CLIMATE CHANGE

FOR ECONOMISTS

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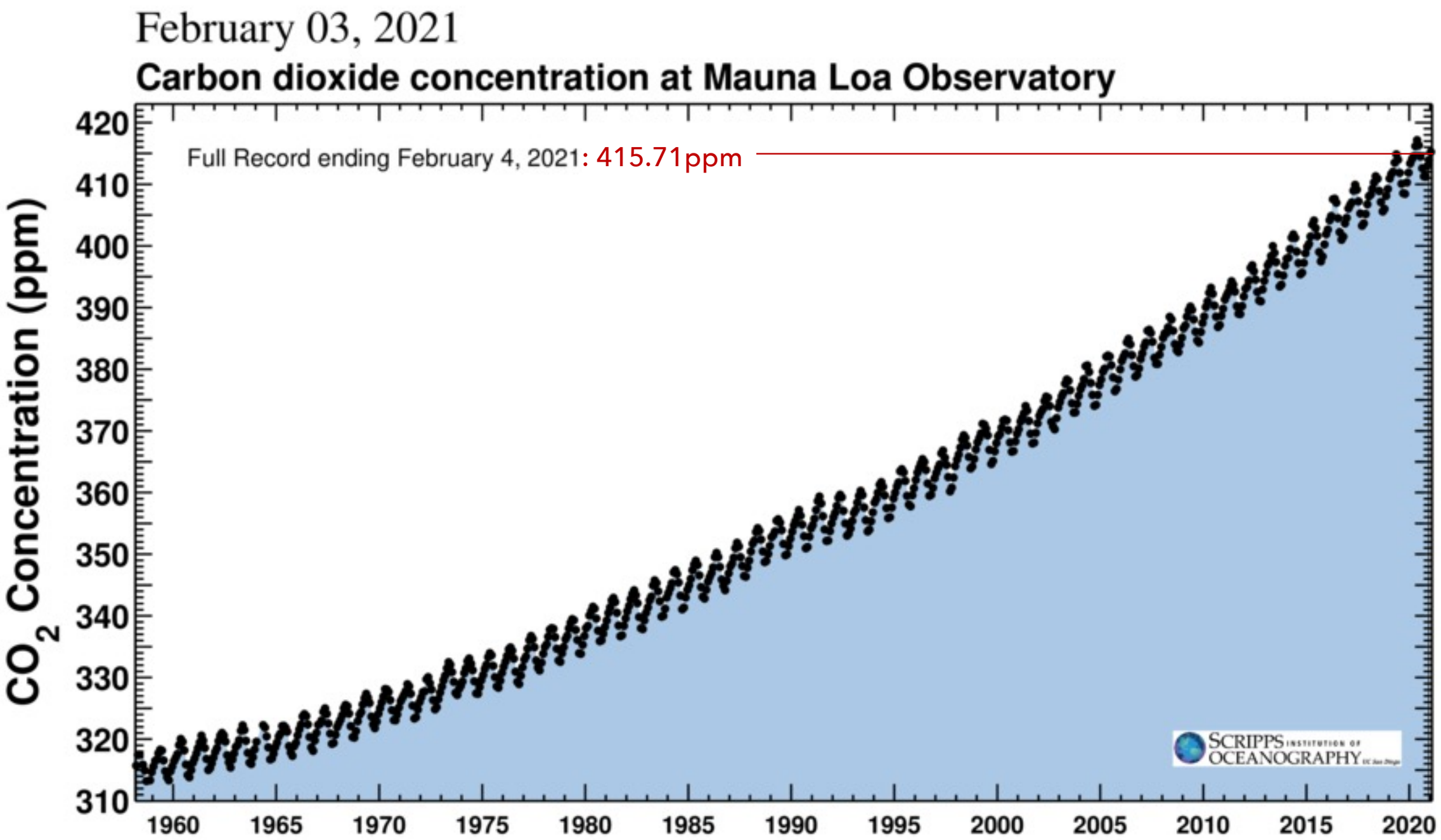
CO_2 CONCENTRATION IN THE ATMOSPHERE

THE (CHARLES DAVID) KEELING CURVE – UC-SAN DIEGO



Measuring temperature and CO_2 concentration with ice-cores

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19 cm long section of GISP 2 ice core from 1855 m showing annual layer structure illuminated from below by a fiber optic source. Section contains 11 annual layers with summer layers (arrowed) sandwiched between darker winter layers.

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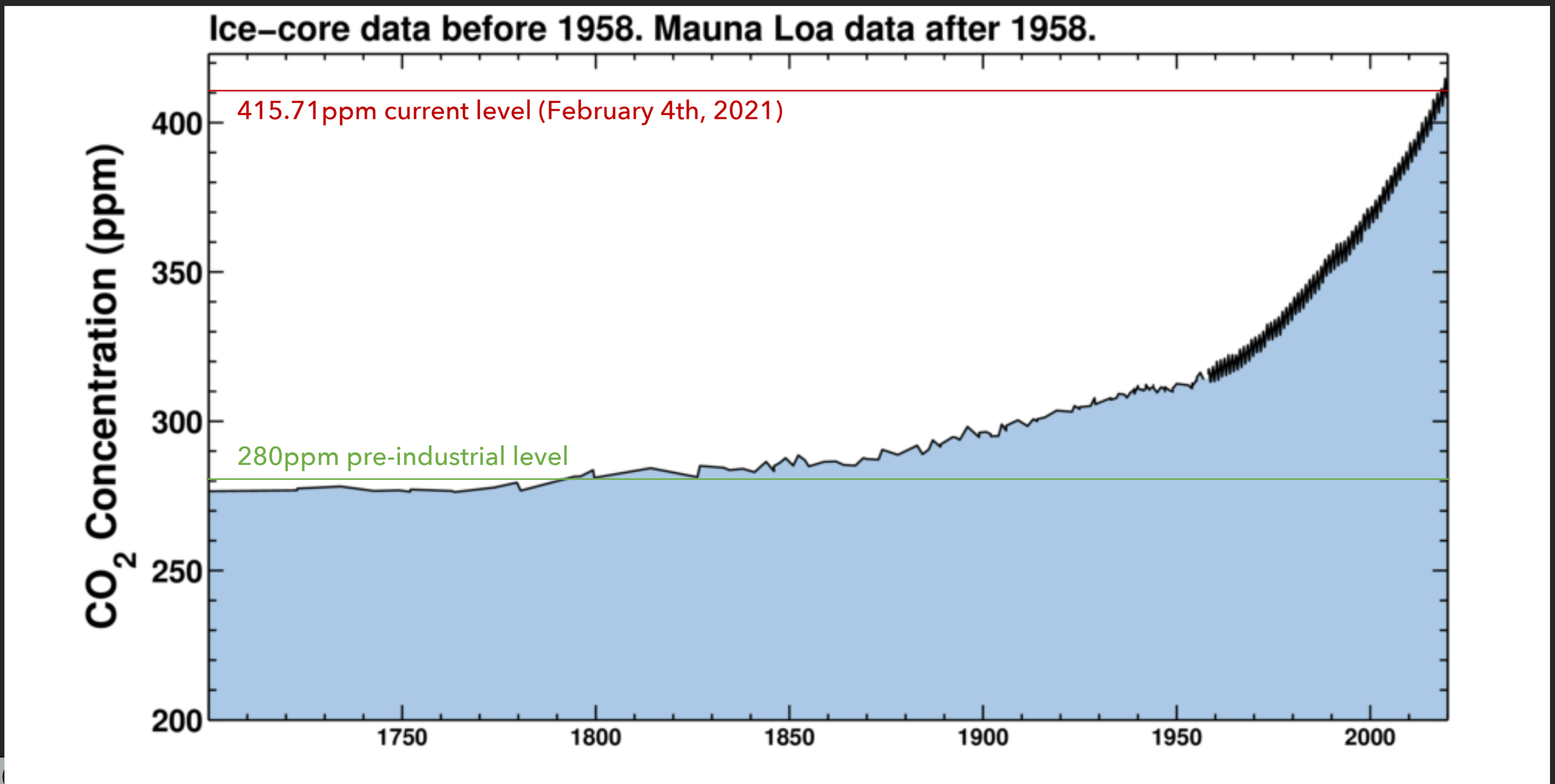

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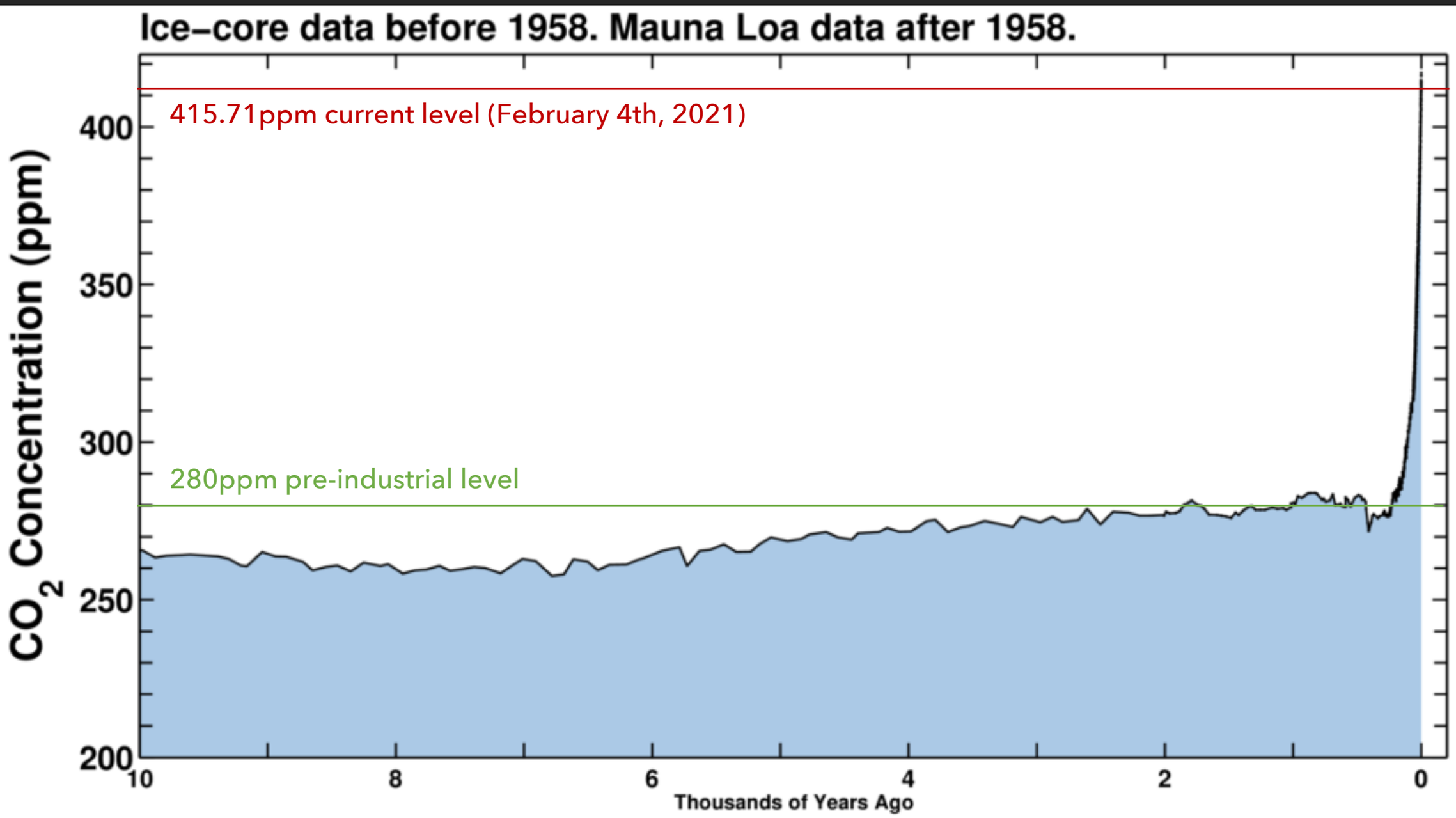

CO_2 CONCENTRATION IN THE ATMOSPHERE

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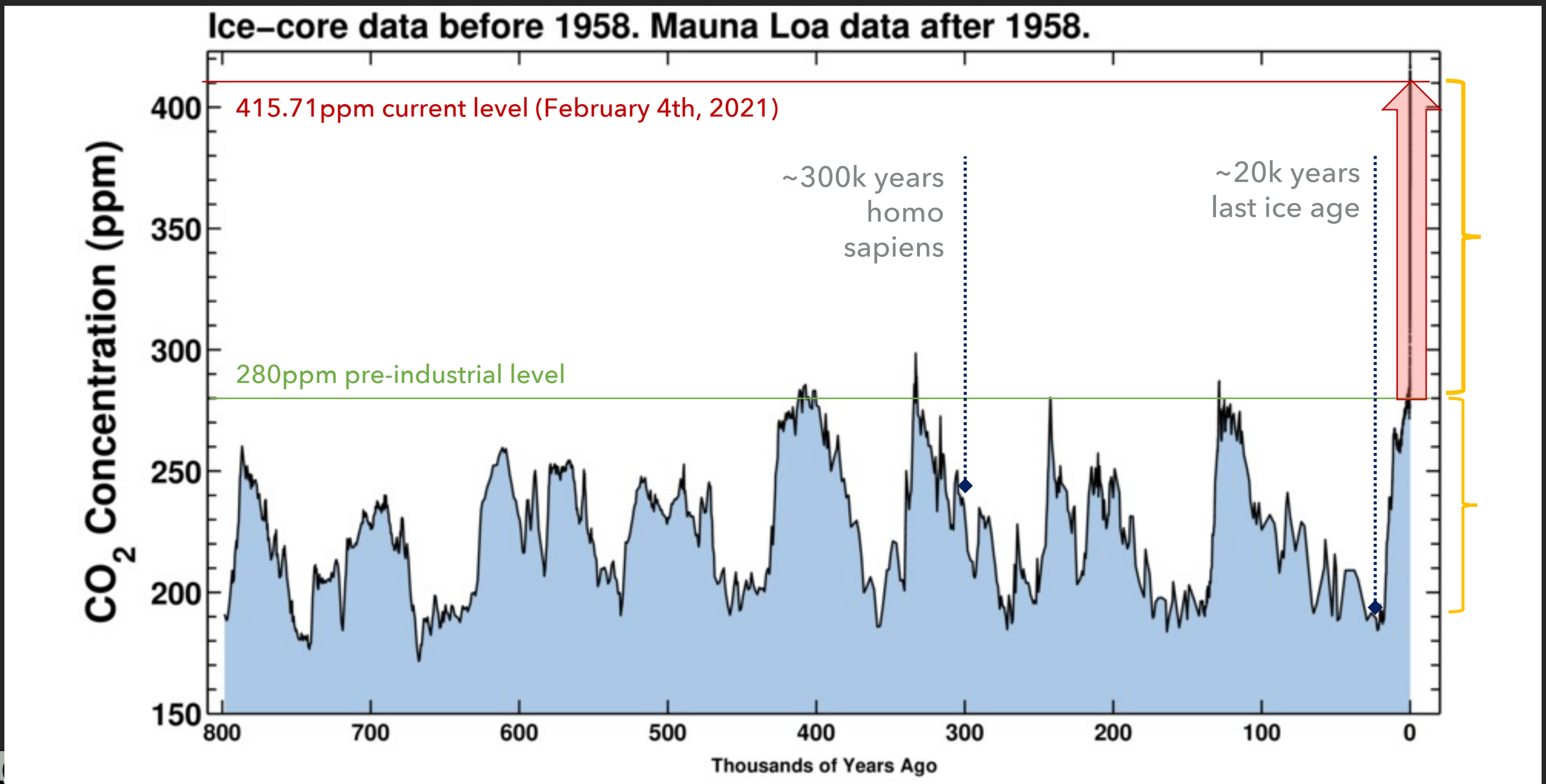
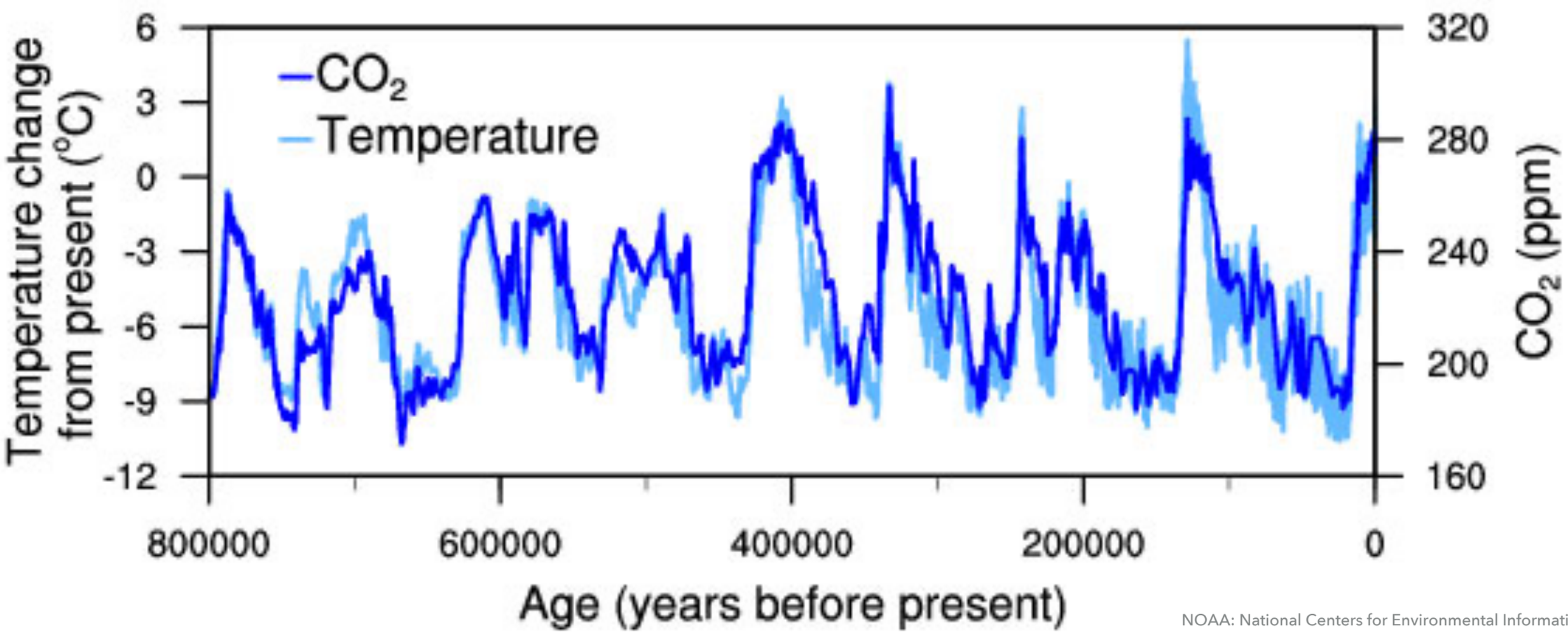


TEMPERATURE MOVES WITH CO_2 CONCENTRATION IN THE ATMOSPHERE



NOAA: National Centers for Environmental Information

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10 Facts

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INDEX: 10 FACTS

1. Humans are the cause and changes are unprecedented
   - Greenhouse effect
   - Carbon cycle
2. Impacts are already visible
3. There is a near linear relationship between cumulative anthropogenic CO_2 emissions and “short term” temperature increase
4. Each temperature change target is associated with a carbon budget
5. Emissions are closely link to the economic activity and have not peaked yet
6. Energy and CO2 (+ methane) are the most relevant players
7. We have made progress, but not enough
8. World mitigation gains have been driven by energy efficiency and not by greener energy.
9. OECD countries show some recent greening in their energy composition
10. Many countries have decoupled economic growth from CO2 emissions, even if we take offshored production into account.
    - Still many open questions.

