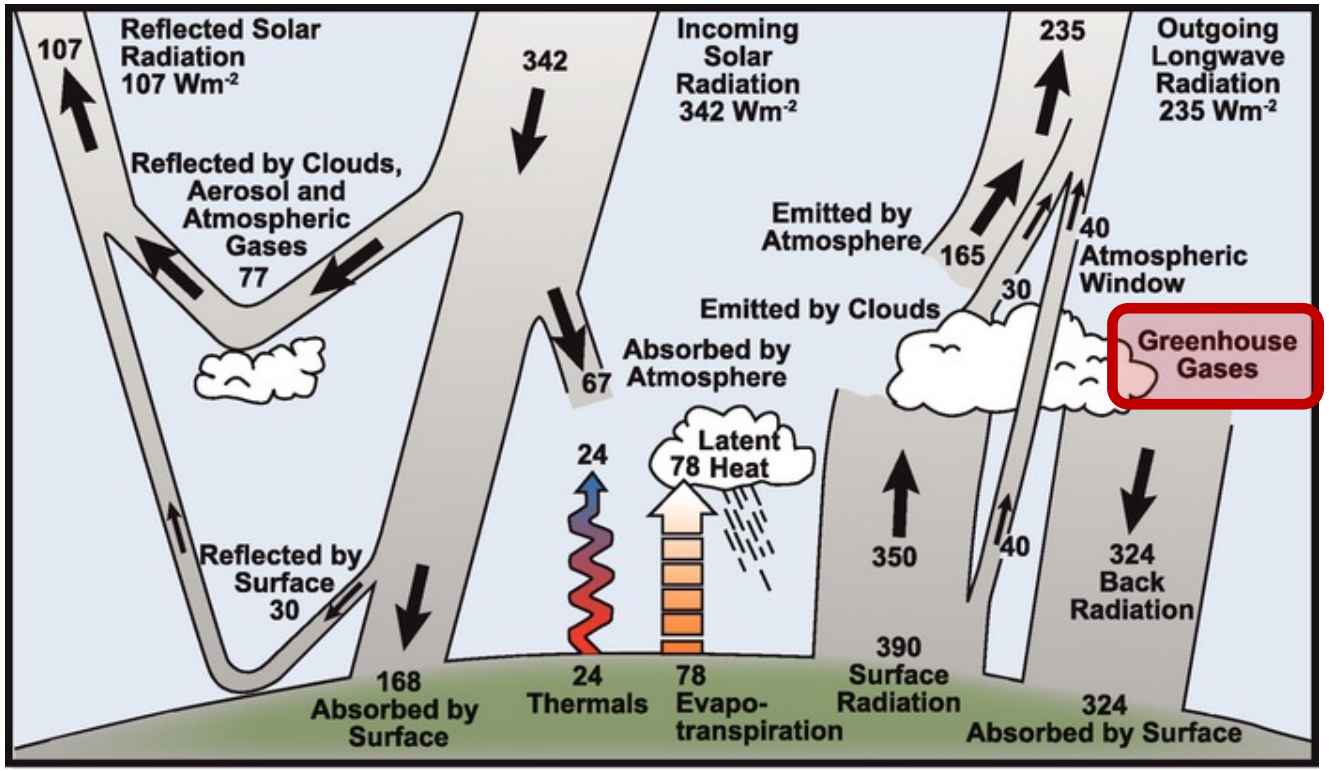


Kármán Line: Edge of space
100km above sea level

Image credit: NASA

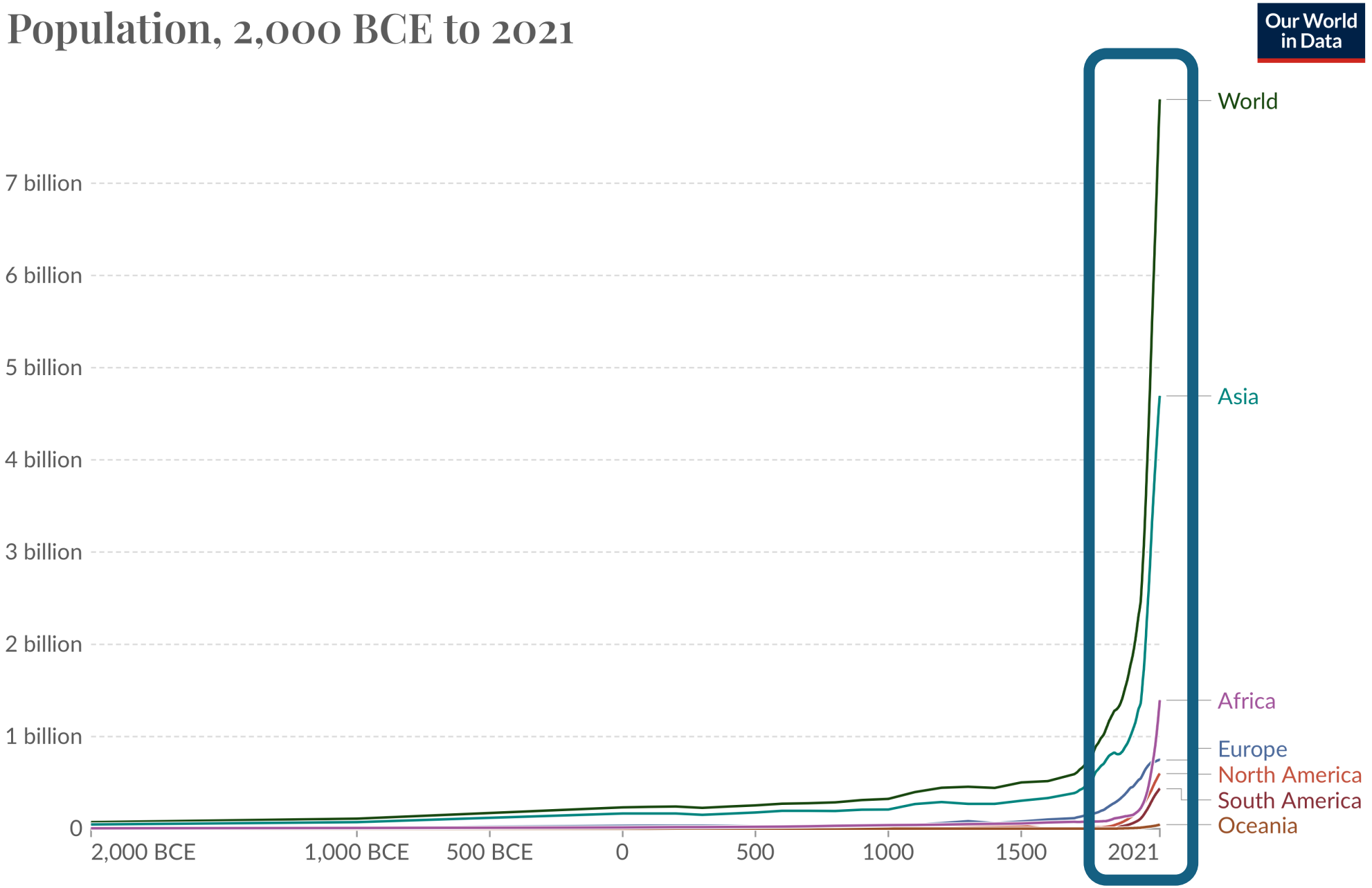
# A delicate balance

- 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



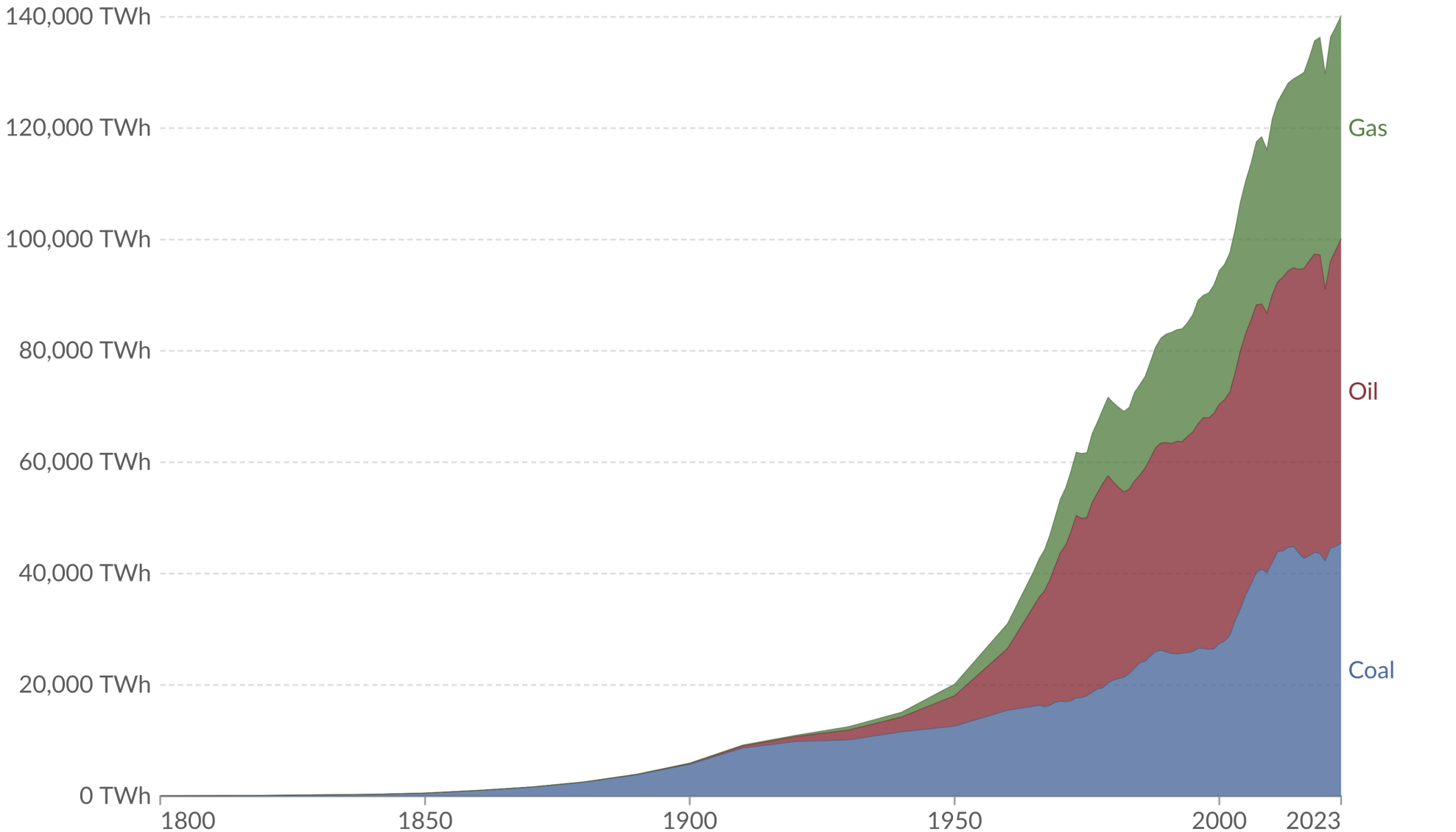

**Data source:** HYDE (2017); Gapminder (2022); UN (2022)
**Note:** Historical country data is shown based on today's geographical borders.

OurWorldInData.org/population-growth | CC BY

# Global fossil fuel consumption

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

Our World in Data



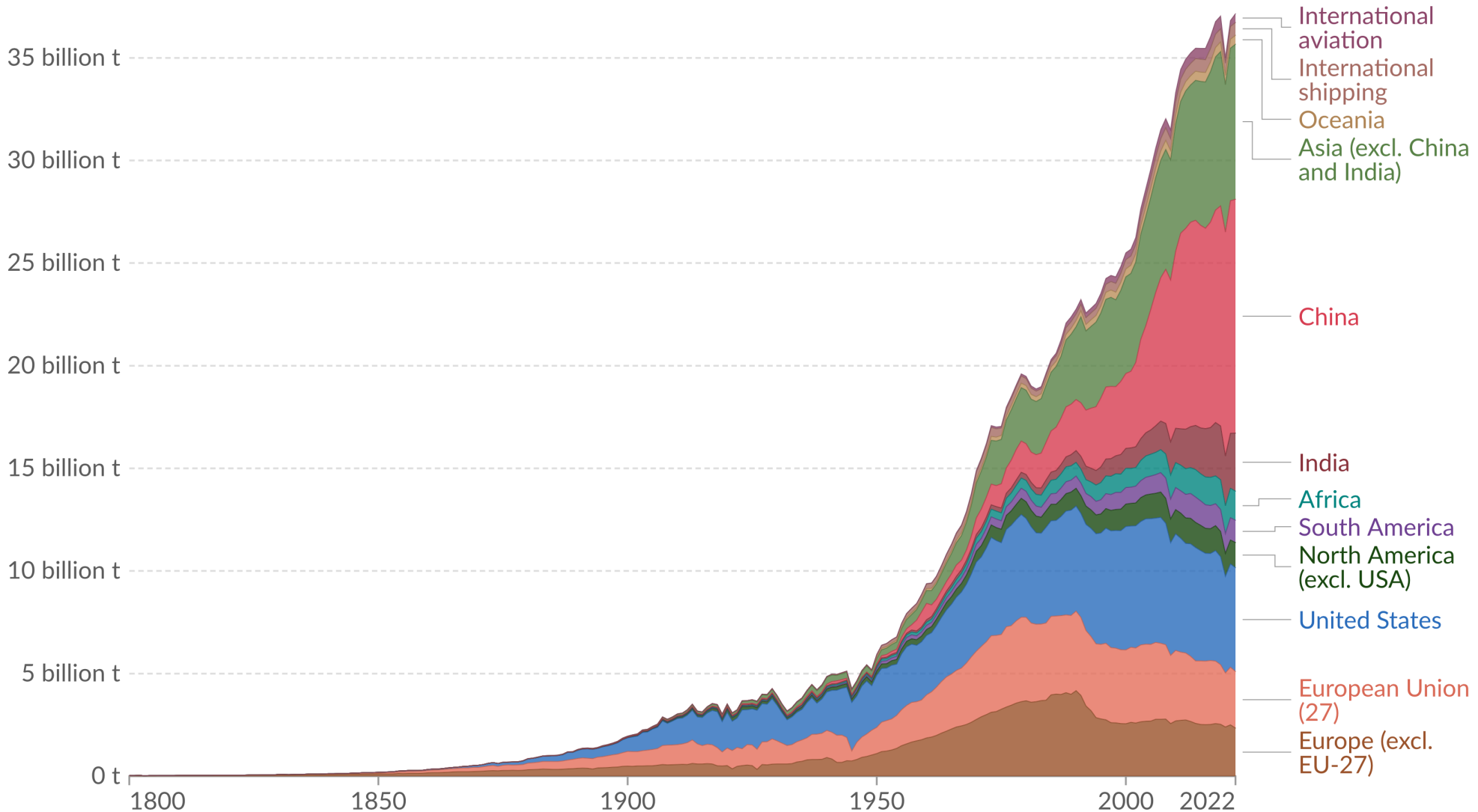

**Data source:** Energy Institute - Statistical Review of World Energy (2024); Smil (2017)

OurWorldInData.org/fossil-fuels | CC BY

# Annual $CO_2$ emissions by world region

Our World in Data

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.



