



GLOBAL CARBON BUDGET

2023

Acknowledgements

The work presented here has been possible thanks to the enormous observational and modelling efforts of the institutions and networks below

Atmospheric CO₂ datasets

NOAA/GML (Lan et al., 2023)

Scripps (Keeling et al., 1976)

Atmospheric O₂ datasets

Scripps (Keeling 2023)

Fossil CO₂ emissions

Andrew and Peters, 2023

CDIAC-FF (Hefner and Marland, 2023)

UNFCCC 2023

Energy Institute 2023

Consumption emissions

Peters et al., 2011

GTAP (Narayanan et al., 2015)

Land-use change

Houghton and Castanho 2023

BLUE (Hansis et al., 2015)

OSCAR (Gasser et al., 2020)

GFED4 (van der Werf et al., 2017)

FAO-FRA and FAOSTAT

HYDE (Klein Goldewijk et al., 2017)

LUH2 (Hurtt et al., 2020)

MapBiomas (Souza et al., 2020)

Land models

CABLE-POP | CLASSIC | CLM5.0 | DLEM | eDV3 | ELM | IBIS | ISAM | ISBA-CTrip | JSBACH | JULES-ES | LPJ-GUESS | LPJml | LPJ-wsl | LPX-Bern | OCN | ORCHIDEEv3 | SDGVM | VISIT

Climate forcing

 CRU (Harris et al., 2014) | JRA-55 (Kobayashi et al., 2015)

Ocean models

ACCESS | CESM-ETHZ | FESOM-2.1-RECoM2 | MICOM-HAMOCC (NorESM-OCv1.2) | MOM6-COBALT (Princeton) | MPIOM-HAMOCC6 | MRI-ESM2-2 | NEMO3.6-PISCESv2-gas (CNRM) | NEMO-PISCES (IPSL) | NEMO-PlankTOM12

fCO₂ based ocean flux products

CMEMS-LSCE-FFNNv2 | Jena- MLS | JMA-MLR | LDEO-HPD | MPI-SOMFFN | NIES-ML3 | OS-ETHZ-GRaCER | UoEx-Watson

Surface Ocean CO₂ Atlas

 SOCATv2023

Atmospheric inversions

CAMS | CAMS-Satellite | CarbonTracker Europe | COLA | CT-NOAA | CMS-Flux | GCASv2 | GONGGA | IAPCAS | Jena CarboScope | MIROC4-ACTM | NISMON-CO2 | THU | UoE in-situ

Earth system models

CanESM2 | IPSL-CM6—CO₂-LR | MIROC-ES2L | MPI-ESM1-2-LR

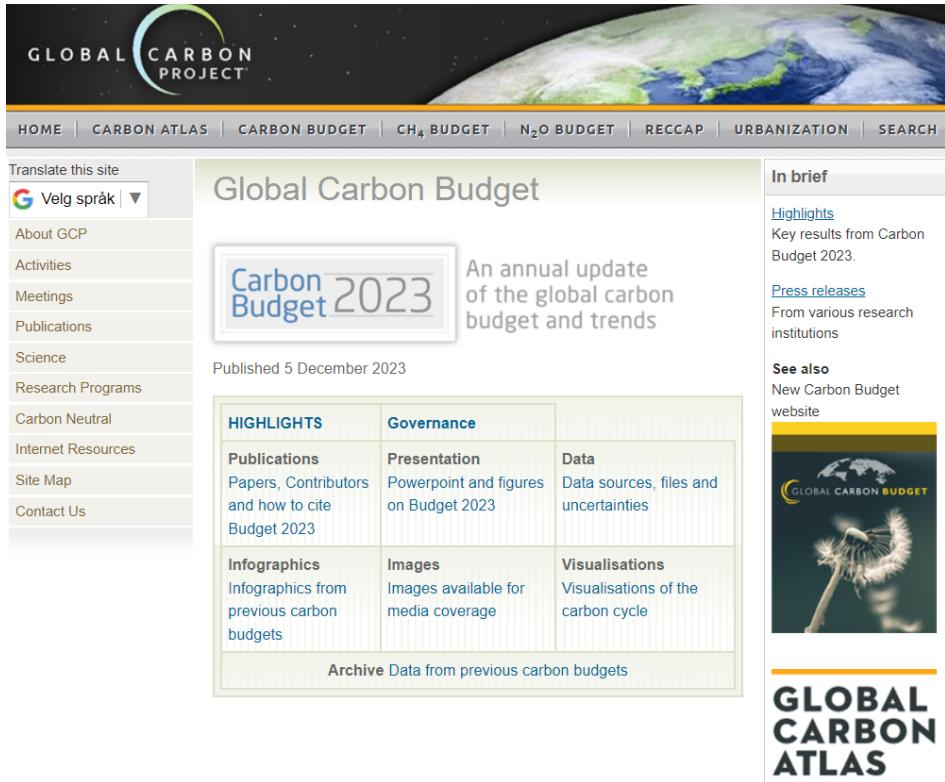
Full references provided in [Friedlingstein et al 2023](#)

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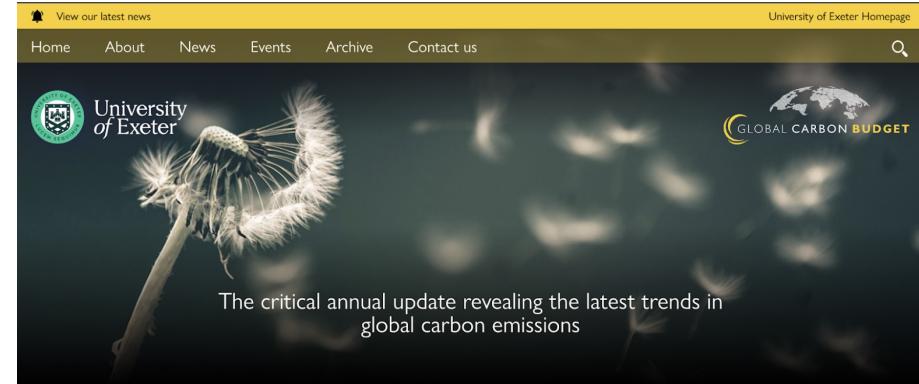
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Data Access and Additional Resources



The screenshot shows the 'Carbon Budget 2023' page. At the top, there's a banner with the text 'Carbon Budget 2023' and 'An annual update of the global carbon budget and trends'. Below this, it says 'Published 5 December 2023'. The main content area has two columns: 'HIGHLIGHTS' and 'Governance'. Under 'HIGHLIGHTS', there are links for 'Publications' (Papers, Contributors and how to cite Budget 2023), 'Infographics' (Infographics from previous carbon budgets), and 'Archive' (Data from previous carbon budgets). Under 'Governance', there are links for 'Presentation' (Powerpoint and figures on Budget 2023), 'Images' (Images available for media coverage), and 'Visualisations' (Visualisations of the carbon cycle). To the right, there's a sidebar with 'In brief' sections for 'Highlights' (Key results from Carbon Budget 2023) and 'Press releases' (From various research institutions), and a 'See also' section for the 'New Carbon Budget website'. A large image of a dandelion is on the right side of the page.

More information, data sources and data files:
<http://www.globalcarbonproject.org/carbonbudget>
 Contact: Pep.Canadell@csiro.au



The screenshot shows the University of Exeter homepage. At the top, there's a yellow header bar with links for 'View our latest news', 'Home', 'About', 'News', 'Events', 'Archive', 'Contact us', and a search icon. The main content area features a large image of a dandelion. In the top right corner of the image, there's a logo for 'GLOBAL CARBON BUDGET'. Below the image, the text reads 'The critical annual update revealing the latest trends in global carbon emissions'.

More information, data sources and data files:
<https://globalcarbonbudget.org/carbonbudget>

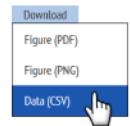


The screenshot shows the Global Carbon Atlas website. The main title is 'Global Carbon Atlas' with the subtitle 'A platform to explore and visualize the most up-to-date data on carbon fluxes resulting from human activities and natural processes'. Below this, there are two main sections: 'Country emissions' and 'Carbon Story'. The 'Country emissions' section features a world map with black dots representing CO₂ emissions. An orange button labeled 'Enter' is located at the bottom left of the map. The 'Carbon Story' section features a circular graphic showing a city skyline and a forest, with an orange button labeled 'Enter' at the bottom right.

More information, data sources and data files:
www.globalcarbonatlas.org
 (co-funded in part by BNP Paribas Foundation)

Download of figures and data

Global Carbon Budget



To download figures or data, use the Download menu to the upper right of each figure. The precision provided in the data files is not indicative of certainty. For example, the data file says that global emissions in 2018 were 36.444 GtCO₂, but this should be quoted as 36.4 GtCO₂. CSV data files have been prepared for many but not all figures on this page.

Slide 07

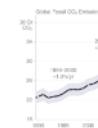
Perturbation of the carbon cycle



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Slide 09

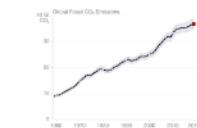
Global fossil fuel and cement emissions



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Slide 10

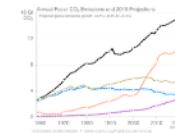
Global fossil fuel and cement emissions



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Slide 11

Emissions of the top four emitters



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Slide 12

Emissions of the top four emitters



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Slide 13

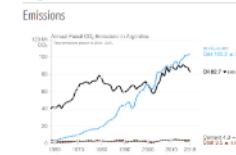
Per-capita emissions of the top four emitters



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Additional country figures

Argentina Emissions



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Argentina Emissions



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Argentina Energy



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Argentina Energy



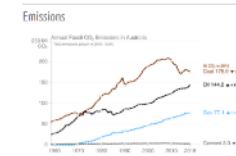
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Argentina Kaya Identity



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Australia Emissions



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Australia Emissions



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Australia Energy



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Figures and data for most slides available from tinyurl.com/GCB23figs
and from <https://globalcarbonbudget.org/carbonbudget>

All the data is shown in billion tonnes CO₂ (GtCO₂)

1 Gigatonne (Gt) = 1 billion tonnes = 1×10^{15} g = 1 Petagram (Pg)

1 kg carbon (C) = 3.664 kg carbon dioxide (CO₂)

1 GtC = 3.664 billion tonnes CO₂ = 3.664 GtCO₂

(Figures are available from <https://globalcarbonbudget.org/carbonbudget>)

Most figures in this presentation are available for download as PNG, PDF and SVG files from tinyurl.com/GCB23figs along with the data required to produce them.