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FACT 1: HUMANS ARE THE CAUSE AND CHANGES ARE UNPRECEDENTED

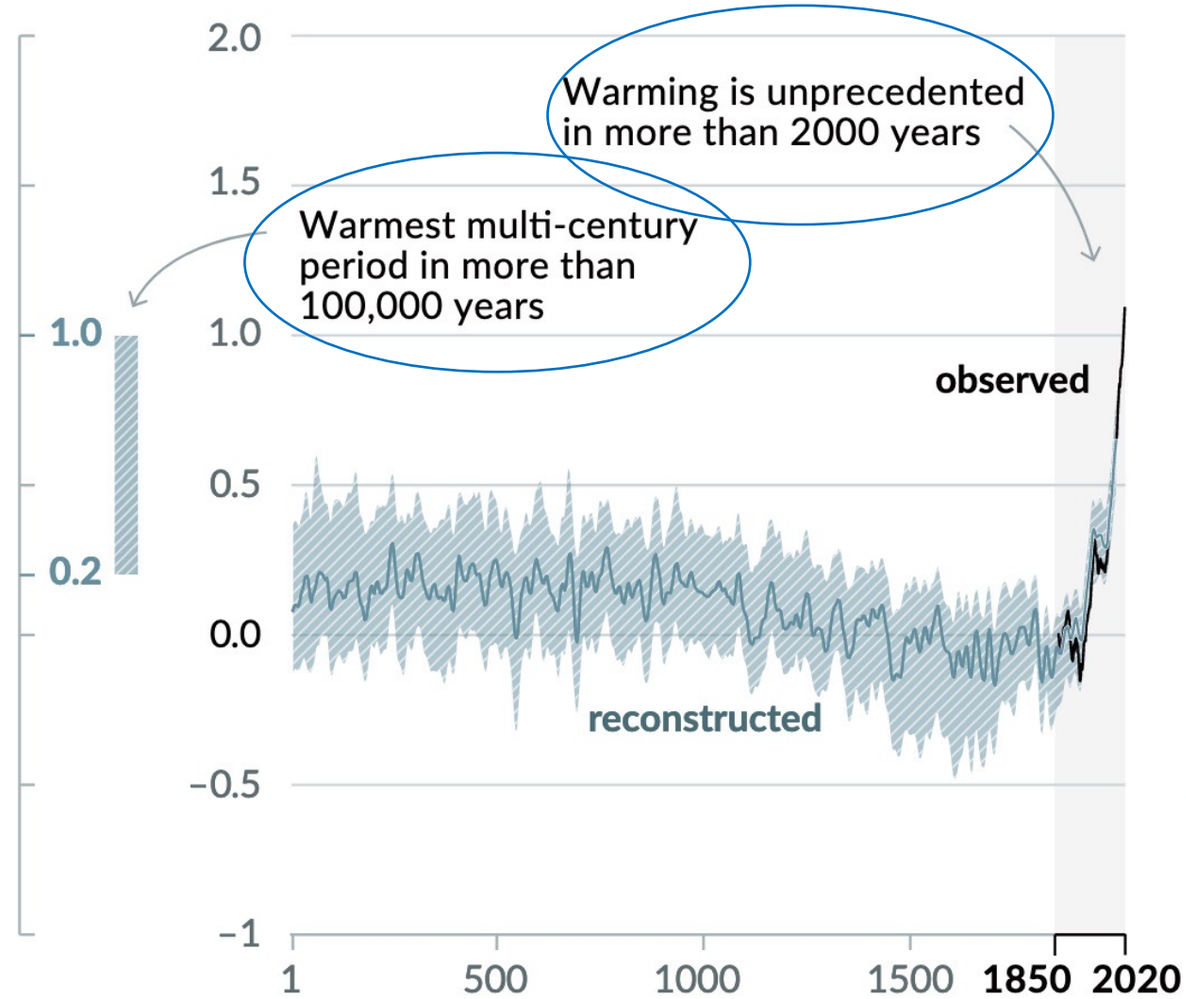
A. The Current State of the Climate

1. It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred.
2. The scale of recent changes across the climate system as a whole – and the present state of many aspects of the climate system – are unprecedented over many centuries to many thousands of years

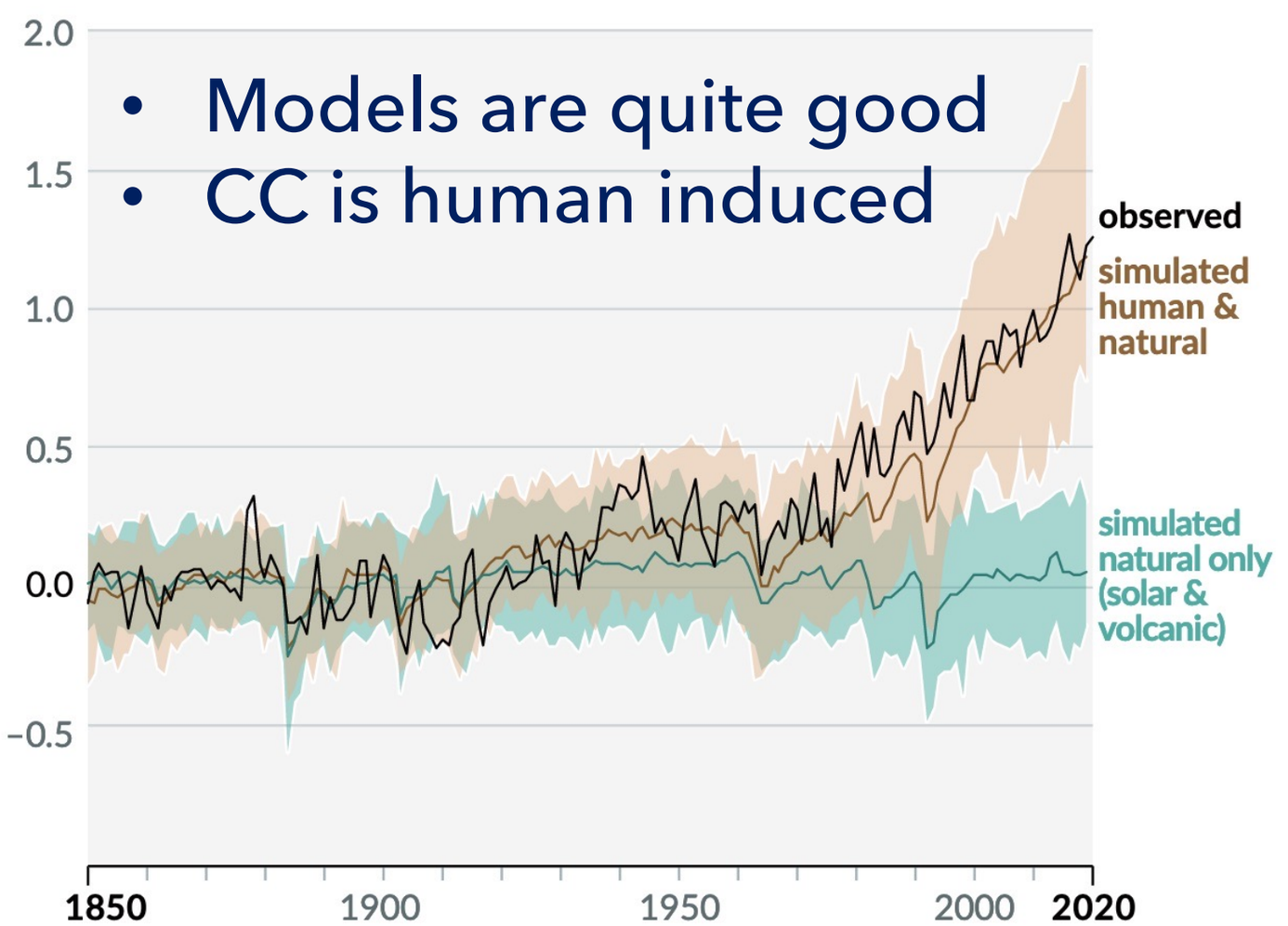
Changes in global surface temperature relative to 1850–1900

Figure SPM.1
AR6 WGI SPM

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



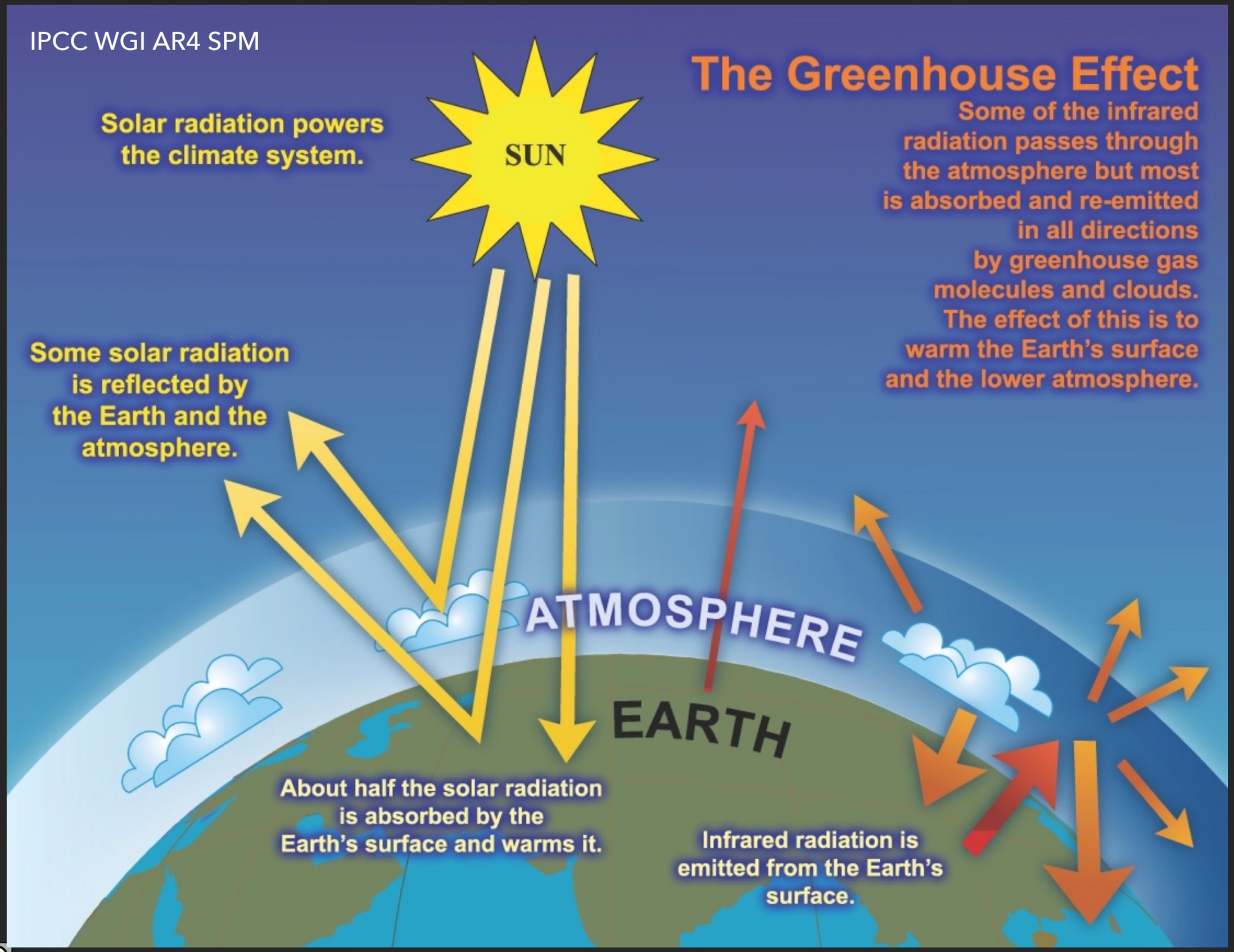
(b) Change in global surface temperature (annual average) as **observed** and simulated using **human & natural** and **only natural** factors (both 1850–2020)



GREENHOUSE EFFECT

Universitat Pompeu Fabra Barcelona

IPCC WGI AR4 SPM



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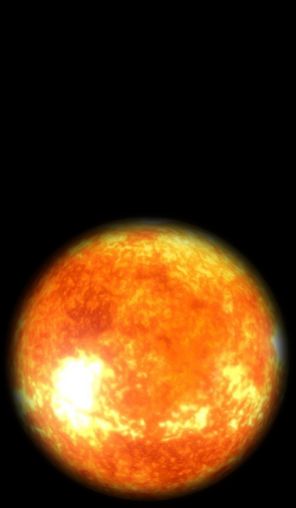
GREENHOUSE EFFECT: SIMPLIFIED ENERGY BUDGET (THERMODYNAMICAL EQUILIBRIUM)

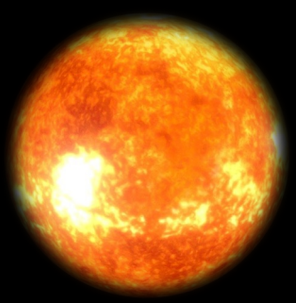


Same distance and same volume as Earth

Infrared radiation [it balances the energy received]

SURFACE TEMPERATURE

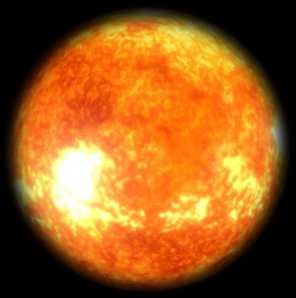
Black object [0 Albedo] 5.3°C



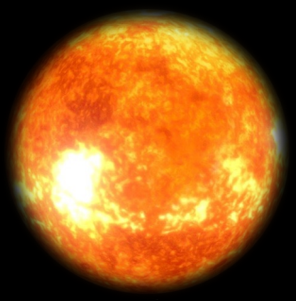
30%

30% Albedo -18°C

Greenhouse effect: +33°C



Albedo + Atmosphere +14°C



Albedo + Atmosphere+ CO_2

Earth needs to warm further to be able to emit the same infrared radiation

Radiative forcing: the difference between the energy in and the energy out

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Warming from Human Influence: GHG and Aerosols

1. Observed warming is driven by emissions from human activities from GHG
2. GHG warming is partly masked by aerosol cooling