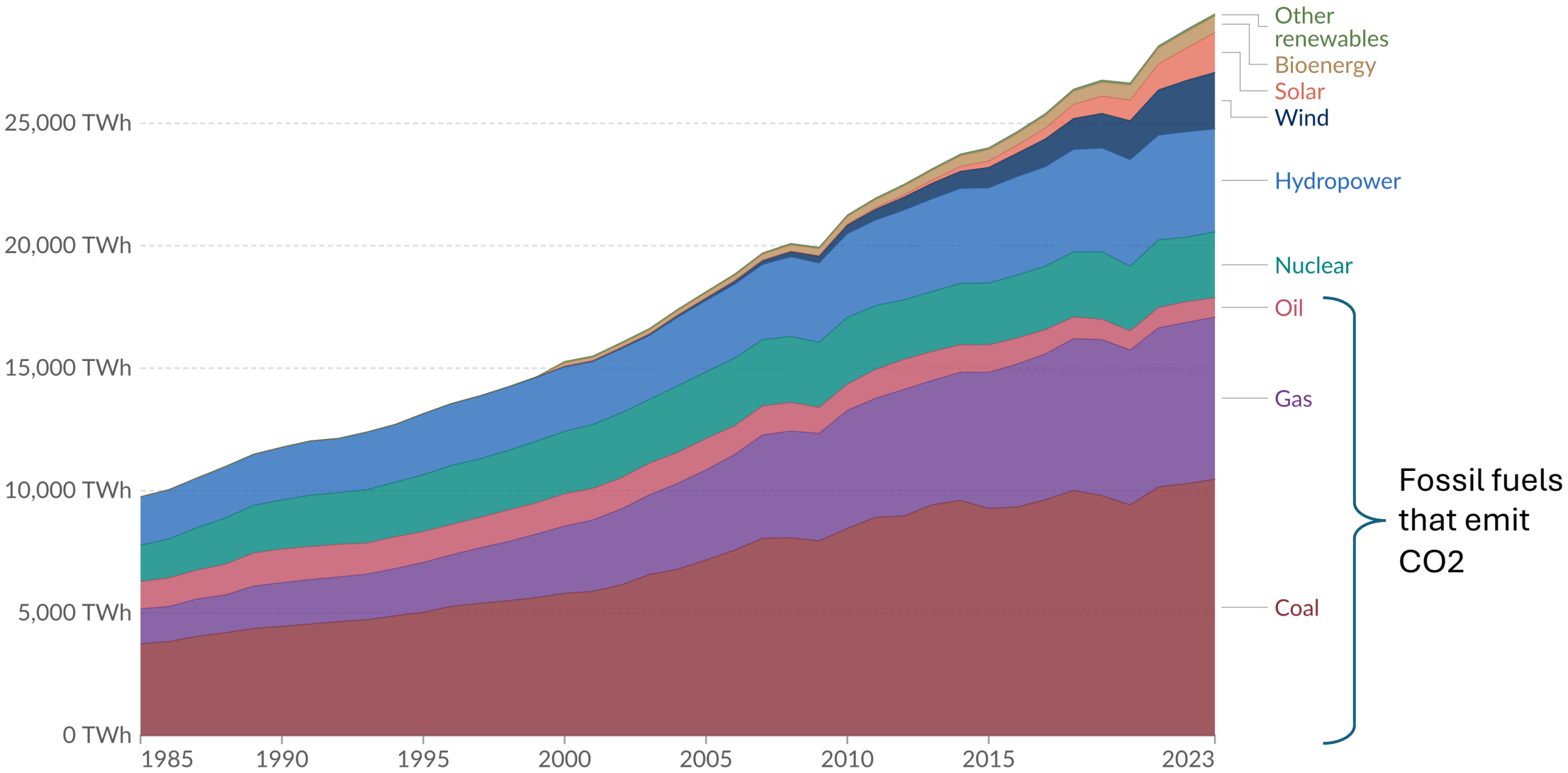

**Data source:** Global Carbon Budget (2023)

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

# Electricity production by source, World

Measured in terawatt-hours[1].

Our World in Data




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

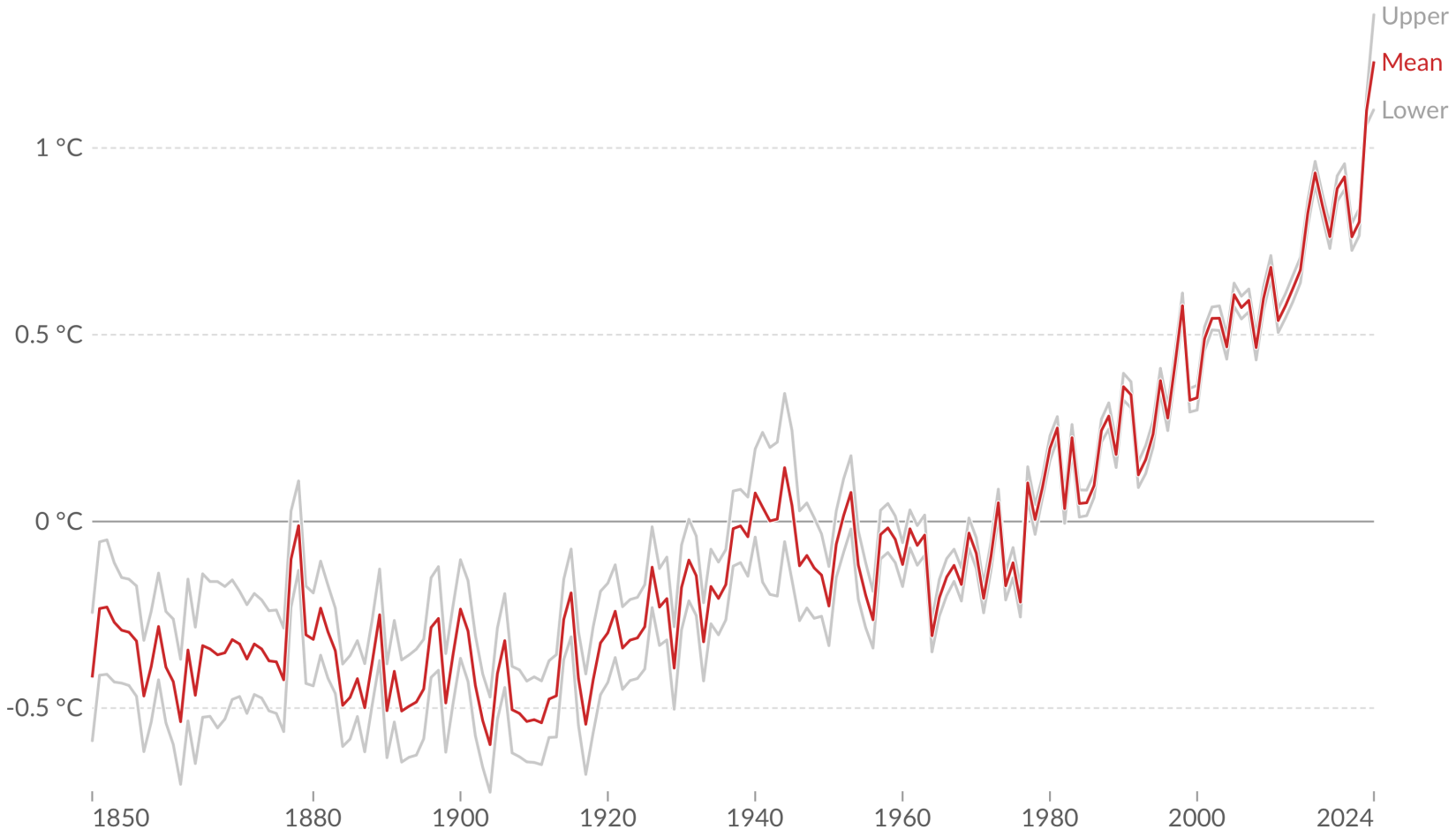
OurWorldInData.org/energy | CC BY

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


AIR TRANSPORT
THAWING PERMAFROST
COAL MINING
COAL PLANTS
OIL PRODUCTION
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.




**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

Our World in Data

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)

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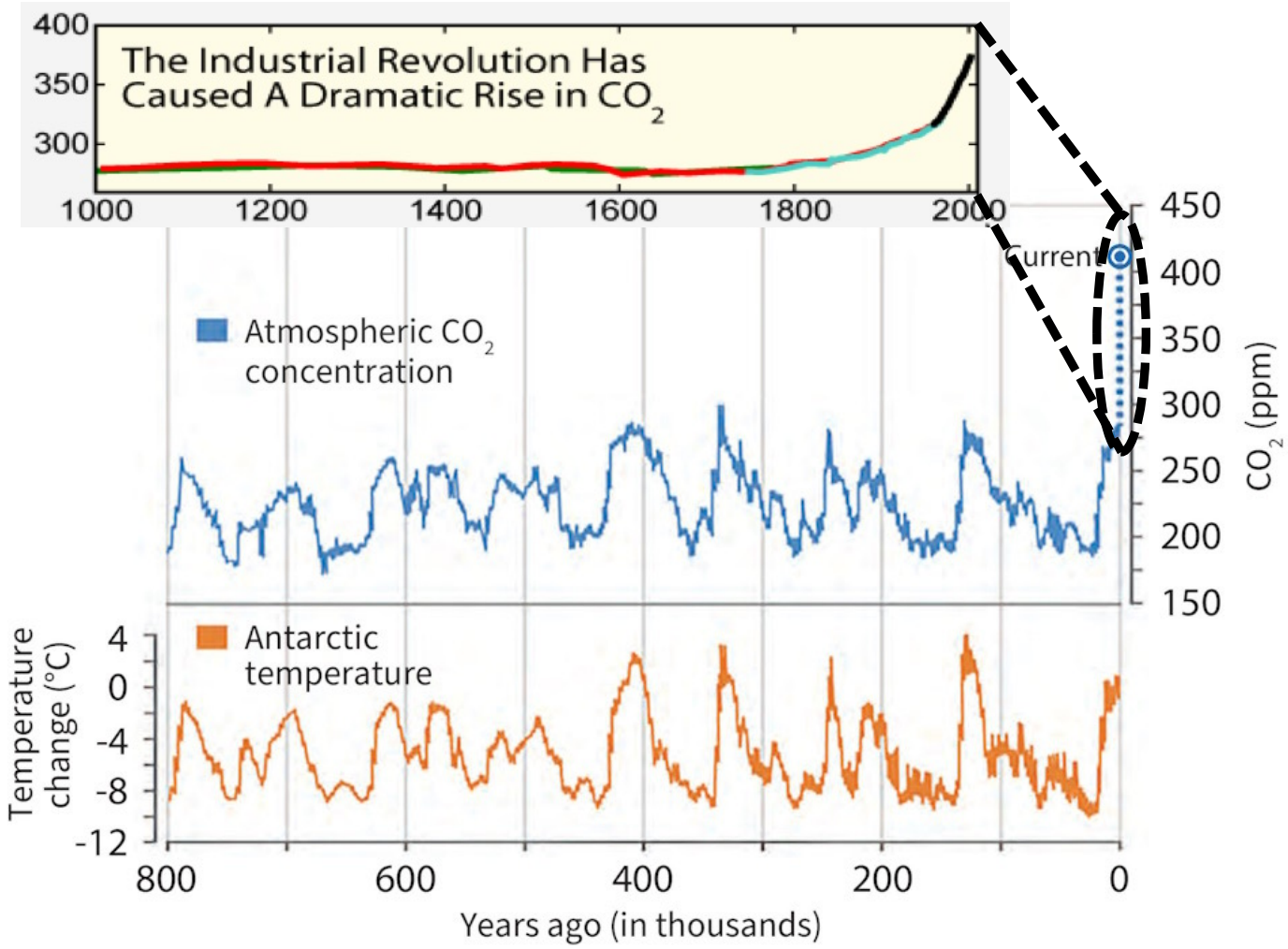
OurWorldInData.org/climate-change | CC BY

# Unprecedented impact of human activity

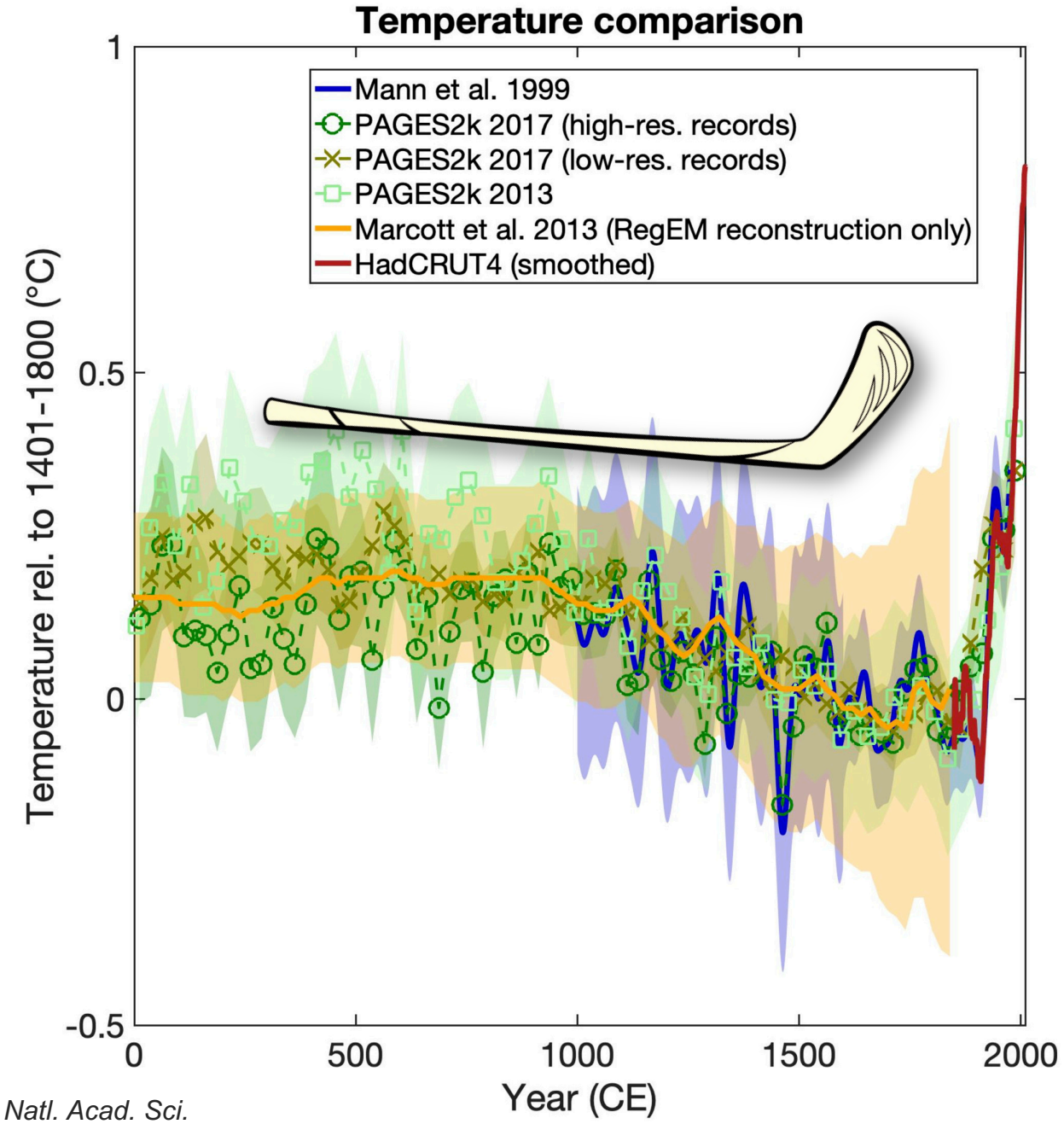
- “The cyclical pattern of temperature variations constitutes the ice age/interglacial cycles…
- During these cycles, changes in CO2 concentrations (in blue) track closely with changes in temperature (in orange)…
- As the record shows, the recent increase in atmospheric CO2 concentration is unprecedented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