Disclaimer

The Global Carbon Budget and the information presented here are intended for those interested in learning about the carbon cycle, and how human activities are changing it. The information contained herein is provided as a public service, with the understanding that the Global Carbon Project team make no warranties, either expressed or implied, concerning the accuracy, completeness, reliability, or suitability of the information.



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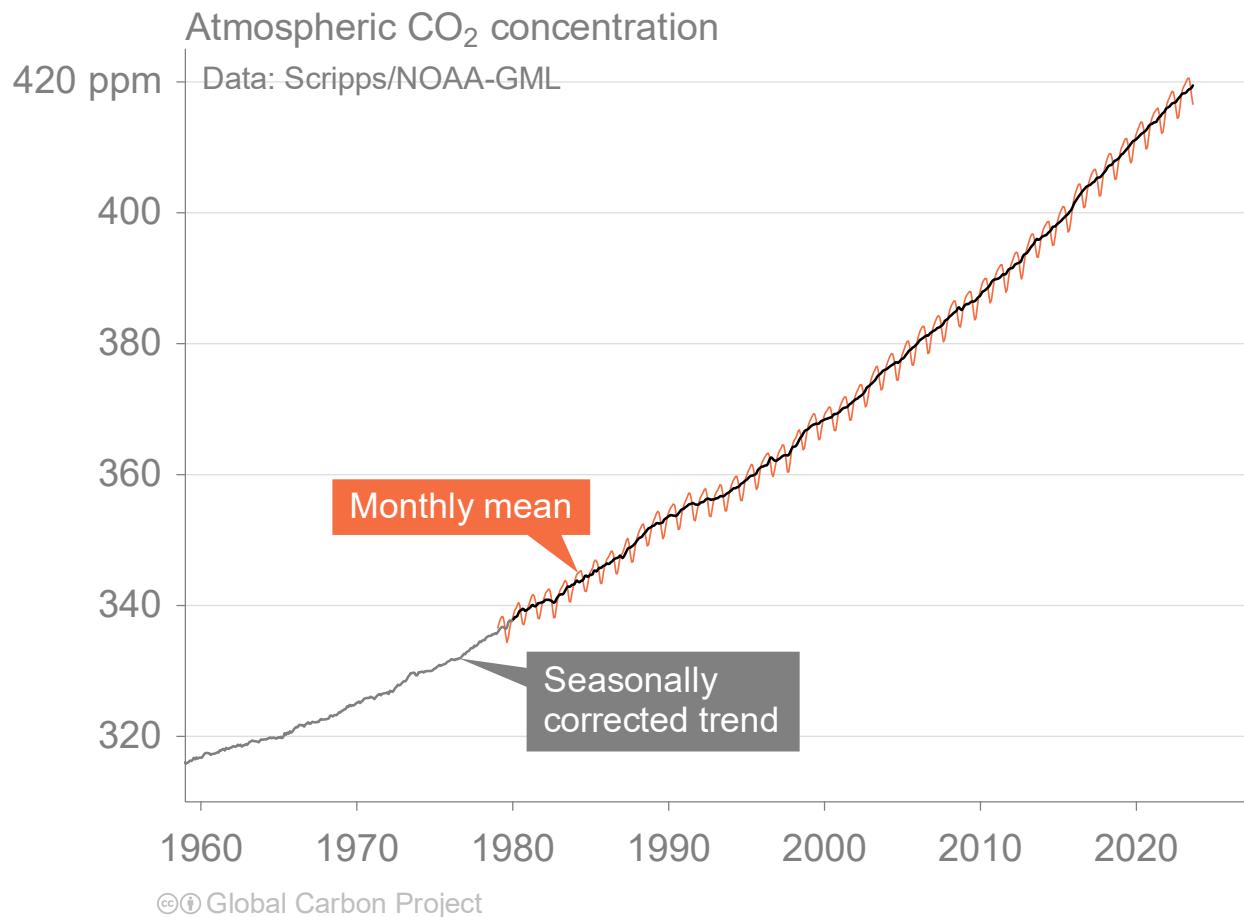
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Atmospheric CO₂ concentration

The global CO₂ concentration increased from ~277 ppm in 1750 to 419.3 ppm in 2023 (up 51%)

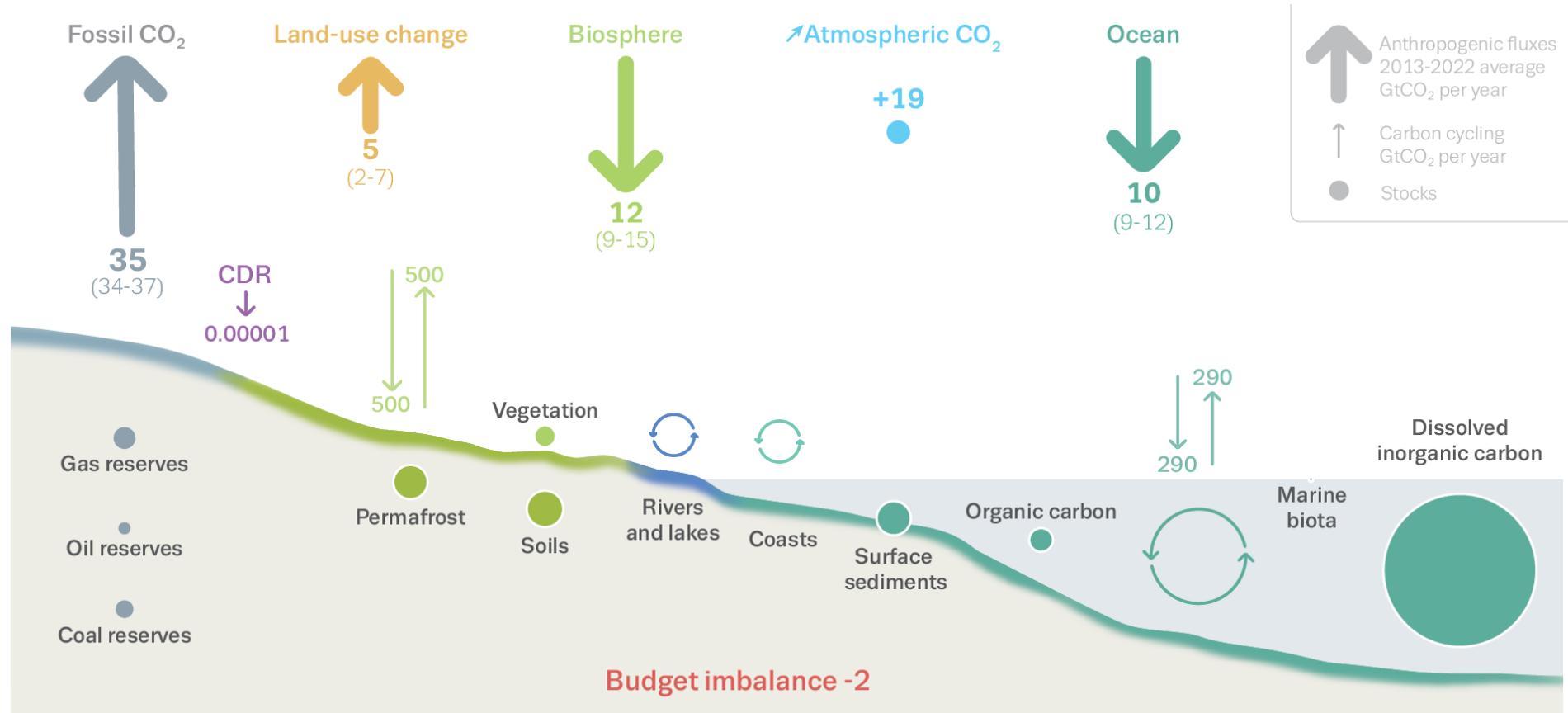


Globally averaged surface atmospheric CO₂ concentration. Data from: NOAA-GML after 1980;
the Scripps Institution of Oceanography before 1980

Source: [NOAA-GML](#); [Scripps Institution of Oceanography](#); [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Anthropogenic perturbation of the global carbon cycle

Perturbation of the global carbon cycle caused by anthropogenic activities,
global annual average for the decade 2013–2022 (GtCO₂/yr)



CDR here refers to Carbon Dioxide Removal besides those associated with land-use that are accounted for in the Land-use change estimate.
The budget imbalance is the difference between the estimated emissions and sinks.

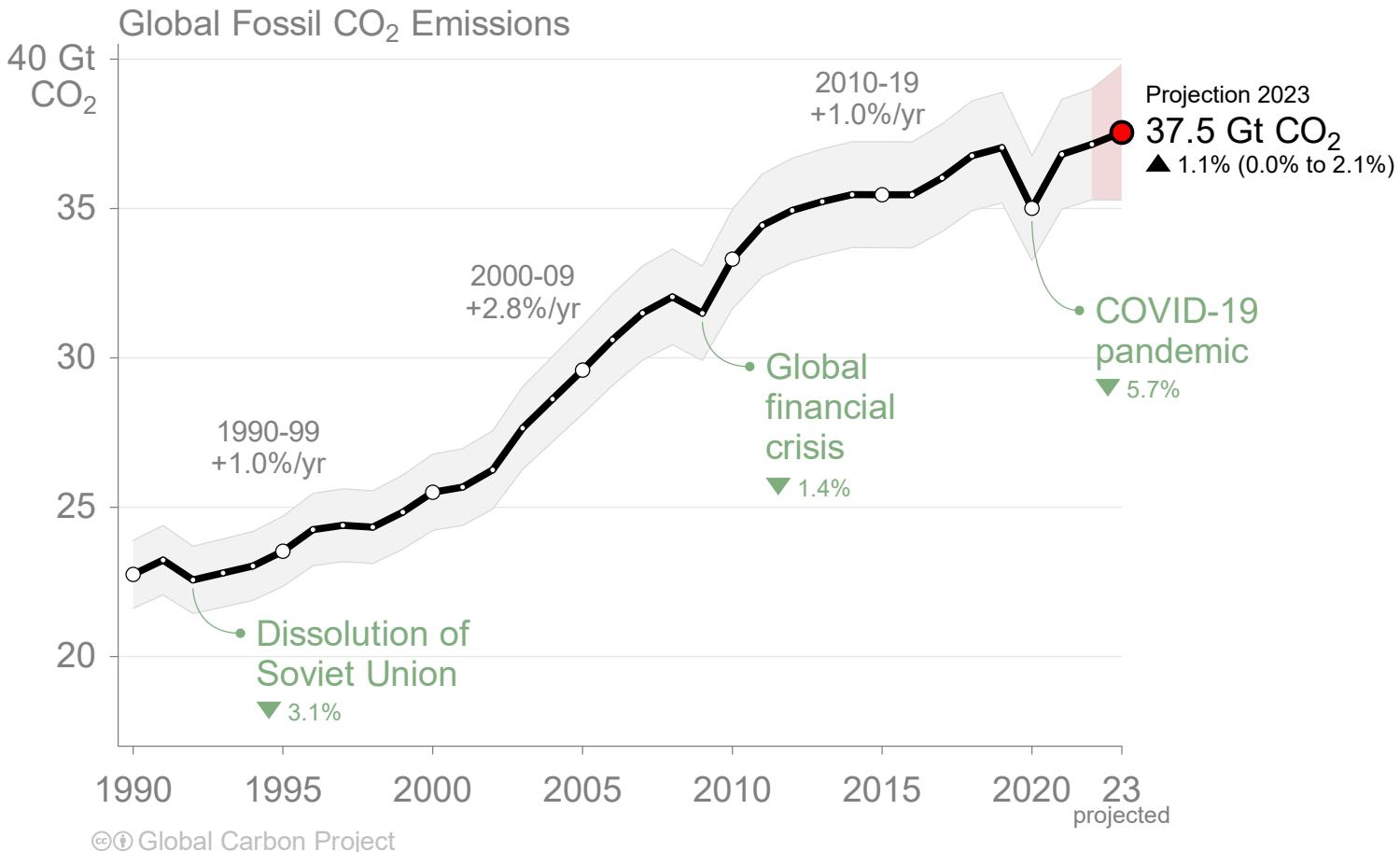
Source: [NOAA-GML](#); [Friedlingstein et al 2023](#); [Canadell et al 2021 \(IPCC AR6 WG1 Chapter 5\)](#); [Global Carbon Project 2023](#)