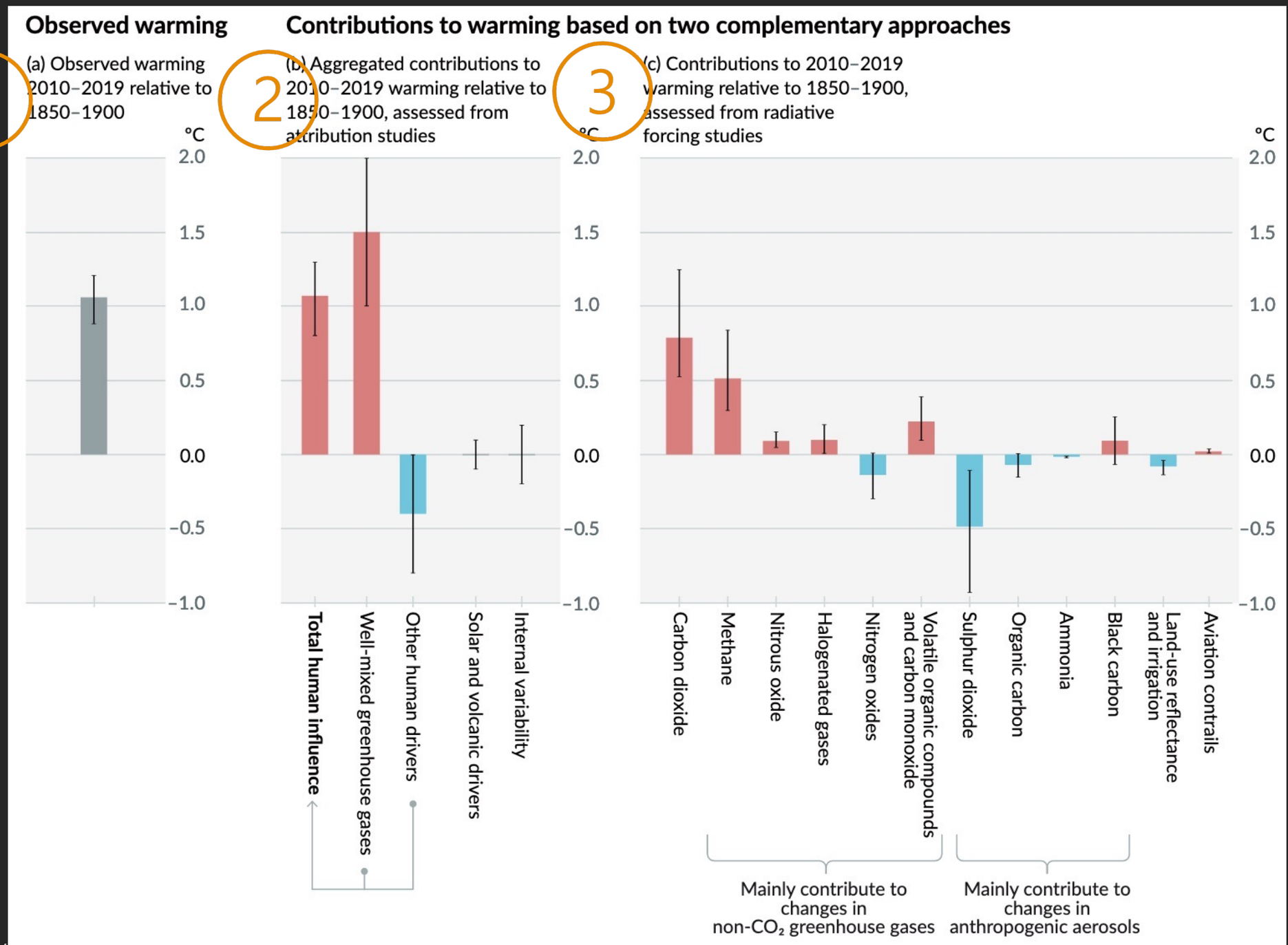

Figure SPM.2
AR6 WGI SPM

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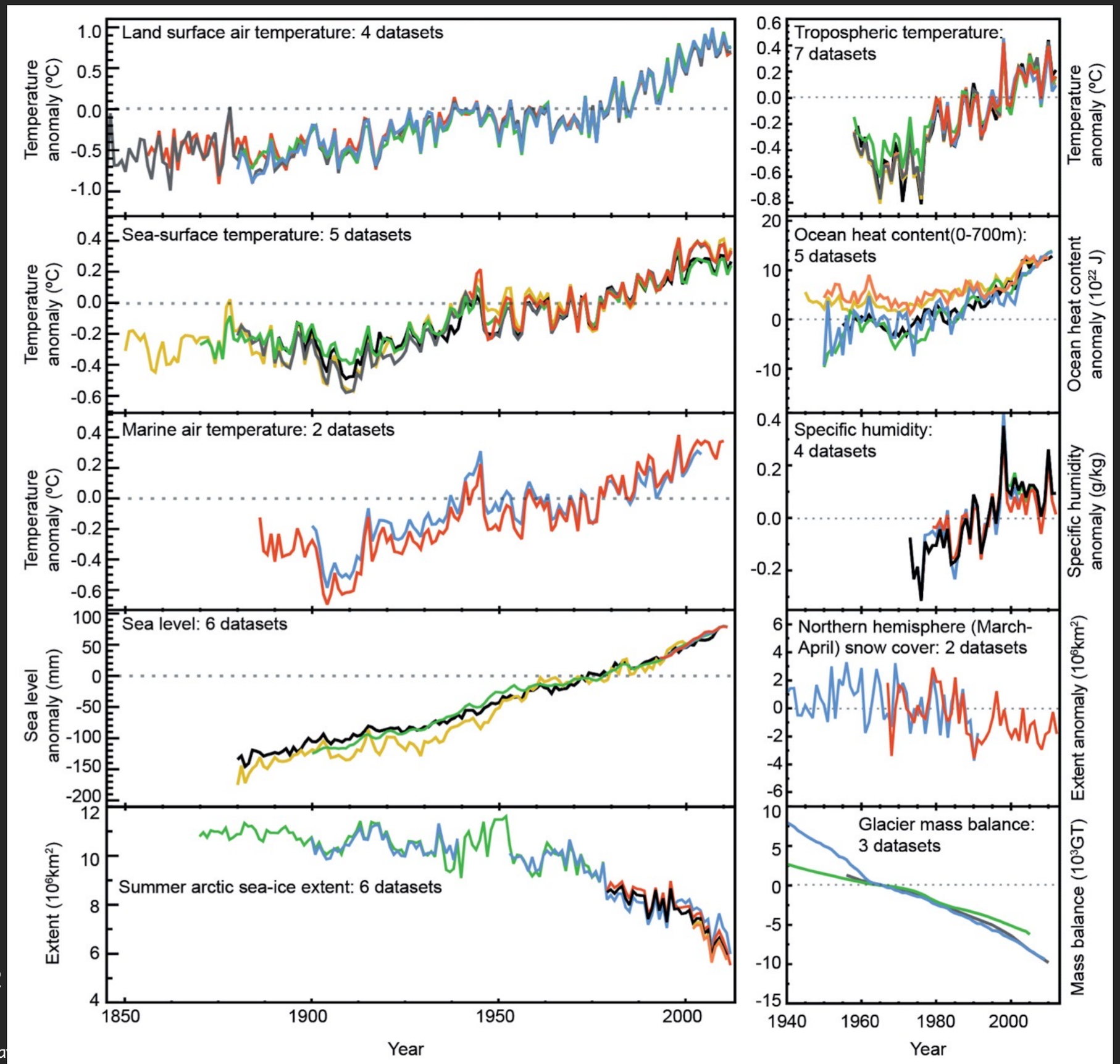
Fact 2: Impacts are already visible

- $\Delta T \sim 1.1$°C
- SLR$\sim 2cm$
- ∇summer artic sea-ice ~6 million Km^2



IPCC WGI AR5 TS

IMPACTS ARE ALREADY VISIBLE

3. Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes

(a) Synthesis of assessment of observed change in **hot extremes** and confidence in human contribution to the observed changes in the world's regions

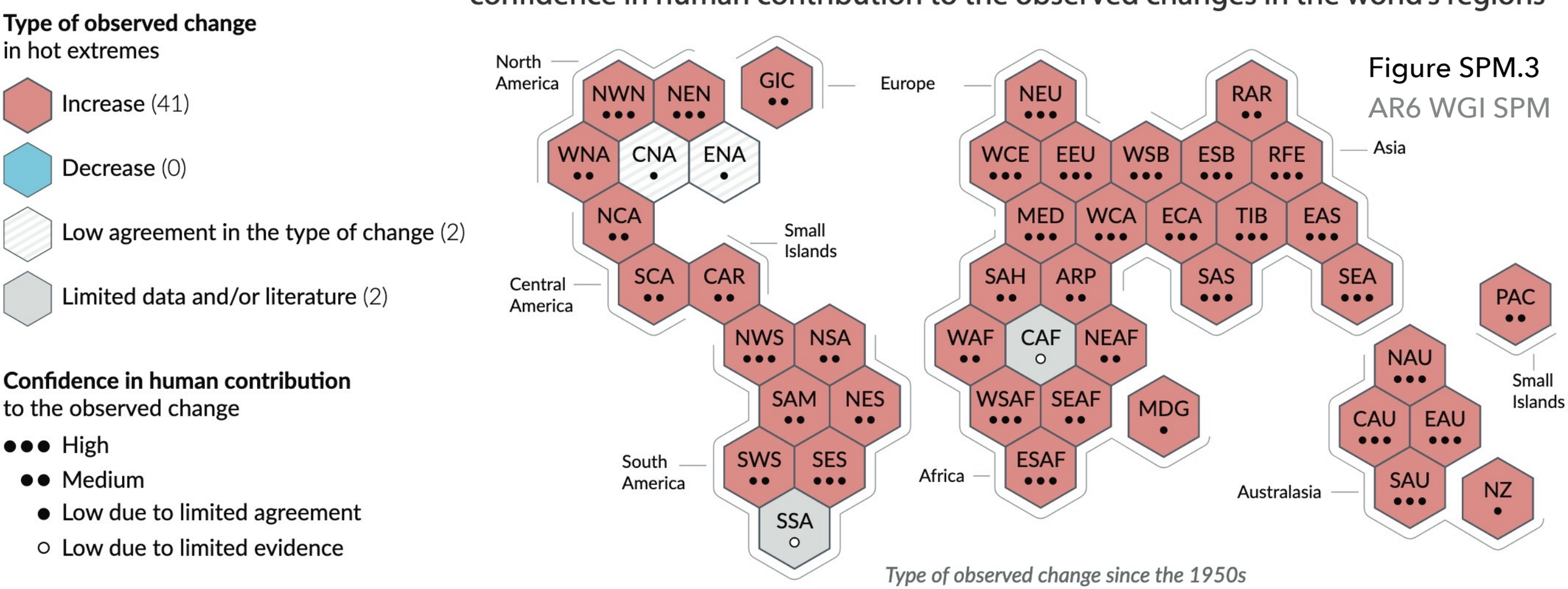


Figure SPM.3
AR6 WGI SPM

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IMPACTS ARE ALREADY VISIBLE

3. Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes

(b) Synthesis of assessment of observed change in heavy precipitation and confidence in human contribution to the observed changes in the world's regions

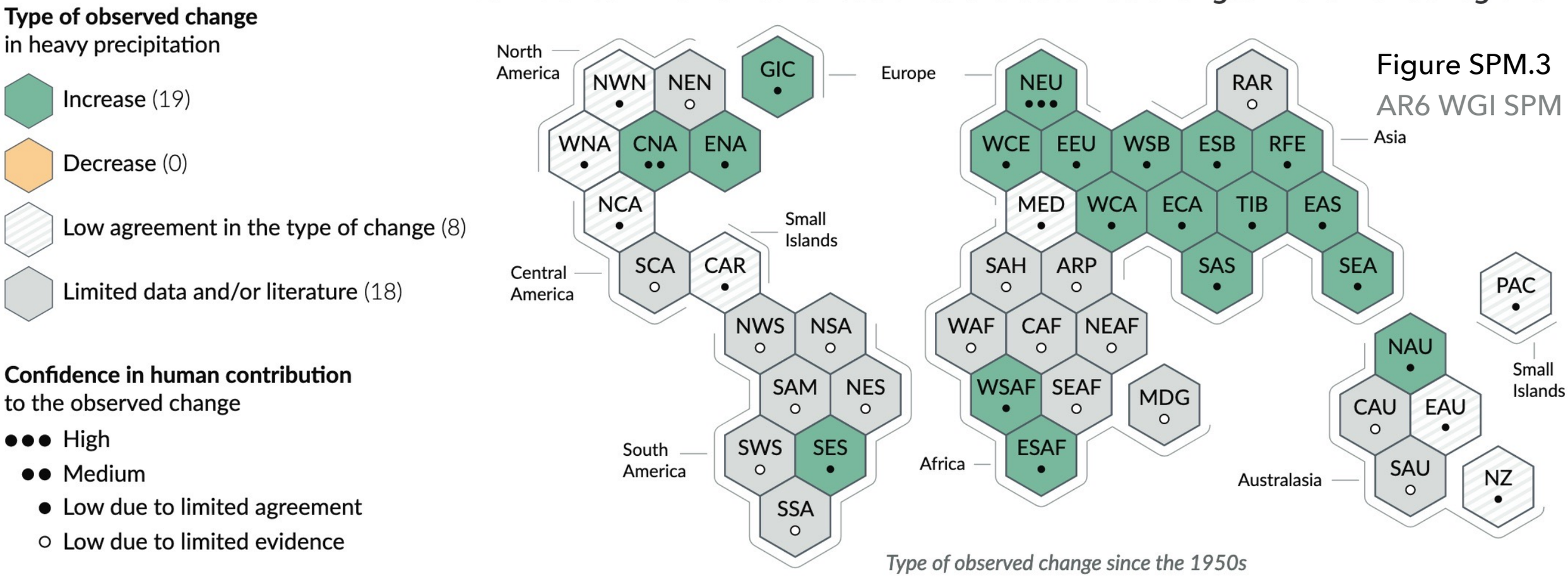

Figure SPM.3
AR6 WGI SPM

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IMPACTS ARE ALREADY VISIBLE

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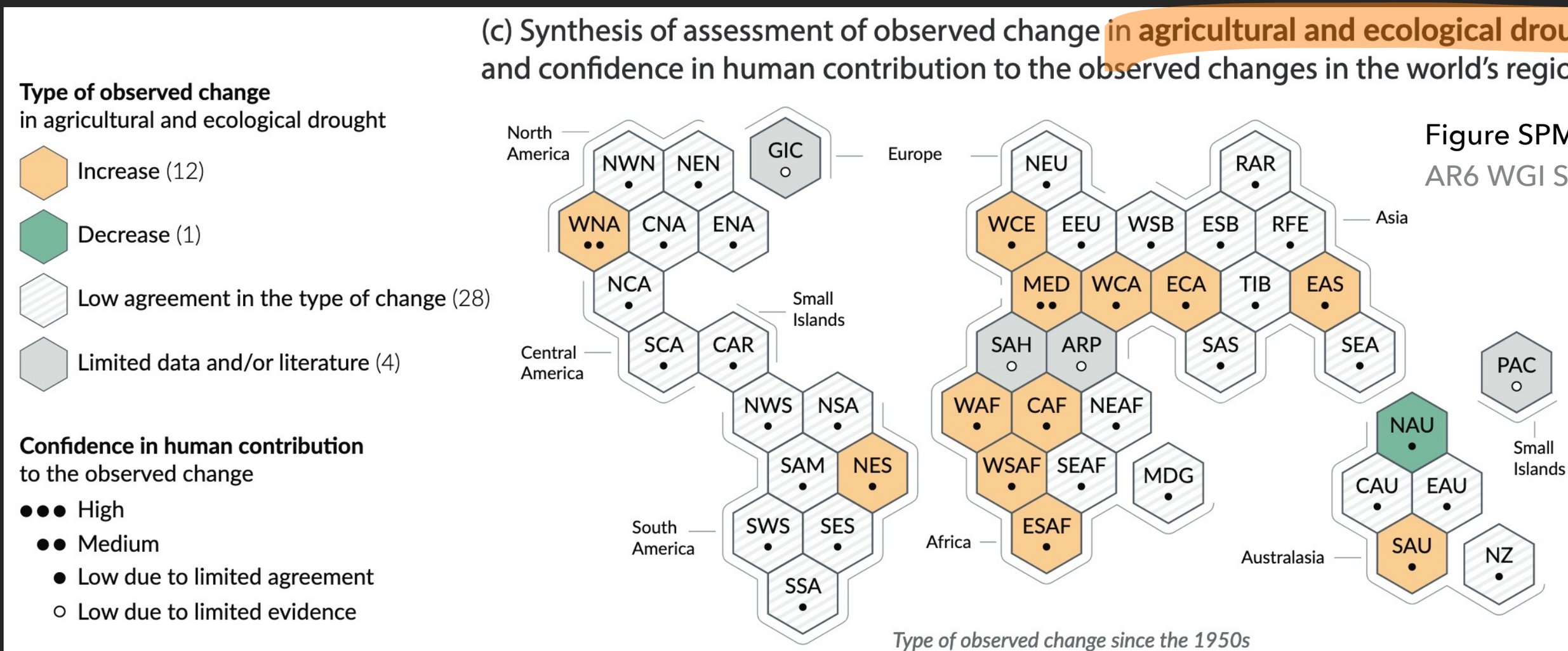

Figure SPM.3
AR6 WGI SPM

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FACT 3: THERE IS A NEAR LINEAR RELATIONSHIP BETWEEN CUMULATIVE ANTHROPOGENIC CO_2 EMISSIONS AND "SHORT TERM" TEMPERATURE INCREASES

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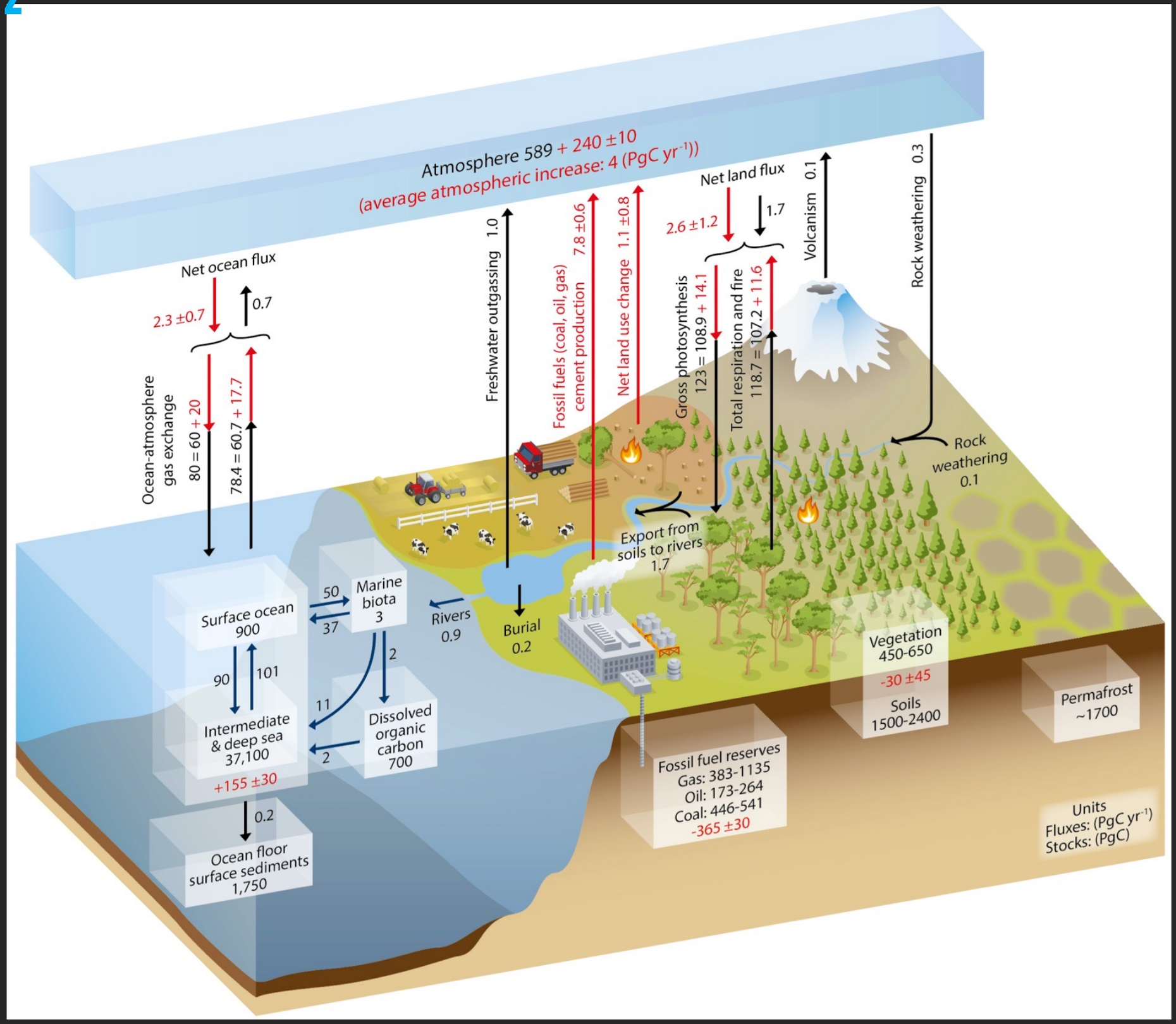
THE CARBON CYCLE

Observations

- Stocks and flows of CO_2
- In natural circumstances, stocks do not play a role (not mobilized), but humans are mobilizing this carbon.
- Emissions from fossil fuels are small compared with natural emissions, but they disrupt the balance.