Source: The Royal Society

# The original “hockey stick graph” (with newer data)

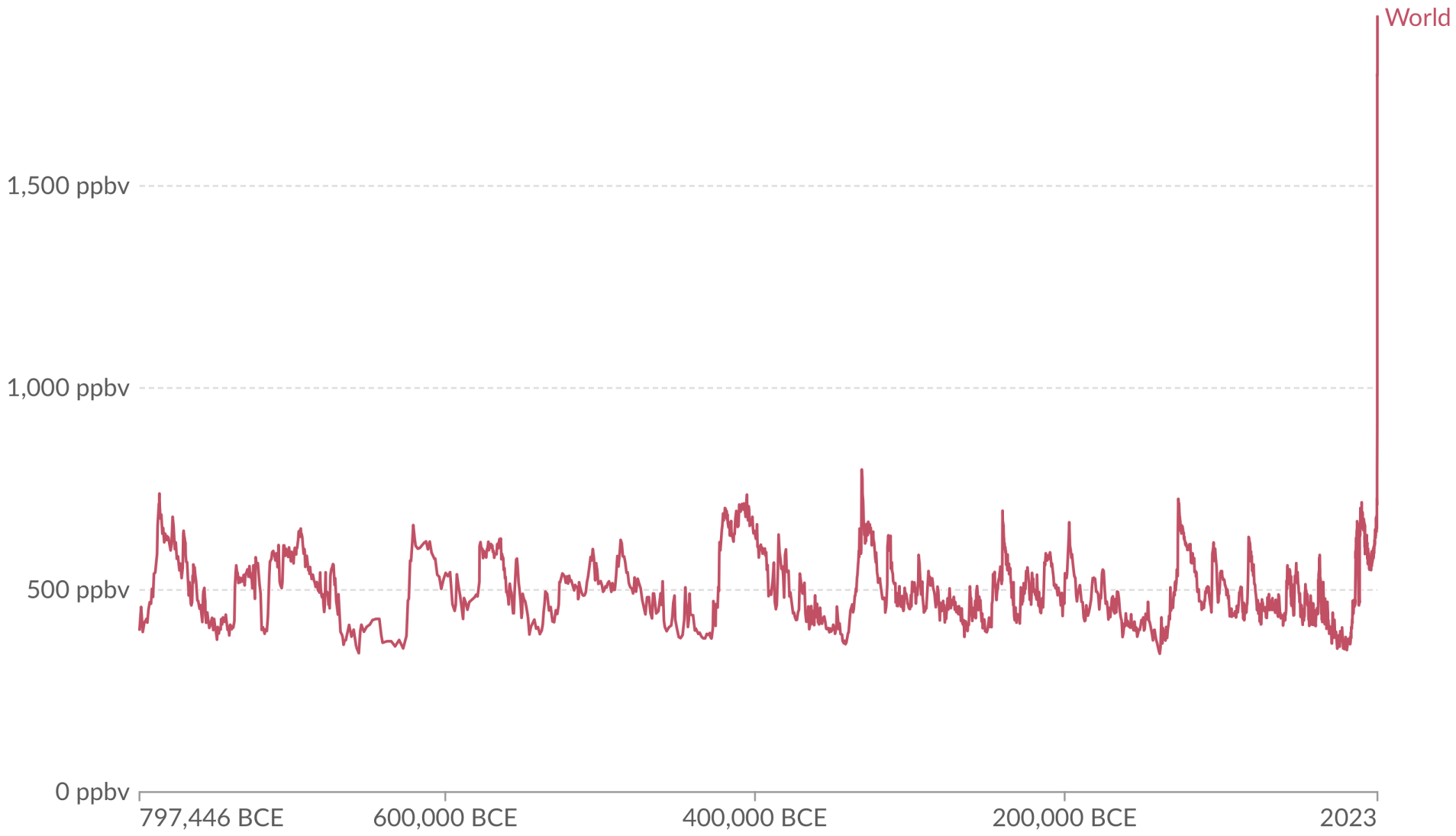
The key message behind the “hockey stick graph” is that, while historical variations in global temperatures are normal, the rate of change after the industrial revolution is unprecedented.




M.E. Mann, Beyond the hockey stick: Climate lessons from the Common Era, *Proc. Natl. Acad. Sci. U.S.A.* 118 (39) e2112797118,https://doi.org/10.1073/pnas.2112797118 (2021).

# Methane concentration in the atmosphere

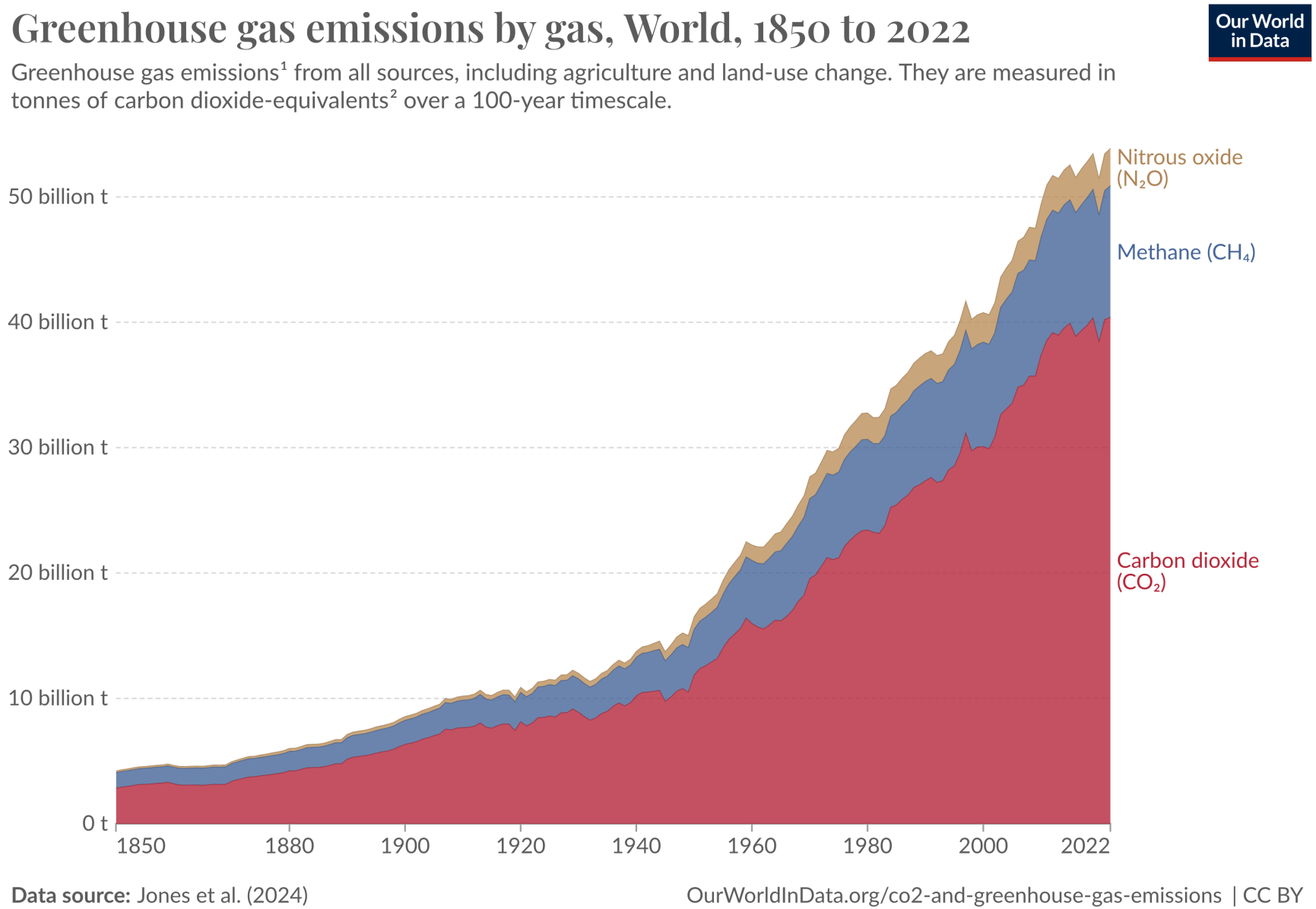
Measured in parts per billion.




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

**Measured in $CO_2e$ (carboned dioxide equivalents)**

Example: Methane is ~28x more effective in trapping heat compared to carbon dioxide over a 100-year period, so the raw amount of methane emitted is ~1/28 of what is shown.



# Greenhouse gas (GHG)

- Group of gases that contribute to global warming and climate change by trapping heat in the atmosphere
- The Kyoto Protocol (1997 UN agreement) covers seven GHGs[1]:
  - **carbon dioxide ($CO_2$)**
  - **methane ($CH_4$)**
  - nitrous oxide ($N_2O$)
  - hydrofluorocarbons (HFCs)
  - perfluorocarbons (PFCs)
  - sulphur hexafluoride ($SF_6$)
  - nitrogen trifluoride ($NF_3$)

[1] Source: European Union

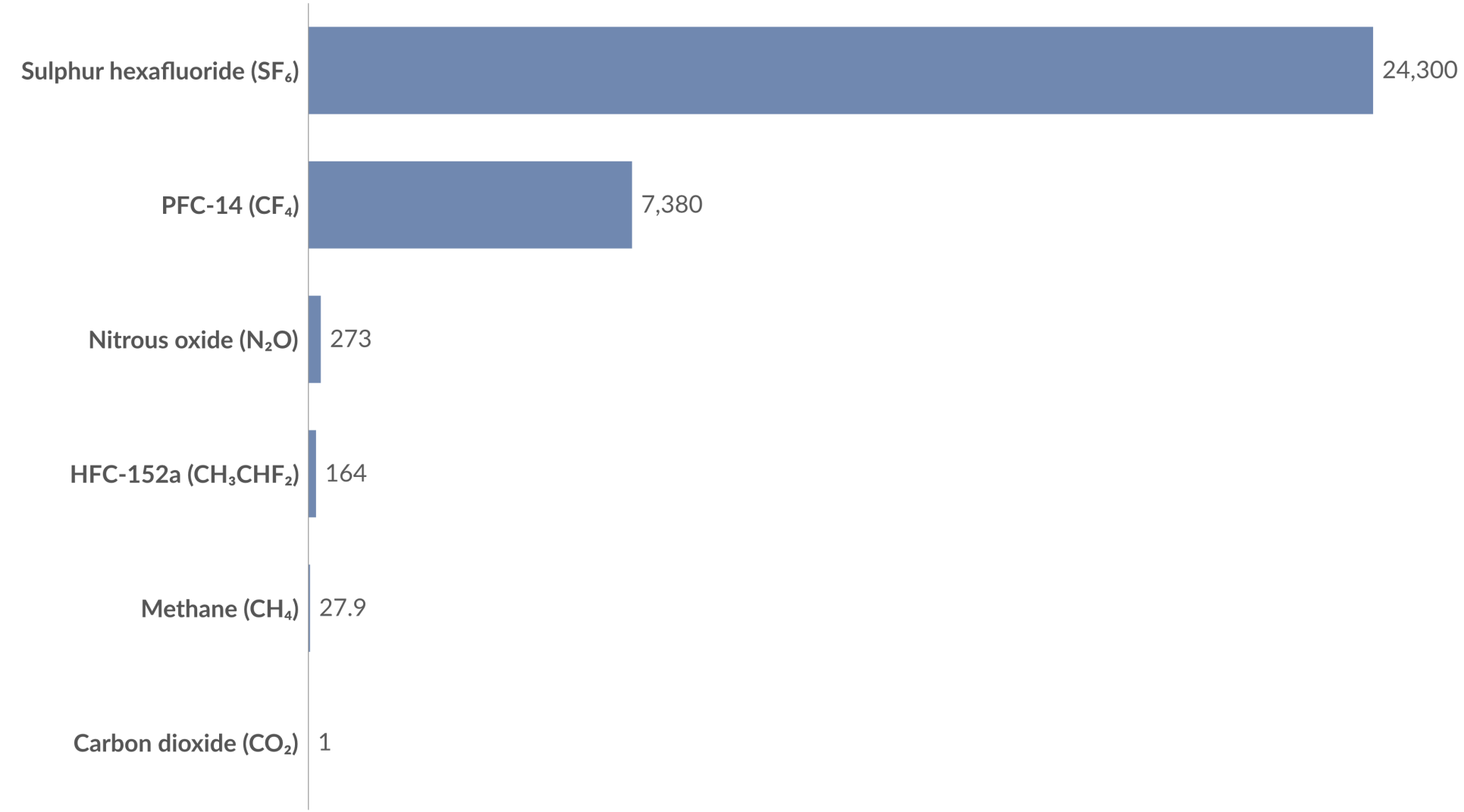
# Accounting for different greenhouse gases

- **Global Warming Potential** (GWP)
  - Measure of how much heat a GHG traps, taking account of how long it remains active in the atmosphere (atmospheric lifetime), relative to $CO_2$
  - GWP is defined for a specific time period (e.g., 20 years, 100 years)
  - CO2 has a GWP over 100 years of 1
    - This is the definition of the baseline
  - Methane ($CH_4$) has the following GWPs:
    - 20 years: 81.2
    - 100 years: 27.9
    - 500 years: 7.95
- **Carbon dioxide equivalent** ($CO_2e$ or $CO_2eq$)
  - Defined as GWP times mass of gas
  - What is 1g of $CH_4$ in $CO_2e$ (100 years)?

# Global warming potential of greenhouse gases relative to CO2

Our World in Data

Global warming potential[1] measures the relative warming impact of one unit mass of a greenhouse gas relative to carbon dioxide over a 100-year timescale.