Key Highlights in 2023

Global Fossil CO₂ Emissions

Global fossil CO₂ emissions: 37.1 ± 2 GtCO₂ in 2022, 63% over 1990

● Projection for 2023: 37.5 ± 2 GtCO₂, 1.1% [0.0% to +2.1%] higher than 2022



Uncertainty is $\pm 5\%$ for one standard deviation
(IPCC "likely" range)

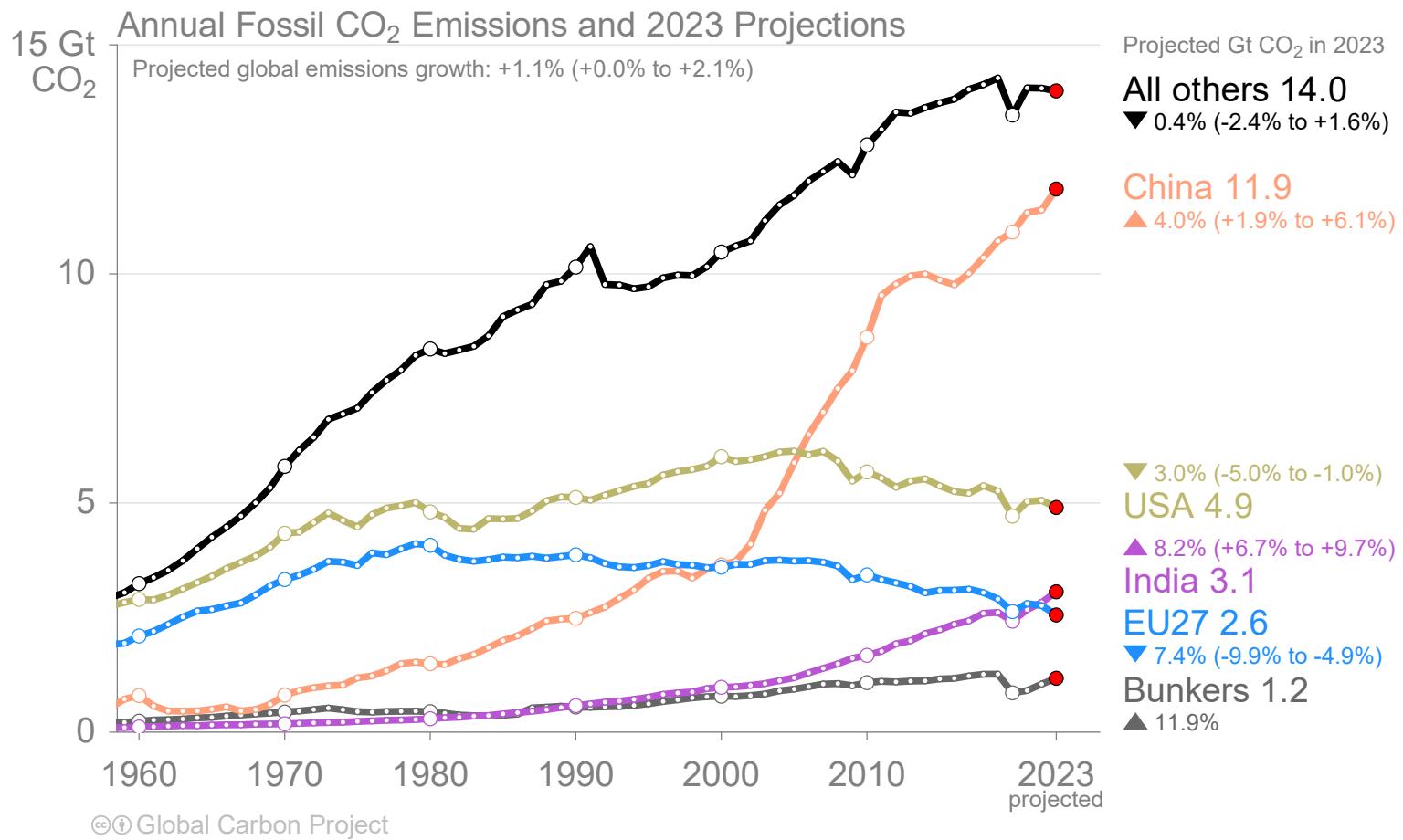
When including cement carbonation, the 2022 and 2023 estimates amount to 36.4 ± 2 GtCO₂ and 36.8 ± 2 GtCO₂ respectively

The 2023 projection is based on preliminary data and modelling.

Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Emissions Projections for 2023

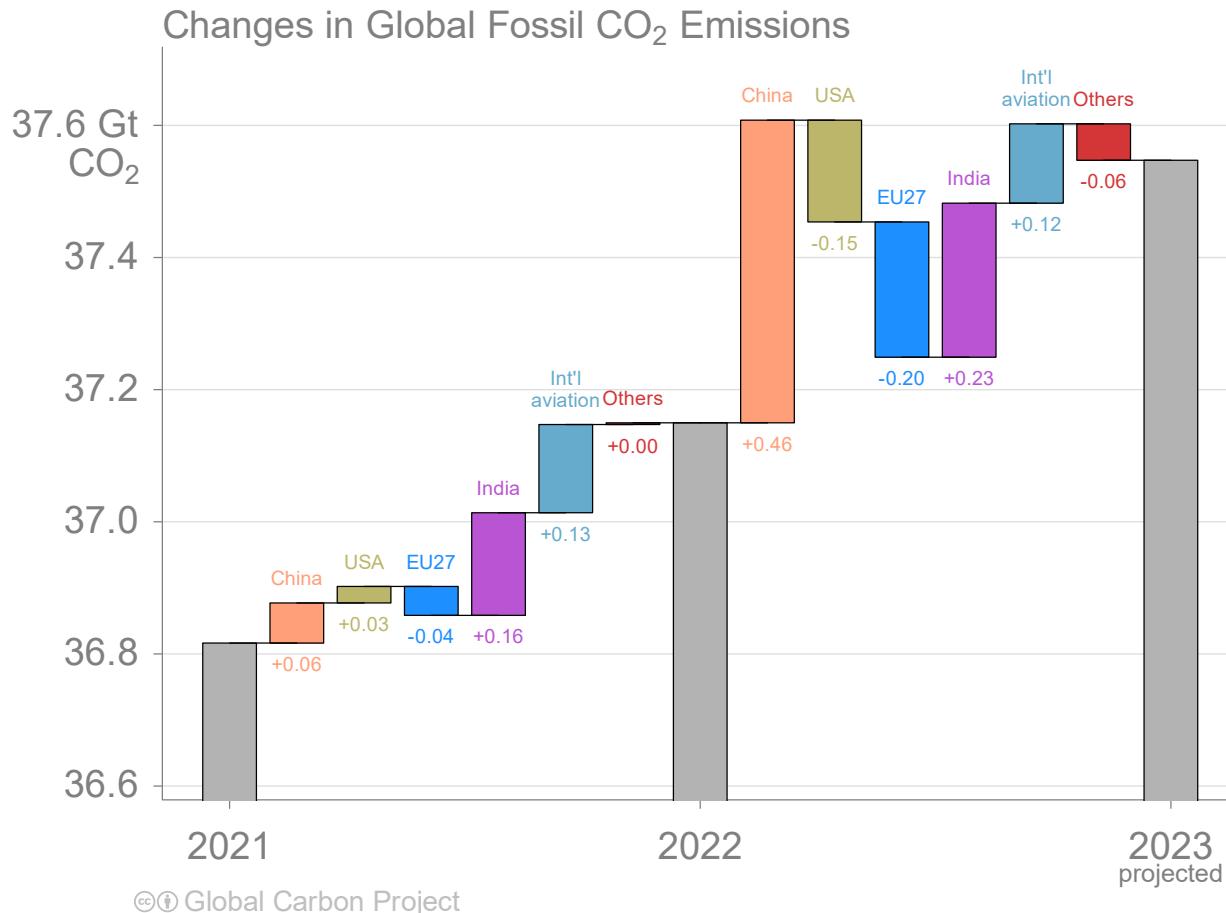
There are sharp contrasts between the projected emissions changes for the top emitters



The 2023 projections are based on preliminary data and modelling.
 'Bunkers' are fossil fuels (oil) used for shipping and aviation in international territory
 Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Fossil CO₂ emissions growth: 2021–2023

Emissions are expected to increase in China, India and international aviation in 2023, and decline in USA, the EU, and the combined rest of the world (Others)



The 2023 projections are based on preliminary data and modelling.
Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Summary of fossil CO₂ emissions in 2022 and 2023