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FACT 3: THERE IS A NEAR LINEAR RELATIONSHIP BETWEEN CUMULATIVE ANTHROPOGENIC CO_2 EMISSIONS AND "SHORT TERM" TEMPERATURE INCREASES

Global surface temperature increase since 1850–1900 (°C) as a function of cumulative CO_2 emissions ($GtCO_2$)

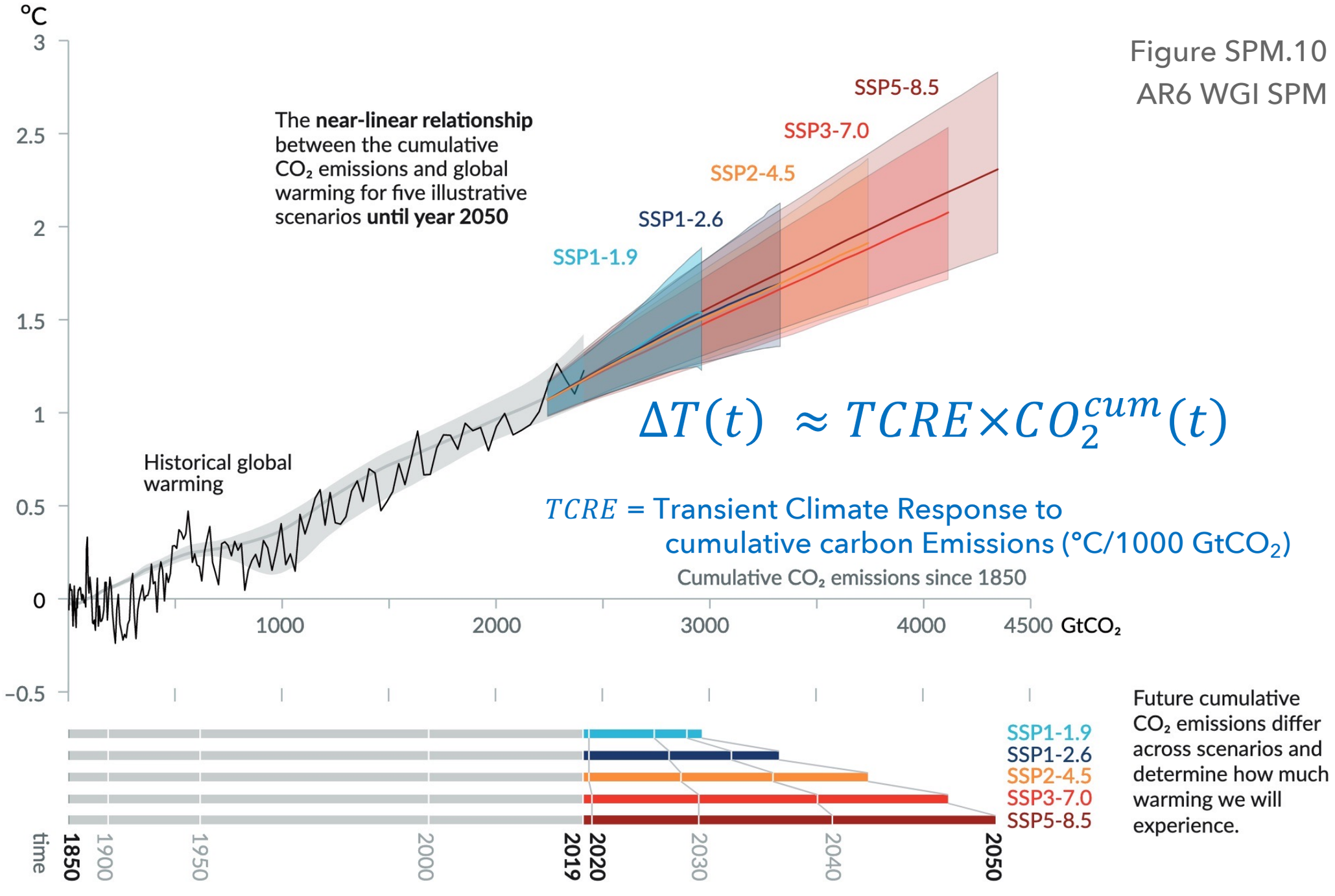

Figure SPM.10
AR6 WGI SPM

For "short-term" effects, we may focus on cumulative emissions and "ignore" the paths.

$TCRE \in [0.27, 0.62]$

Best estimate
0.45
°C/1000 $GtCO_2$

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Fact 4: Each temperature change target is associated with a Carbon budget

Example: The carbon budget for 1.5°C

- Best estimate TCRE = 0.45 °C/1000 $GtCO_2$

- Historical cumulation of emissions (1850-2019) = 2,390 $GtCO_2$

$$\Delta T_{2019} = 0.45 \times 2{,}390 = 1.07°C$$

- If we set a temperature increase target of 1.5°C

Carbon Budget: $\frac{1.5}{0.45} = 3{,}333\ GtCO_2$

- We have already emitted (1850-2019) 2,390 $GtCO_2$

Carbon budget left: $3{,}333 - 2{,}390 = 943\ GtCO_2$

- If we emit 35 $GtCO_2$/year (average last years)

Carbon budget exhausted in $^{943}/_{35} = 27$ years ~2050

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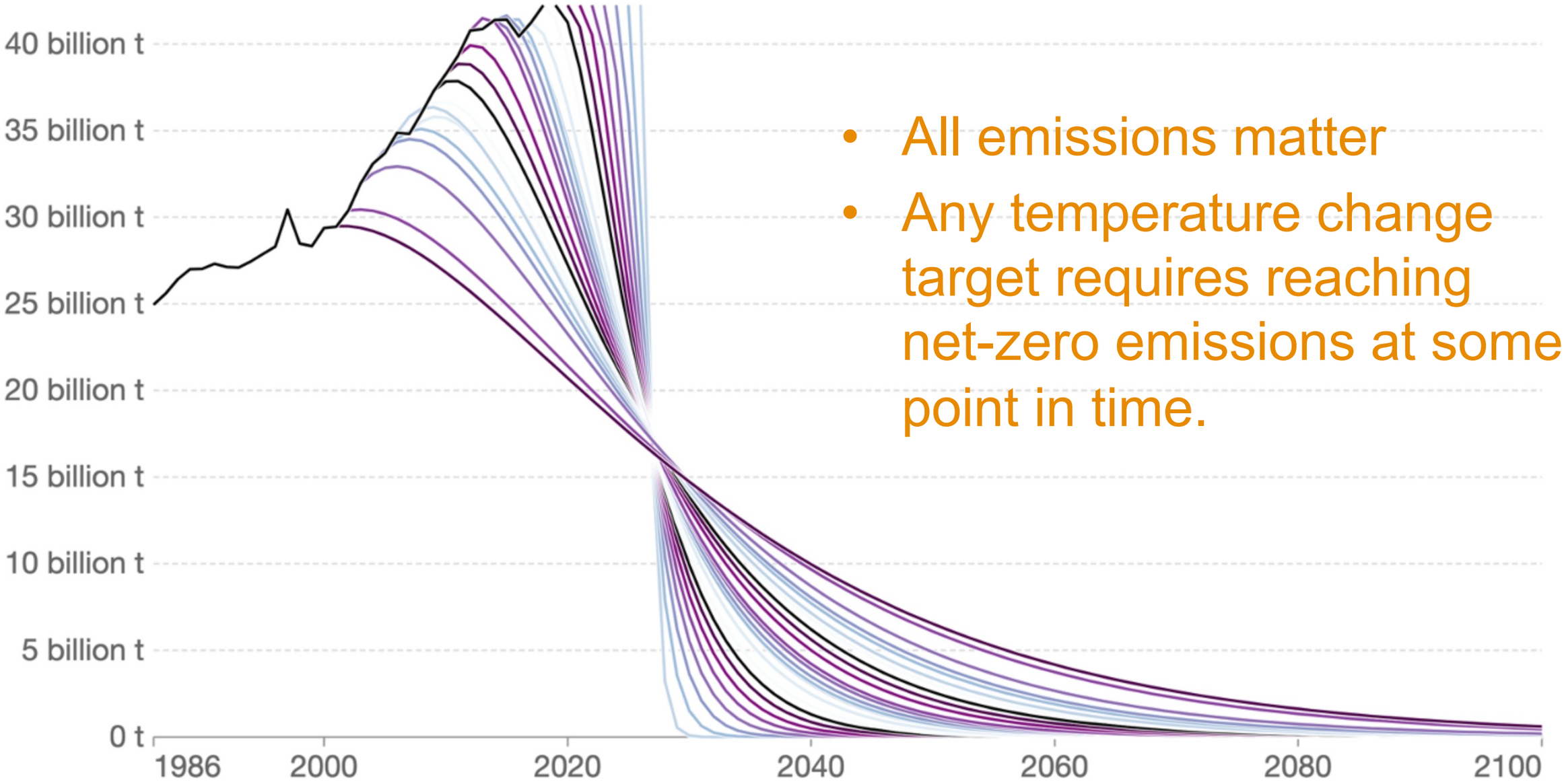
EMISSION PATHS FOR 1.5°C

CO_2 reductions needed to keep global temperature rise below 1.5°C

Our World in Data

Annual emissions of carbon dioxide under various mitigation scenarios to keep global average temperature rise below 1.5°C. Scenarios are based on the CO_2 reductions necessary if mitigation had started – with global emissions peaking and quickly reducing – in the given year.



- All emissions matter
- Any temperature change target requires reaching net-zero emissions at some point in time.

Source: Robbie Andrews (2019); based on Global Carbon Project & IPPC SR15
Note: Carbon budgets are based on a >66% chance of staying below 1.5°C from the IPCC's SR15 Report.
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions • CC BY

Summary

- Climate change is human induced
- The green house effect
- The carbon cycle
- The carbon budget
  - There is a near-linear relationship between cumulative anthropogenic CO_2 emissions and global warming: $\Delta T°\mathrm{C} \cong TCRE \times CO_2^{cum}$
  - A temperature target is associated to a carbon budget
  - A temperature target requires net-zero emissions at some point in time.

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Emissions

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How much is 1tCO_2?

- A balloon with a diameter of 9 meters
- An economy flight Frankfurt to New York
- 3,300 Km with an average petrol car
- Monthly emissions of 2 households in the EU-27 (average 2019-2020)

myclimate.org

- $1GtC = 3.7\ GtC 1GtCO_2$
- $1Gt = 10^9\ t$

- In 2018, the EU-27 emitted 1.11 $GtCO_2$ (1.11×10^9 tCO_2) for electricity and heat; and the World, 16GtCO2
- @$30/tCO2 → 48 billion dollars ; @$220 → 3.5 trillion dollars

https://www.compensators.org/en/compensate-2/

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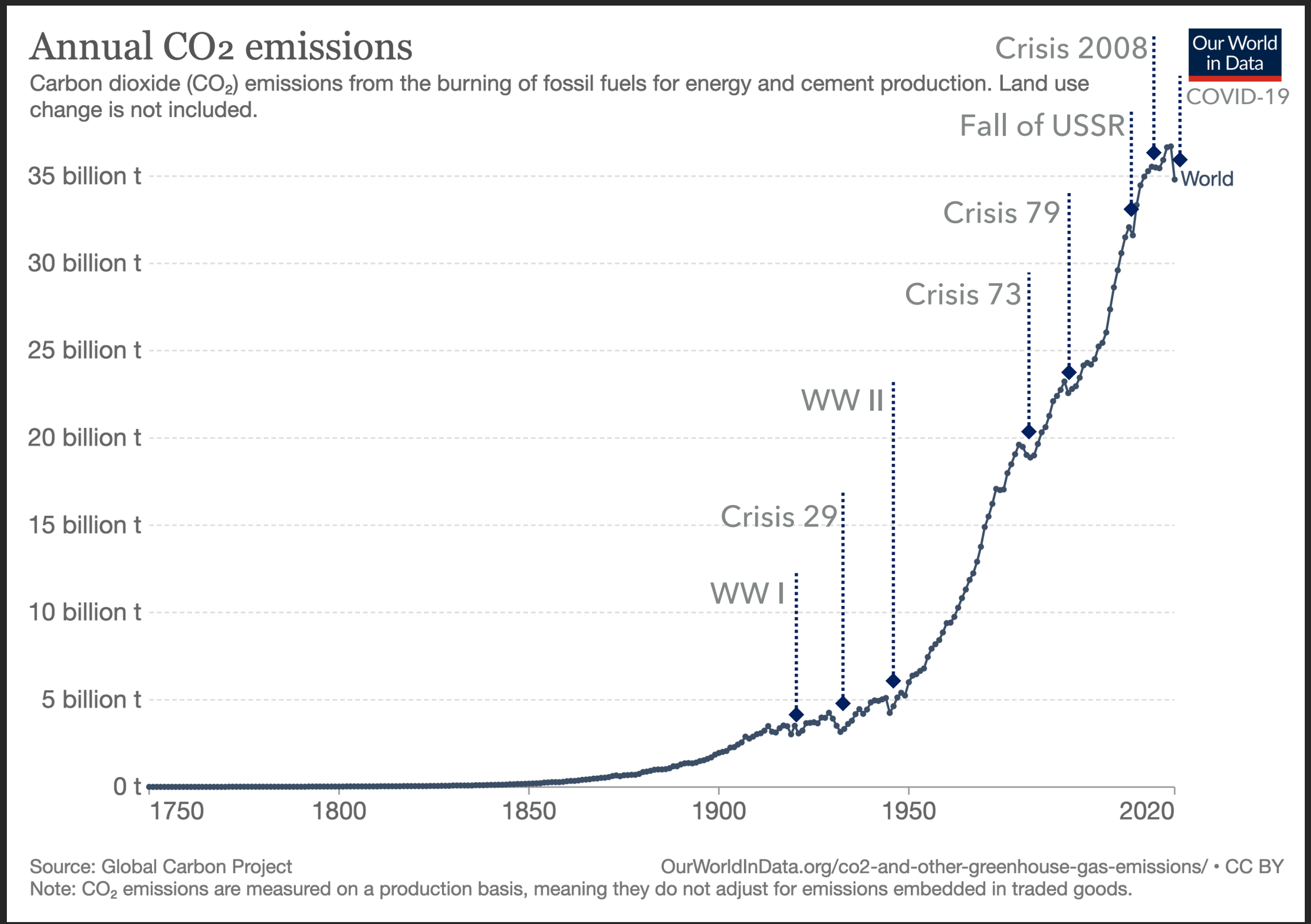
FACT 5: EMISSIONS ARE CLOSELY LINKED TO THE ECONOMIC ACTIVITY AND HAVE NOT PEAKED YET