**Data source:** IPCC (2021)

# 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

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

(b) Change in global surface temperature (annual average) as **observed** and simulated using human & natural and only natural factors (both 1850–2020)

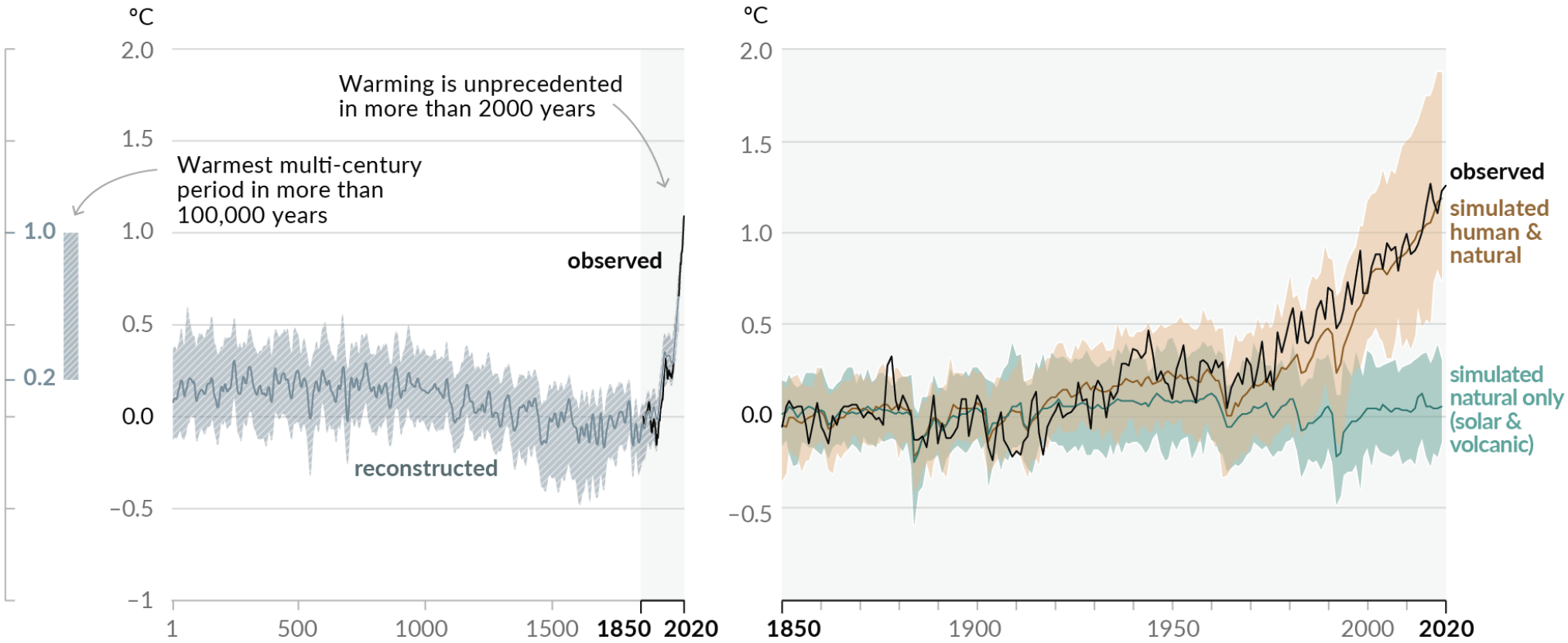
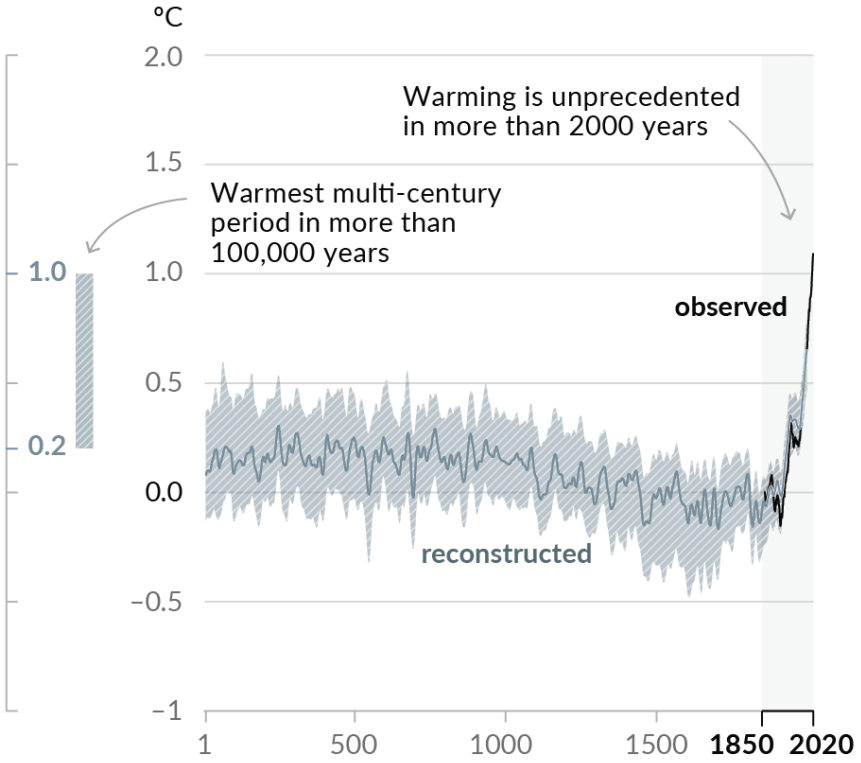


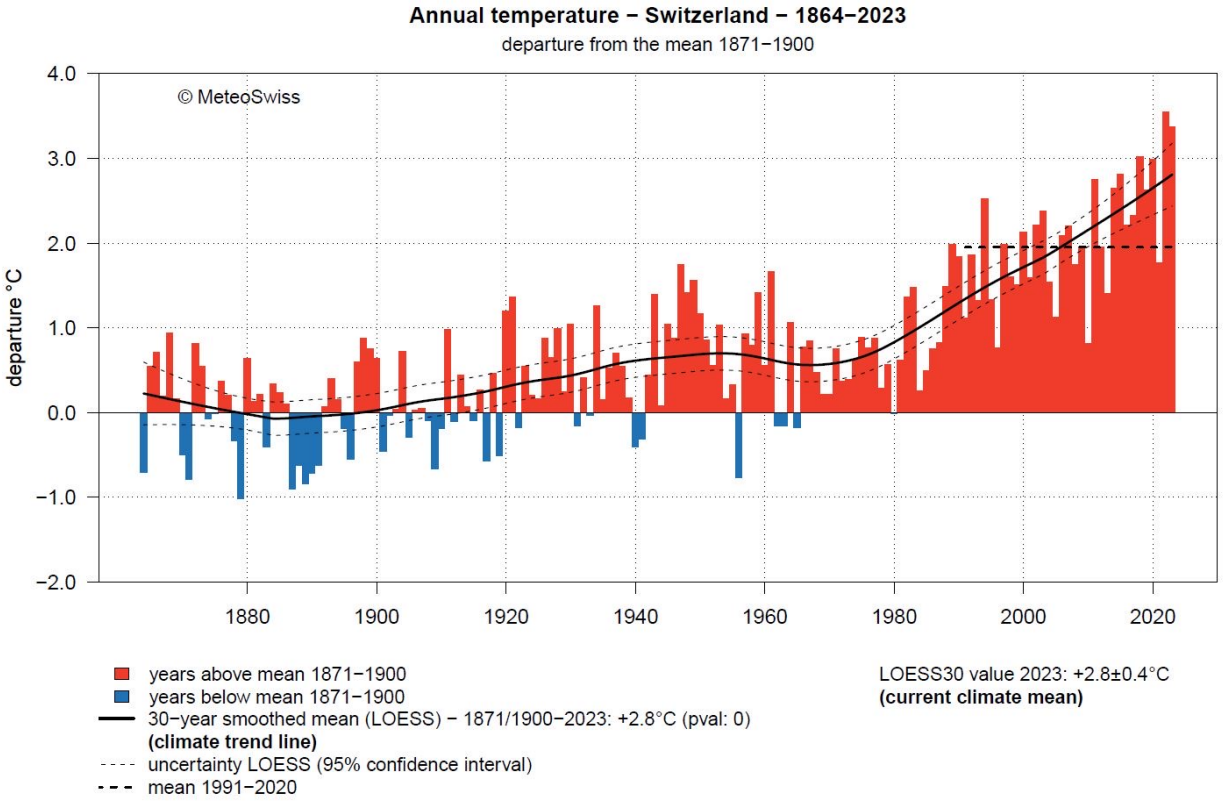

Figure SPM.1 in IPCC, 2021: Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., et al. (eds.)]. Cambridge University Press, Cambridge, UK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

# Warming is about 2x faster in Switzerland

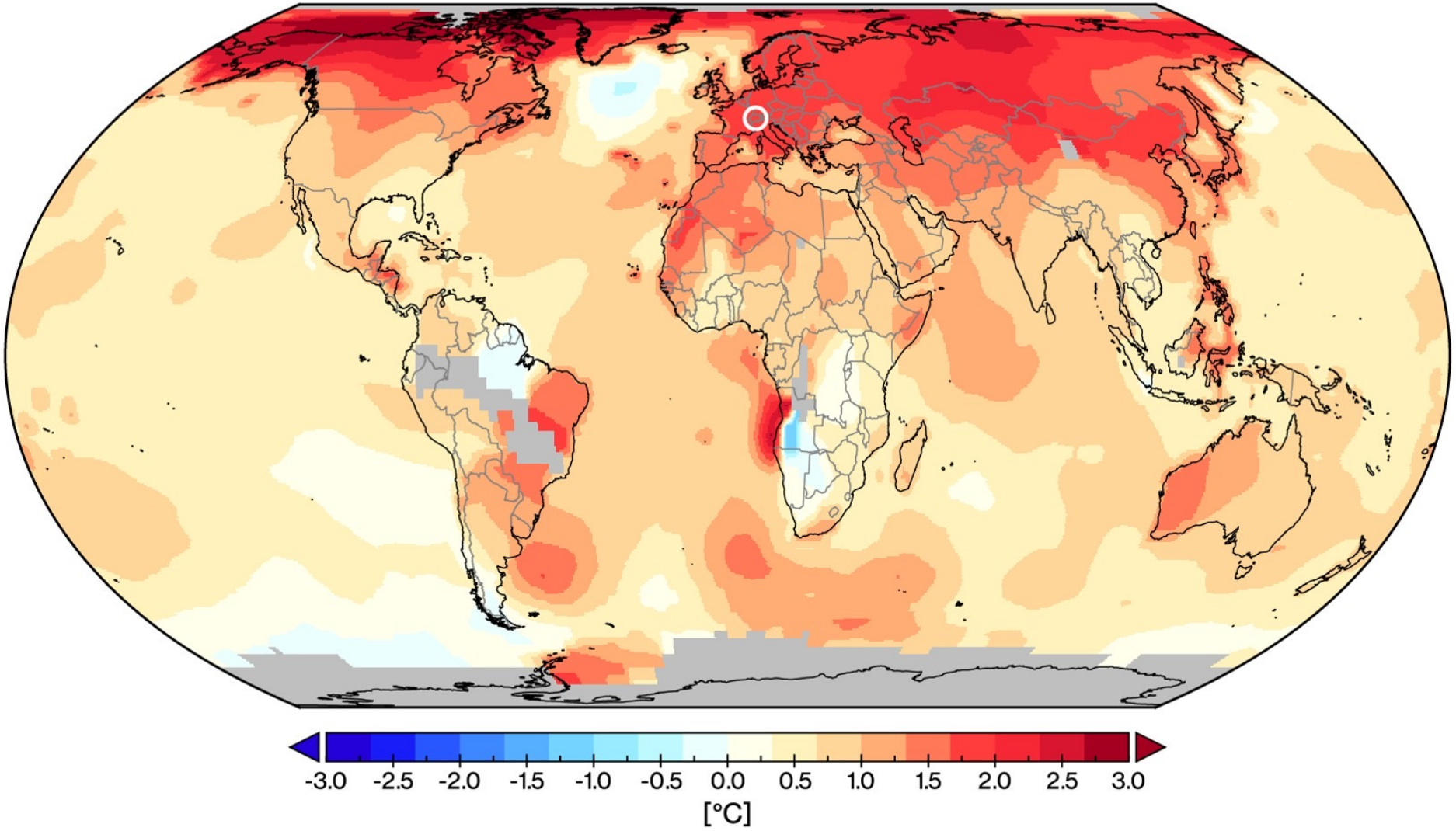
**Changes in global surface temperature relative to 1850–1900**

(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

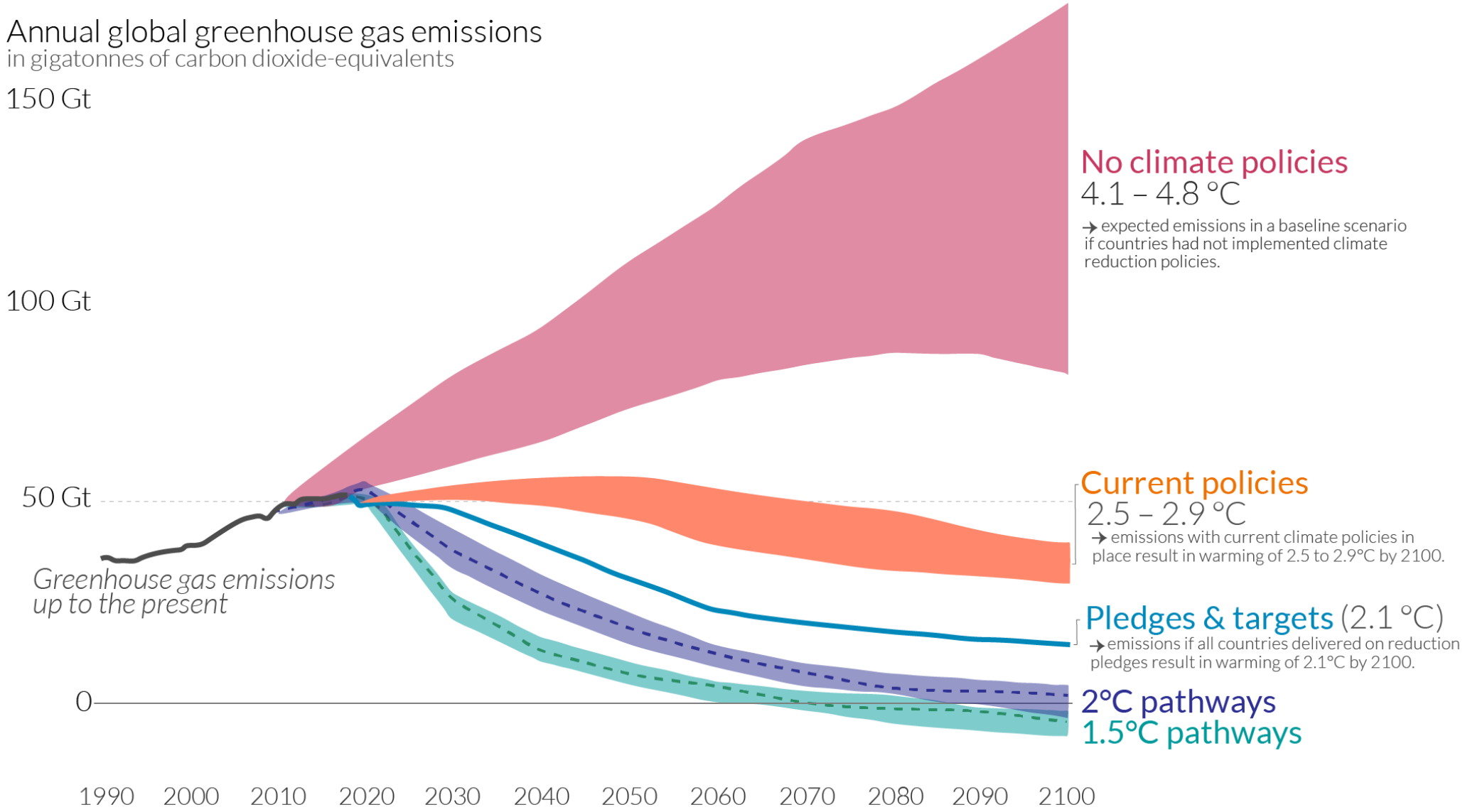
# Climate crisis summary

- All scientists agree that human activities and greenhouse gas emissions (primarily CO2) 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 CO2 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

Our World in Data

– 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.