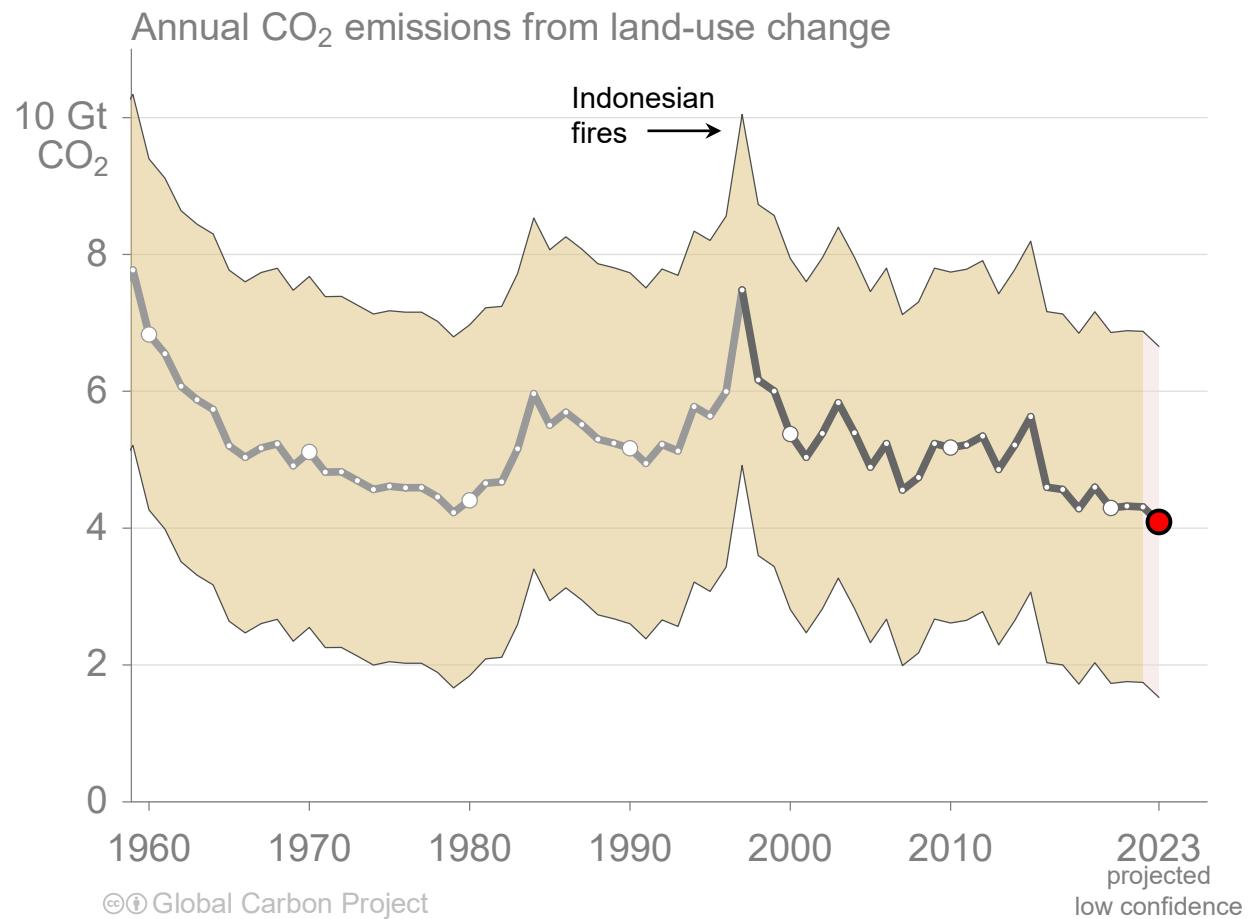
Region / Country	2022 emissions (billion tonnes/yr)	2022 growth (percent)	2023 projected emissions growth (percent)	2023 projected emissions (billion tonnes/yr)
China	11.4	+0.5%	+4.0%	11.9
USA	5.1	+0.5%	-3.0%	4.9
India	2.8	+5.8%	+8.2%	3.1
EU27	2.8	-1.6%	-7.4%	2.6
International bunkers*	1.0	+15.6%	+11.9%	1.2
All others	15.1	+0.0%	-0.4	14.0
World	37.1	+0.9%	+1.1%	37.5
World (incl. cement carbonation)	36.4	+0.9%	+1.1%	36.8

*Emissions from use of international aviation and maritime shipping bunker fuels are not usually included in national totals.
 Cement carbonation sink only included in global (World) estimate.

Source: [Friedlingstein et al 2023; Global Carbon Project 2023](#)

Land-use change emissions

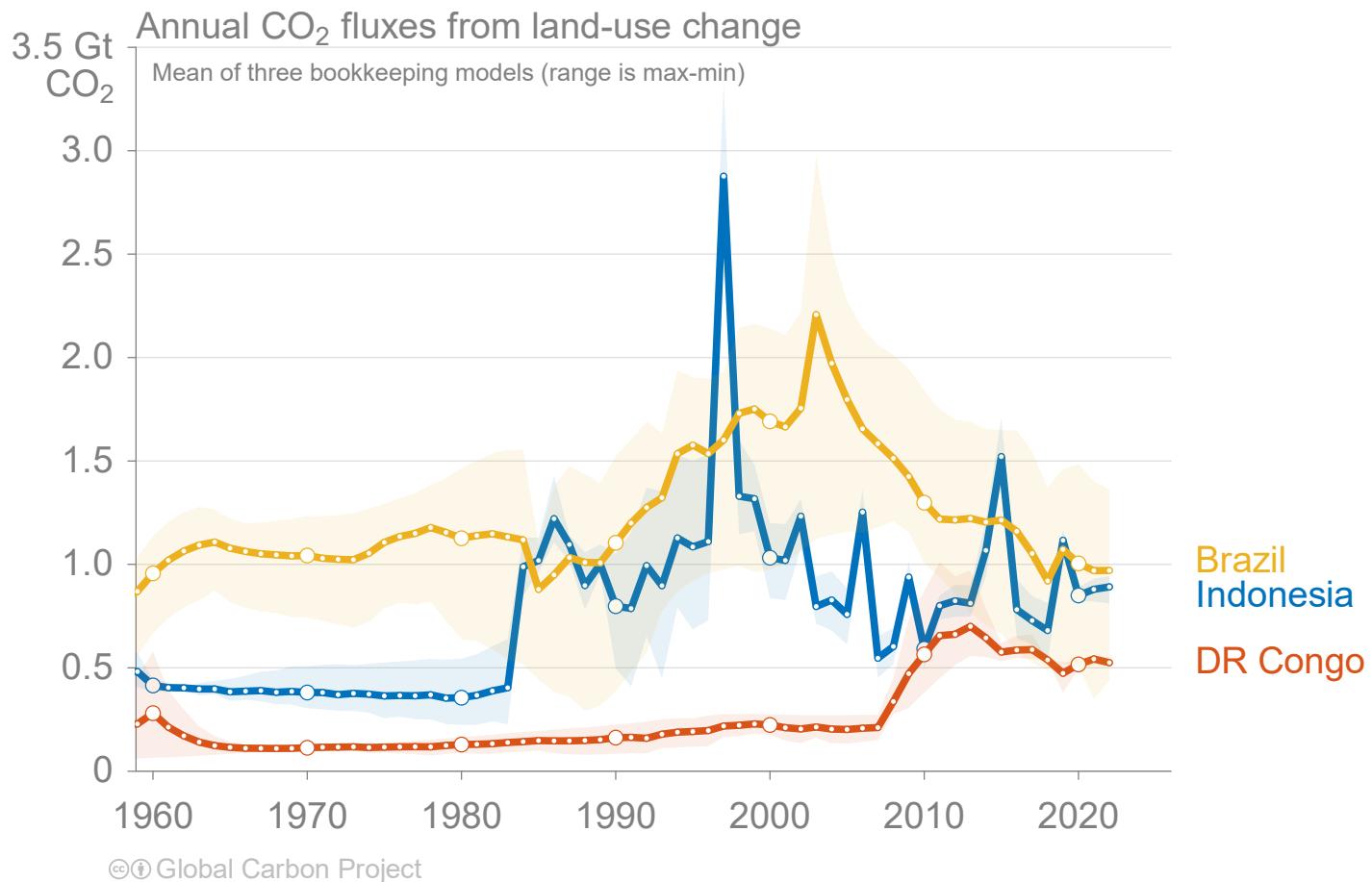
Land-use change emissions are 4.7 ± 2.6 GtCO₂ per year for 2013–2022, and show a negative trend in the last two decades, but estimates are still highly uncertain. • Projection for 2023: 4.1 ± 2.6 GtCO₂



Estimates from three bookkeeping models
Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Land-use change emissions