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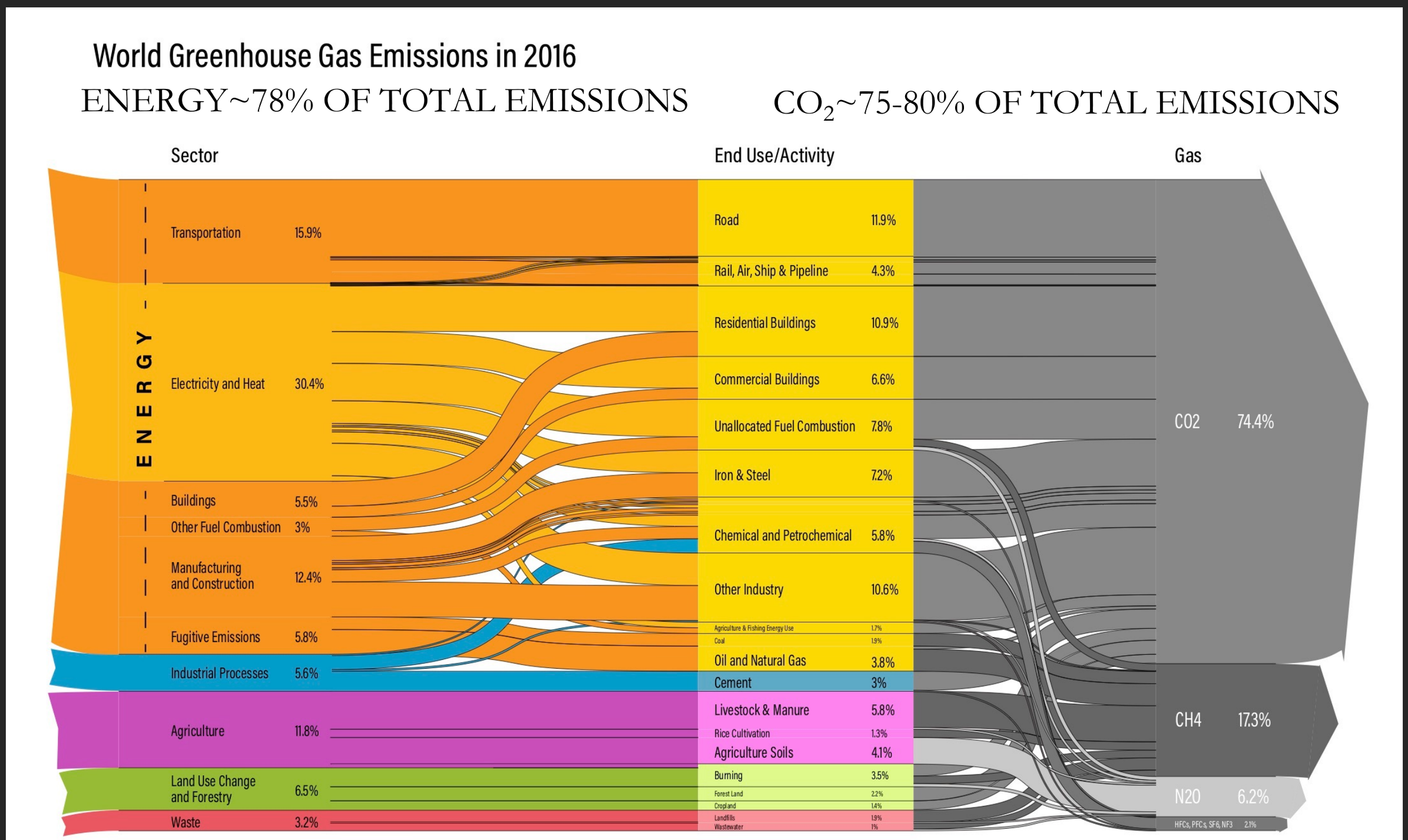
Fact 6: Energy and CO_2 (+Methane) are the most relevant players



Source: Greenhouse gas emissions on Climate Watch. Available at: https://www.climatewatchdata.org

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GREENHOUSE GAS EMISSIONS

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Global greenhouse gas emissions by gas

Greenhouse gas emissions are converted to carbon dioxide-equivalents (CO_2eq) by multiplying each gas by its 100-year 'global warming potential' value: the amount of warming one tonne of the gas would create relative to one tonne of CO_2 over a 100-year timescale. This breakdown is shown for 2016.

Our World in Data

OurWorldinData.org – Research and data to make progress against the world's largest problems.
Source: Climate Watch, the World Resources Institute (2020).

$GWP_{100} = 1$

Lifespan: 100s - ∞ years

Fossil fuels (coal, oil, gas) combustion, cement, and land use

$GWP_{100} = 28$

Lifespan: 20-100 years

Rice, livestock, waste, and gas leakage

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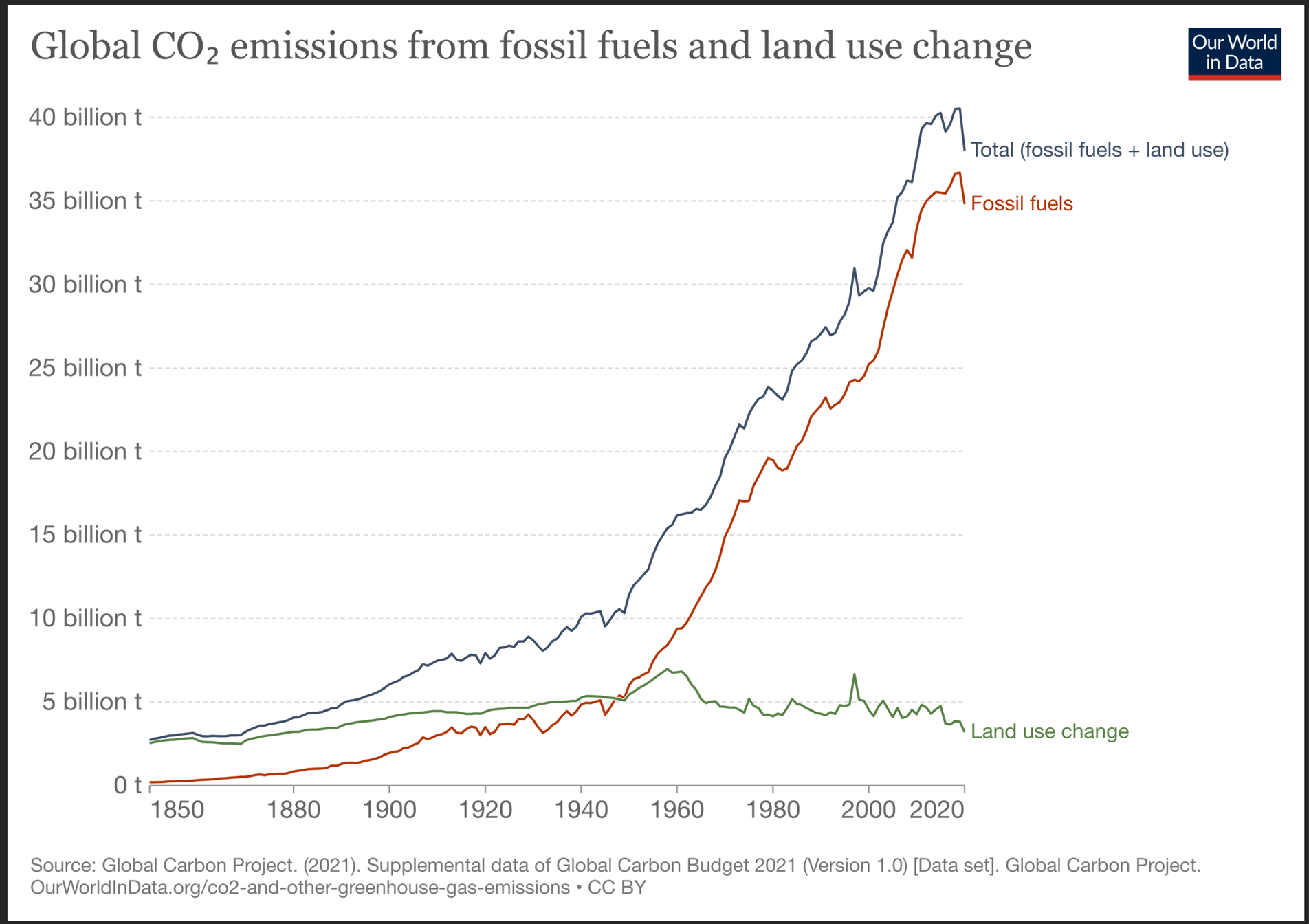
Emissions of CO_2

- Emissions from and land use change are a small fraction of total emissions and have declined in the last years



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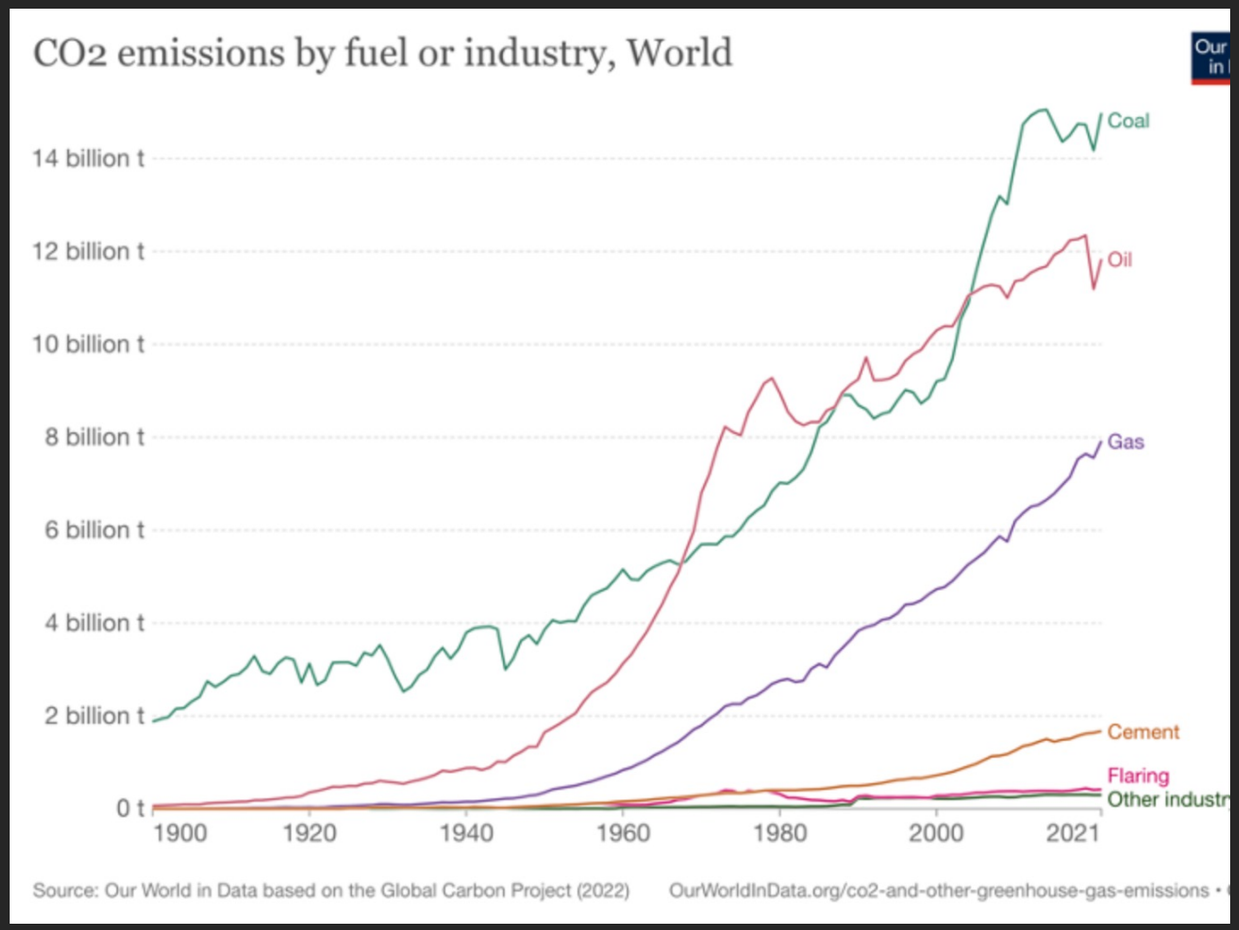
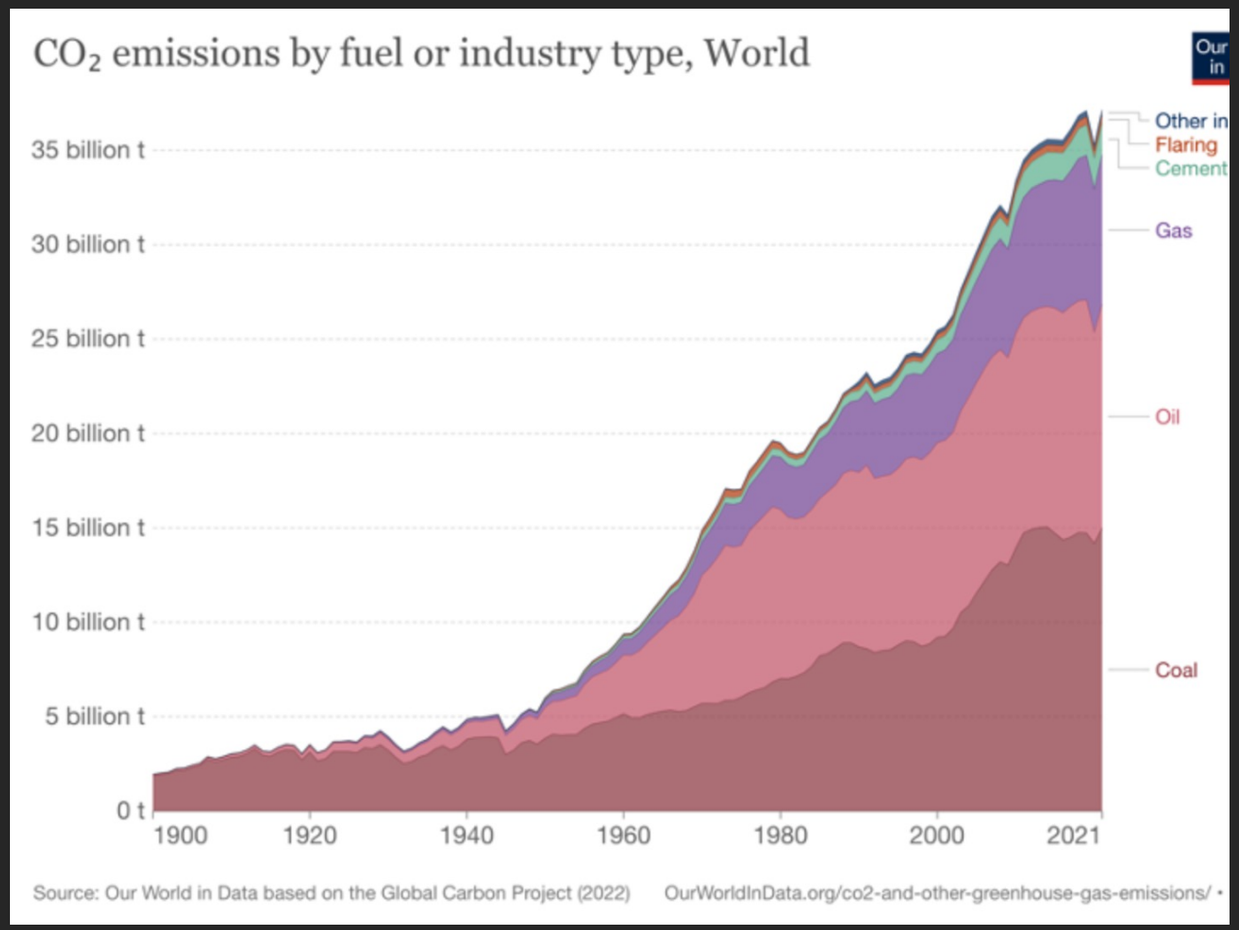
CO_2 EMISSIONS BY FUEL : COAL, OIL AND GAS





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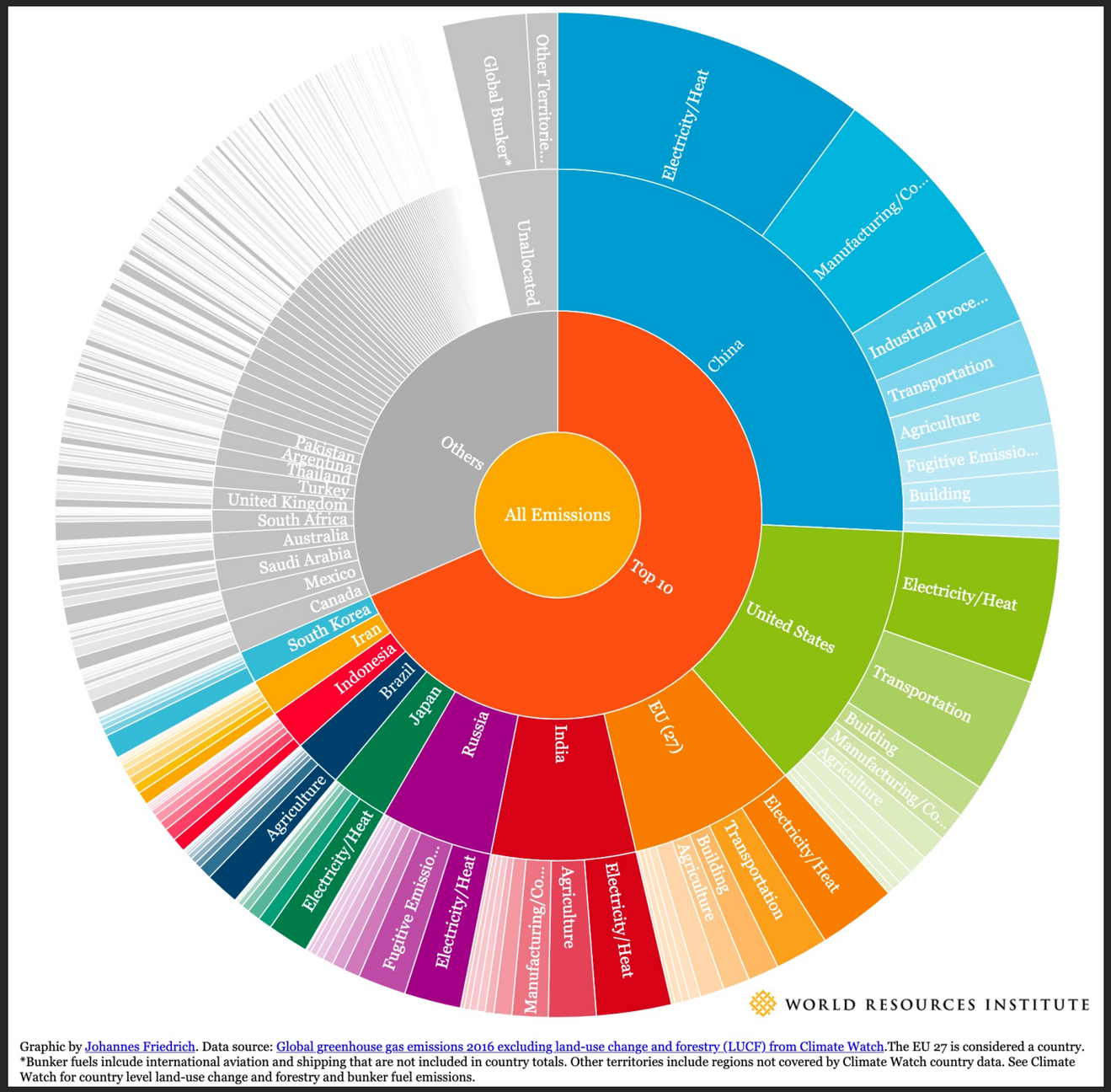
EMISSION EMITTERS



