MUNI
SCI

05 Carbon cycle

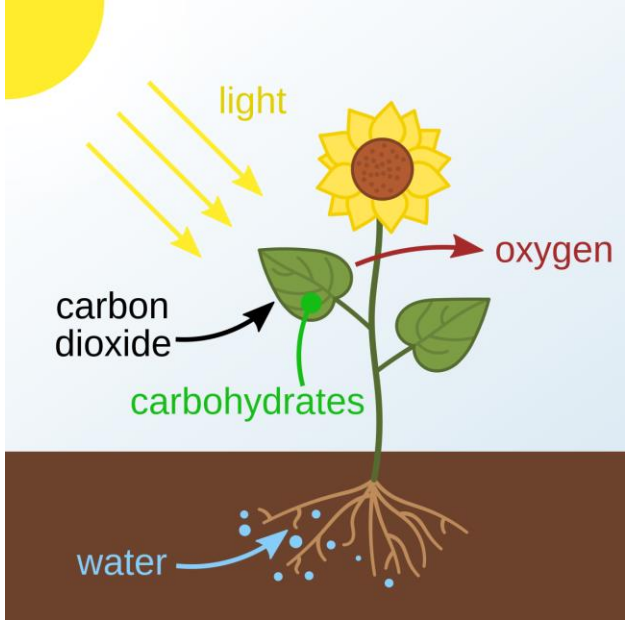
Lukáš Dolák, MSc, PhD

Content of the lecture

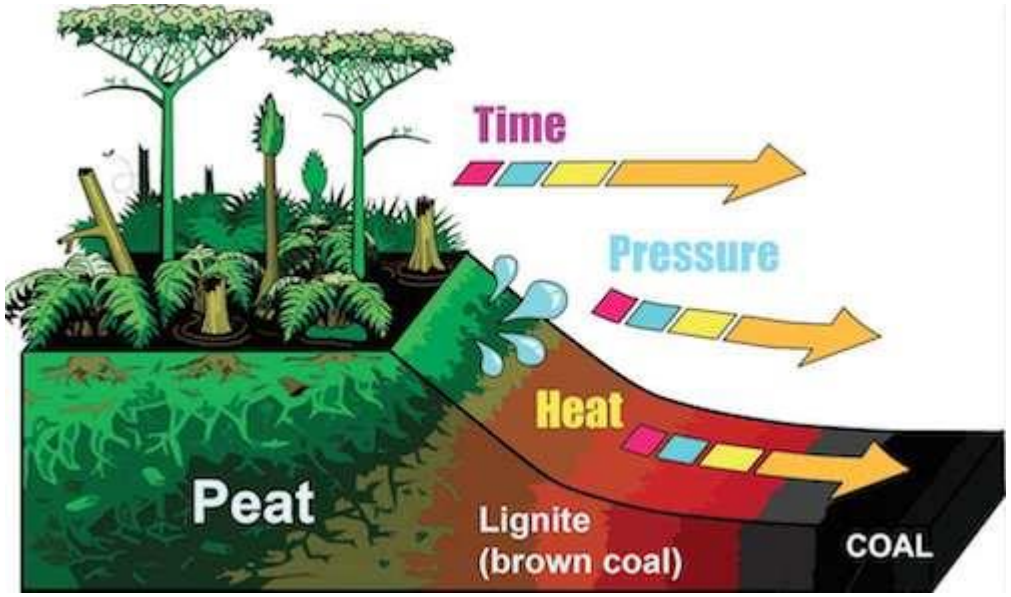
1. Carbon cycle, sources and emissions of CO_2
2. Carbon movement in the atmosphere
3. Course of CO_2 concentration
4. Carbon footprint

Carbon cycle, sources and emissions of CO_2

Carbon cycle

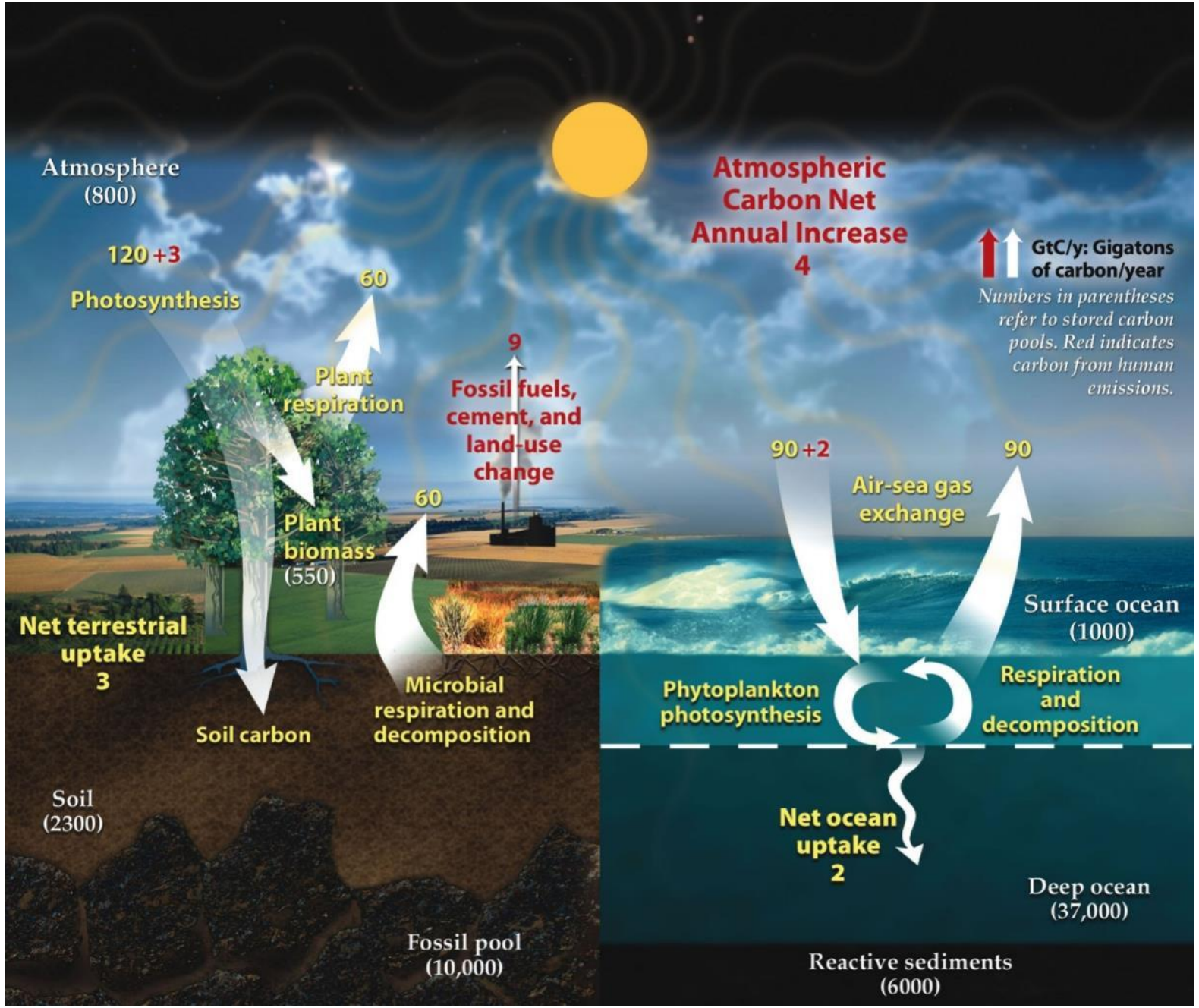


- **Carbon (C)**: the basic building block of organisms
- The process of **photosynthesis**
- **Carbon storage** in the Earth's crust => fossil fuels
- **Carbon release** by **burning** => CO_2



aleklett.wordpress.com, 2013; HN, 2014

Carbon cycle



https://www.youtube.com/watch?v=lWEvBLlUa2E

wikimedia.org, 2018

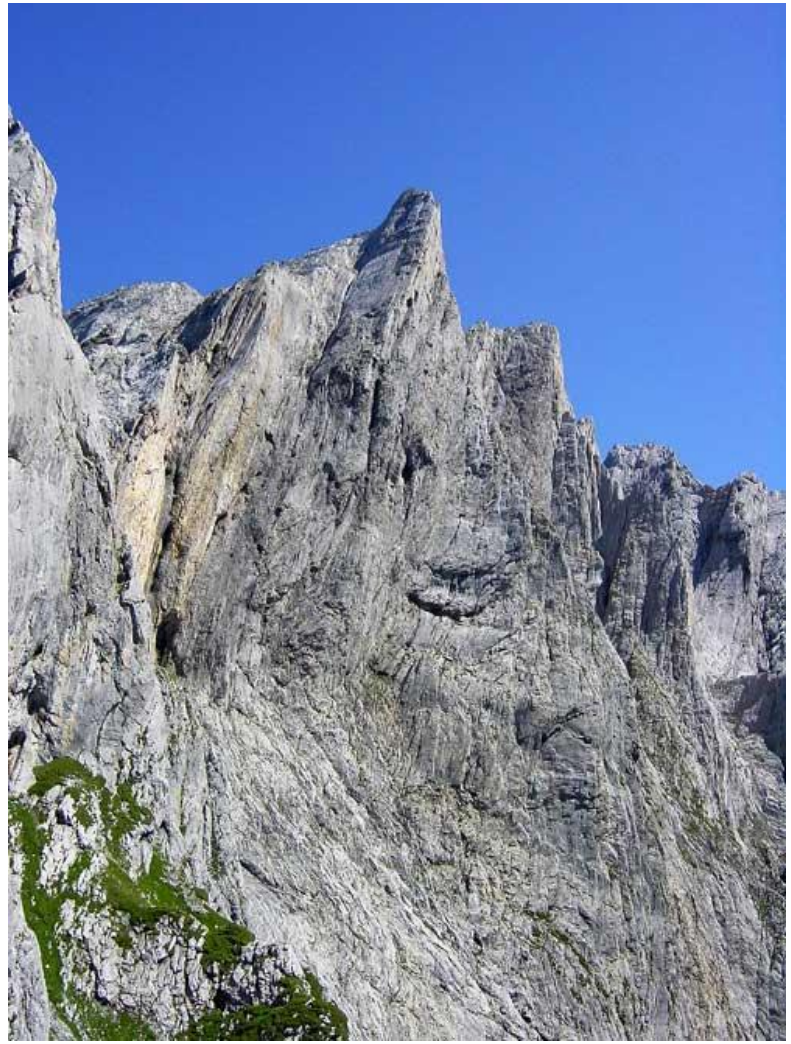

ATMOSPHERE
(industrial machinery chugging frantically)

Reservoirs and sources of natural CO_2

- **1 Gt (*gigatonne*)** = 1 billion tonnes = 1 000 000 000 000 kg

- **100 million Gt**: the Earth's crust
  - active volcanoes 0.3 Gt/year = 0.8% of anthropogenic CO_2
- 37 000 Gt: **oceans and seas**
- 1440–1600 Gt: **permafrost**
- 800 Gt: **atmosphere** (of which about 5% is anthropogenic)
- 550 Gt: **biosphere**