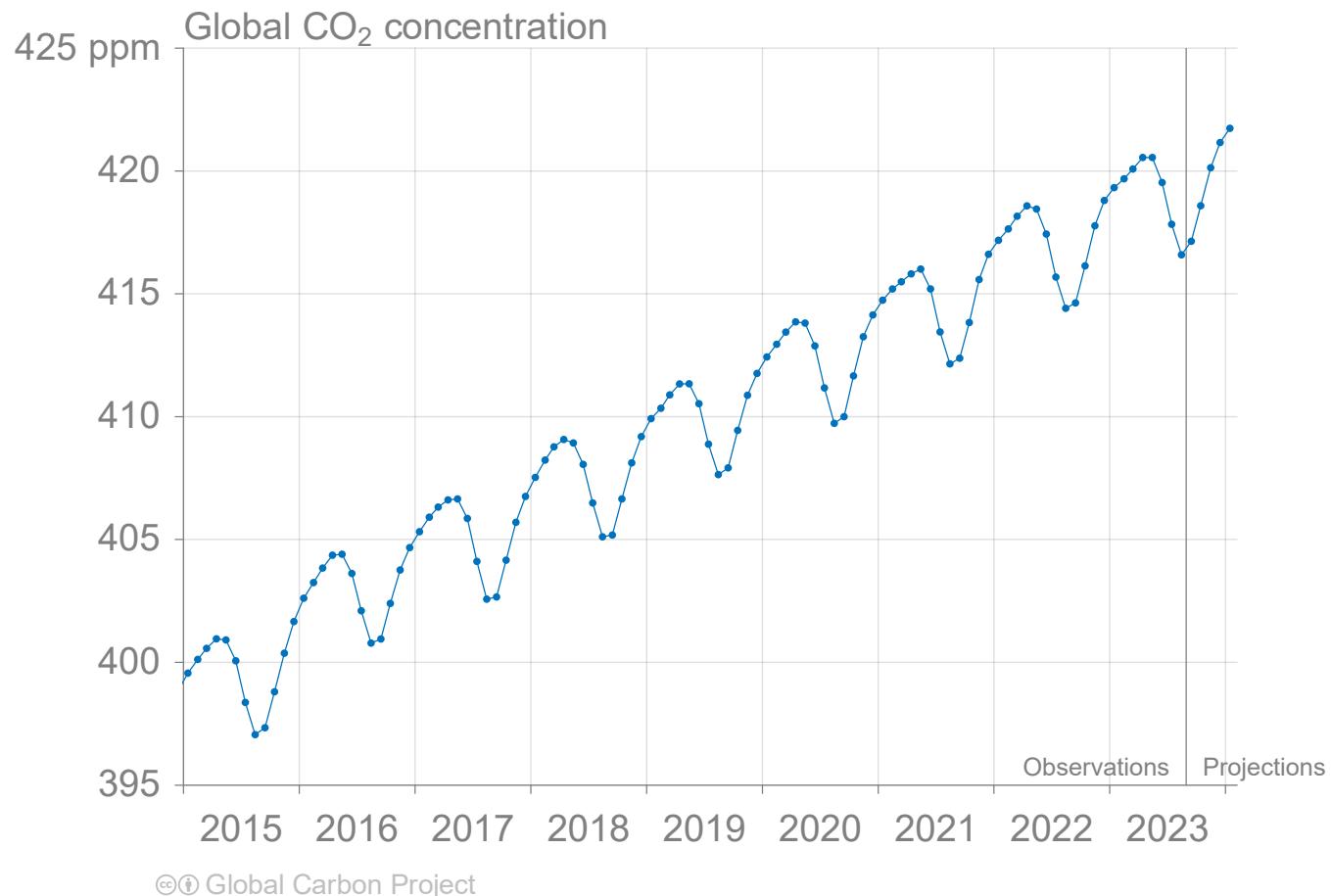
Combined land-use change emissions from Brazil, Indonesia, and the Democratic Republic of the Congo make up 55% of the global net land-use change emissions



Estimates from three bookkeeping models
Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Forecast of global atmospheric CO₂ concentration

The global atmospheric CO₂ concentration is forecast to average 419.3 parts per million (ppm) in 2023, increasing by 2.4 ppm.
A bigger increase is expected in 2024 when the current El Niño has full effect.

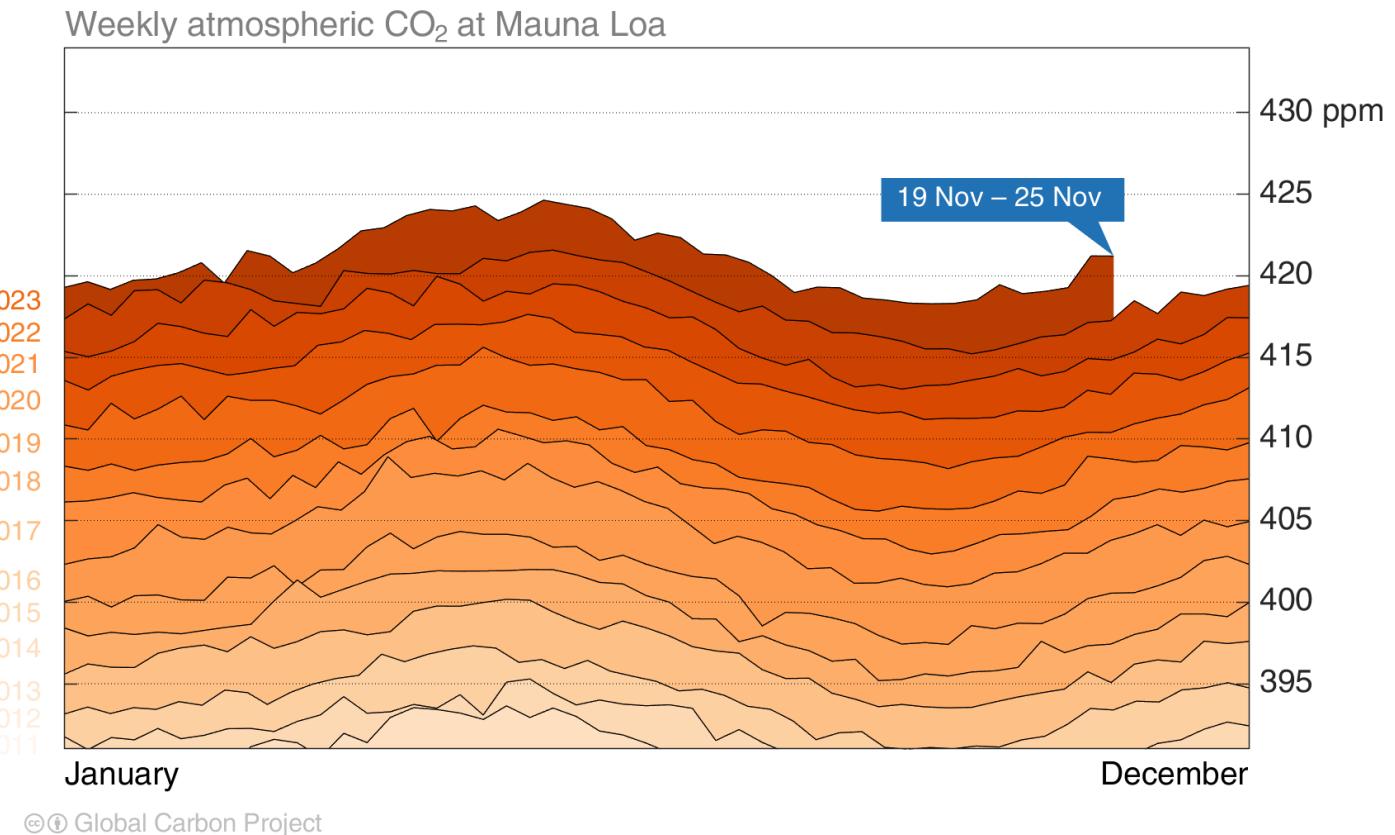


© Global Carbon Project

Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

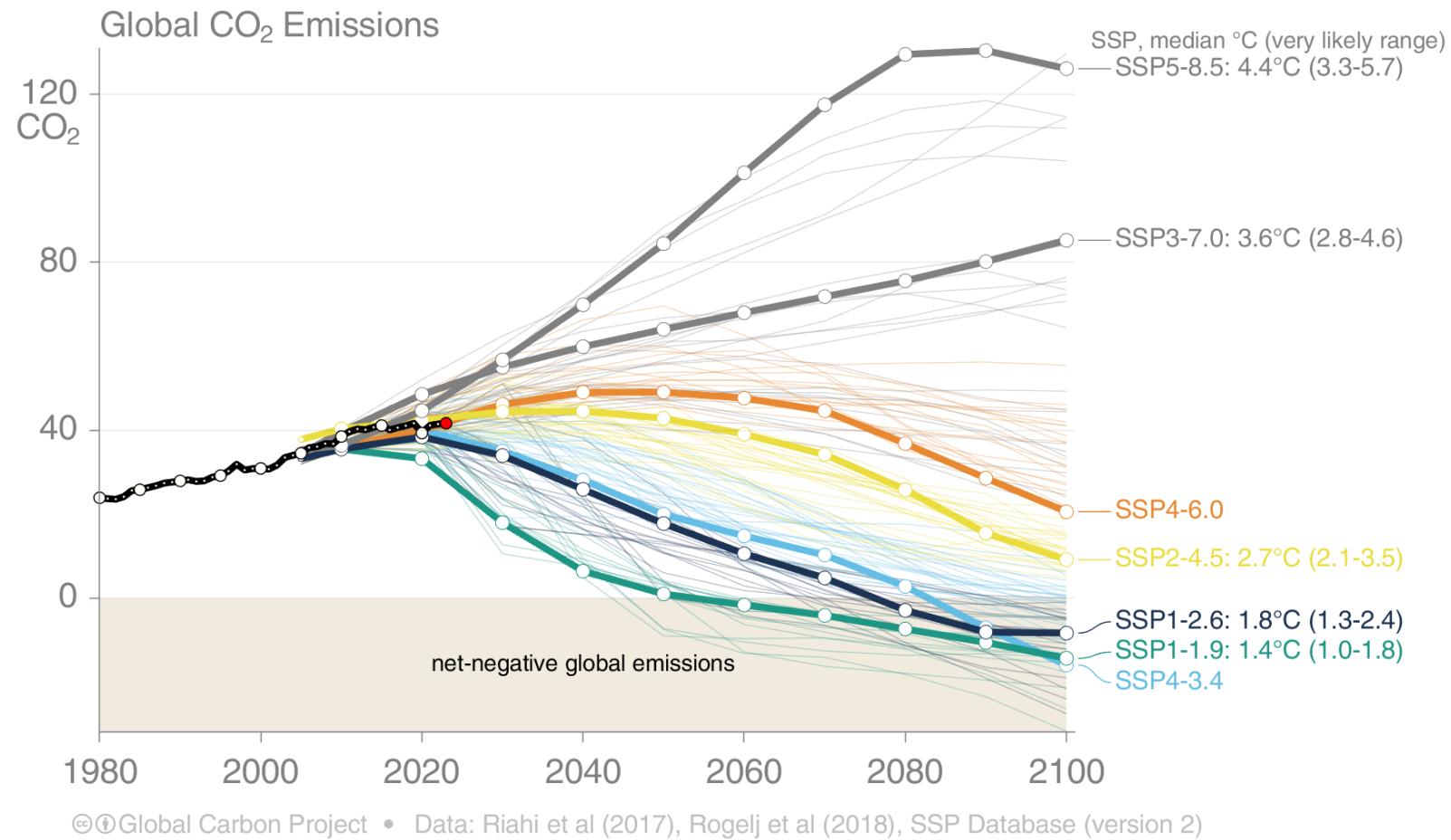
Mauna Loa atmospheric CO₂

Atmospheric CO₂ concentration has increased every single year, including in 2020 – despite the drop in fossil CO₂ emissions – because of continued emissions



Shared Socioeconomic Pathways (SSPs)

The SSPs were designed to span the range of potential outcomes. Total CO₂ emissions are currently tracking in the middle of the range. The temperature outcomes are based on assessed scenarios in IPCC AR6 Working Group I.