Graphic by Johannes Friedrich. Data source: Global greenhouse gas emissions 2016 excluding land-use change and forestry (LUCF) from Climate Watch.The EU 27 is considered a country. *Bunker fuels inlcude international aviation and shipping that are not included in country totals. Other territories include regions not covered by Climate Watch country data. See Climate Watch for country level land-use change and forestry and bunker fuel emissions.

https://www.wri.org/upload/circlechart2019/circle_state.htm

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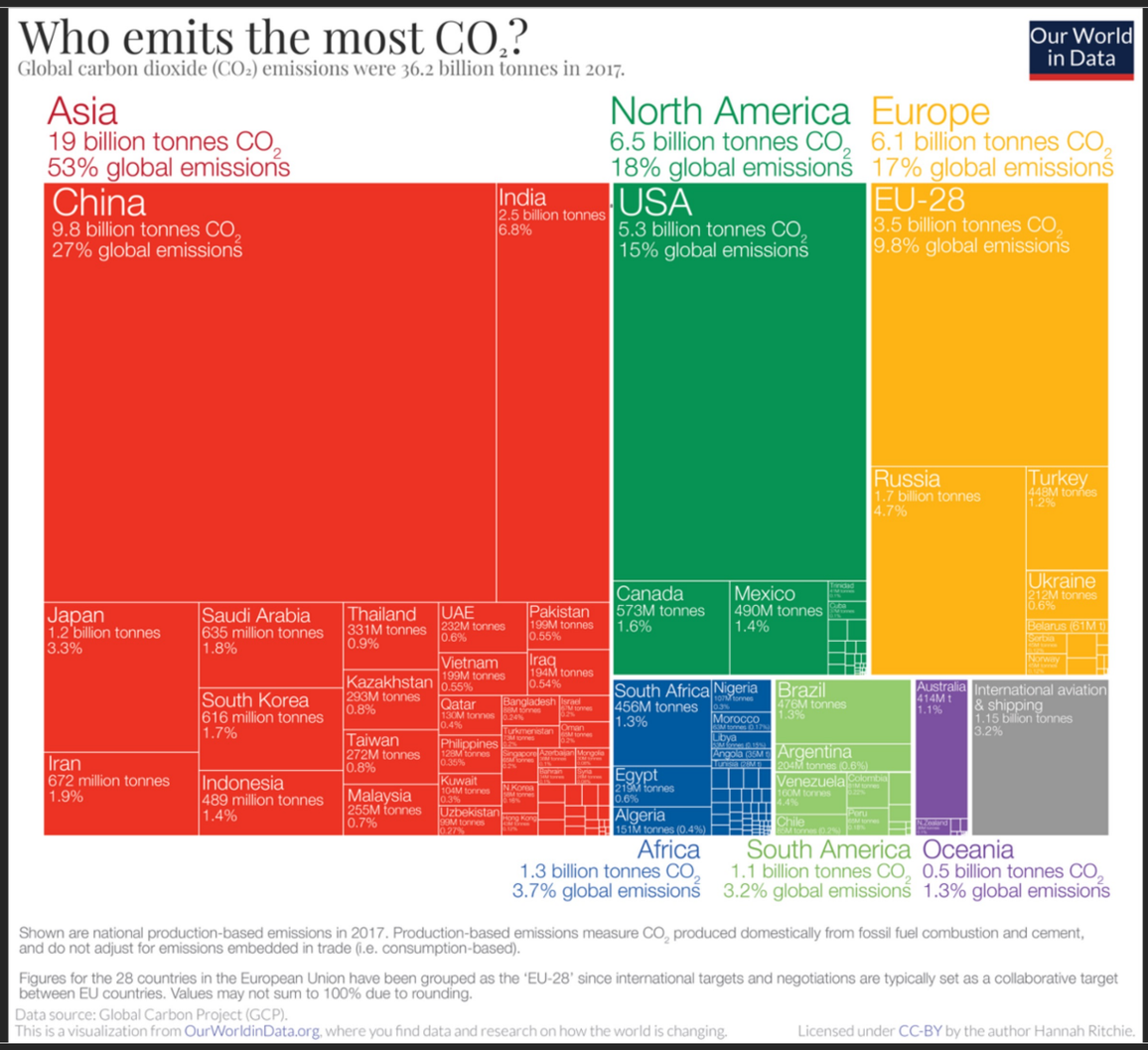
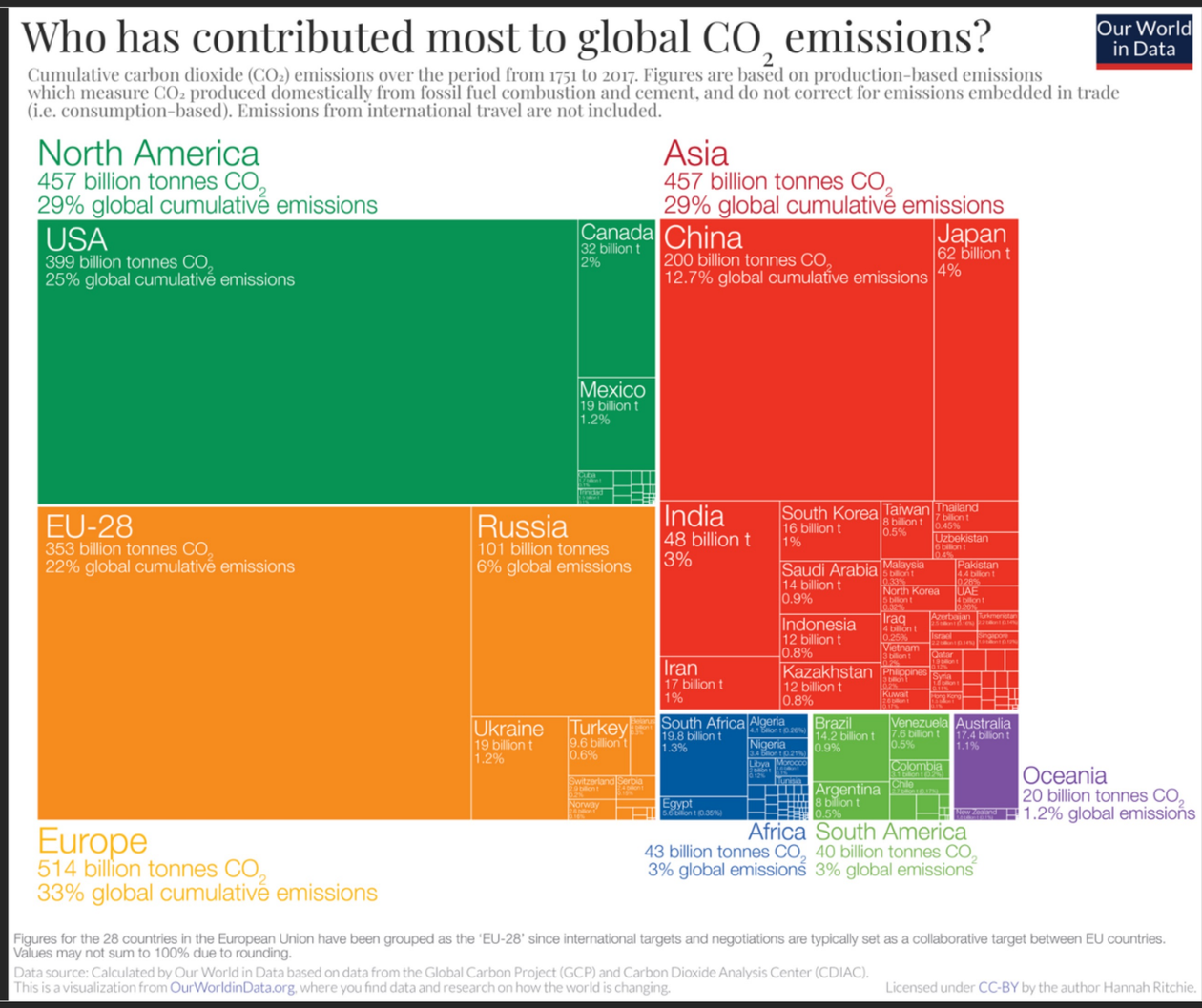
Annual and Cumulative Emissions of CO_2 by Region/country





- Asia (CHINA, India & Japan) contribute more than 50% of total emissions
- USA and EU-28 contribute 35%
- USA and EU-28 have contributed more than 50% of total emissions
- Asia (China, India & Japan) have contributed 29% of total emissions

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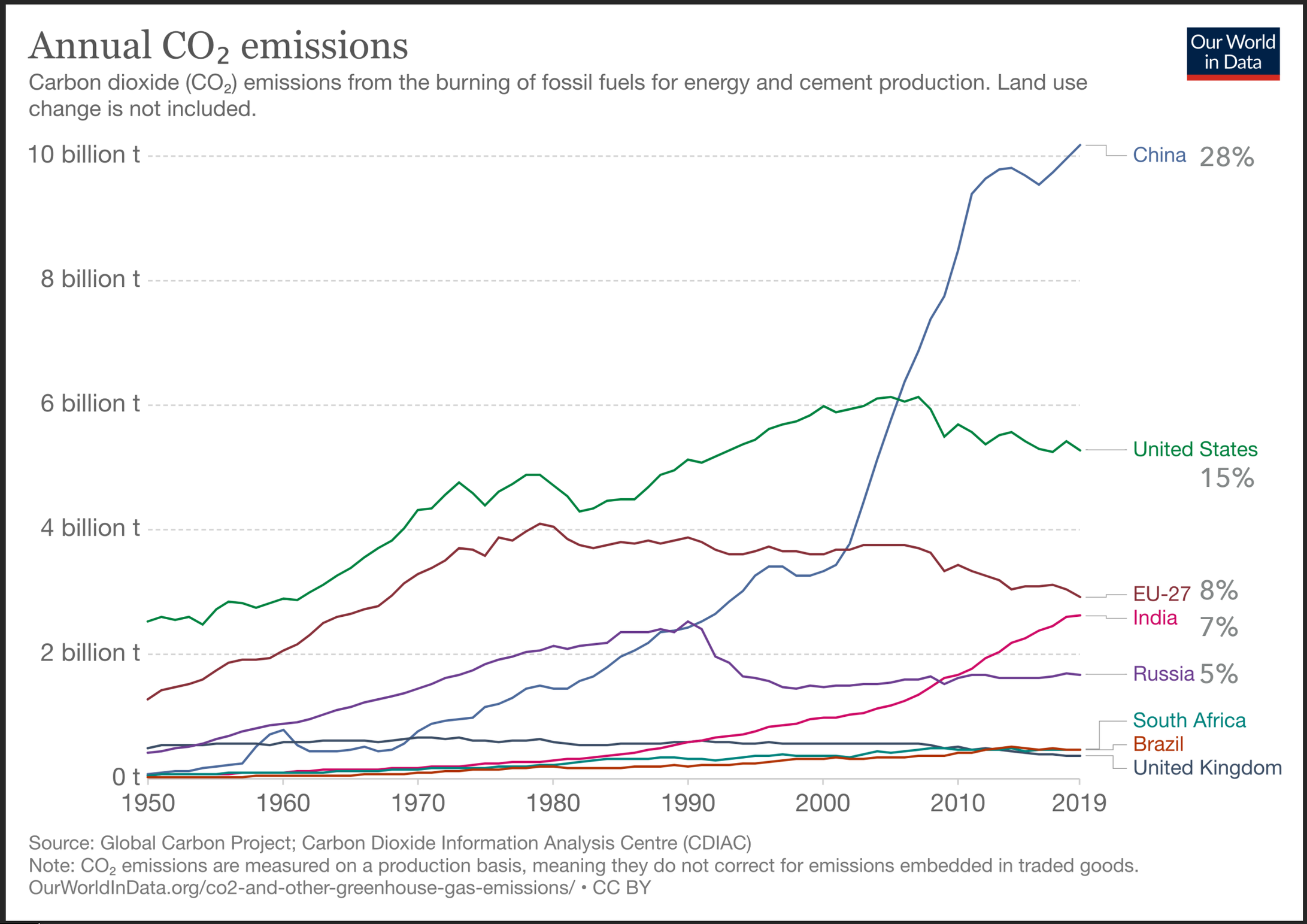
Since 2006, China is the larger emitter of CO_2



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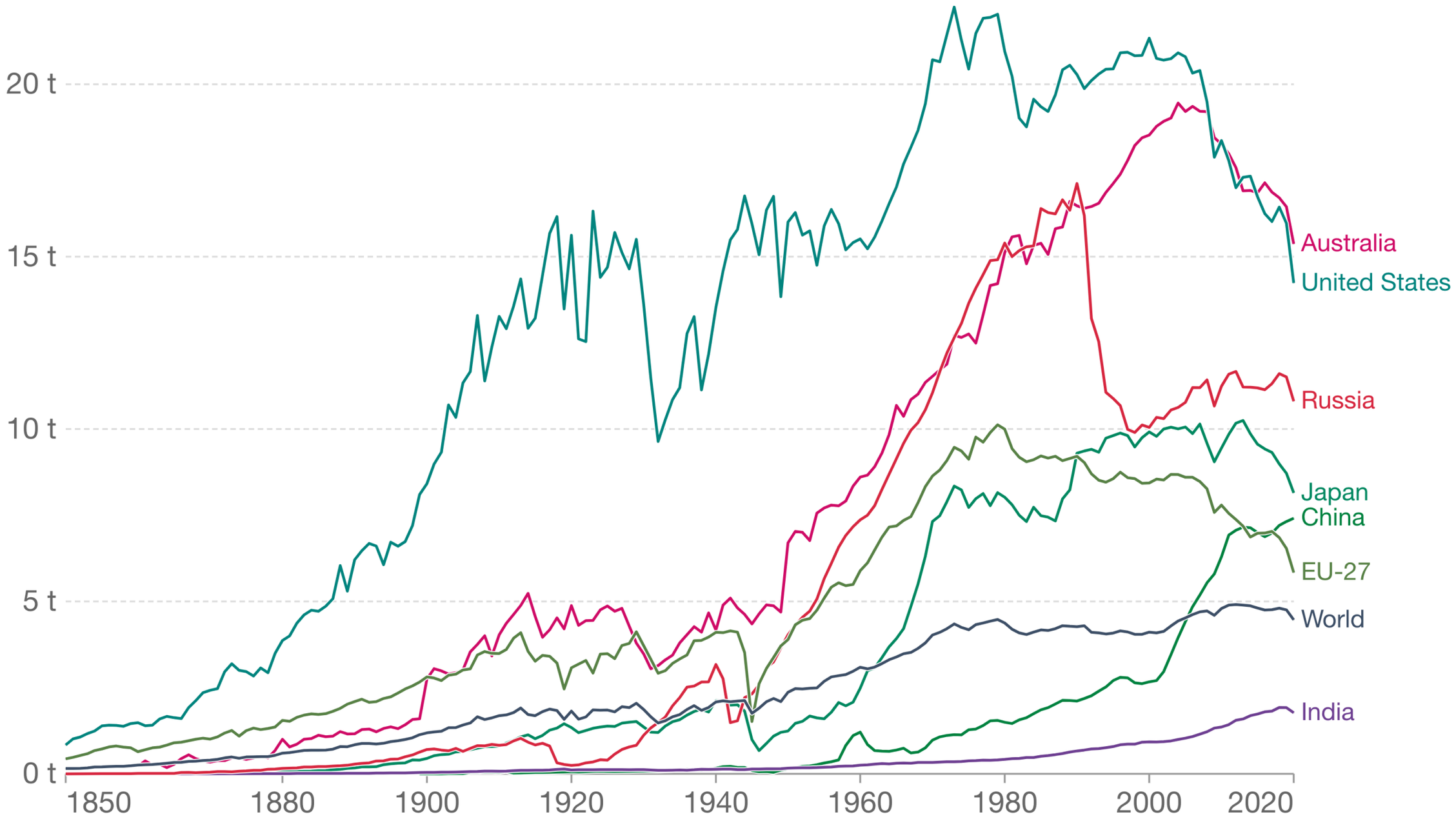
USA, AUSTRALIA & RUSSIA HAVE LARGER PER CAPITA EMISSIONS

Per capita CO_2 emissions

Carbon dioxide (CO_2) emissions from the burning of fossil fuels for energy and cement production. Land use change is not included.