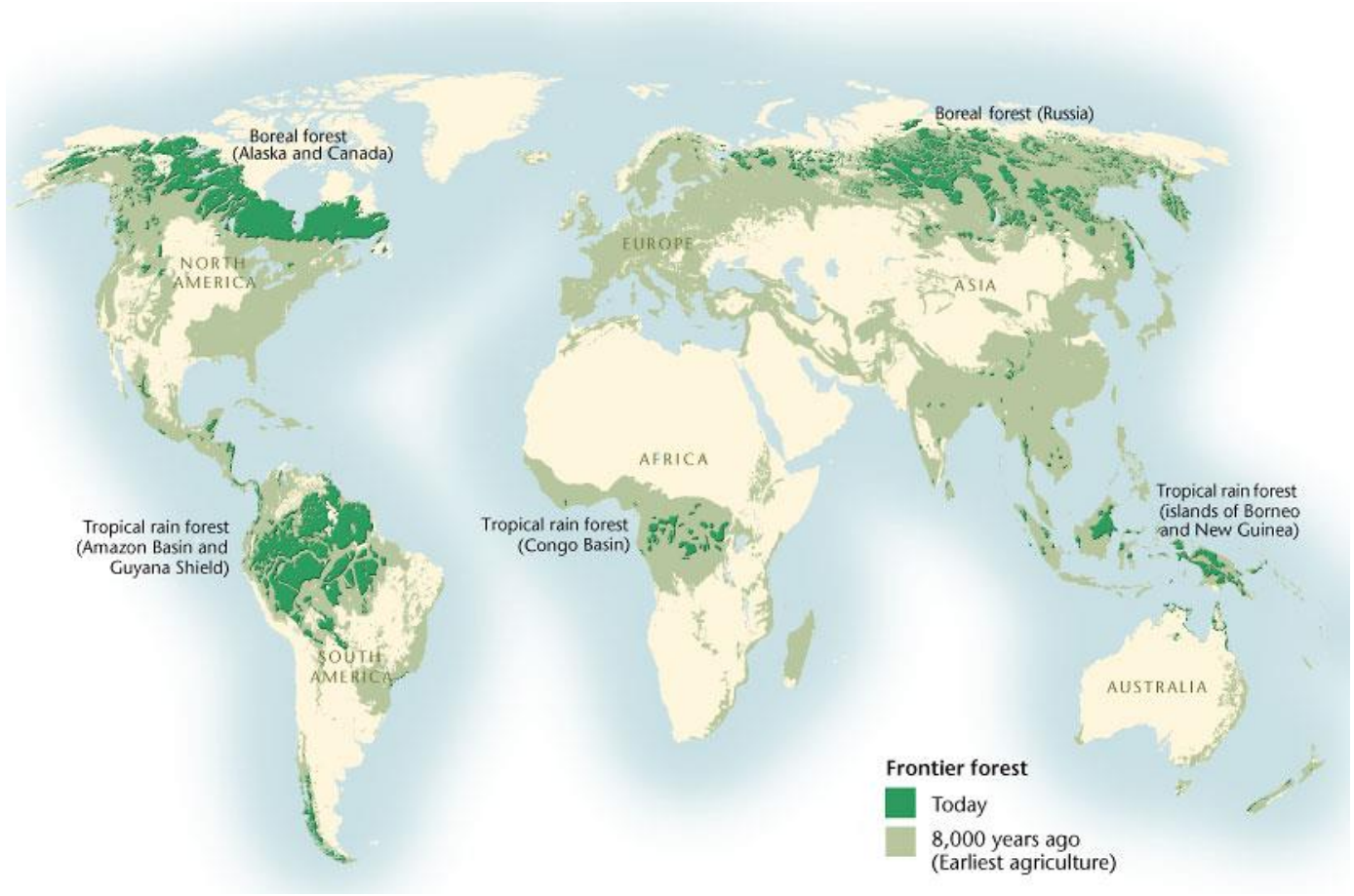
Reservoirs and sources of natural CO_2



- **Long-term carbon reservoirs**:
  - limestones, fossil fuels
- **Intermediate-term carbon reservoirs**:
  - deep-sea sediments, soil, marshes
- **Short-term carbon reservoirs**:
  - upper ocean, northern hemisphere forests, Amazonia
  - rainorests: 0.4 Gt/year (more than car traffic in the US in 2015)

Reservoirs and sources of natural CO_2

- **Factors influencing CO_2 fluctuations**:
  - **northern hemisphere**:
    - forests
  - **southern hemisphere**:
    - ocean x atmosphere interaction

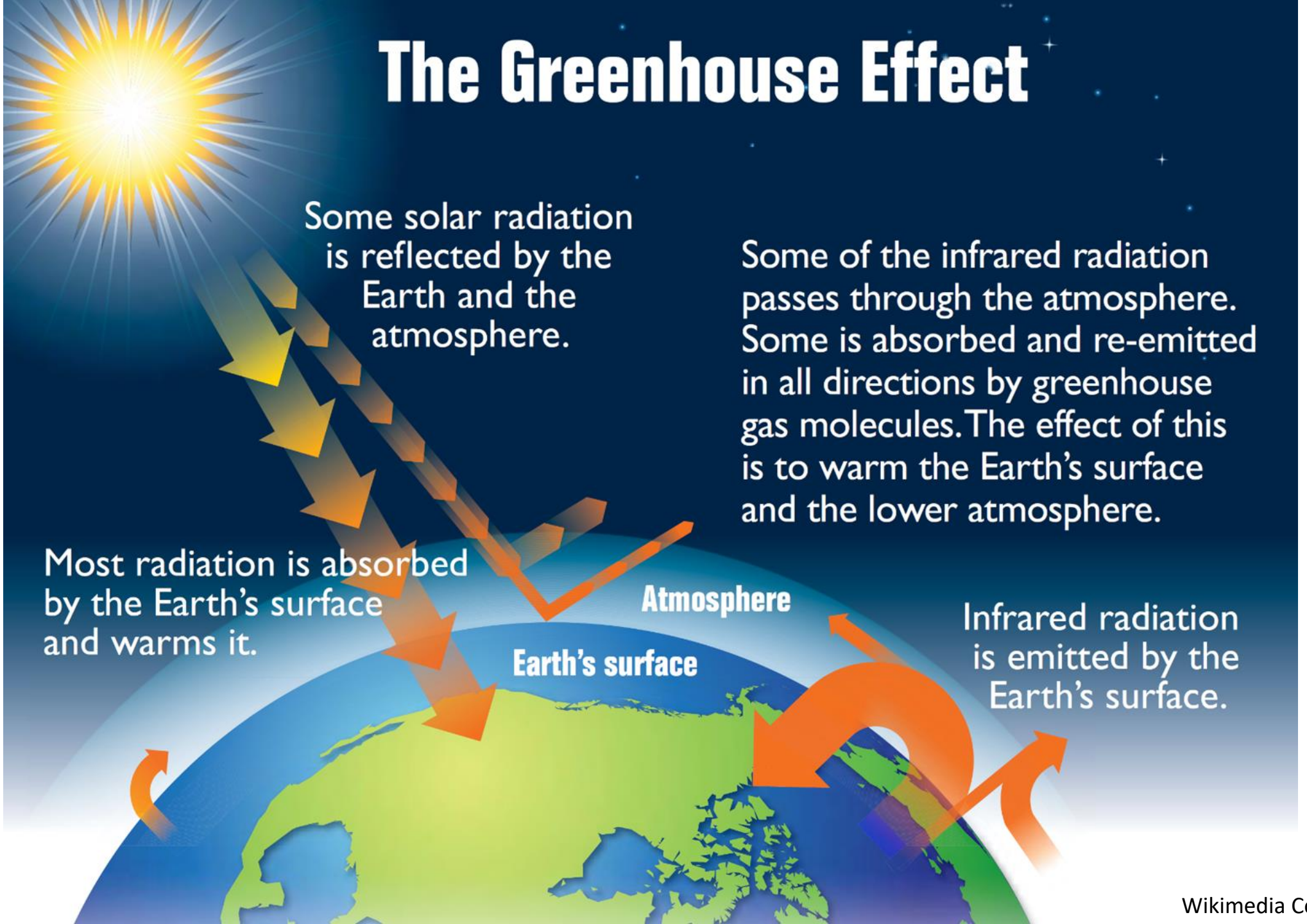


Sources of anthropogenic CO_2

- **Human respiration**: approx. 240 kg/year = 0.00000000024 Gt
- **Humans (1990)**: 20 Gt
- **Humans (2023)**: 40.7 Gt (about 5% of total natural resources)
- But!

  $\Rightarrow$ total anthropogenic emissions of all greenhousegasses (GHGs) =

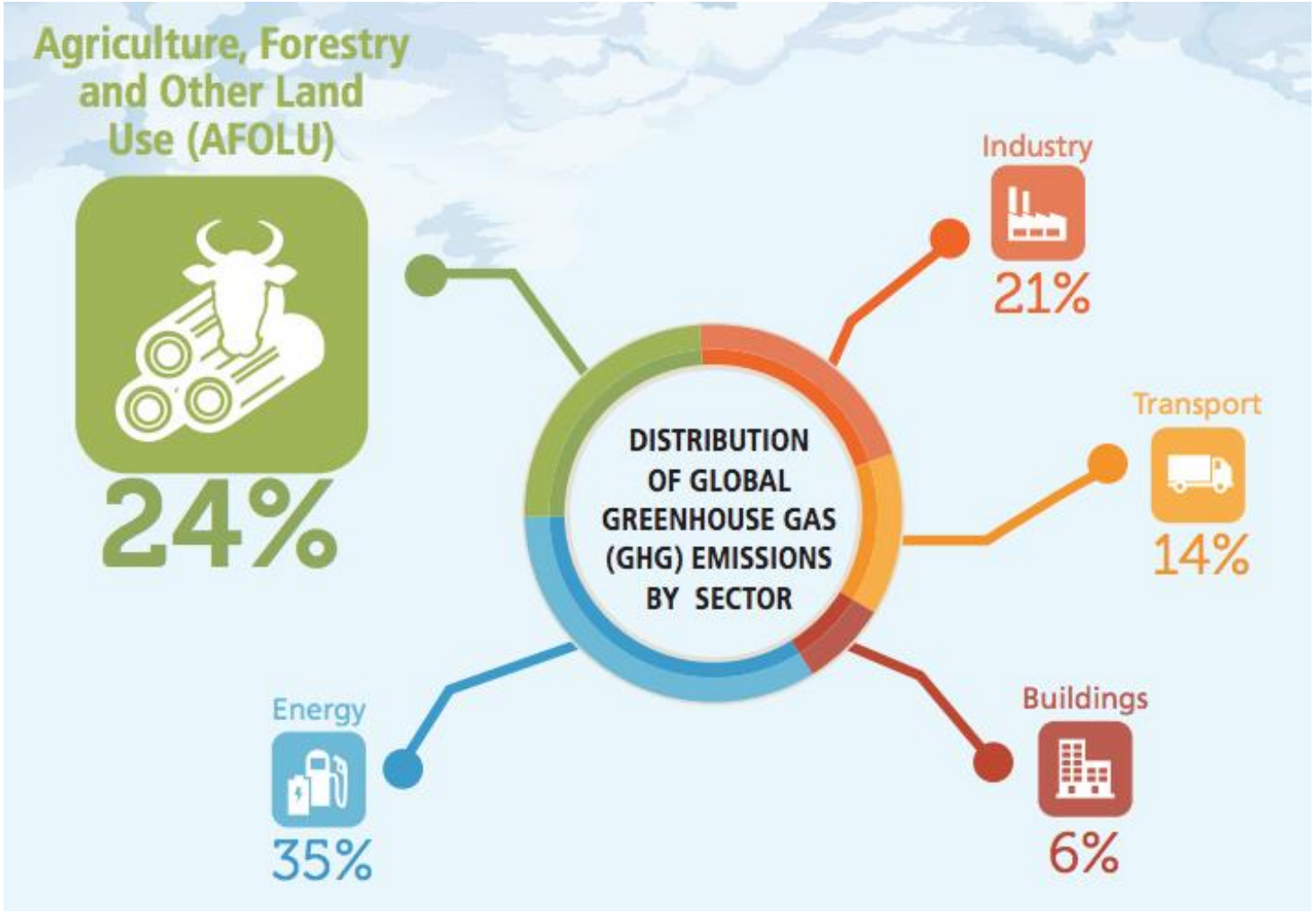
  56 Gt CO_{2ekv} (2022)
- **Anthropogenic CO_2 emissions over the last 250 years**: 2 355 Gt (= 8000 volcanoes)
  - increase >3.5 W/m^2 = >2.4 °C