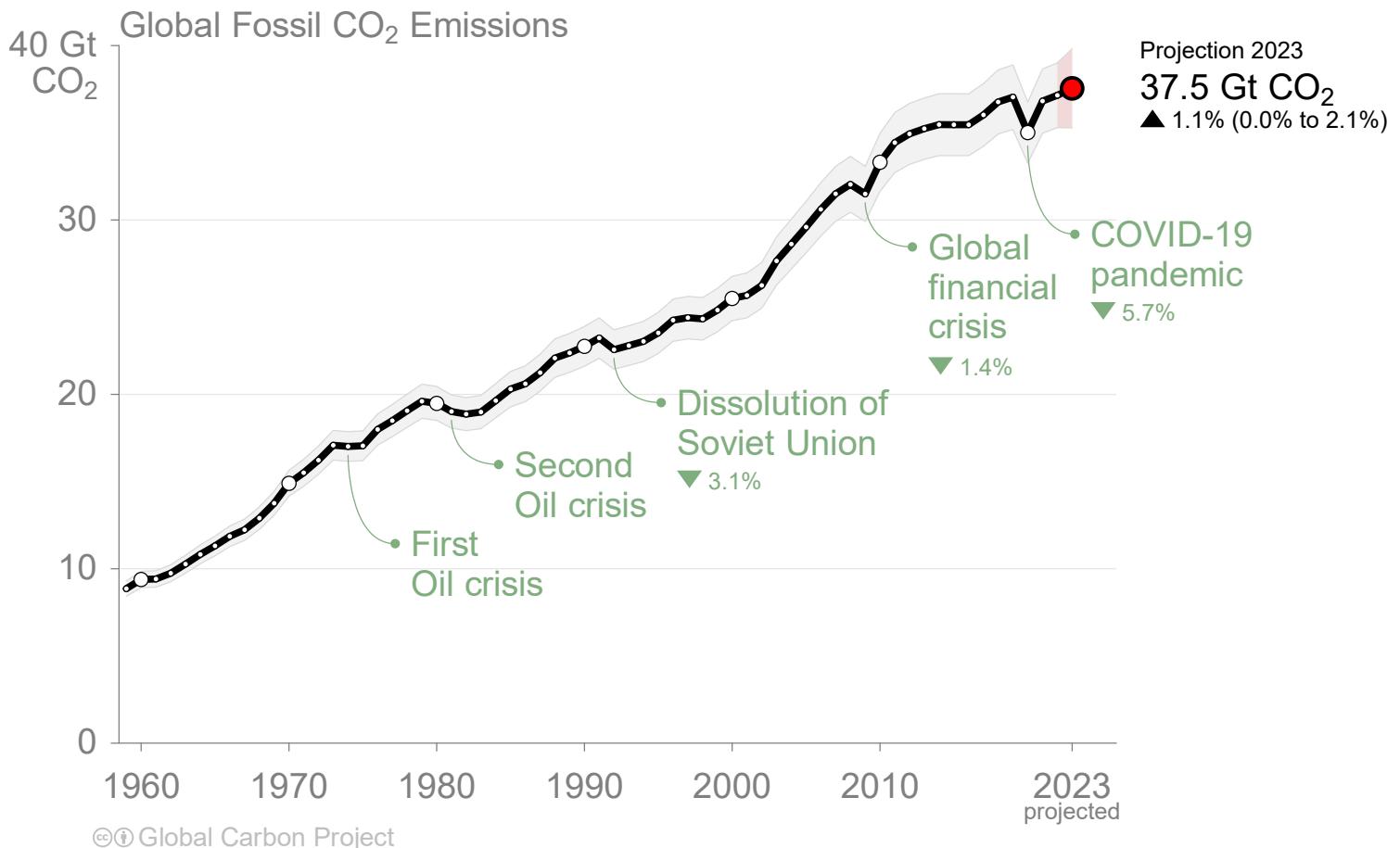
This set of quantified SSPs are based on the output of six Integrated Assessment Models (AIM/CGE, GCAM, IMAGE, MESSAGE, REMIND, WITCH).
Net emissions include those from land-use change and bioenergy with CCS.

Source: [Riahi et al. 2016](#); [Rogelj et al. 2018](#); [IIASA SSP Database](#); [IAMC](#); [Global Carbon Project 2023](#)

Global fossil CO₂ emissions

Global fossil CO₂ emissions

Global fossil CO₂ emissions have risen steadily over the last decades.
Emissions are set to grow again in 2023.



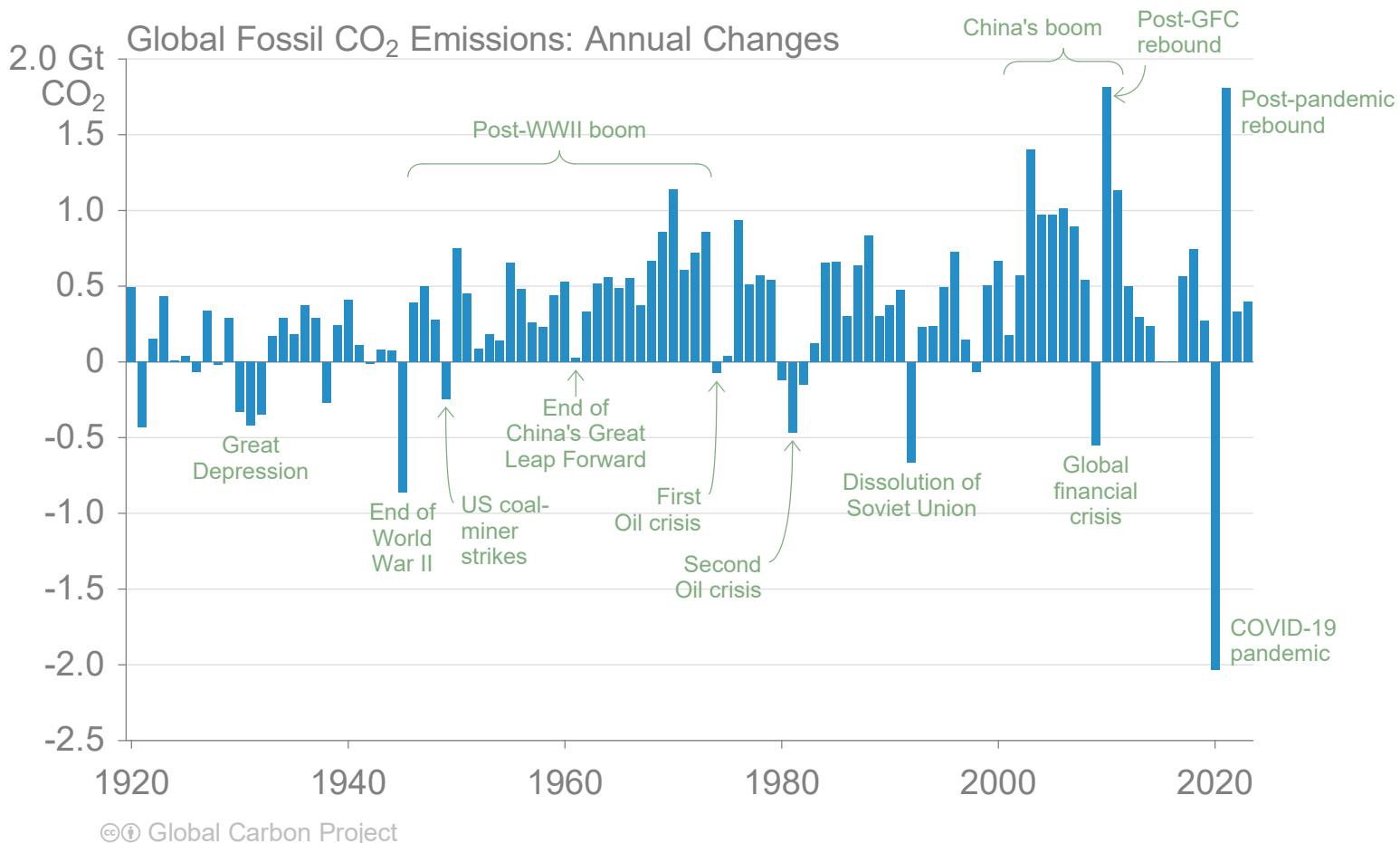
When including cement carbonation, the 2023 estimate is 36.8 ± 2 GtCO₂.

The 2023 projection is based on preliminary data and modelling.

Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Global fossil CO₂ emissions

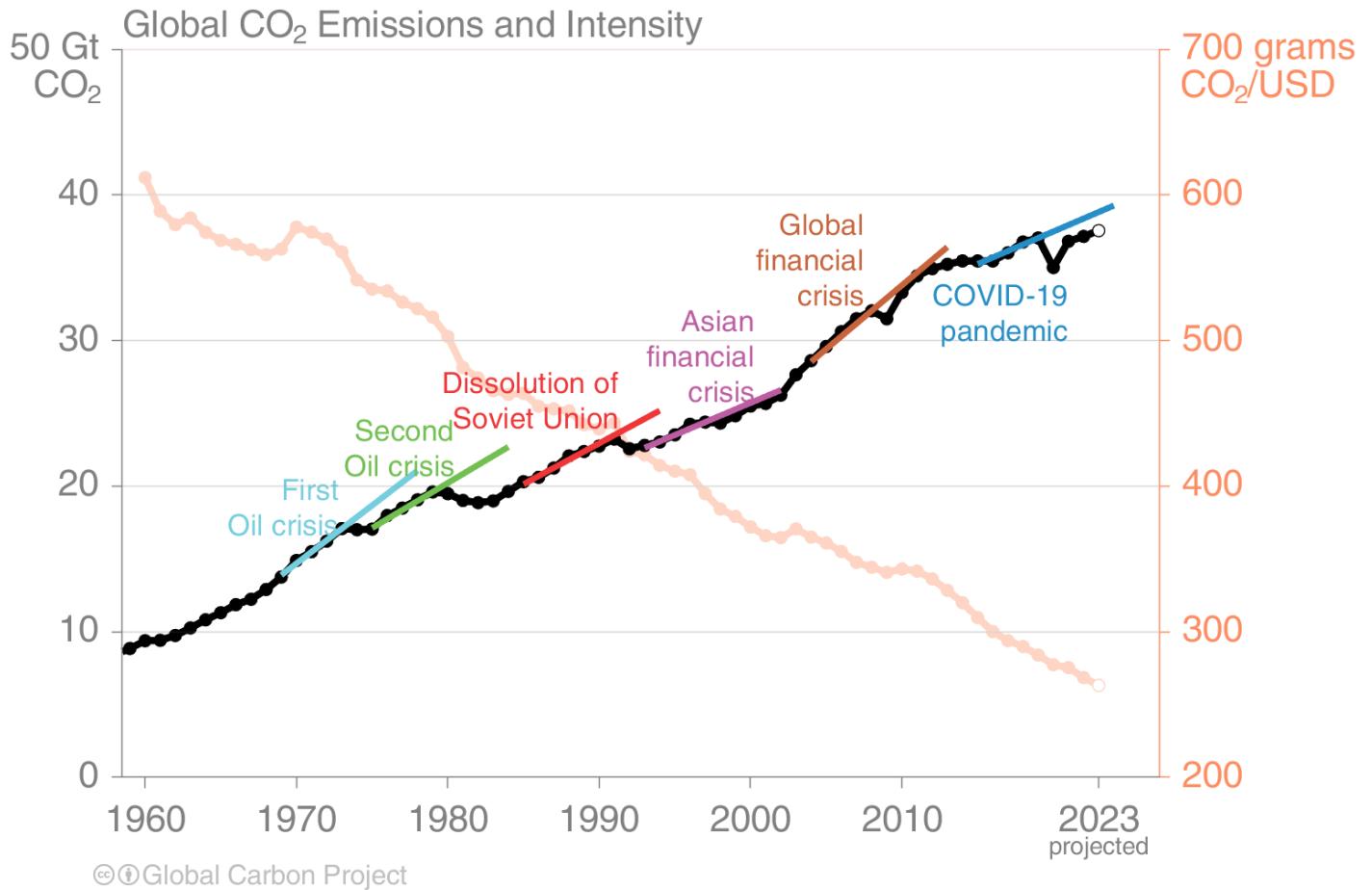
For the last 100 years, it has generally taken a crisis to drive global emissions reductions. To stabilise temperatures, intentional, planned, sustained global reductions must begin.