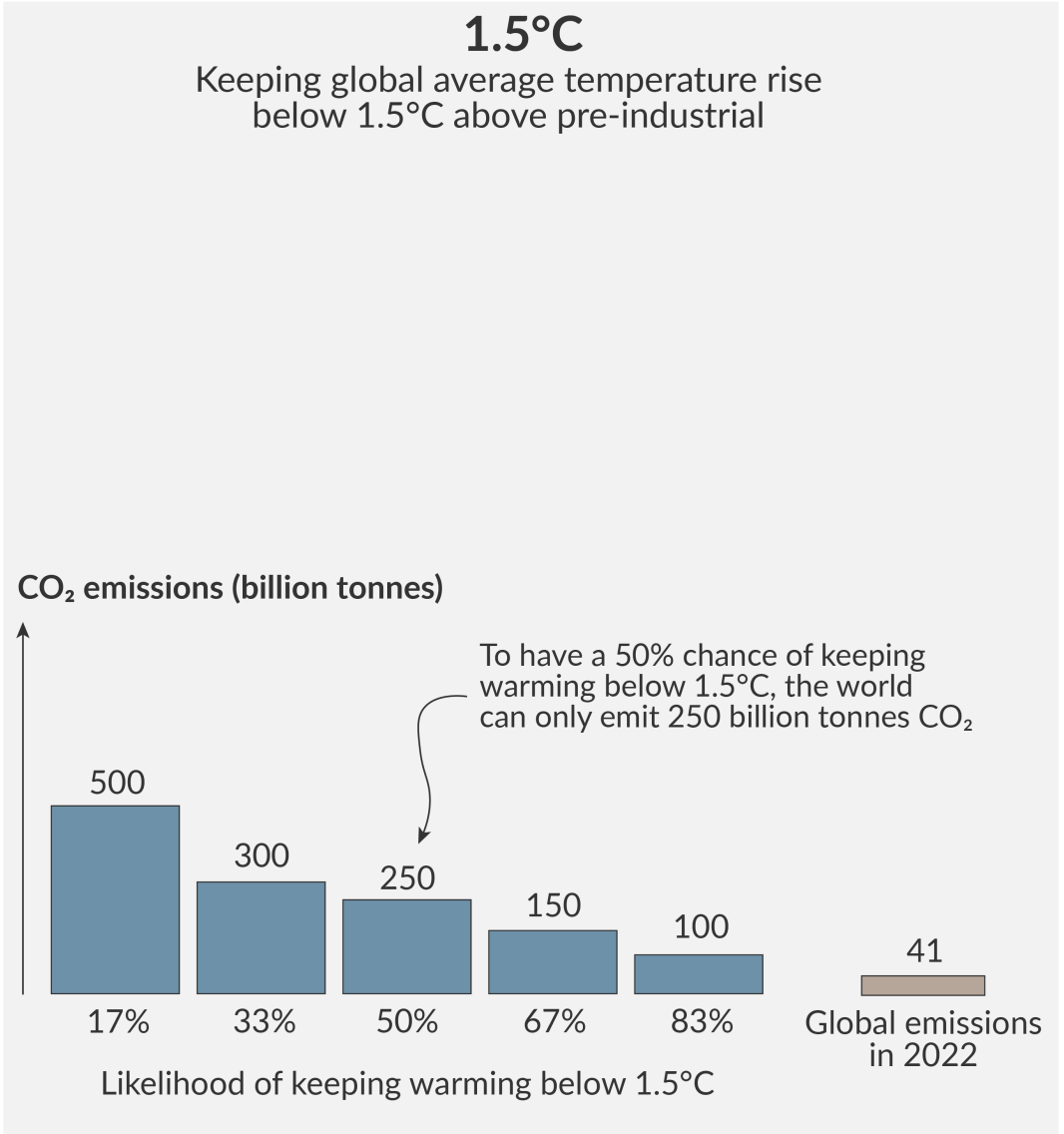


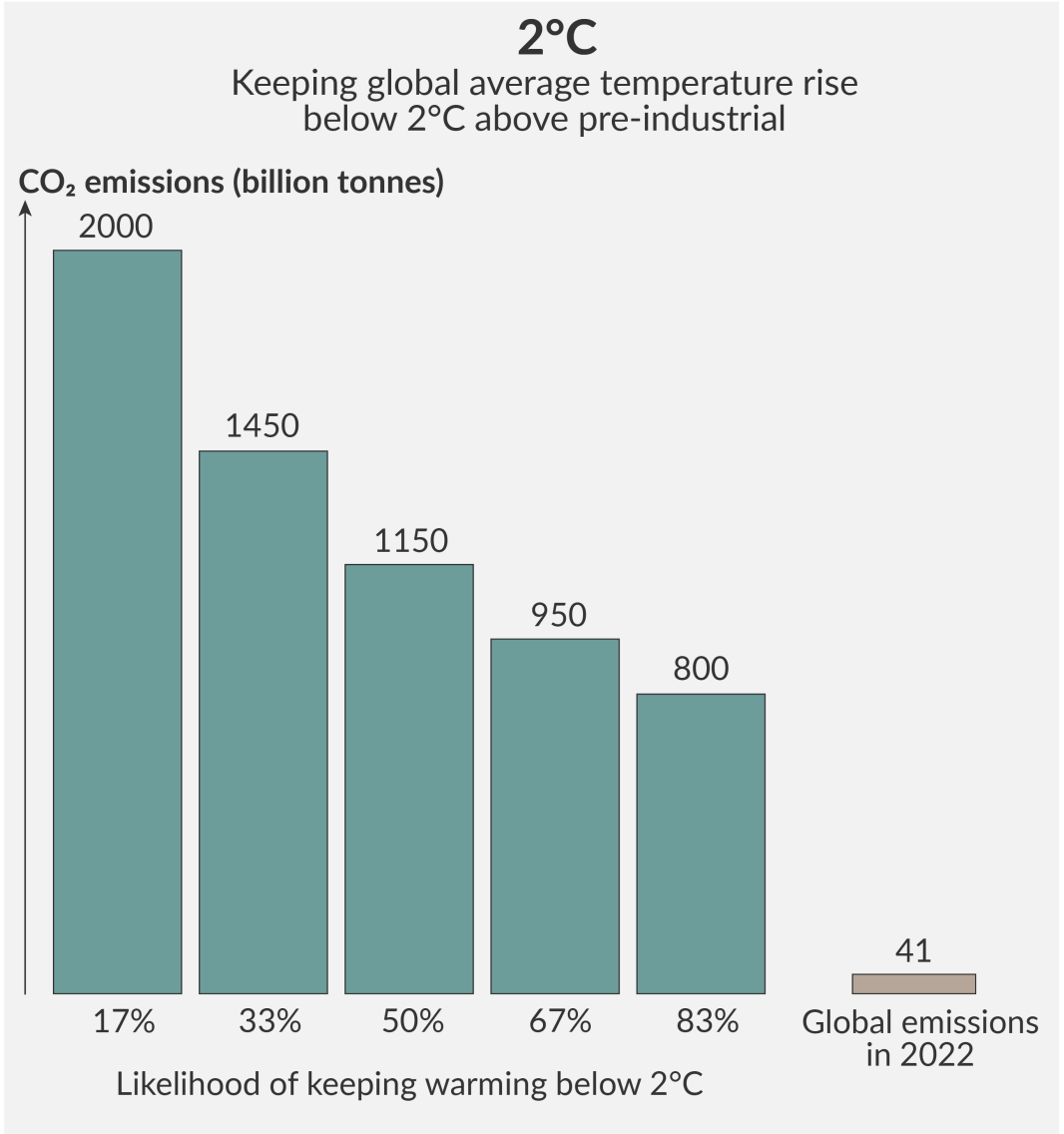

Data source: Climate Action Tracker (based on national policies and pledges as of November 2021).
OurWorldinData.org – Research and data to make progress against the world's largest problems.

# 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.

Our World in Data



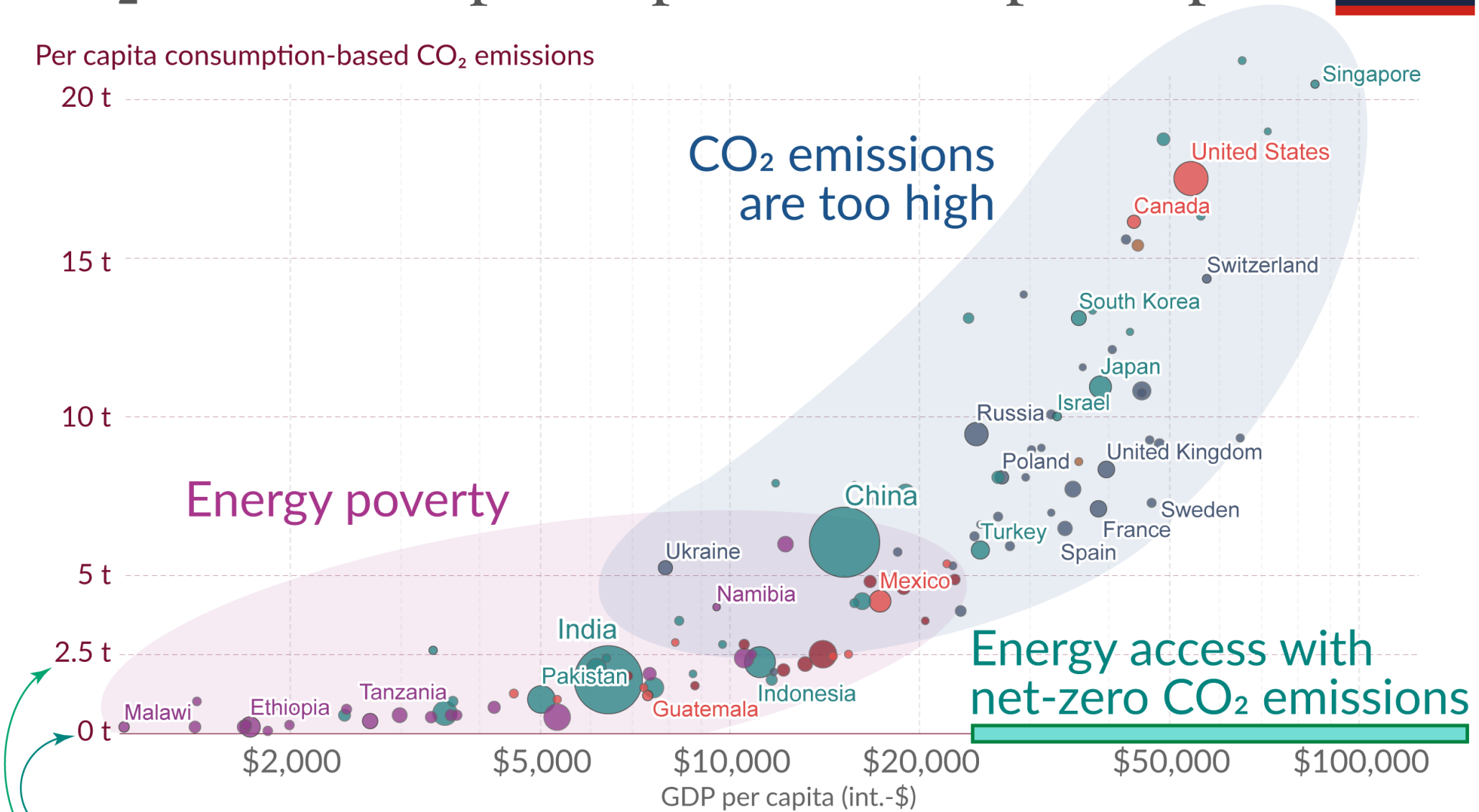




**Data source:** Budgets from Forster et al. (2023). Current emissions data from the Global Carbon Project.

OurWorldinData.org – Research and data to make progress against the world's largest problems.

# $CO_2$ emissions per capita vs GDP per capita

Our World in Data

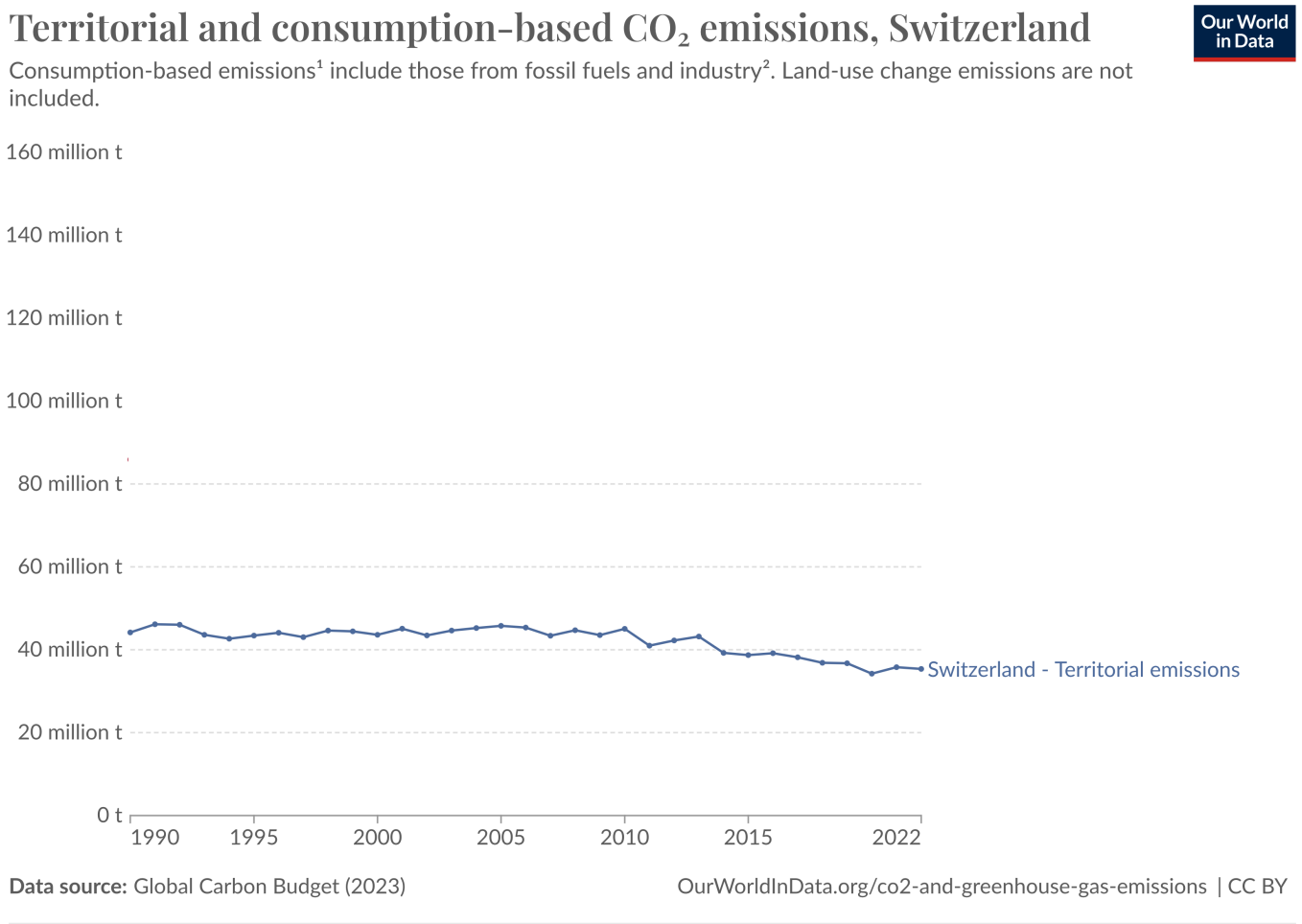



To end climate change the long-run goal is that net-emissions decline to zero.
Bringing emissions down to 2.4 tonnes per person would mean we have halved emissions from their current level (4.8t), a big milestone.