Wikimedia Commons 2015

Sources of anthropogenic CO_2 according to sectors

land use changes:
ca 6% GHG emissions



ecowarriorprincess.net, 2016

Anthropogenic CO_{2ekv} emissions (2022 – comparison)

	2022 vs 1990	2022 vs 2005	2022 vs 2021
Power Industry	↗ +92%	↗ +34%	→ +1%
Industrial Combustion and Processes	↗ +95%	↗ +43%	→ 0%
Buildings	→ 0%	→ +3%	→ 0%
Transport	↗ +72%	↗ +22%	→ +5%
Fuel Exploitation	↗ +56%	↗ +22%	→ +3%
Agriculture	↗ +21%	↗ +15%	→ +1%
Waste	↗ +58%	↗ +32%	→ +2%
All sectors	↗ +62%	↗ +27%	→ +1%

Greenhousegasses emission report, 2023

Sources = Sinks

34.4 $GtCO_2/yr$

87%

13%

5.3 $GtCO_2/yr$

17.3 $GtCO_2/yr$

44%

29%

11.6 $GtCO_2/yr$

22%

8.9 $GtCO_2/yr$

Budget Imbalance:
(the difference between estimated sources & sinks)

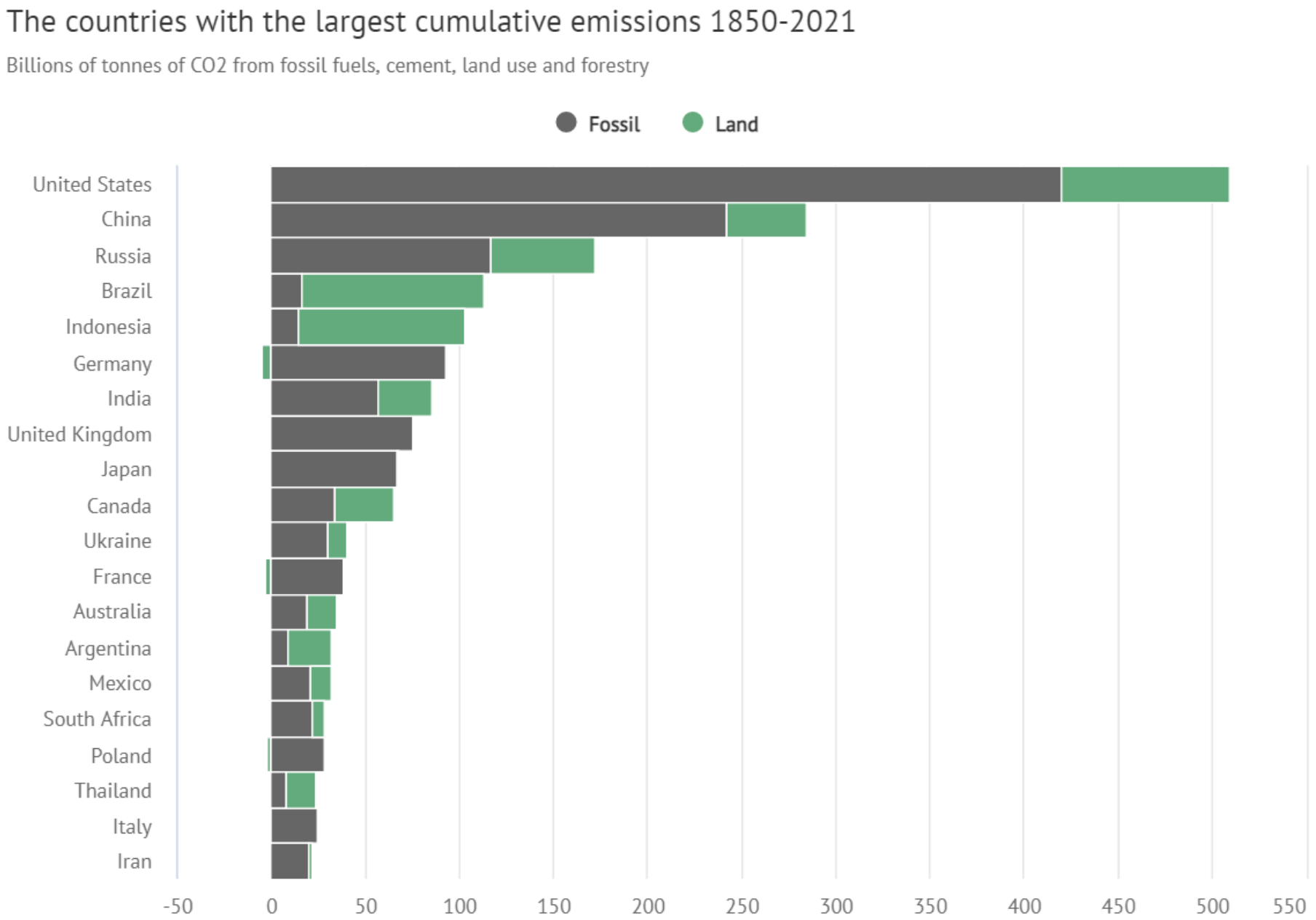
5%

1.9 $GtCO_2/yr$

Global Carbon Project, 2018

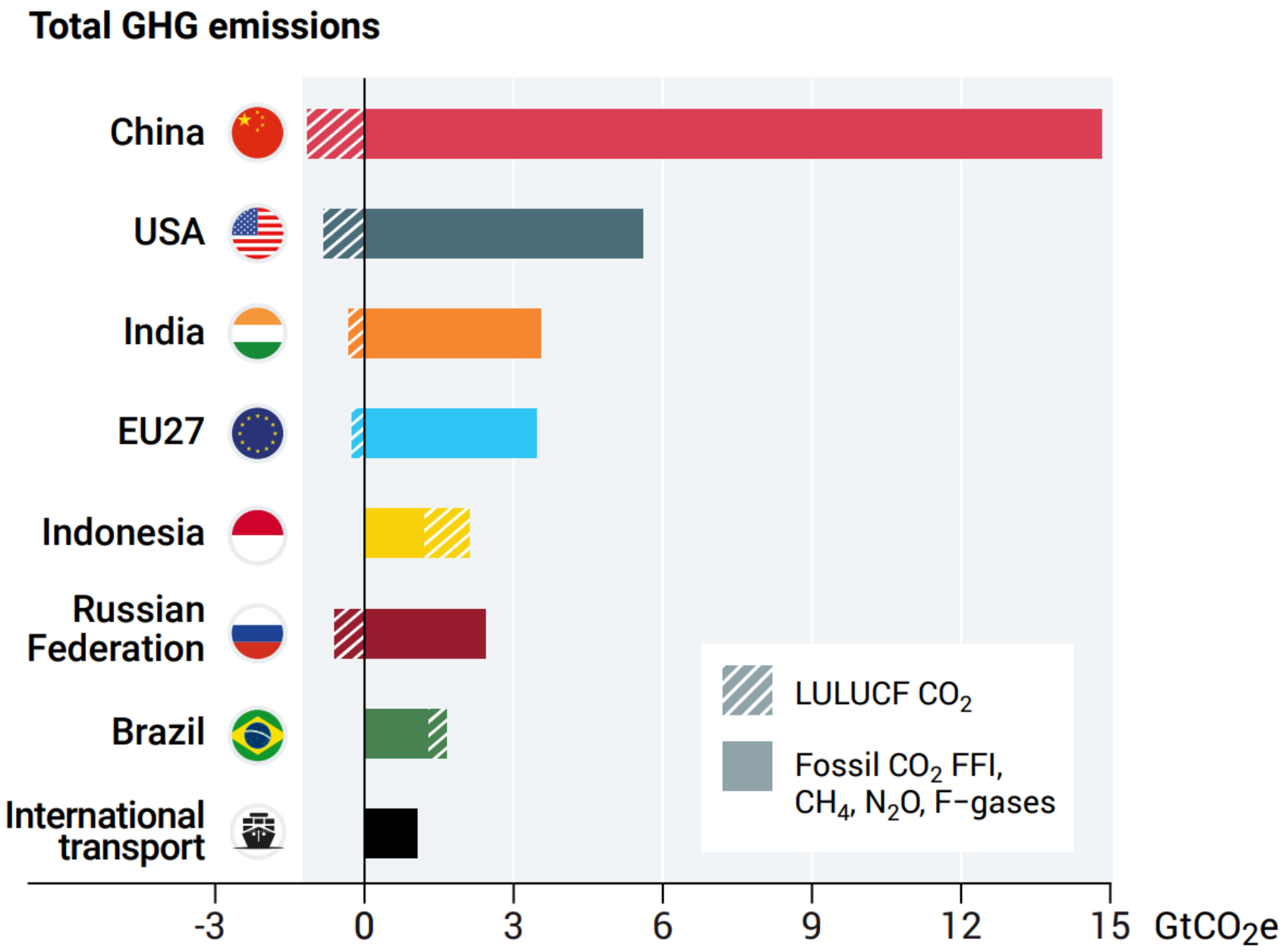
Sources of anthropogenic CO_2

- **Transportation**:
  - car: 100–150 g/km



Carbon Brief 2021

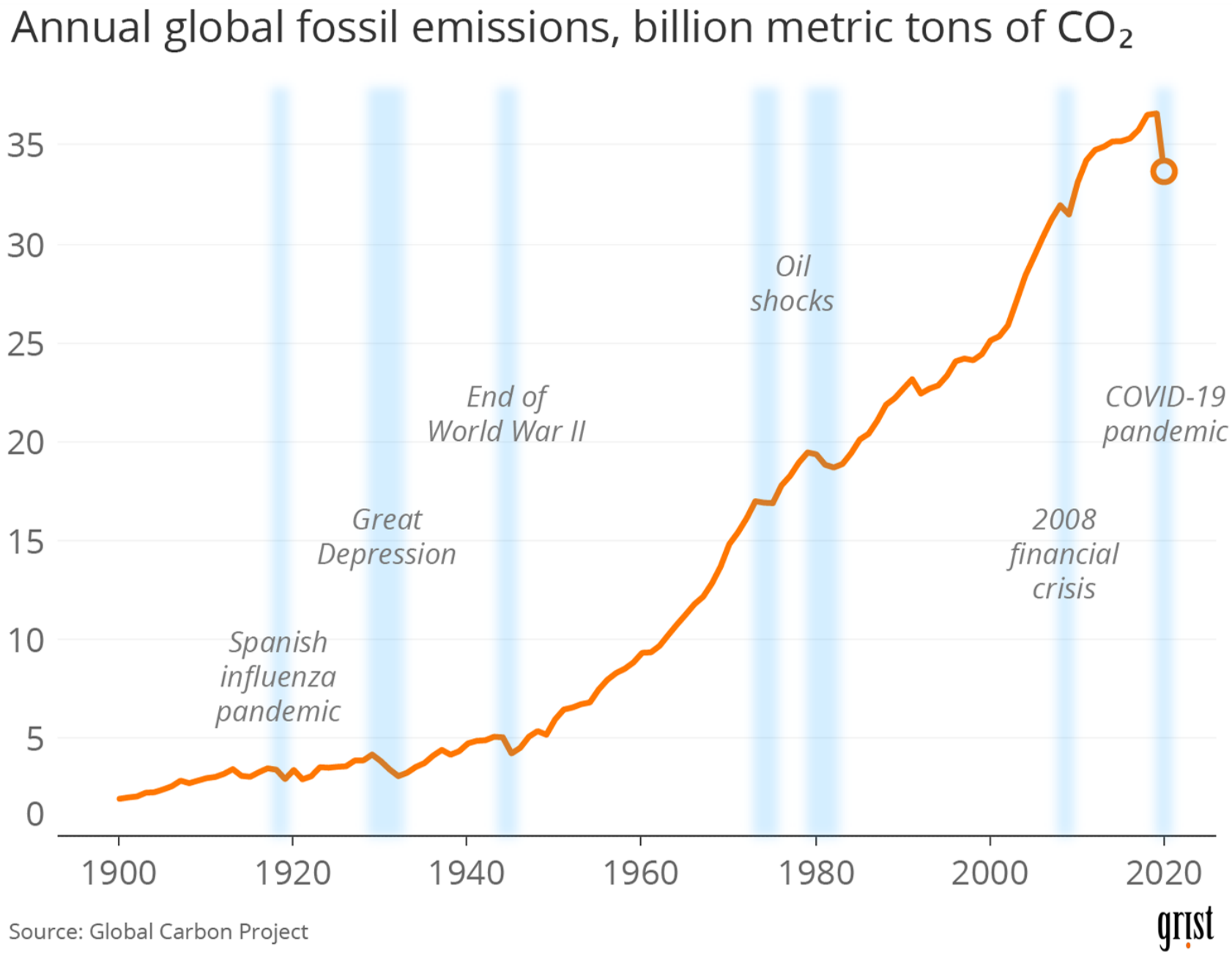
Annual CO_{2ekv} emissions – World (2020)



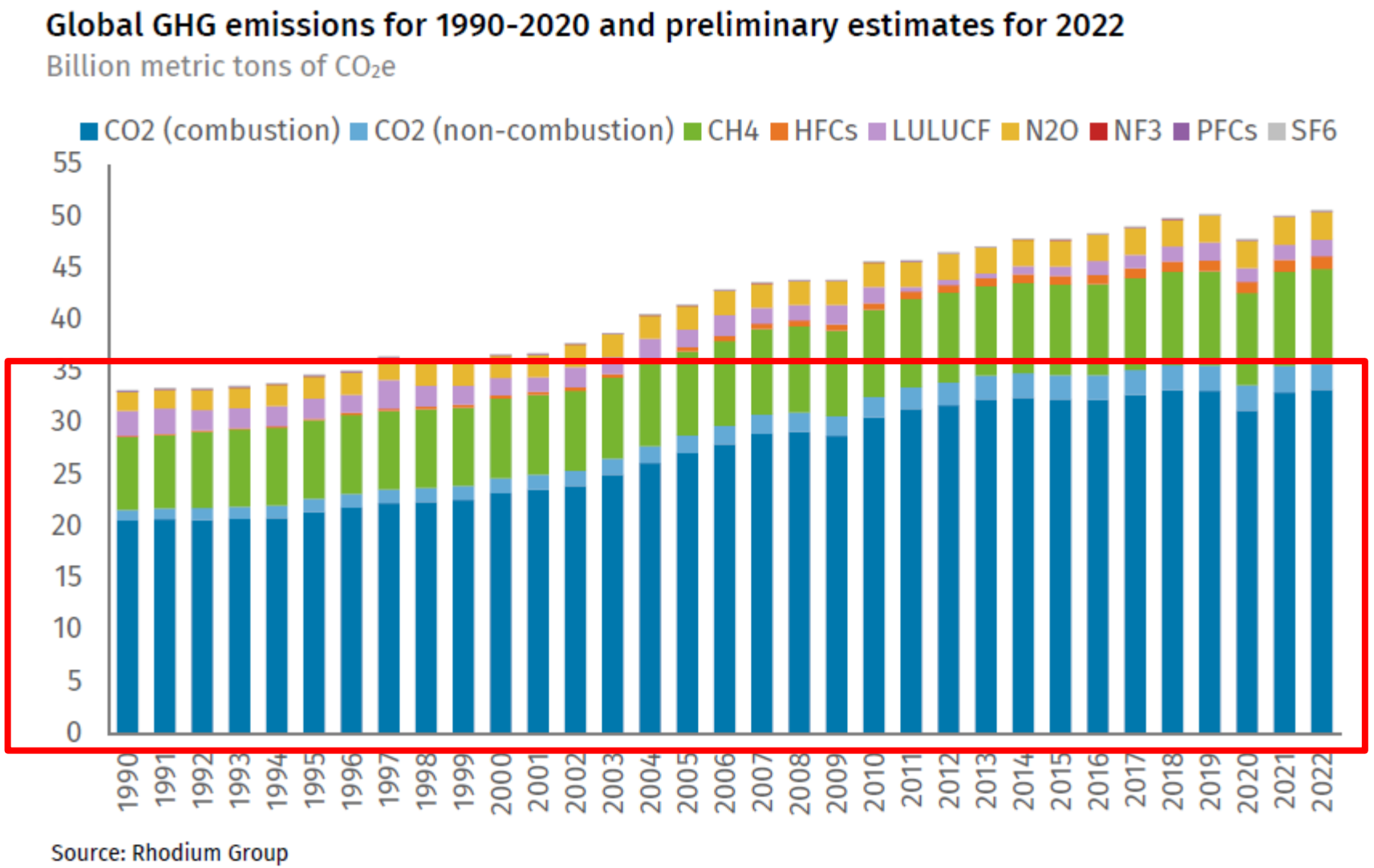
Emissions Gap Report, 2022

Annual CO_2 emissions - World (1900–2020)

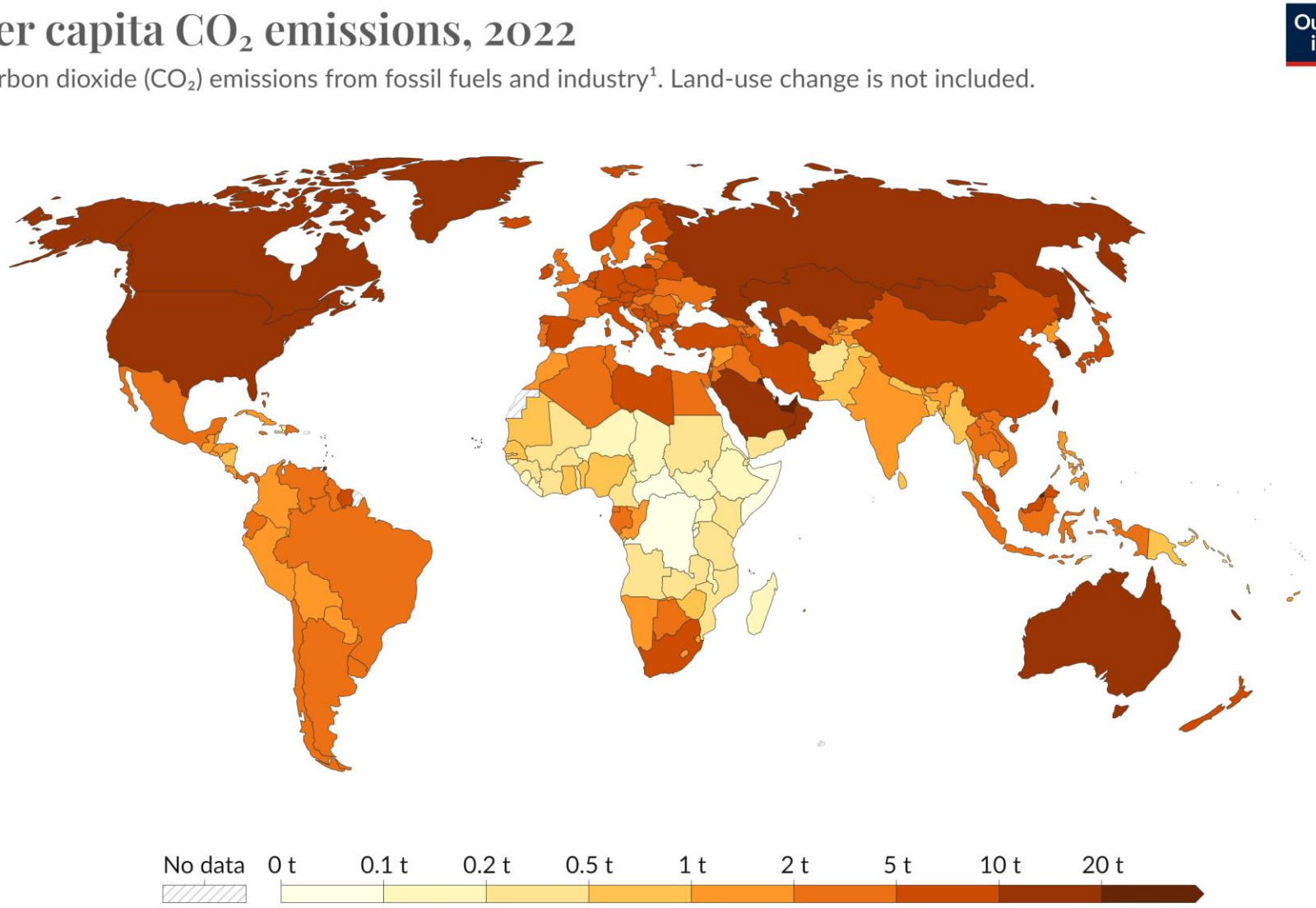
at the current rate of emissions growth, there is a 50% chance of exceeding 1.5 °C by 2040



Annual CO_{2ekv} emissions – World (1990 – 2022)