The 2023 projection is based on preliminary data and modelling.
Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Fossil CO₂ emission intensity

Global CO₂ emissions growth has generally resumed quickly from global crises.
 Emission intensity has steadily declined but not sufficiently to offset economic growth.

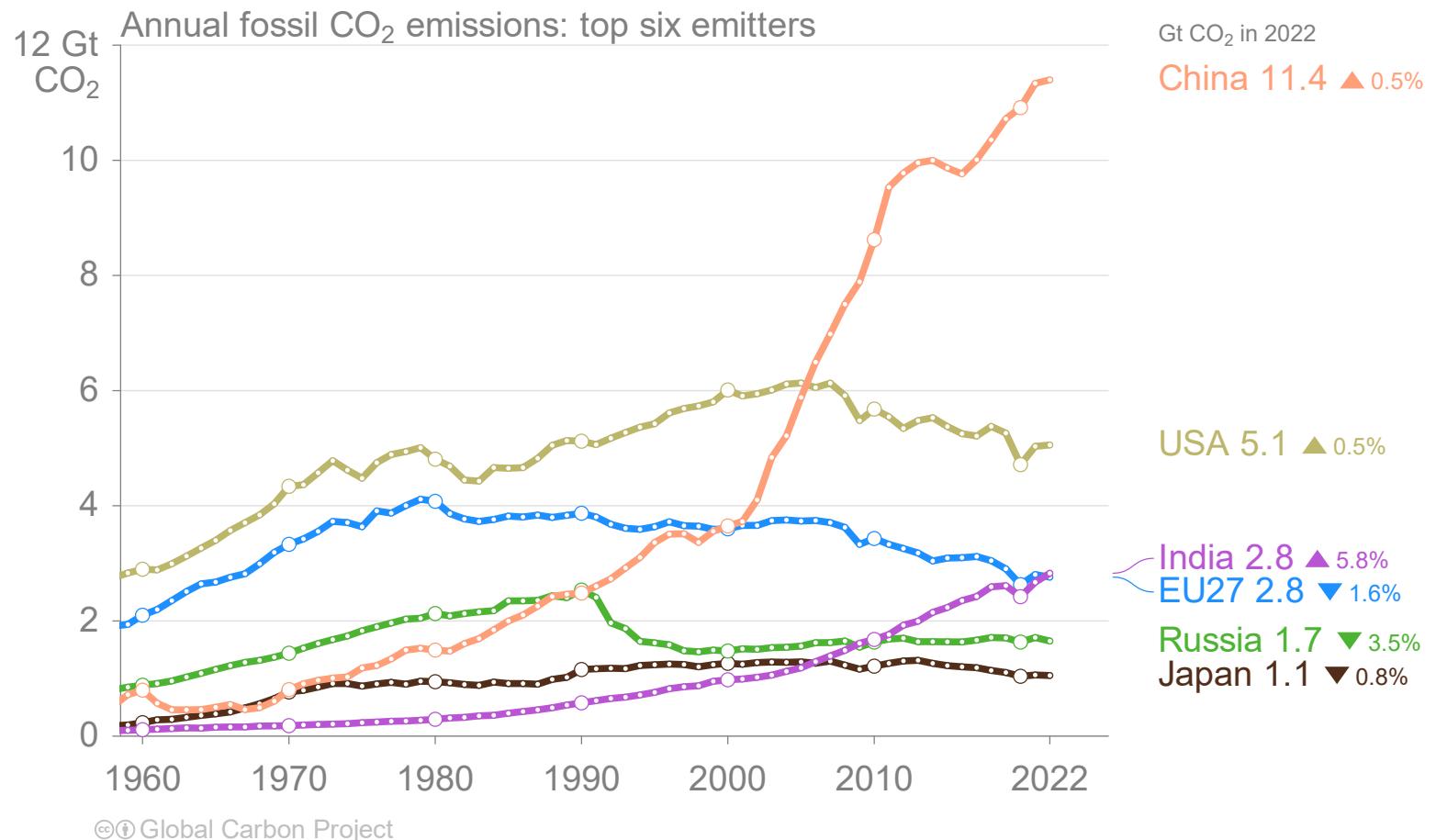


Each trend line is based on the five years before the crisis and extended to five years after.
 Economic activity is measured in purchasing power parity (PPP) terms in 2017 US dollars.
 Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Fossil CO₂ emissions by country

Top emitters: Fossil CO₂ emissions to 2022

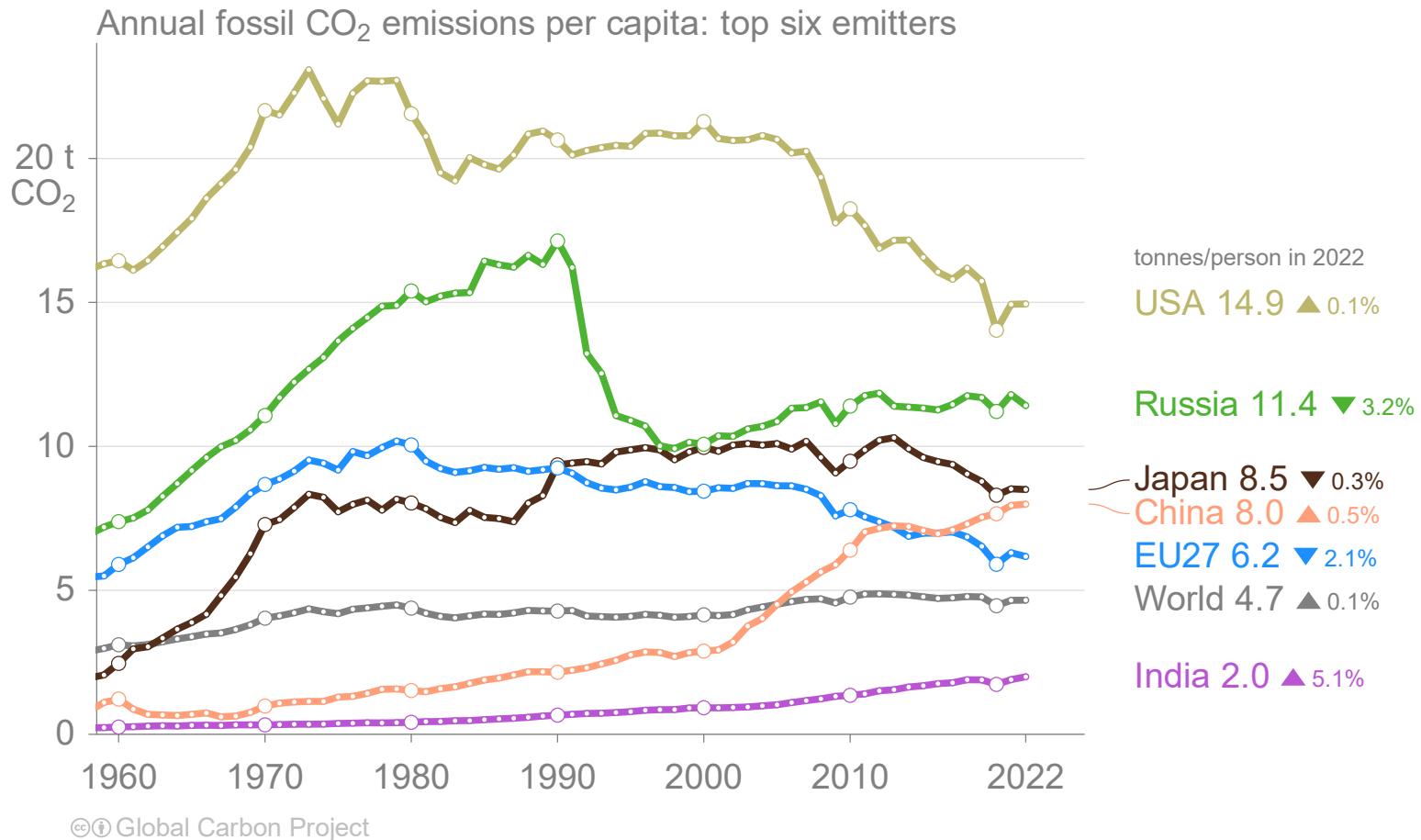
The top six emitters in 2022 covered 67% of global emissions
China 31%, United States 14%, India 8%, EU 7%, Russia 4%, and Japan 3%



International aviation and maritime shipping (bunker fuels) contributed 2.8% of global emissions in 2022.
Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Top emitters: Fossil CO₂ emissions per capita to 2022

Countries have a broad range of per capita emissions reflecting their national circumstances