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

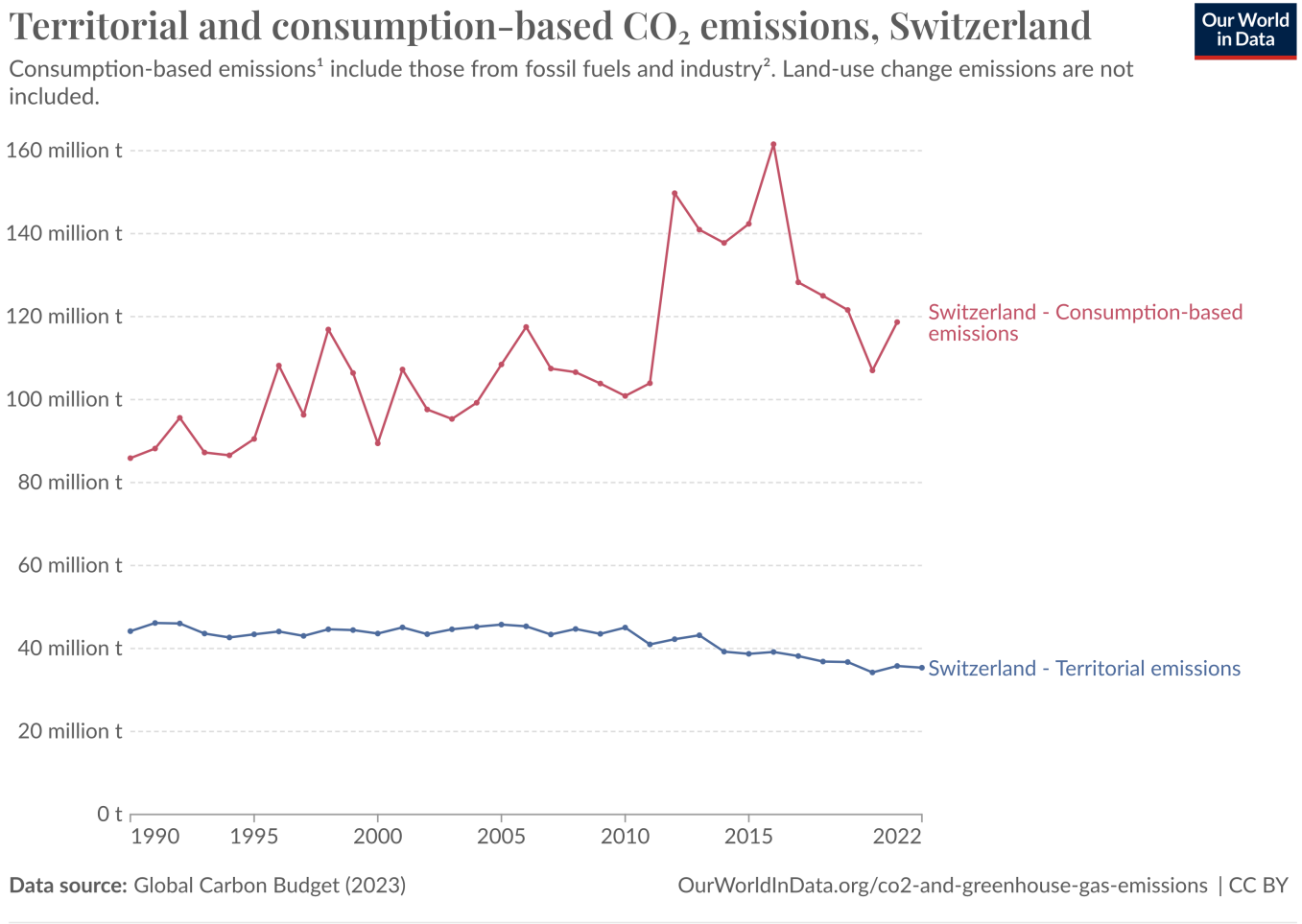
# Swiss $CO_2$ emissions

- 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
  - Example: 3x more air transport than the European average



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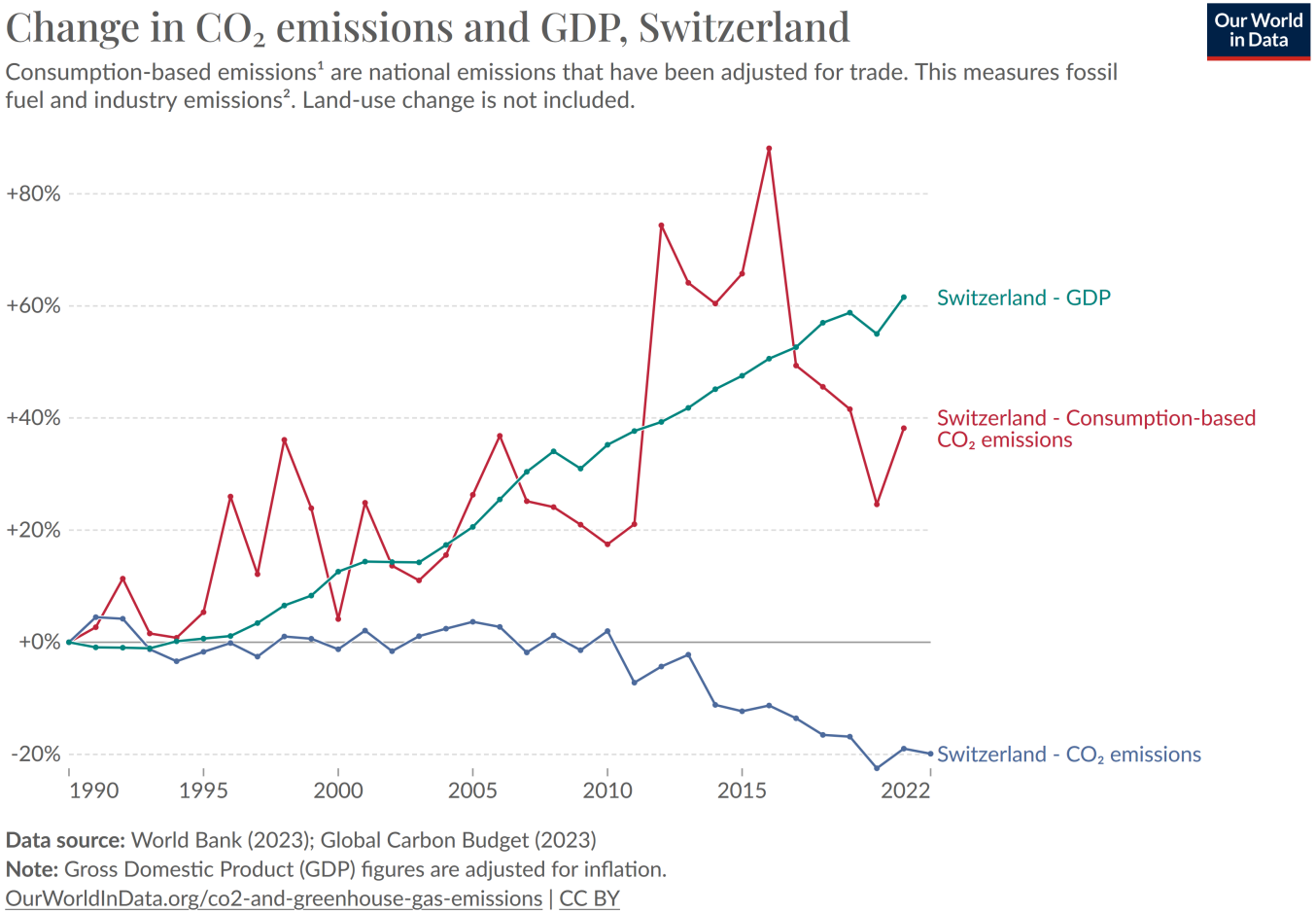
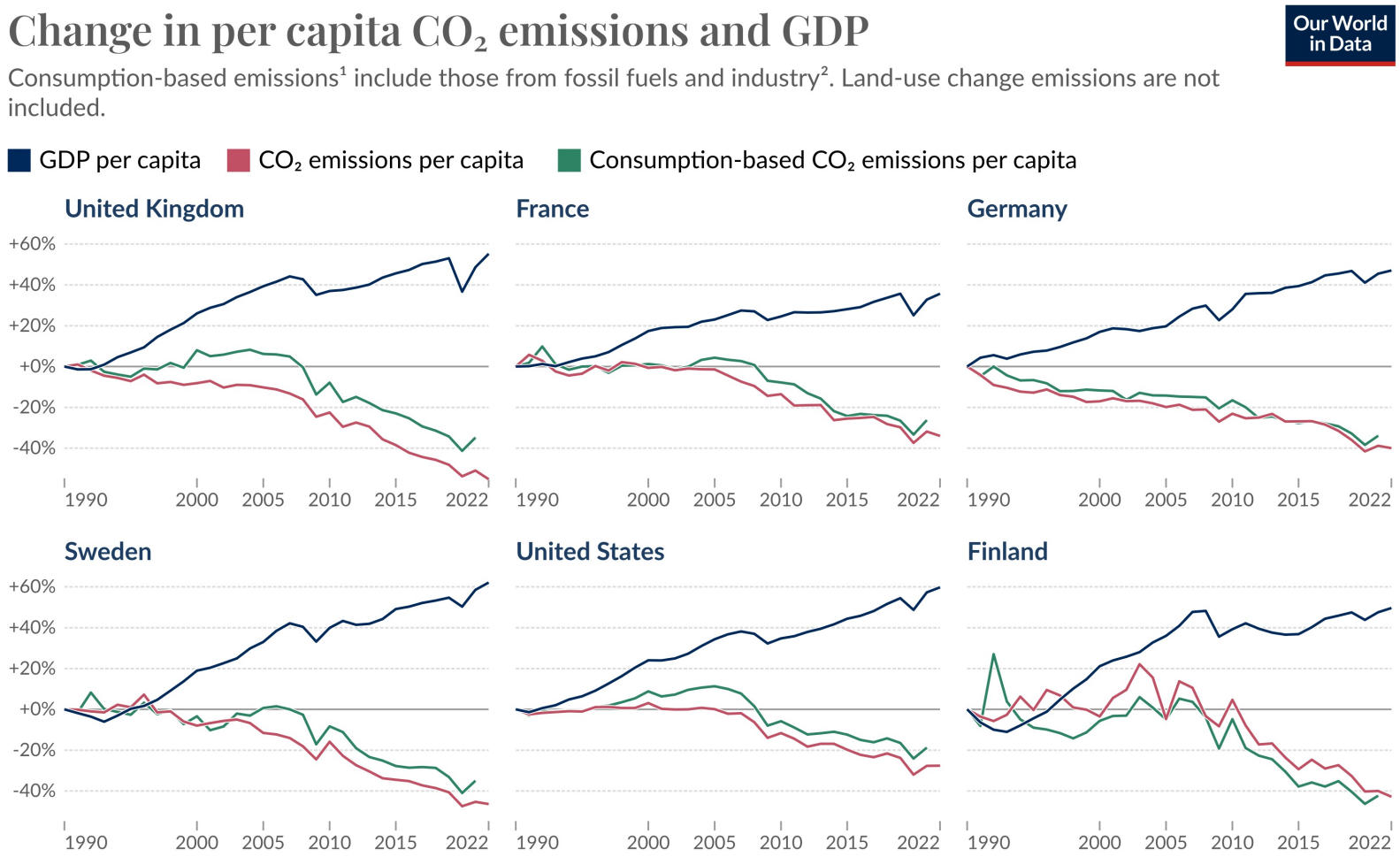


Some countries (not many) have been able to **decouple** economic growth from both territorial carbon emissions and consumption-based carbon emissions