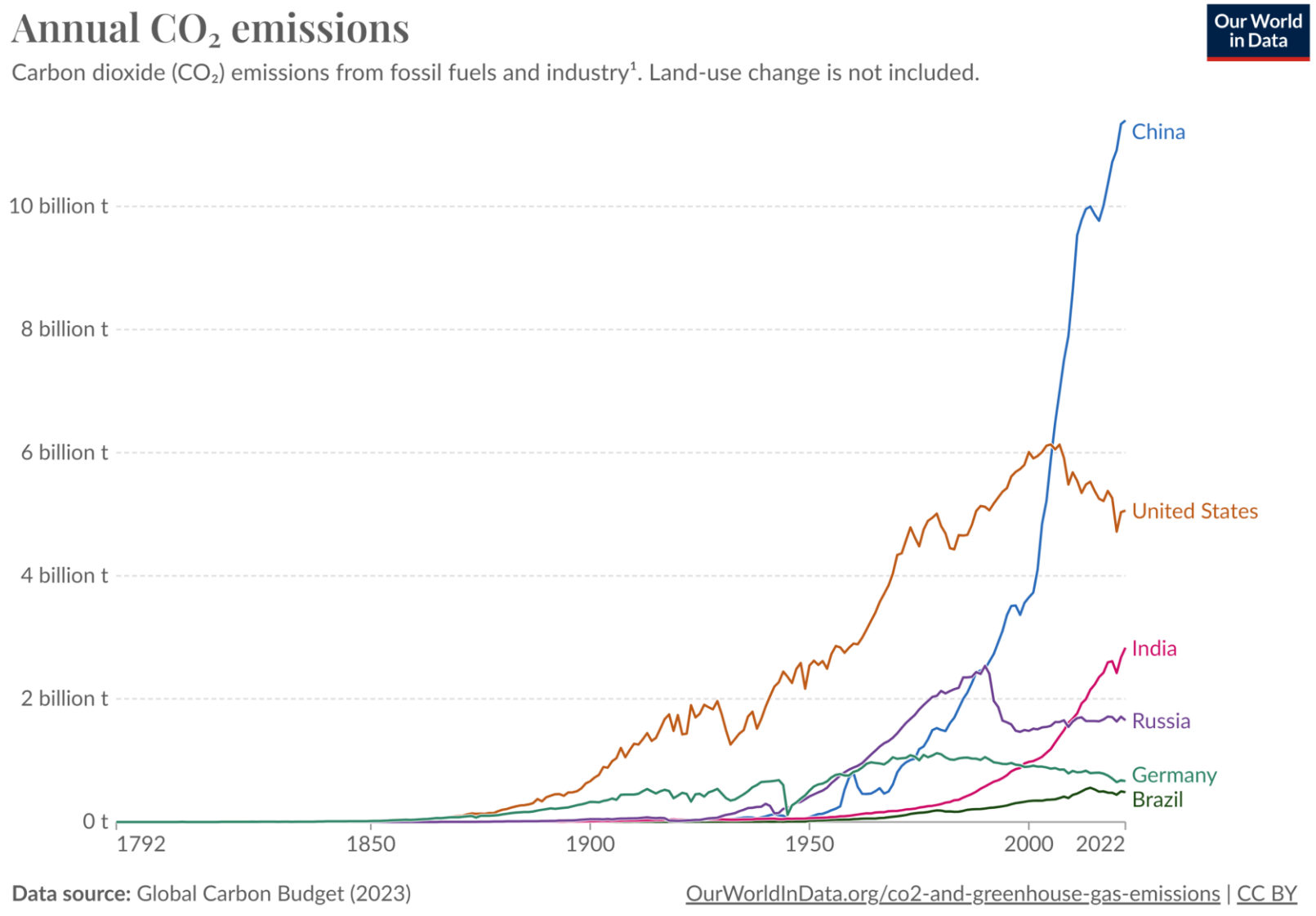


Annual CO_2 emissions - world (2022)



https://ourworldindata.org/co2-emissions

Annual CO emissions$_2$ - selected countries (1792–2022)



1. Fossil emissions: Fossil emissions measure the quantity of carbon dioxide (CO_2) emitted from the burning of fossil fuels, and directly from industrial processes such as cement and steel production. Fossil CO_2 includes emissions from coal, oil, gas, flaring, cement, steel, and other industrial processes. Fossil emissions do not include land use change, deforestation, soils, or vegetation.

ourworldindata.org/co2-emissions, 2024

Carbon movement in the atmosphere

Carbon movement in the atmosphere

- The production of CO_2 and O_2 has kept the atmosphere relatively stable **over the last 500 million years**
  - dynamic system balance (self-regulation processes)

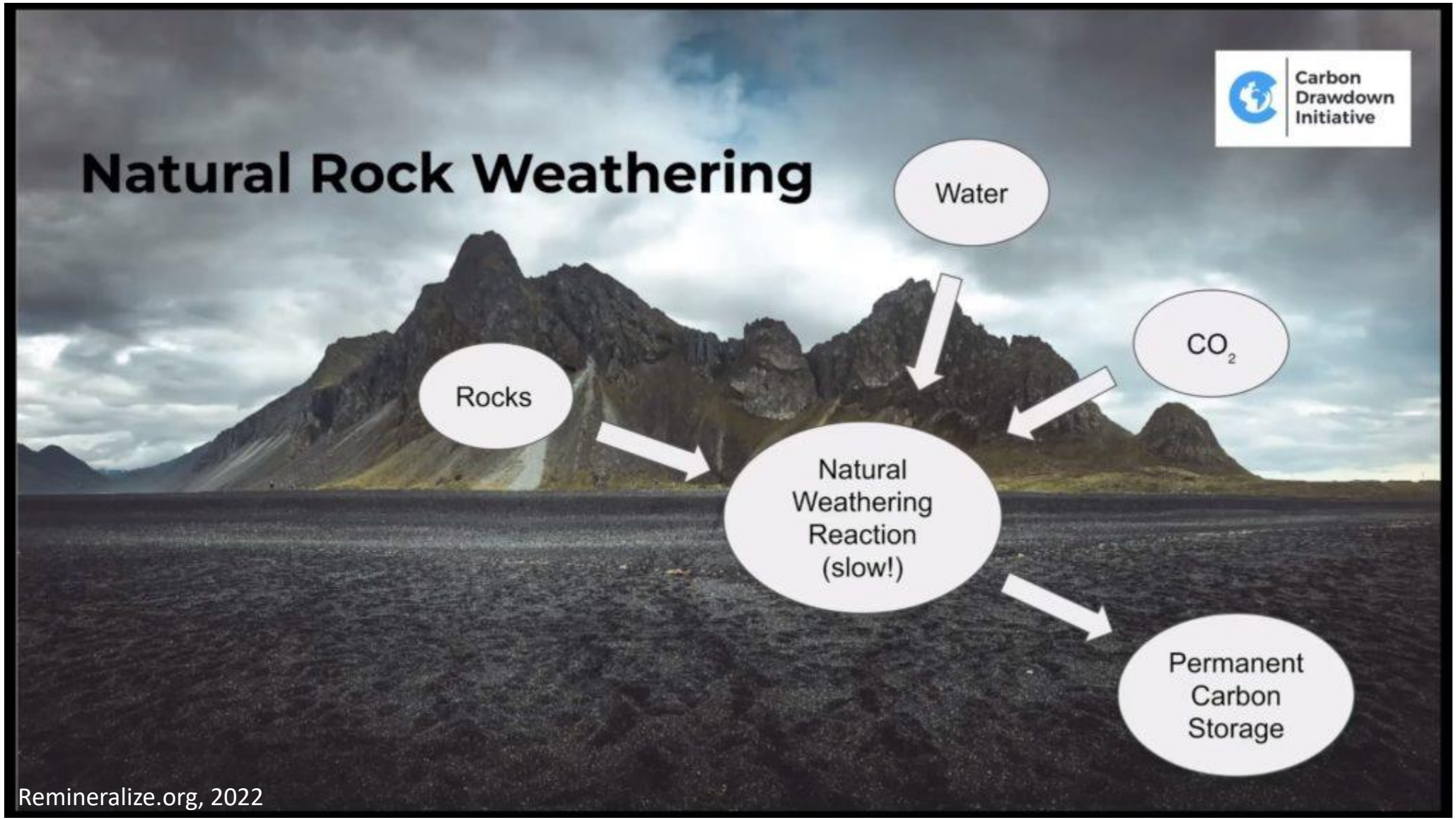
- **The most important atmospheric cycles**:
  - **biological**: respiration and photosynthesis (approx. 20 years)
  - **geochemical**: sedimentation on $CaCO_3$ (hundreds of millions of years)

Carbon sinks

- **Weathering**:
  - chemical reaction of rocks with atmospheric substances in the form of gases and dissolved sub stances in water (carbonation)

- **Dissolving in ocean water** (binding to microorganisms) and **precipitation** (washing out by precipitation – pH 5.6)
  - decline in the ocean's ability to sequester CO_2: - 4% (2011–2020)

Weathering


Natural Rock Weathering
Carbon Drawdown Initiative
Water
CO_2
Rocks
Natural Weathering Reaction (slow!)
Permanent Carbon Storage
Remineralize.org, 2022

Carbon sinks – soil

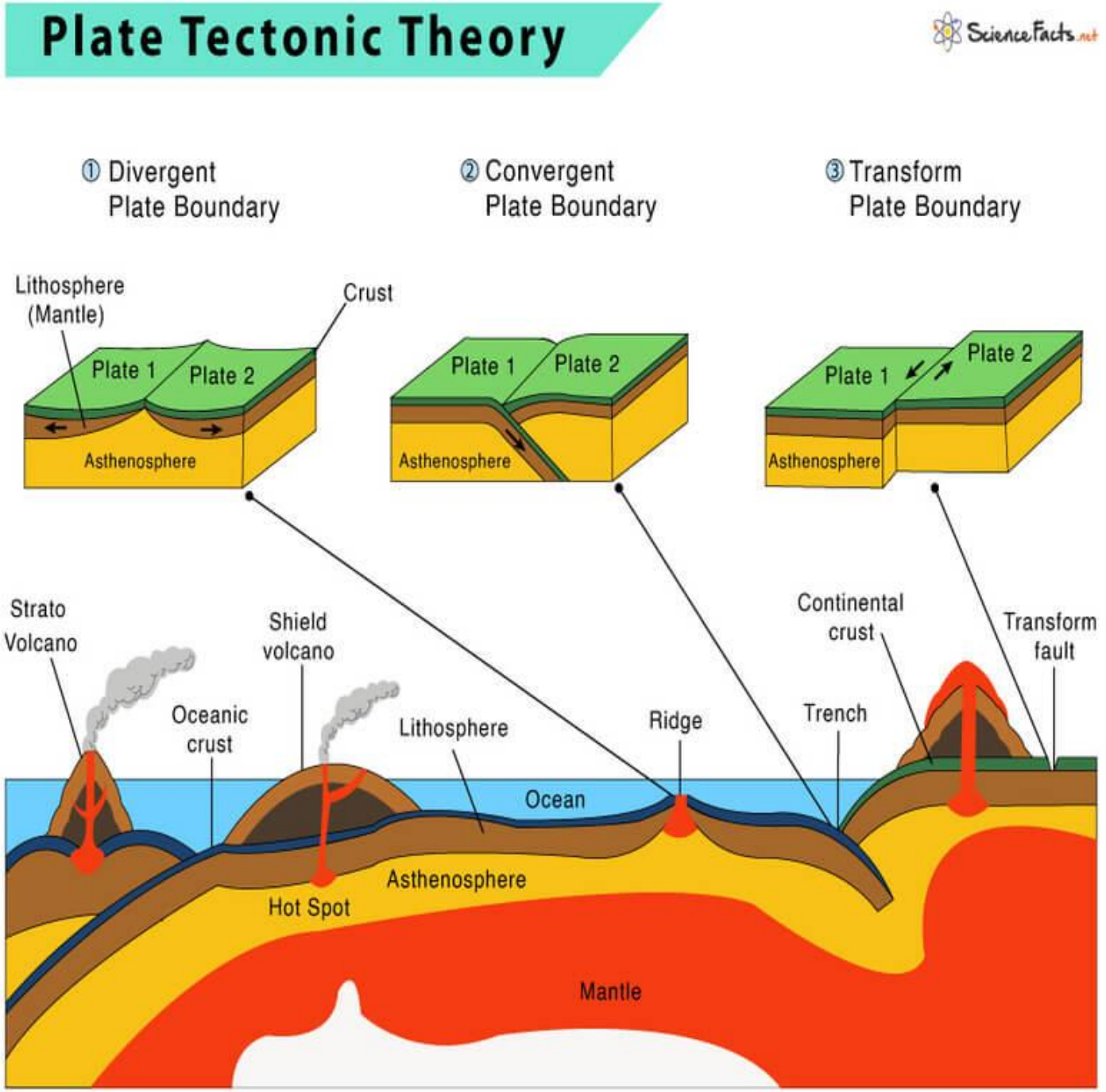
- Storage of carbon in the soil air, in the form of humus, living organisms, etc.
  - **rapid oxidation** of carbon with **increasing temperature** and precipitation (low carbon content in the tropics)
  - **decline in soil CO_2 fixation capacity**: - 17% (2011–2020)
- Soil under steppe stores more carbon than forests in the long term

Carbon sinks – vegetation

- **Vegetation through photosynthesis**: 19 Gt/year
  - **the world's peatlands**: twice more CO_2 than all the forests on Earth (3% of the land cover)
  - **1 ha of peatland in Indonesia**: approx. 20 t CO_2 /year
- 1 ha of spruce forest in the central Europe:
  - **captures 7 t CO_2/year** (equivalent to 70 000 km of driving a car)
  - **releases 15 t of O_2** (the equivalent of 1 person's oxygen for 1 year)
- To absorb all anthropogenic CO_2, it would be enough to reforest an area the size of Asia and North America...