Our World in Data



Source: Our World in Data based on the Global Carbon Project OurWorldInData.org/co2-and-other-greenhouse-gas-emissions/ • CC BY
Note: CO_2 emissions are measured on a production basis, meaning they do not adjust for emissions embedded in traded goods.

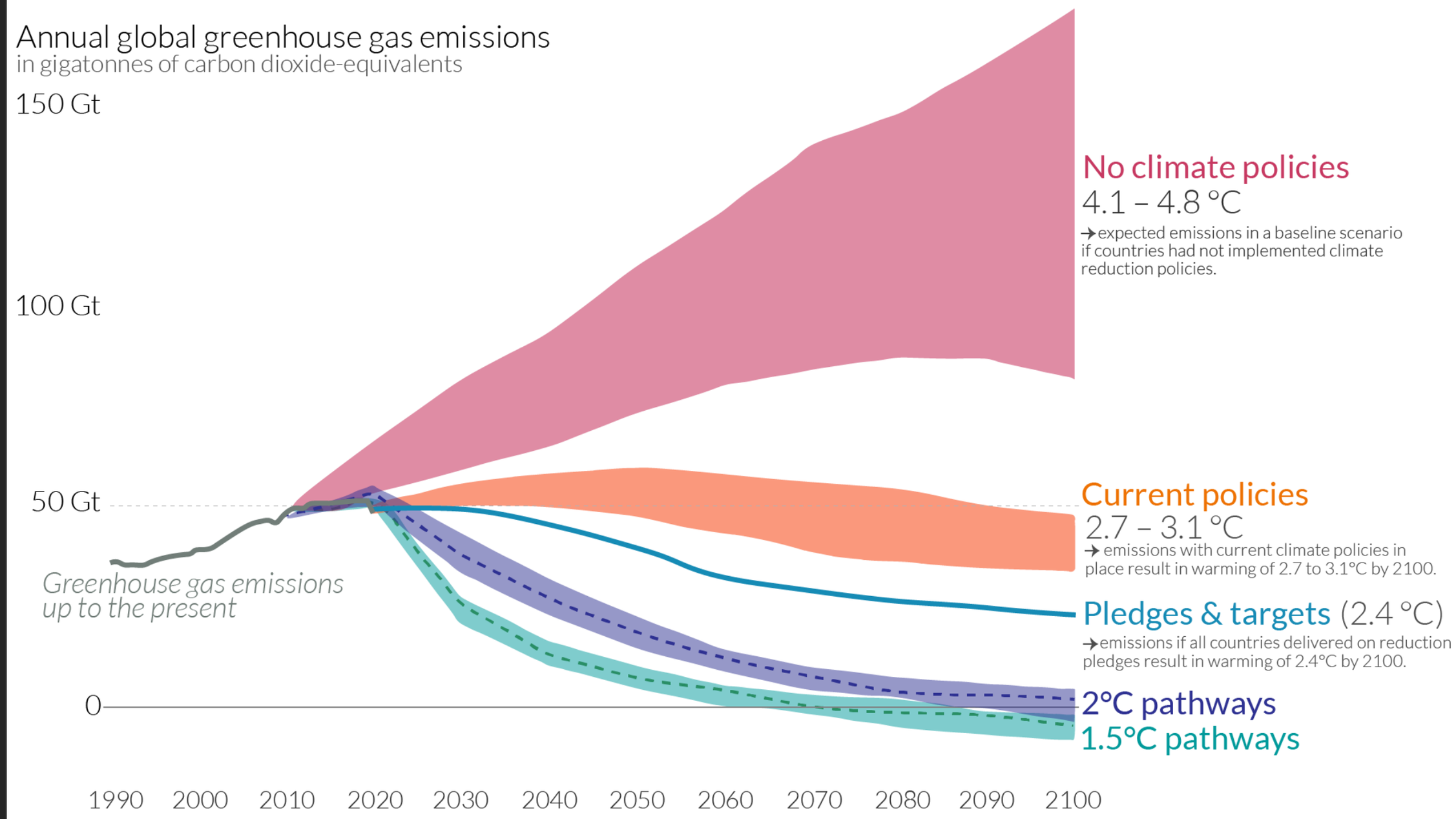
number to: l.lavador@upf.edu

FACT 7: WE HAVE MADE SOME PROGRESS BUT NOT ENOUGH

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 May 2021).
OurWorldinData.org – Research and data to make progress against the world's largest problems.

Last updated: July 2021.

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What determines total CO_2 emissions?

The 'Kaya Identity' breaks down total emissions into the key elements driving them.

Our World in Data

Total CO_2 emissions = **Population** x **CO_2 emissions per person**

Income (Goods and services per person (measured in $)) x **Technology** ($CO_2$ emissions per $)

Energy intensity (Energy consumed per $) x **Carbon intensity** (CO_2 emitted per unit of energy consumed.)

$$\textit{Total } CO_2 \textit{ emissions} = \textit{Population} \times \frac{\textit{GDP}}{\textit{Population}} \times \frac{\textit{Energy}}{\textit{GDP}} \times \frac{CO_2}{\textit{Energy}}$$

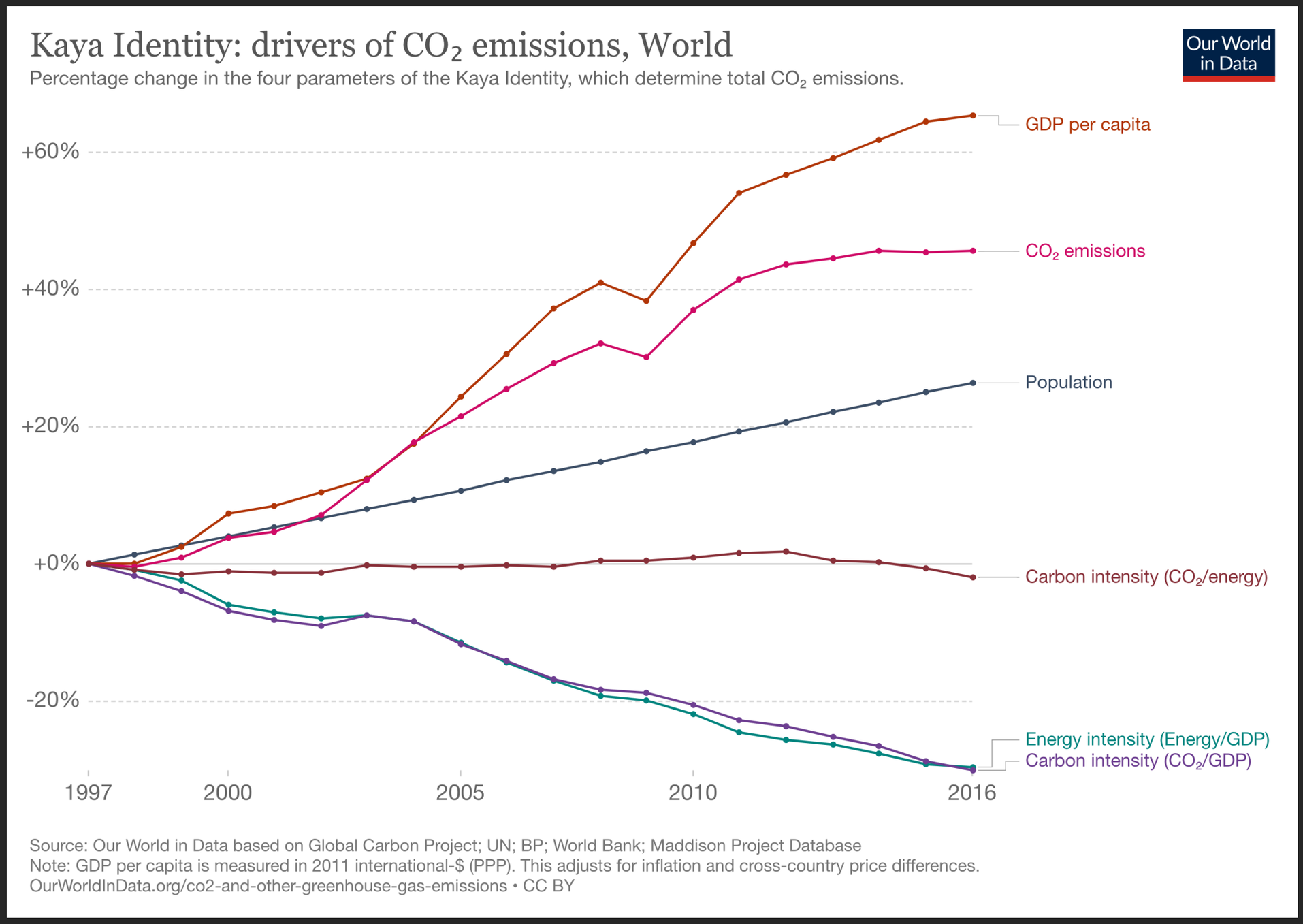
↓ energy intensity by:

- Improving energy efficiency
- Switching to less intensive industries

↓ carbon intensity by:

- Switching to renewable energy
- Switching to nuclear energy
- Substituting gas for coal (partial)
- Capturing & storing fossil CO_2 (CCS)

Fact 8: World mitigation gains are driven by energy efficiency and not by greener energy



- Partial decoupling of GDP and emissions
- The increase of population has been more than compensated by the fall of energy intensity
- Carbon intensity of energy has barely changed

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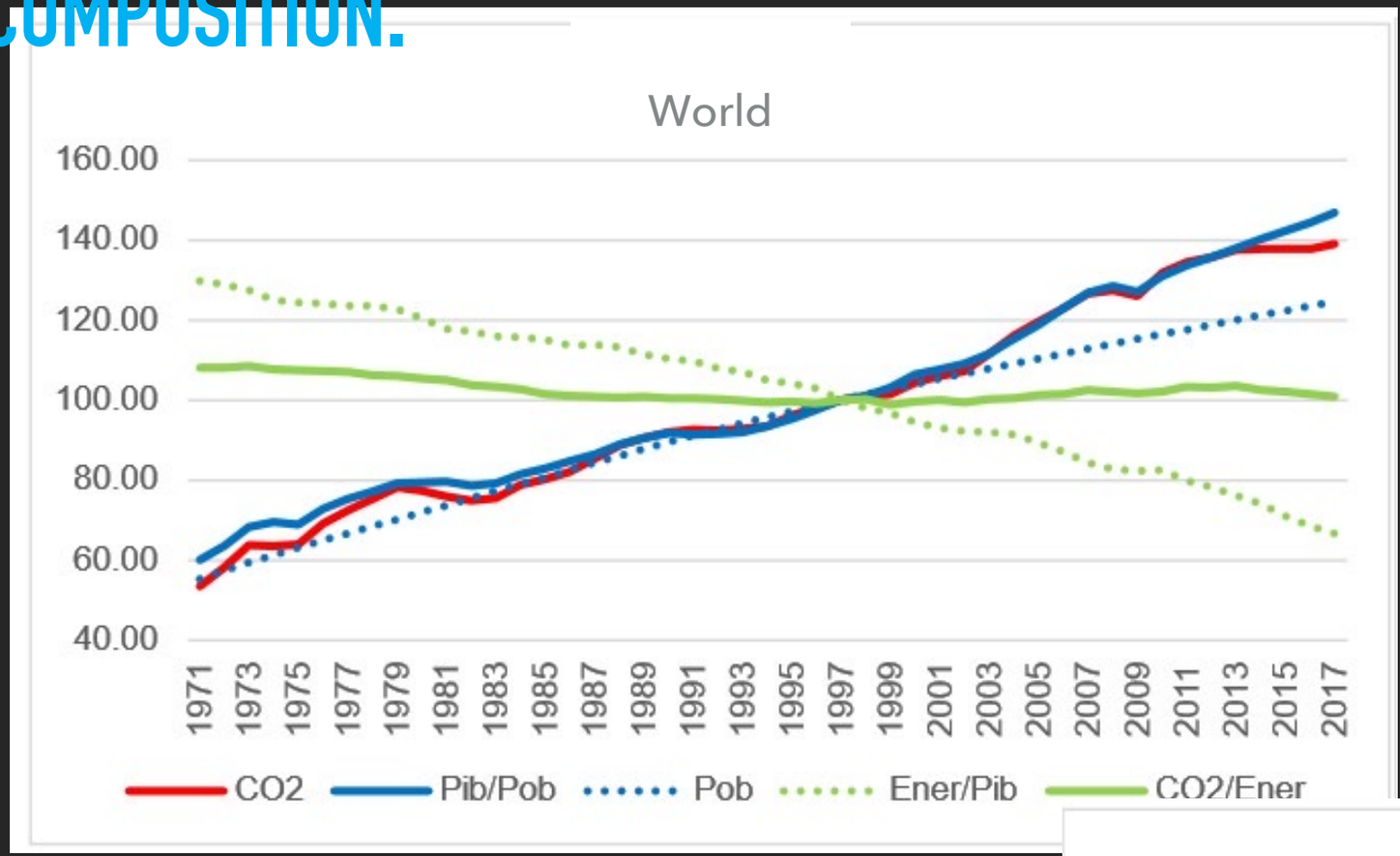
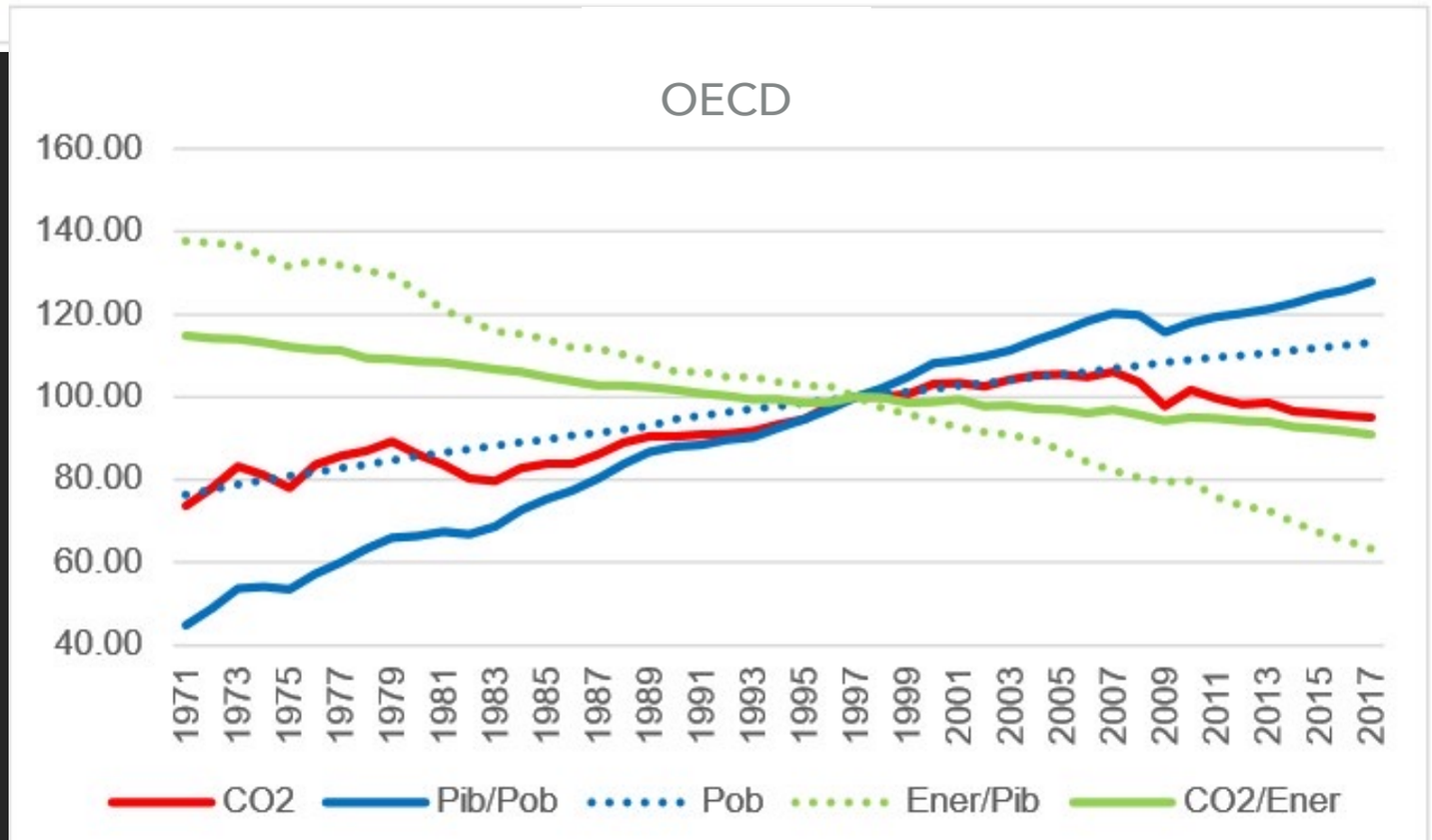
Fact 9: OECD countries show some recent greening in their energy composition.



Emission Accounting
1997-2017

- World emission gains are driven by energy efficiency, and not by greener energy.