🇸🇪

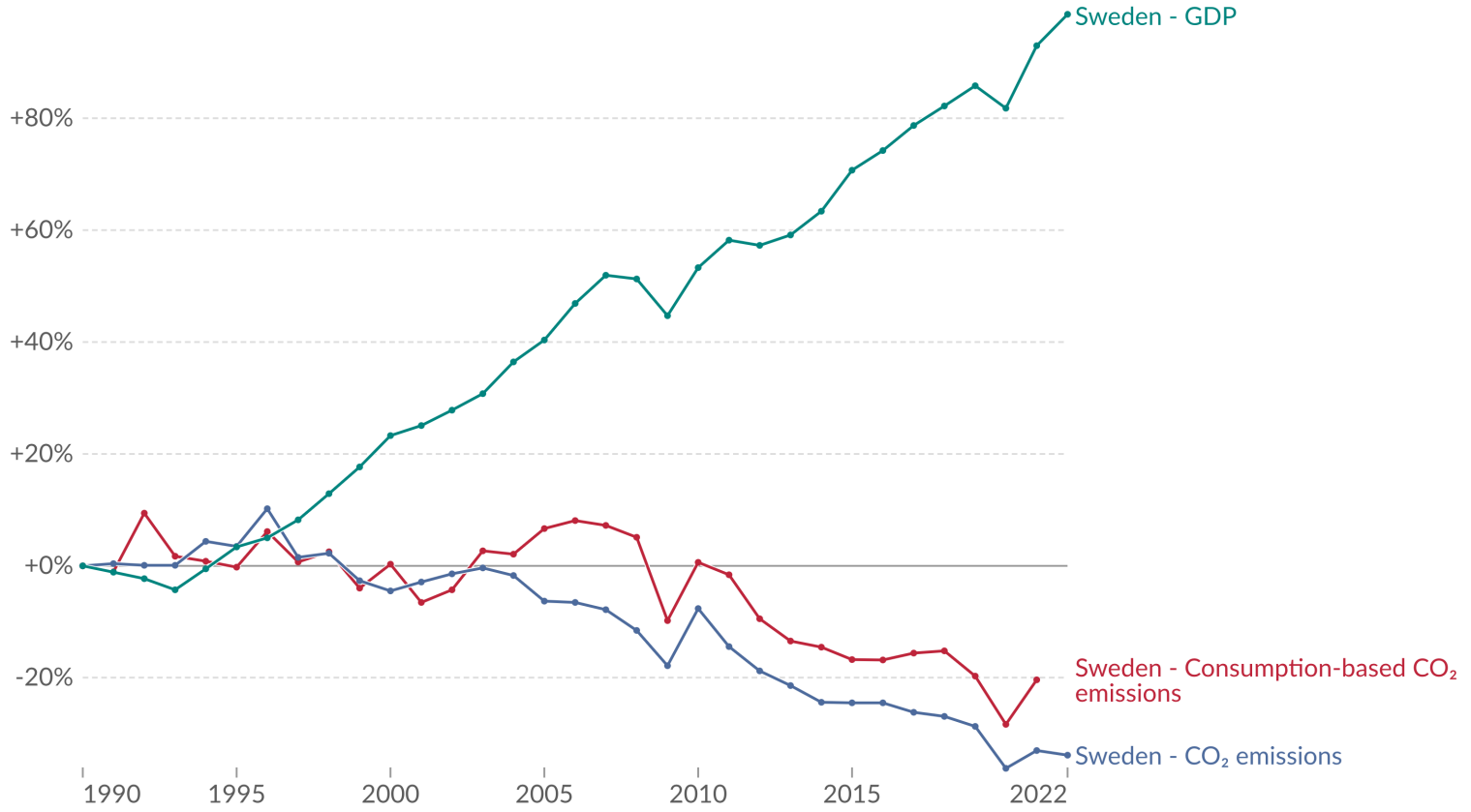
## Some elements from Sweden

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

### Change in $CO_2$ emissions and GDP, Sweden

Our World in Data

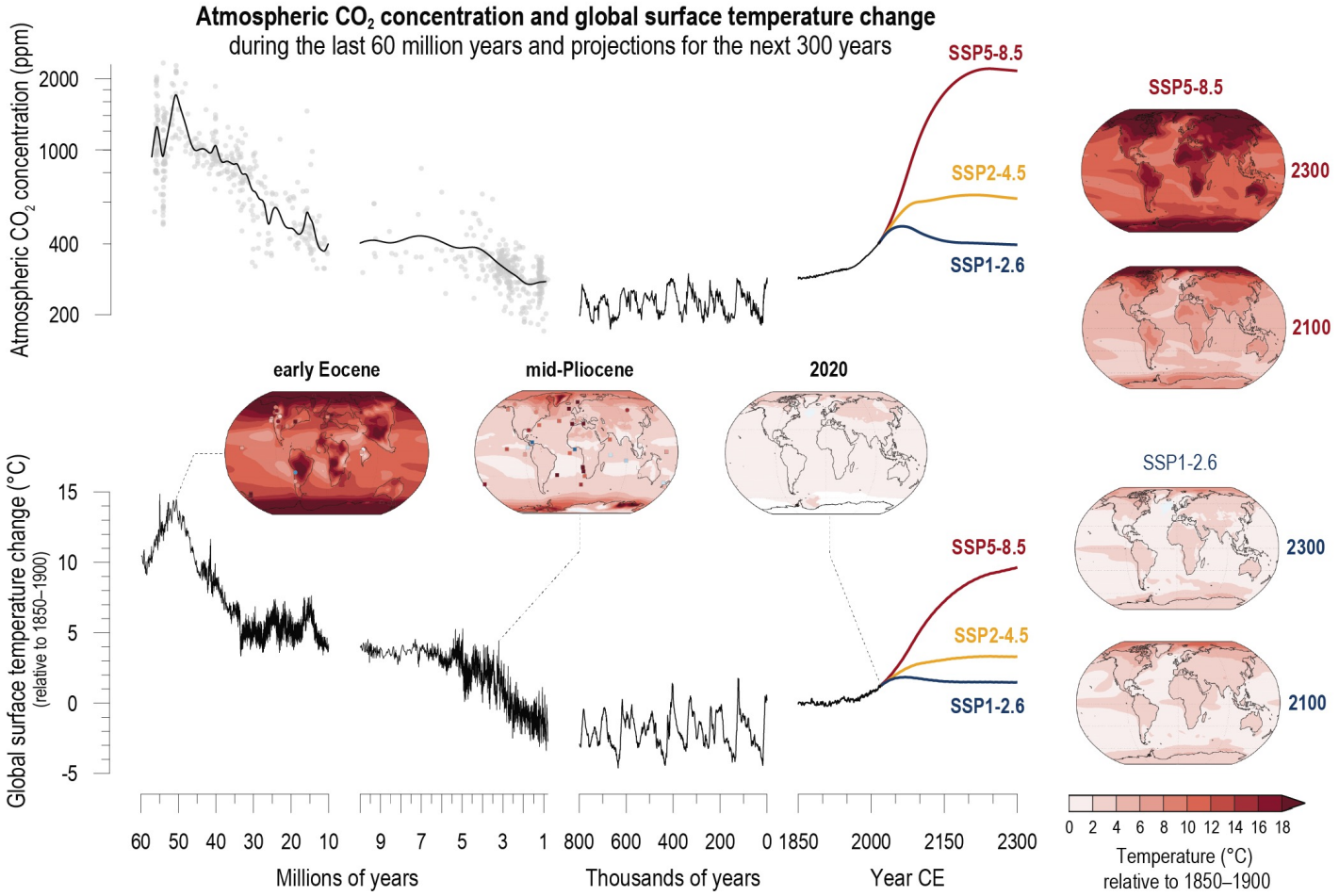
Consumption-based emissions[1] are national emissions that have been adjusted for trade. This measures fossil fuel and industry emissions[2]. Land-use change is not included.




**Data source:** World Bank (2023); Global Carbon Budget (2023) OurWorldInData.org/co2-and-greenhouse-gas-emissions | CC BY
**Note:** Gross Domestic Product (GDP) figures are adjusted for inflation.

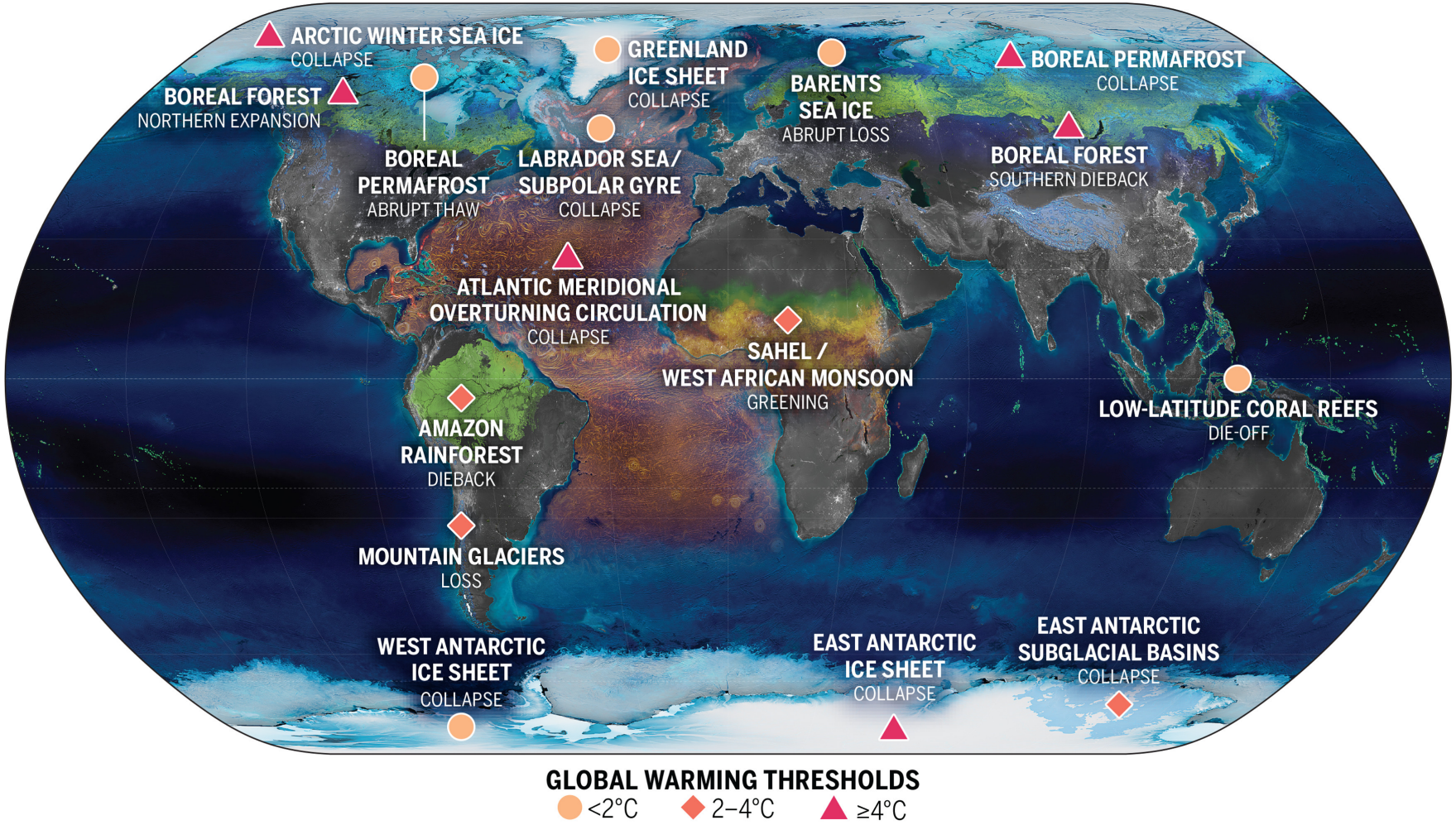
# Is it a problem?

- Let's take a 60-million-year perspective compared to future scenarios
- Middle scenario: climate of the mid Pliocene (~3-5 million years ago)
- 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!