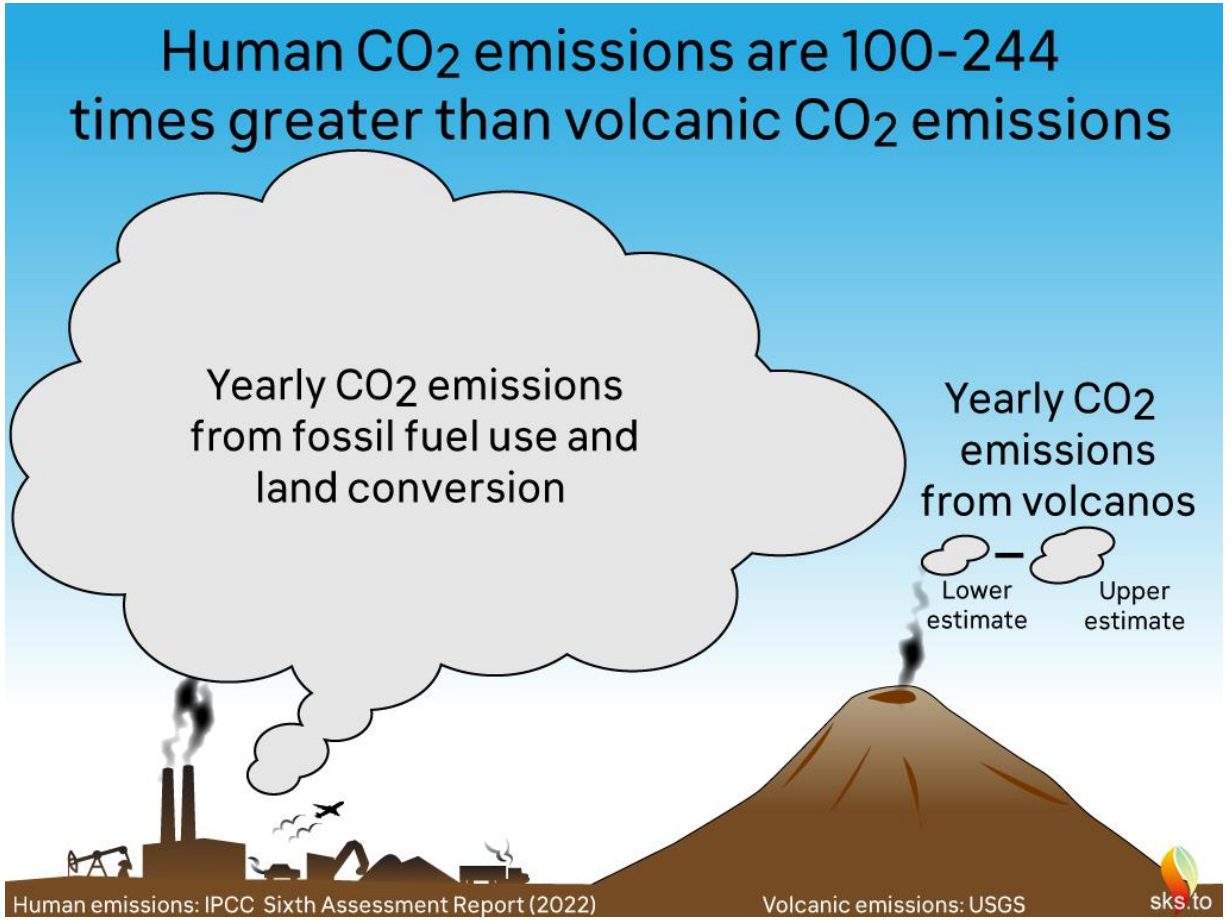
Carbon sinks and releases – geochemical cycle

- **Plate tectonics**:
  - uneven recycling of the Earth's crust, hydrosphere and part of the atmosphere
- **Subduction**:
  - absorption of carbon, suplphur, fossil fuels, etc. out of the atmosphere



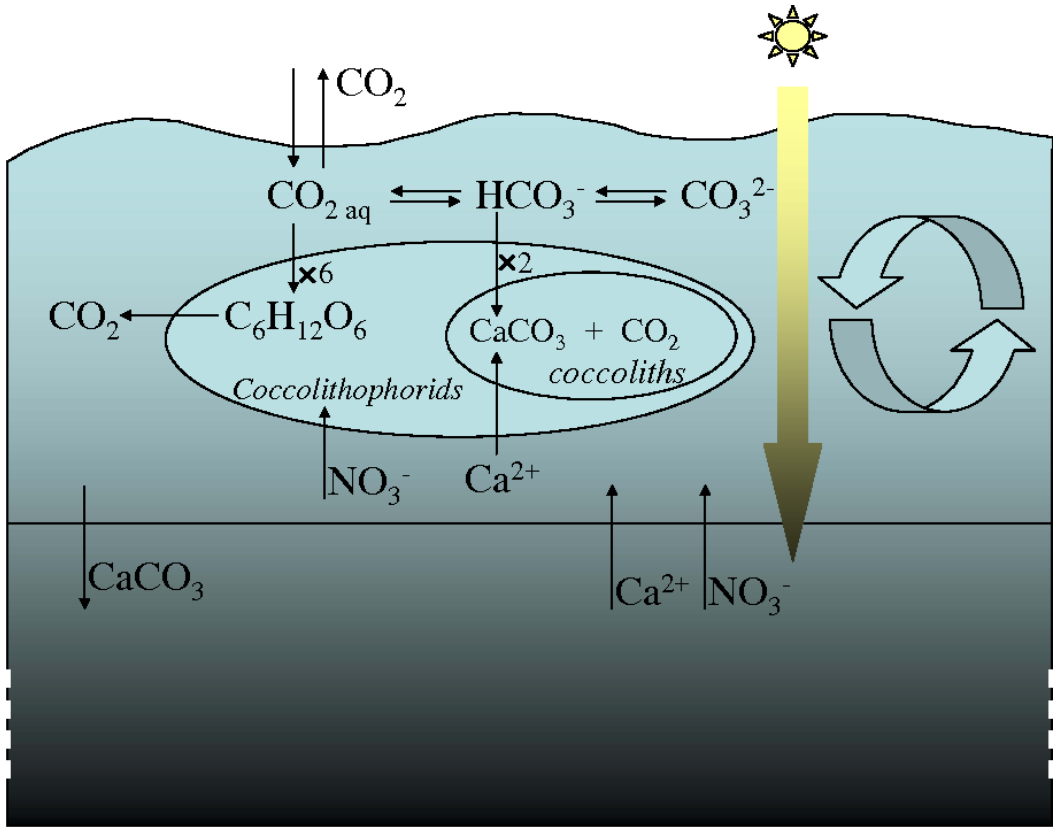
Carbon sinks and releases – geochemical cycle

- **Volcanic eruptions (releases)**:
  - unexpected entry of "buried" CO_2 into the atmosphere
  - the absence of limestone 3 billion years ago - no CO_2 as a part of volcanic eruptions



Carbon biological pump

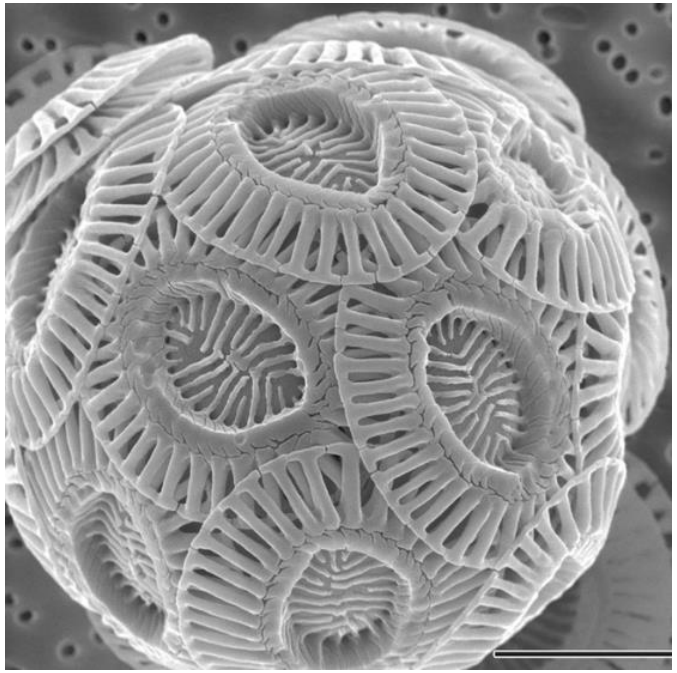
- **Transfer** of a **substance (CO_2) by organisms** between different environments
- **Deposition of atmospheric CO_2** by calcic algae in the of shells
- After death, sinking of the calcic algae to the bottom and CO_2 accumulation in the lithosphere



Bernard et al. 2009

Carbon biological pump – example

- **The area of the Atlantic Ocean between Scotland and Iceland:**
  - algae of the genus Emiliania
  - **phosphorus** and **nitrogen** rich **upwelling streams**
  - **strong winds**, especially during winter storms, remove the upper ocean layer and facilitate the ascent of nutrient-rich currents – algae overgrowth – shell formation – die-off – sinking to the bottom – limestone formation



alga of the genus Emiliania

Taylor, 2011

Carbonation process

- **Formation of carbonates** ($CaCO_3$, $FeCO_3$, etc.) by synthesis of **CO_2 dissolved in water** with **weathering products** containing Ca, Mg, Na, Fe, K (alkalis)
- Negative feedback leading to lower CO_2 concentration and global temperature derease

Carbonation process

- **Inorganic feedback**:
  - intense **weathering** of rocks in **warm climates**
  - **CO_2 binding by alkalis** and carbonate formation
  - **weakening** of the **greenhouse effect**
  - **decrease in air temperature** and intensity of weathering
  - **reduced CO_2 binding** by alkalis
  - strengthening of the greenhouse effect
  - increase in temperature...