- OECD countries show some greening in their energy composition and reductions of CO_2



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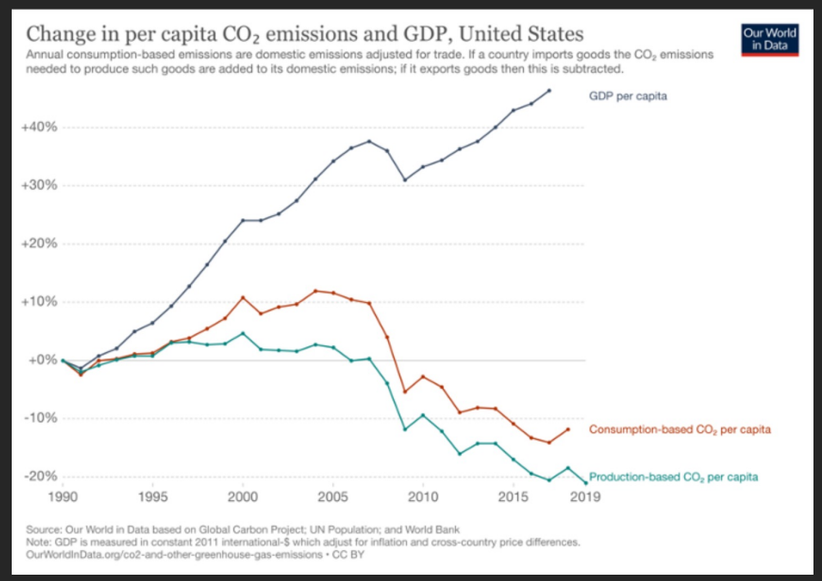
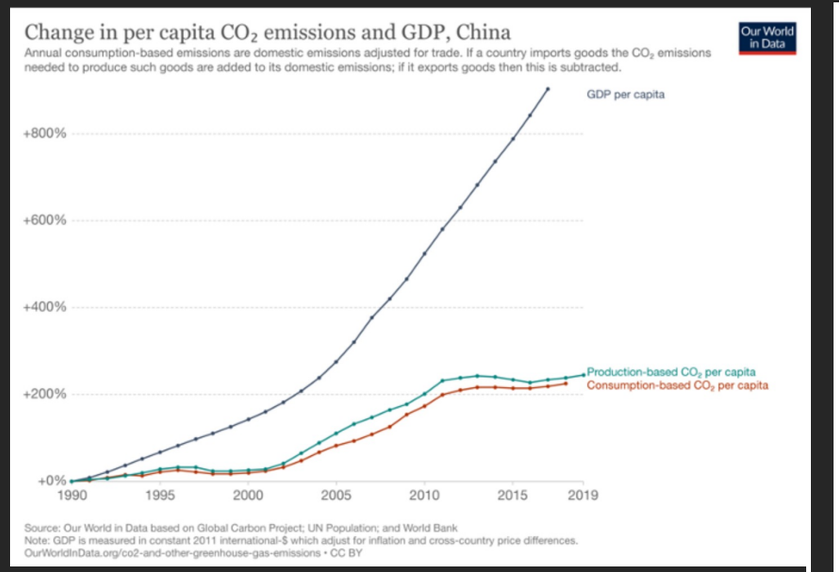
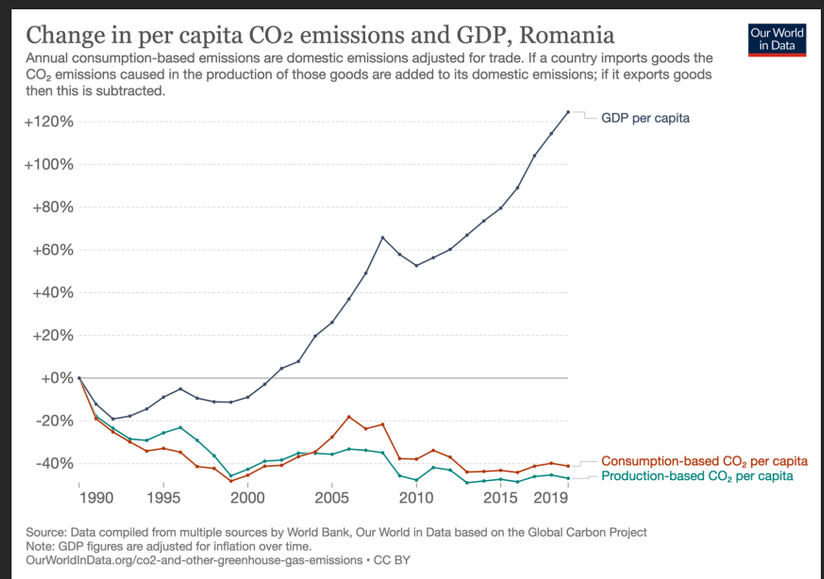
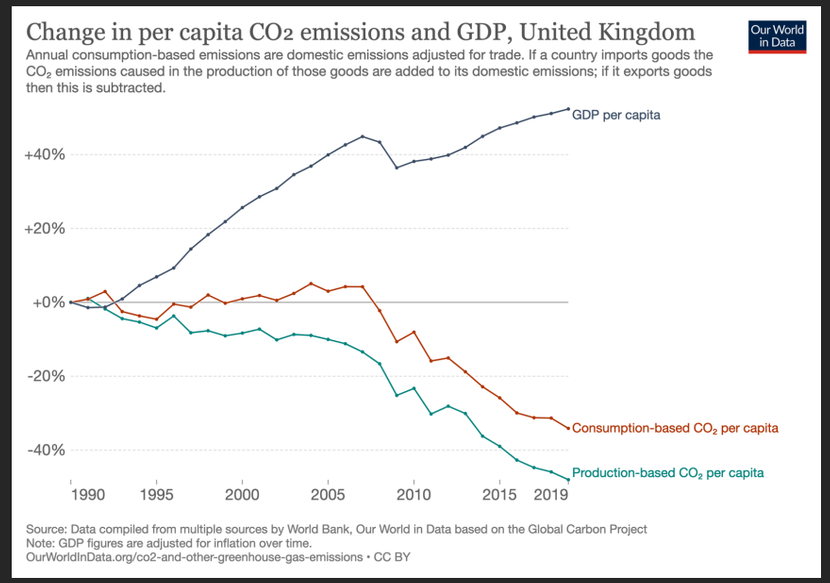
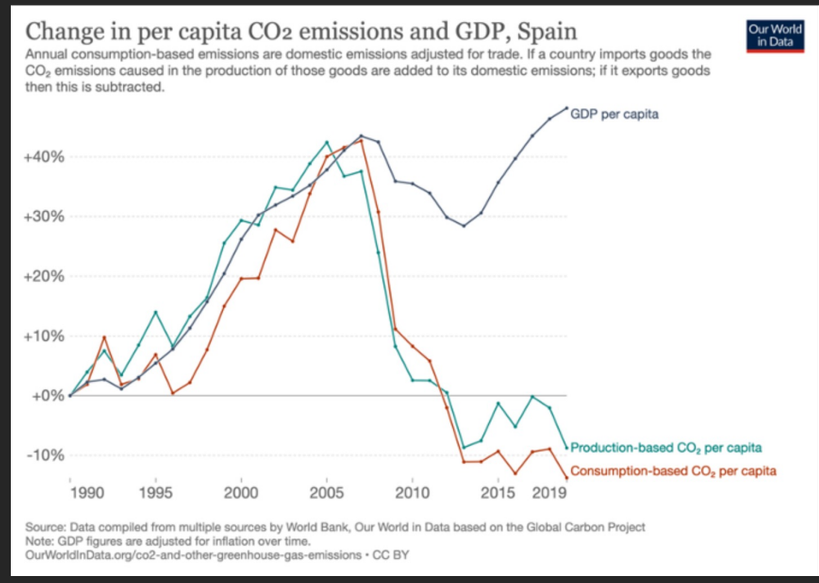
Fact 10: Many countries have decoupled economic growth from CO_2 emissions, even if we take offshored production into account

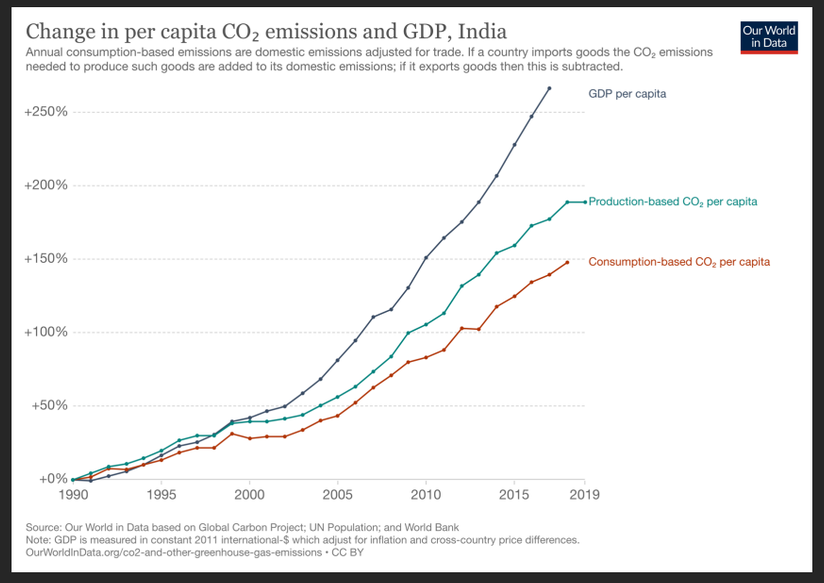












https://ourworldindata.org/grapher/co2-emissions-and-gdp-per-capita?time=1990..2019

Still many open questions

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Example of of shoring emissions: Ireland 2000s

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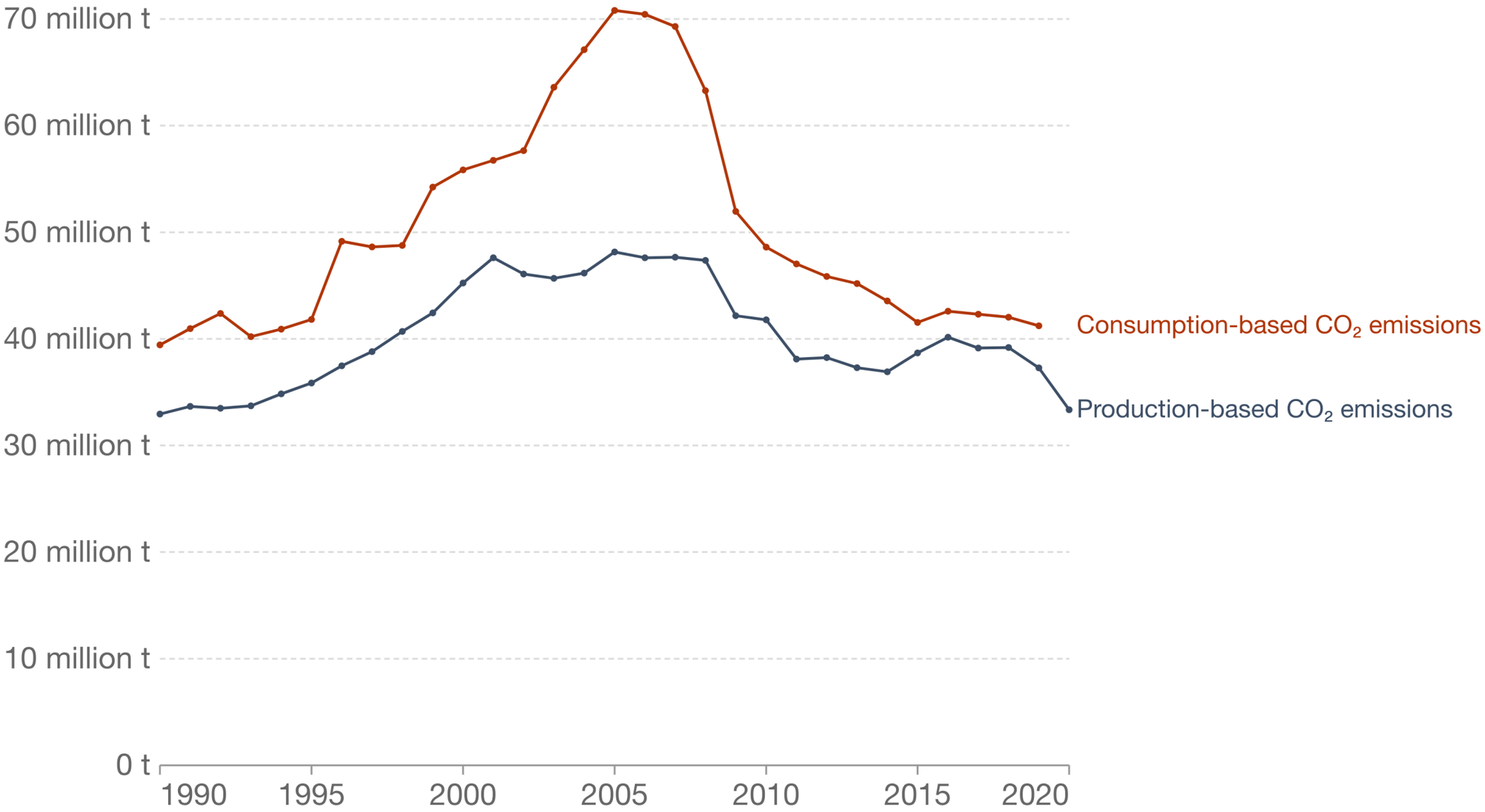
Production vs. consumption-based CO_2 emissions, Ireland

Our World in Data

Annual consumption-based emissions are domestic emissions adjusted for trade. If a country imports goods the CO_2 emissions needed to produce such goods are added to its domestic emissions; if it exports goods then this is subtracted.



Source: Global Carbon Project

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

Note: This measures CO_2 emissions from fossil fuels and cement production only – land use change is not included.

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WILL DEVELOPING COUNTRIES MANAGE DECOUPLING?

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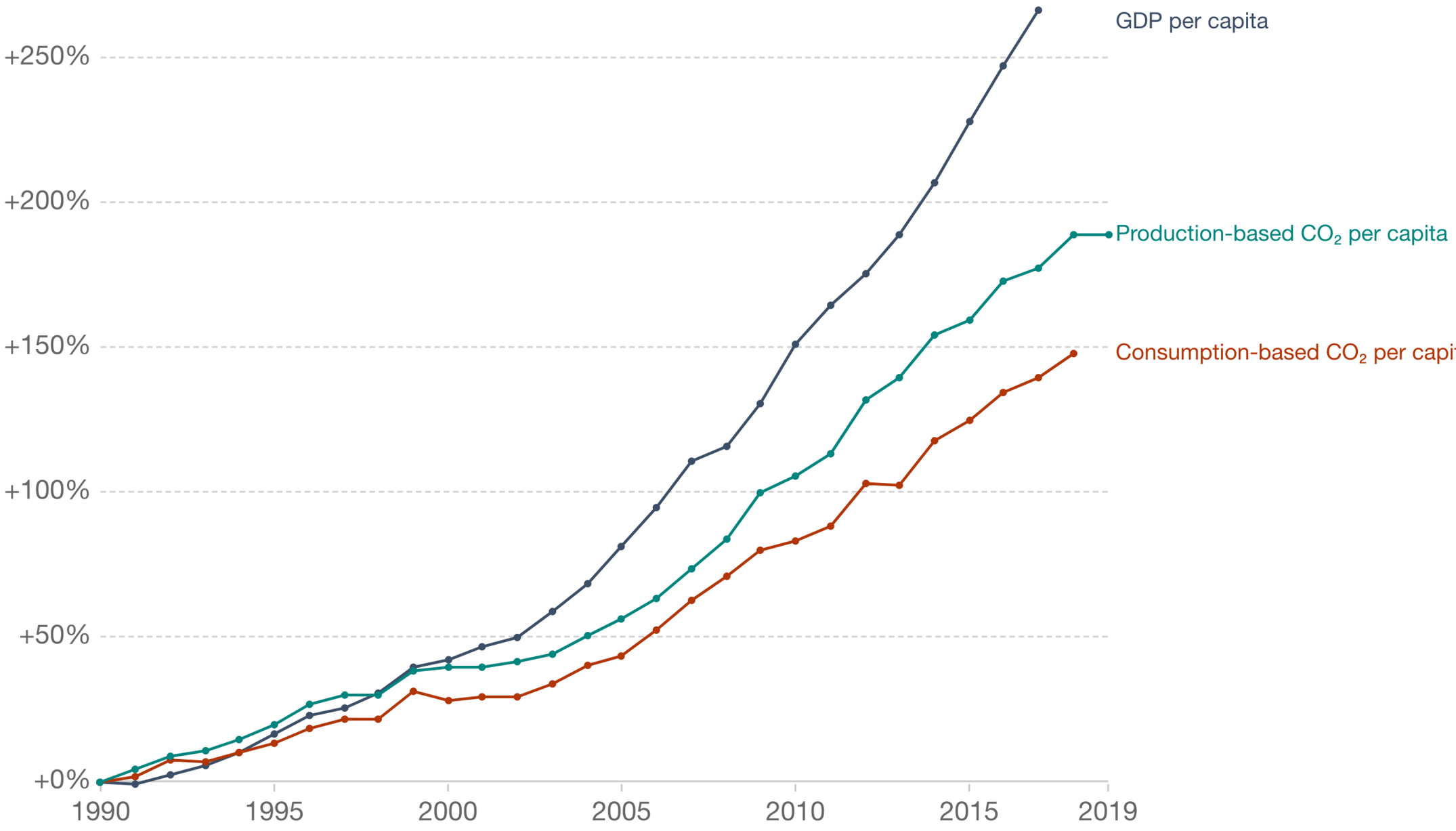
Change in per capita CO_2 emissions and GDP, India

Our World in Data

Annual consumption-based emissions are domestic emissions adjusted for trade. If a country imports goods the CO_2 emissions needed to produce such goods are added to its domestic emissions; if it exports goods then this is subtracted.



Source: Our World in Data based on Global Carbon Project; UN Population; and World Bank
Note: GDP is measured in constant 2011 international-$ which adjust for inflation and cross-country price differences.
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions • CC BY

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