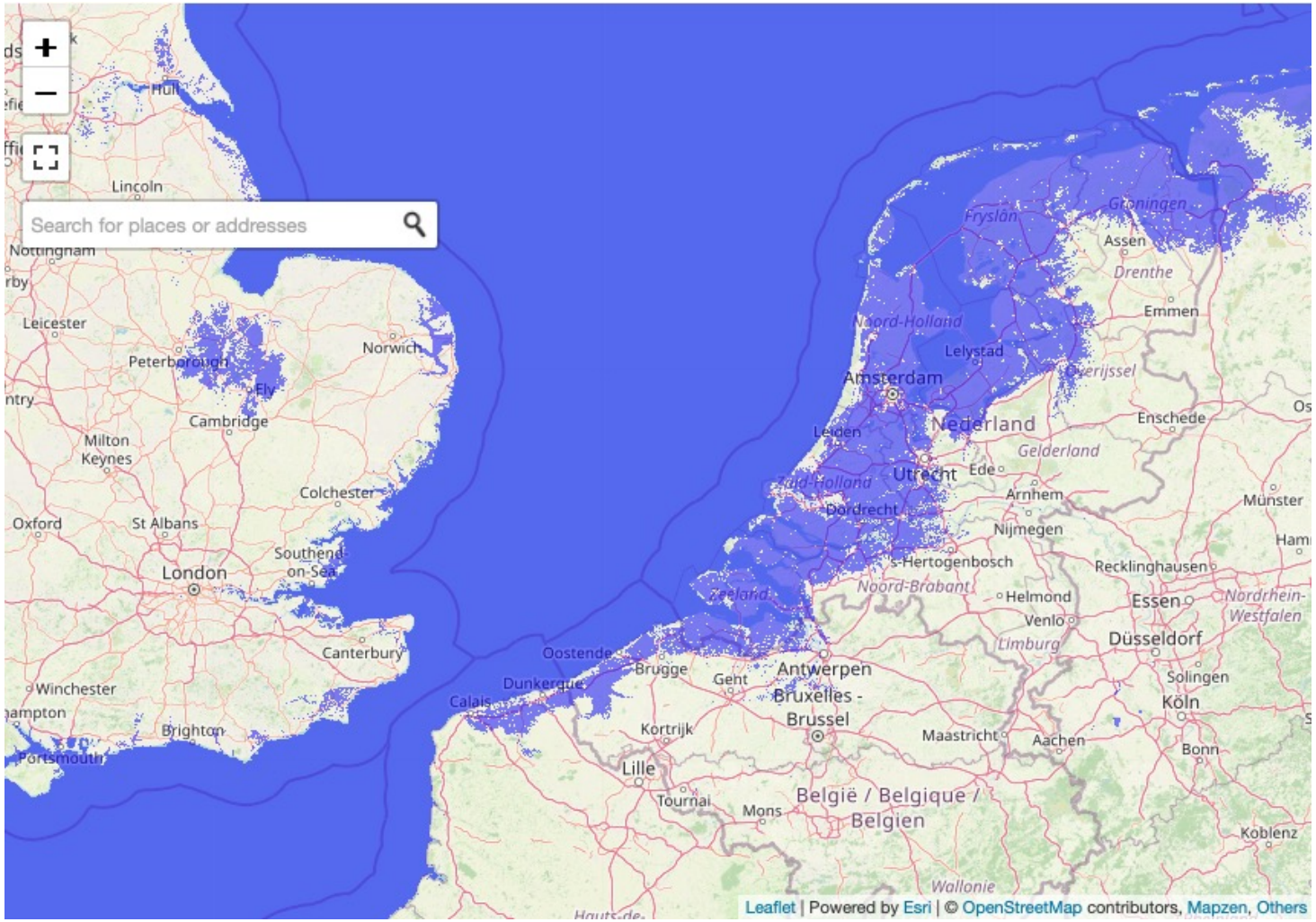
# Impacts from climate change

- 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

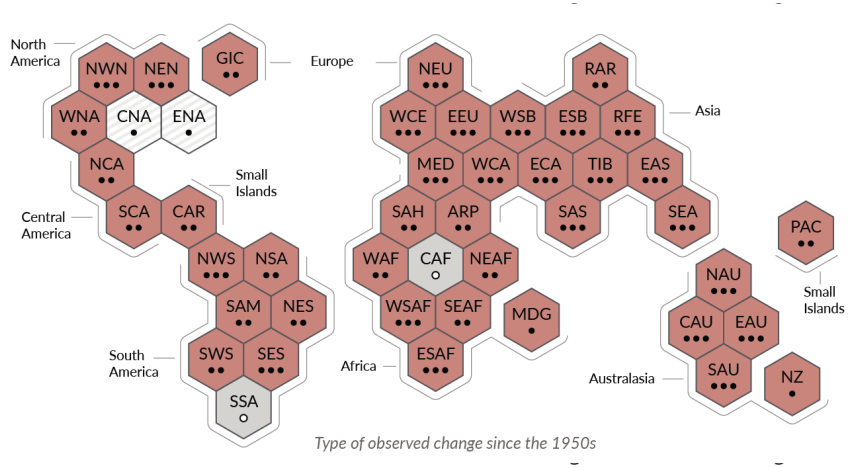
1m of sea level rise



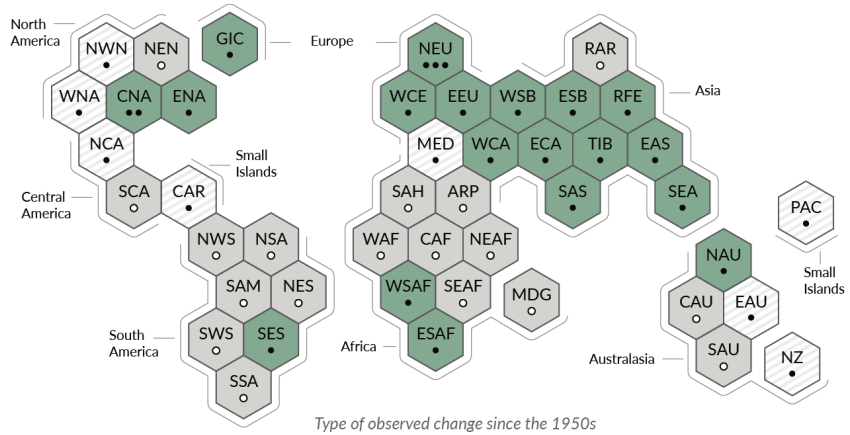
# Acute weather impacts

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

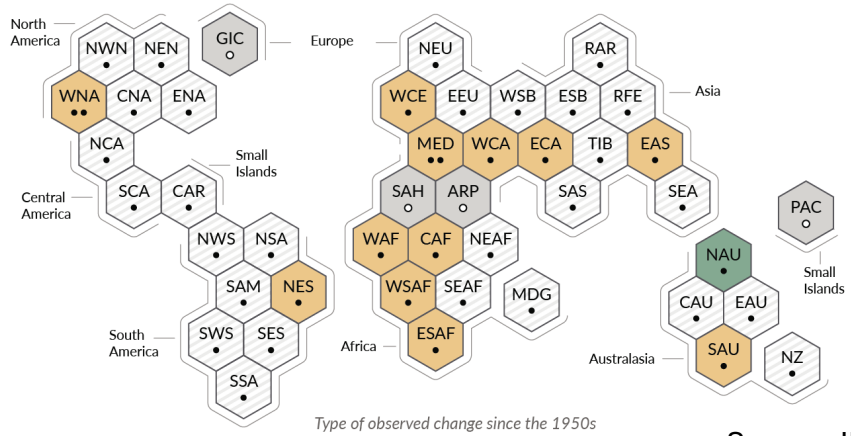
## Extreme heat




## Extreme rain



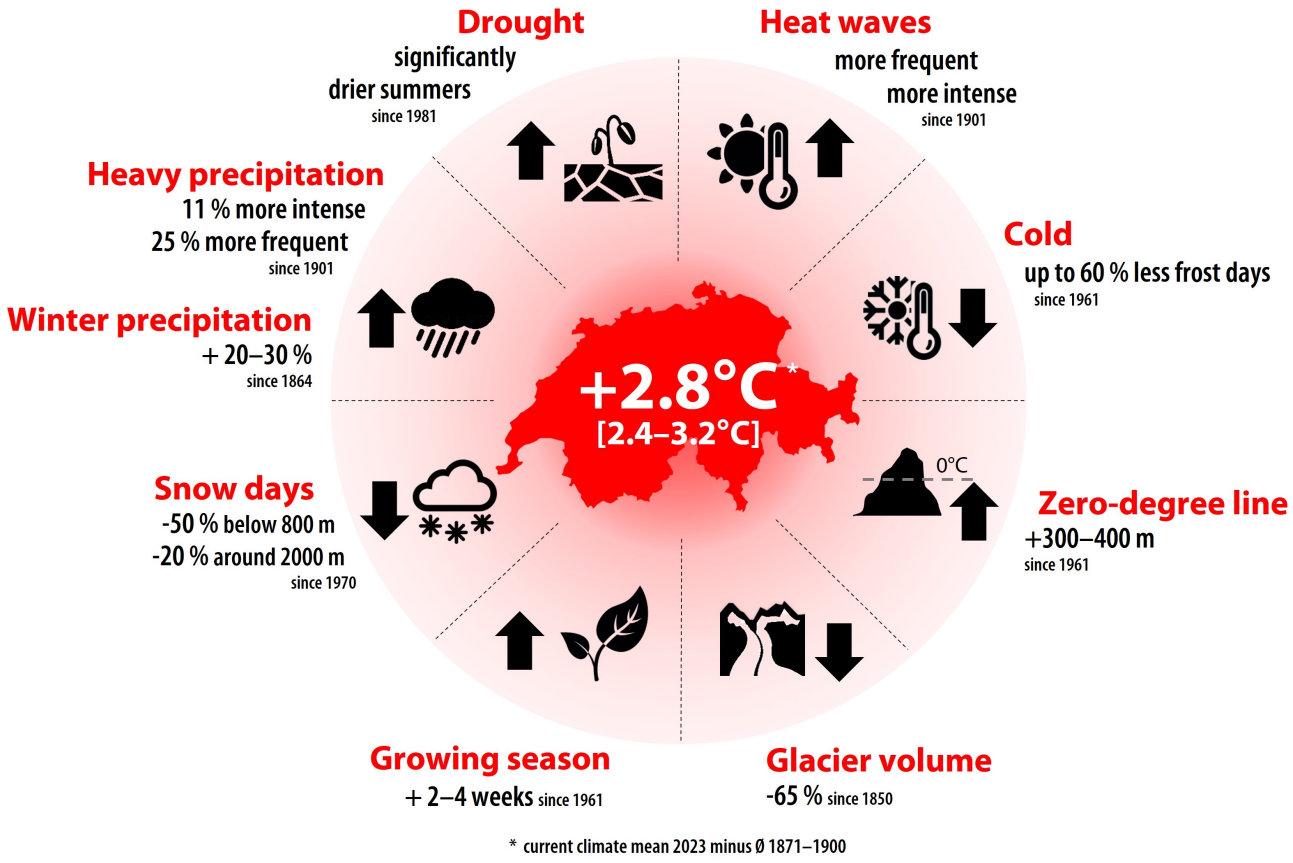

## Drought




Source: IPCC

# Impacts from climate change in Switzerland

- Some very specific impacts in alpine regions




Source: MeteoSwiss

# A summary of CO2 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

# How do you define sustainability?

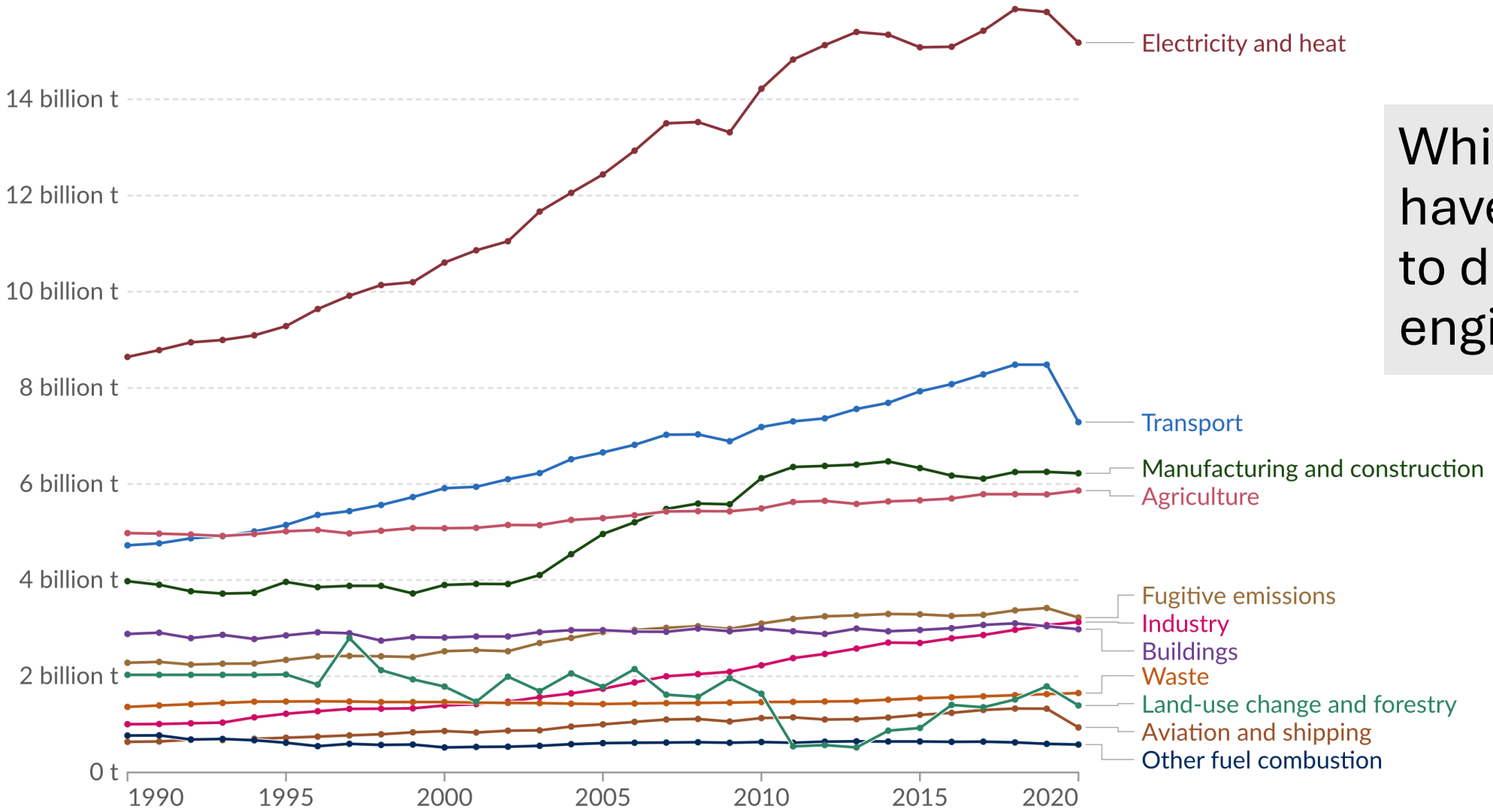
- Break into small groups of 2-3
  - Discuss the question: “what is the definition of sustainability”
  - Write down your definition
  - Be prepared to share back with the class
- Take inspiration from ENV-101 last year, as well as other knowledge you may have
- I will post summary slides of definitions to know after class on Moodle

# Sustainability in civil engineering

# Greenhouse gas emissions by sector, World

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

Our World in Data



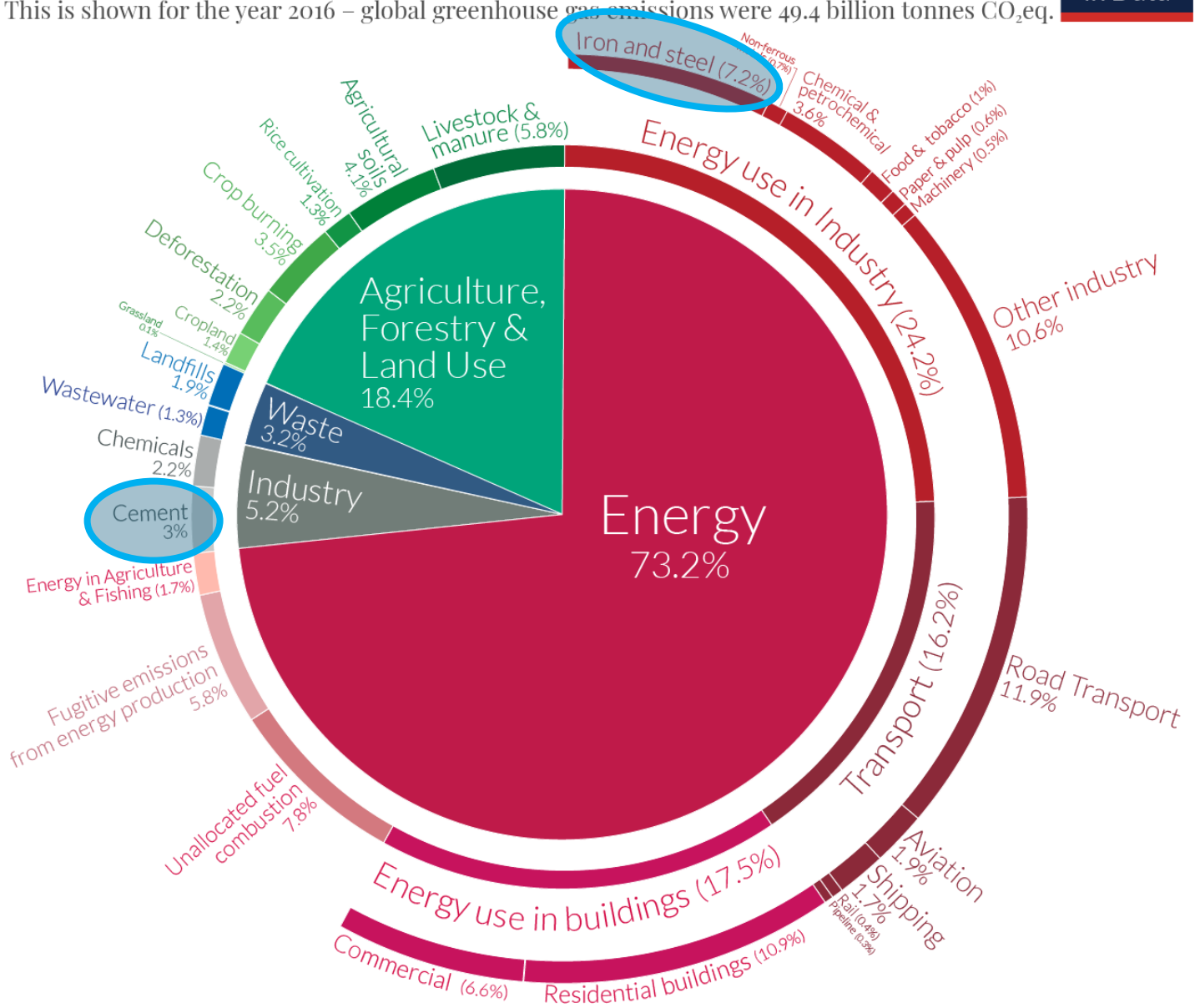

Which of these have something to do with civil engineering?

**Data source:** Climate Watch (2023)
**Note:** Land-use change emissions can be negative.

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

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

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



# UN Sustainable Development Goals (SDGs)


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)

# What do you expect to learn in this course?

- Email your class delegates by the end of the week: Friday, September 12
  - Answer the question: What do I expect to learn in CIVIL-239 – Engineering a sustainable built environment?
- Class delegates: send me a detailed summary by Tuesday, September 16
- I will address the comments next week in class