Course of CO_2 concentration

Course of CO_2

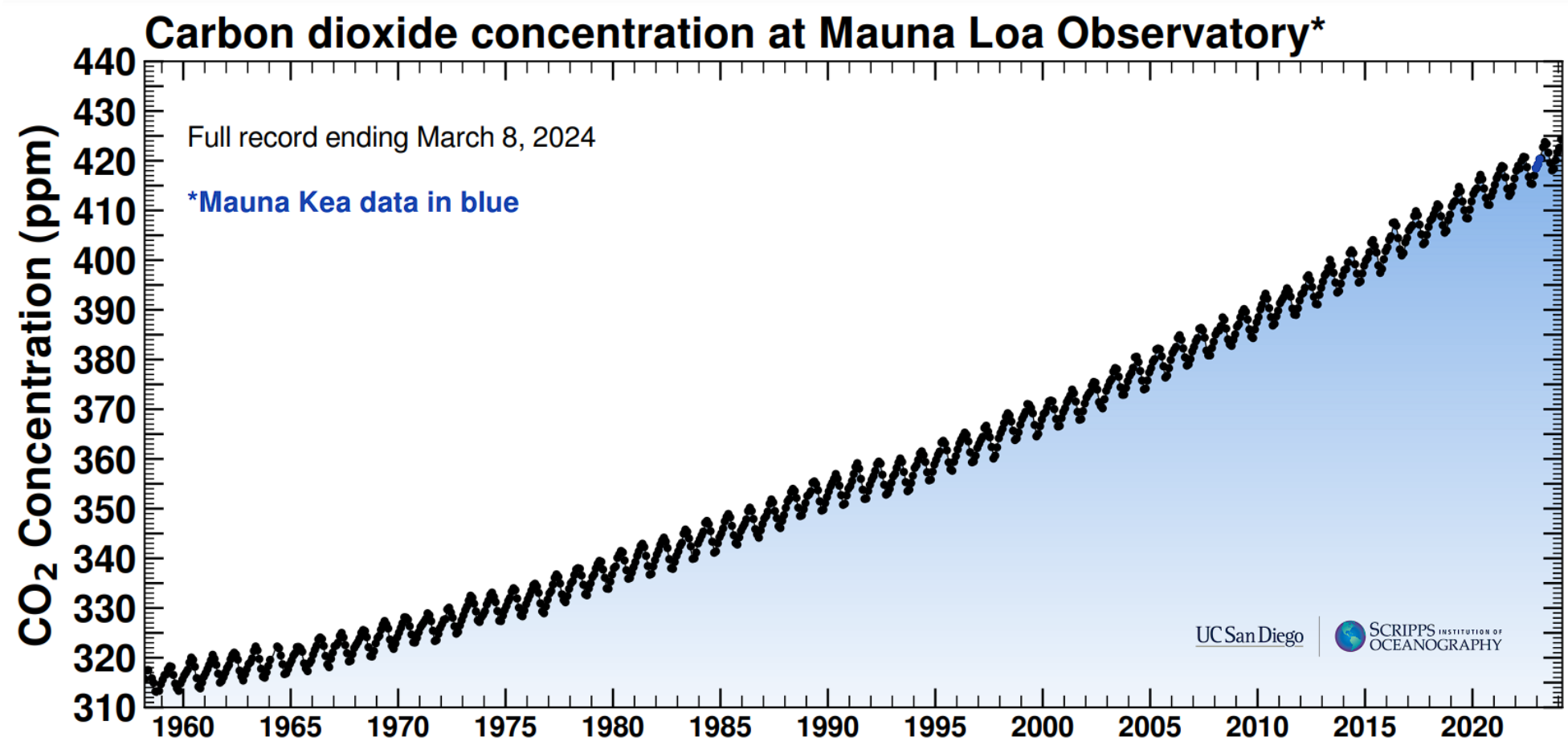
- **Measured in ppm** (parts per million)
- **800 000 years before the Industrial Revolution**: 180–280 ppm (0.028%)
- **1993**: 360 ppm (0.036 %)
- **7. 3. 2023**: 420.85 ppm (0.042 %) = Pliocene (3 million years ago)
- **Annual increase**: approx. 2–3 ppm
- **Forecast 2100**: 900 ppm
- **Safe level of CO_2**: 350 ppm

Mar. 7, 2023	**420.85 ppm**
Mar. 7, 2022	**417.88 ppm**
1 Year Change	2.97 ppm (0.71%)

en.co2.earth/ 2022

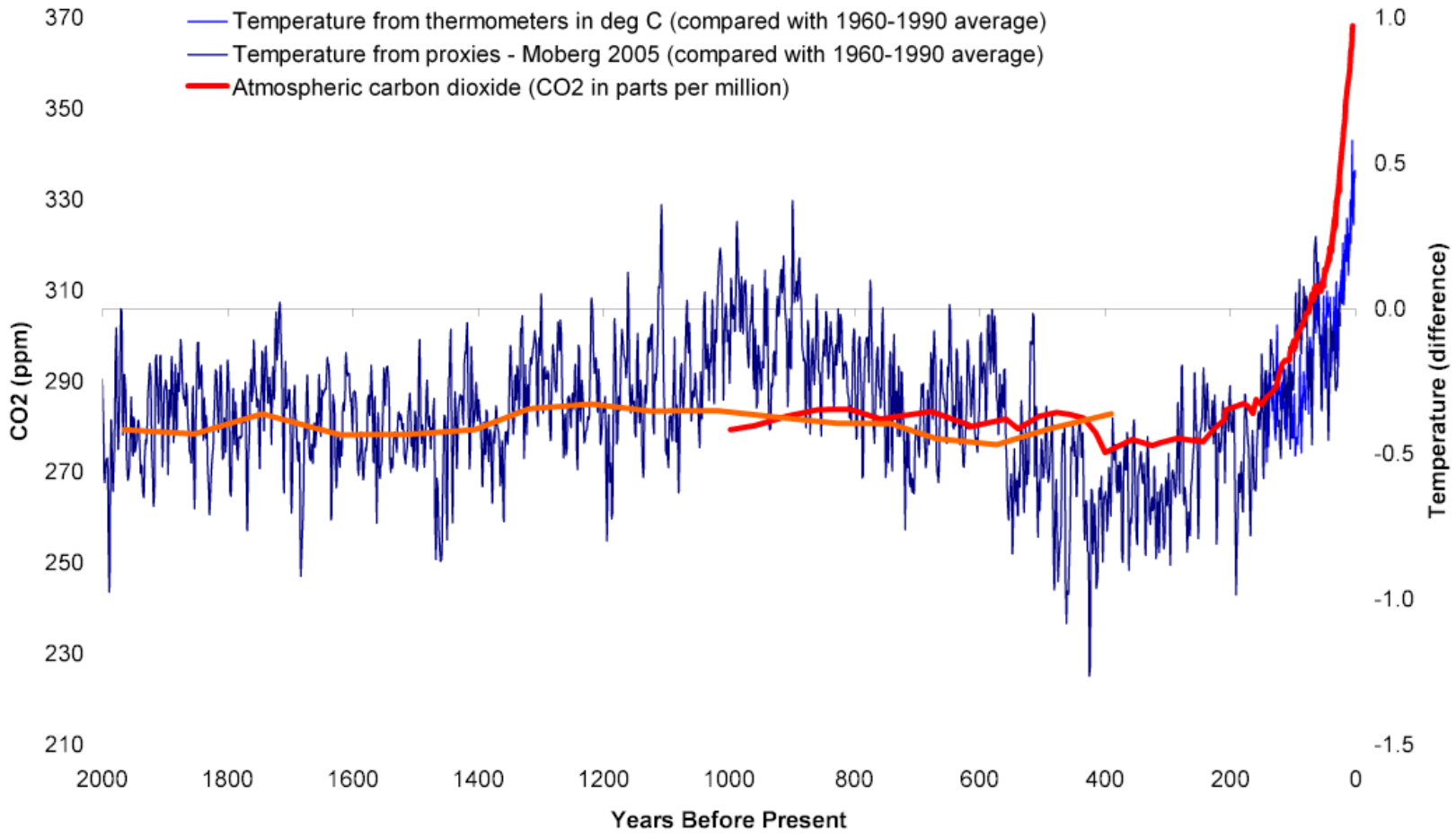
Keeling curve

Graphical representation of the average global atmospheric CO_2 concentration since 1958



keelingcurve.ucsd.edu, 2024

Course of CO_2 and mean air temperature (0–2017)

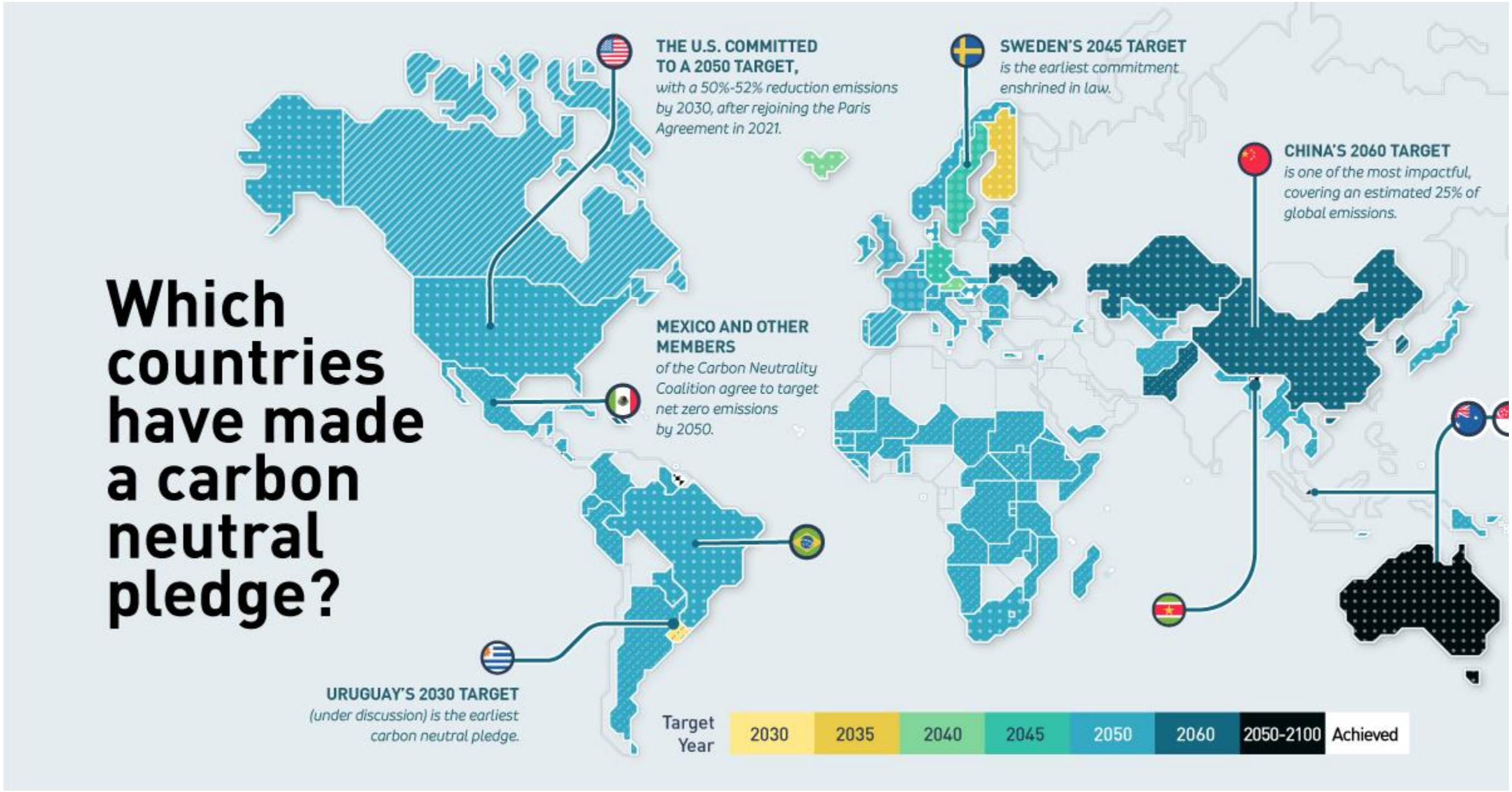


es.earthednet.org, 2017

Carbon budget

- The amount of CO_2 that humankind can emit before global temperature rises by 2.0°C compared to pre-industrial levels
- 1000 Gt CO_2 (2011)
- **Threshold year for emission reductions**: 2020
- **Carbon neutrality**: 2050
  - humankind emits only as much CO_2 as ecosystems can capture – **decarbonising the global economy without fossil fuels**
  - **2050**: achieving neutrality for a 1.5°C global mean temperature rise
  - **2070**: achieving neutrality for not exceeding the global mean temperature by 2.0°C

Which countries have made a carbon neutral pledge?



visualcapitalist.com, 2021

Carbon neutrality

Carbon footprint

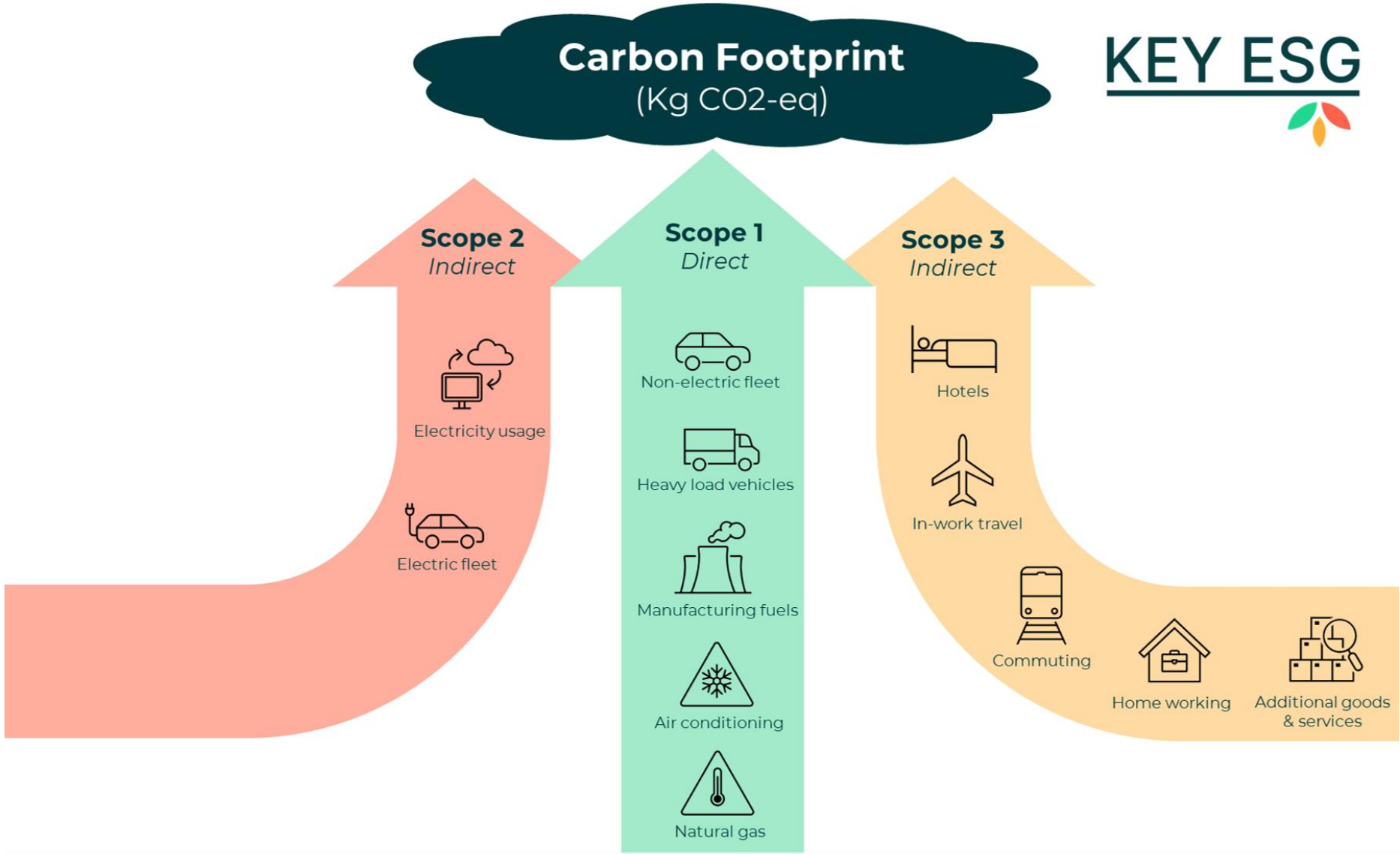
Carbon footprint – definition

- A measure of the impact of human activity on the environment (climate)
- **Amount of greenhouse gases emitted by daily consumption** (electricity use, transport, services, etc.) **expressed in CO_{2ekv}**
- **Primary (direct) footprint**: the amount of CO_2 released by burning fossil fuels, direct checking
- **Secondary (indirect) footprint**: the amount of CO_2 released during the life cycle of products

https://www.carbonfootprint.com/

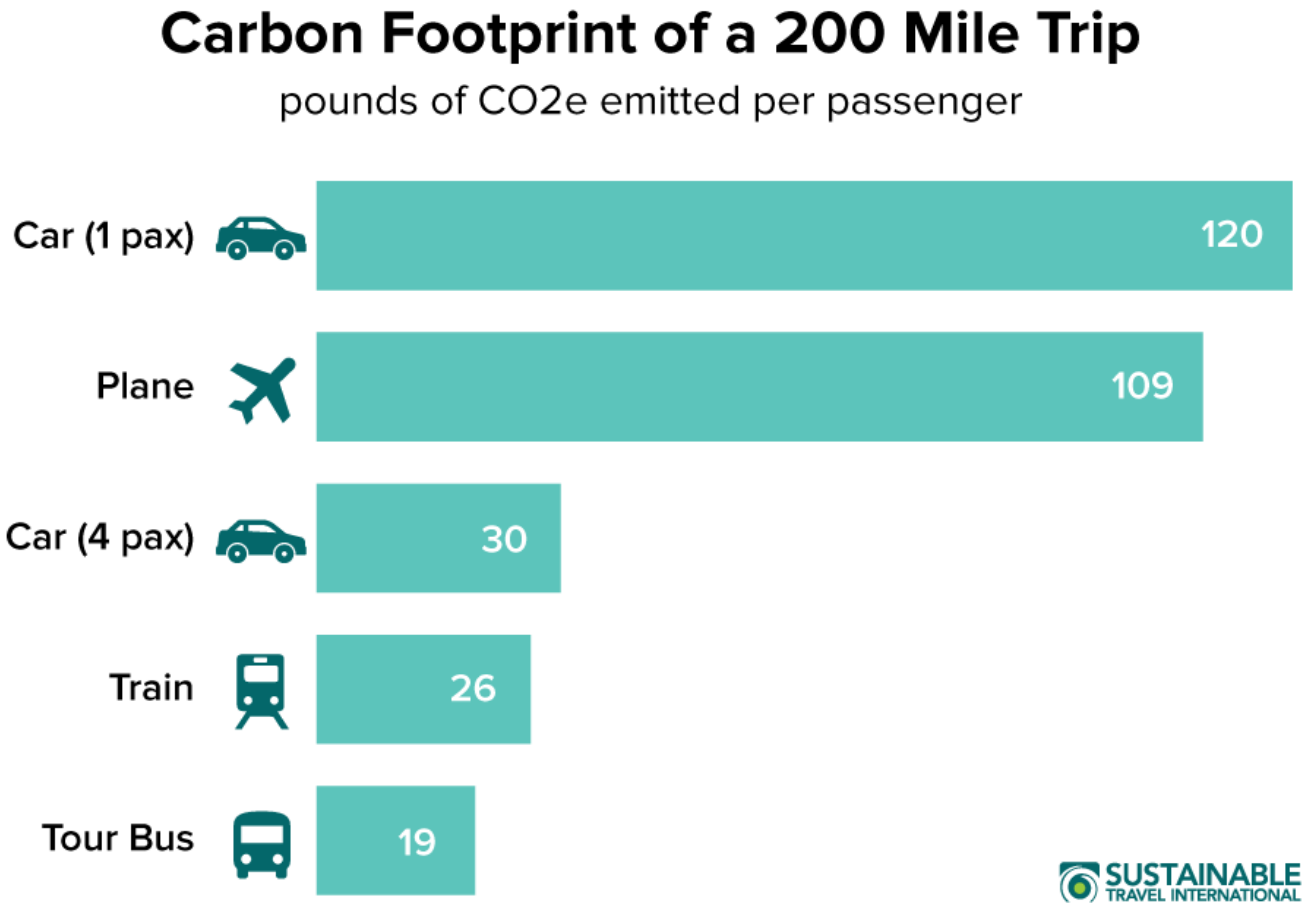
https://uhlikovastopa.cz/kalkulacka

Carbon footprint



How to reduce own carbon footprint

- **No car use**: 2.4 tonnes CO_2/year/person
- **Non-flying**: 1.6 tonnes CO_2 /year/person
- **Use of renewable energy sources for heating and lighting at home**: 1.5 tonnes CO_2/year/person



Source: salatovelisty.cz/, 2017

How to reduce own carbon footprint

- **Reduction of meat consumption by 50%** (reduction of emissions by 40%): 0.8 tonnes CO_2 /year/person

myemissions.green, 2024

How to reduce own carbon footprint

- **Washing in cooler water (at 30 °C)**: 0.247 tonnes CO_2/year/person
- **Recycling**: 0.2125 tonnes of CO_2/year/person
- **Replacing light bulbs with energy saving ones**: 0.1 tonnes CO_2/year/person

What to carry off from the lecture

- Carbon cycle is **one of the best-studied Earth cycles** despite **not everything being known**
- **Anthropogenic CO_2 emissions** represent only **5 %** of all carbon emissions
- **Imbalance of the carbon cycle** caused by humans is already **changing the climate**

What to carry off from the lecture

- **Power industry, industry and agriculture with forestry** are the main sectors emitting CO_2/GHG emissions
- Concentration of global CO_2 emissions **still grows** but its **rate slows down**
- **CO_2 emissions** in the **EU** have been **declining since 1980s**

What to carry off from the lecture

- CO_2 concentrations have **fluctuated** significantly **in the past**, but **without human influence**
- Of the short-term CO_2 sinks, **soil and forests are important for CO_2 sequestration**
- Reducing air travel, travel by car travel with 1 passenger, reducing energy loss of buildings or cutback meat-based diets **have a significant impact** on **decrease** of own **carbon footprint**

Literature and sources

- Daily CO_2 co2.earth/daily-co2
- Keeling curve keelingcurve.ucsd.edu/
- Our world in data: CO_2 emissions ourworldindata.org/co2-emissions

Thank you for your attention