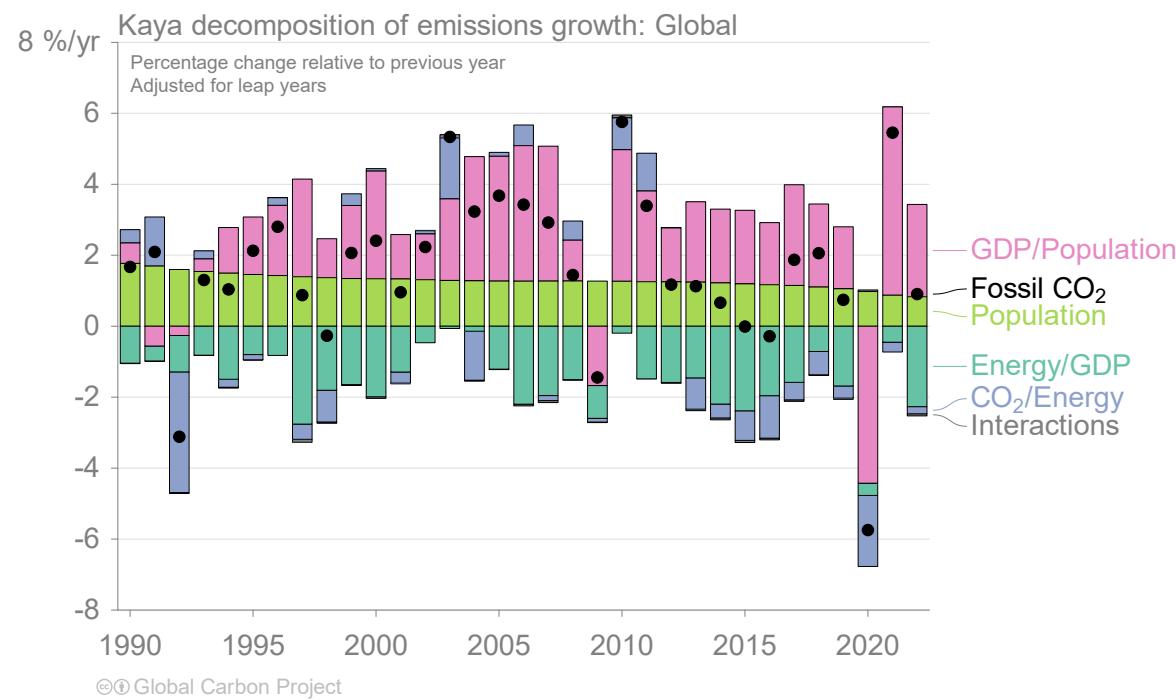


International aviation and maritime shipping (bunker fuels) contributed 2.8% of global emissions in 2022.

Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

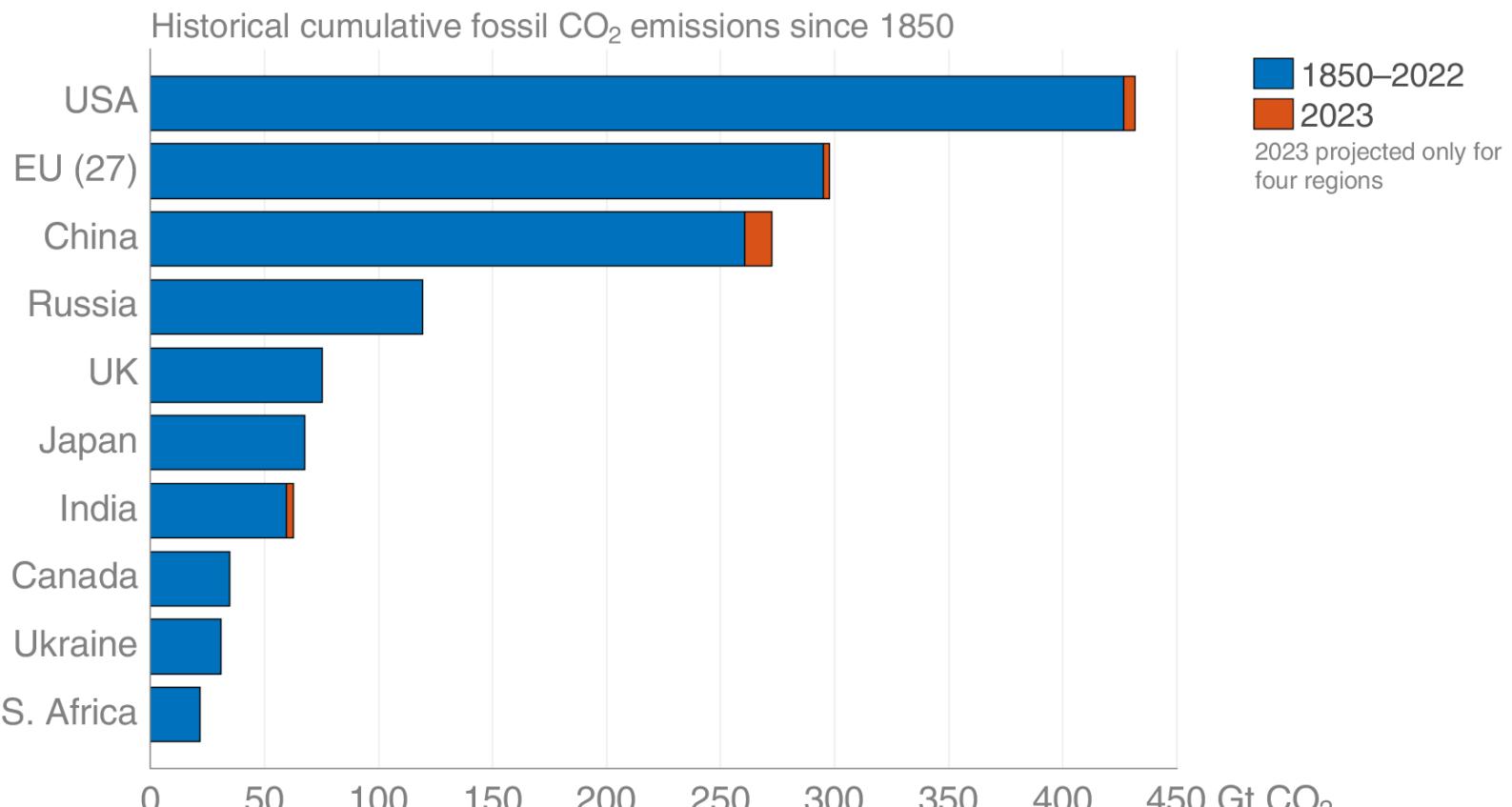
Fossil CO₂ emissions — Kaya decomposition

Globally, decarbonisation and declines in energy per GDP are largely responsible for the reduced growth rate in emissions over the last decade. 2020 was a clear outlier with a sharp decline in GDP.



Historical cumulative fossil CO₂ emissions

The USA and EU have the highest accumulated fossil CO₂ emissions since 1850, but China is a close third.



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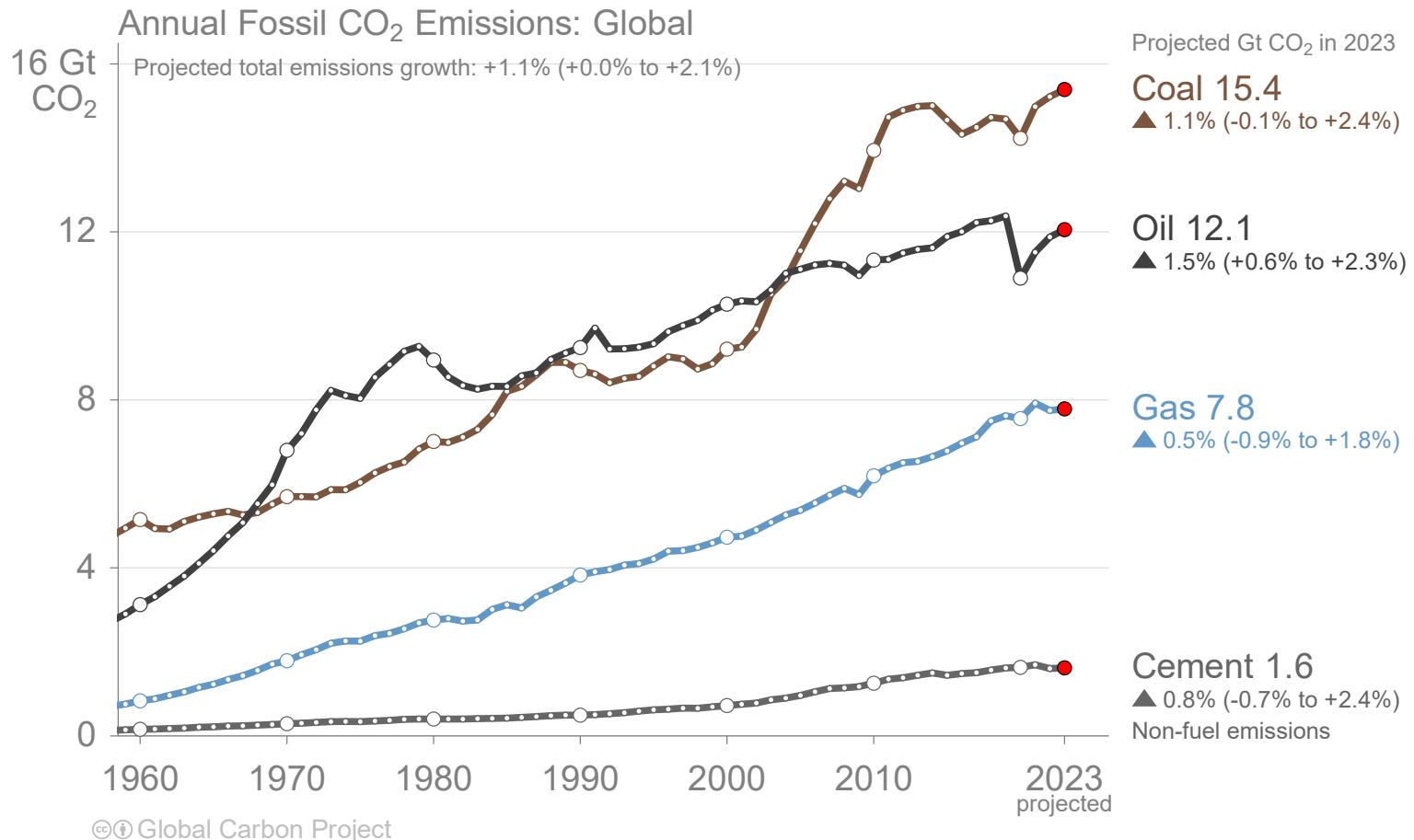
Calculated using territorial emissions.

Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Fossil CO₂ emissions by source

Fossil CO₂ emissions by source

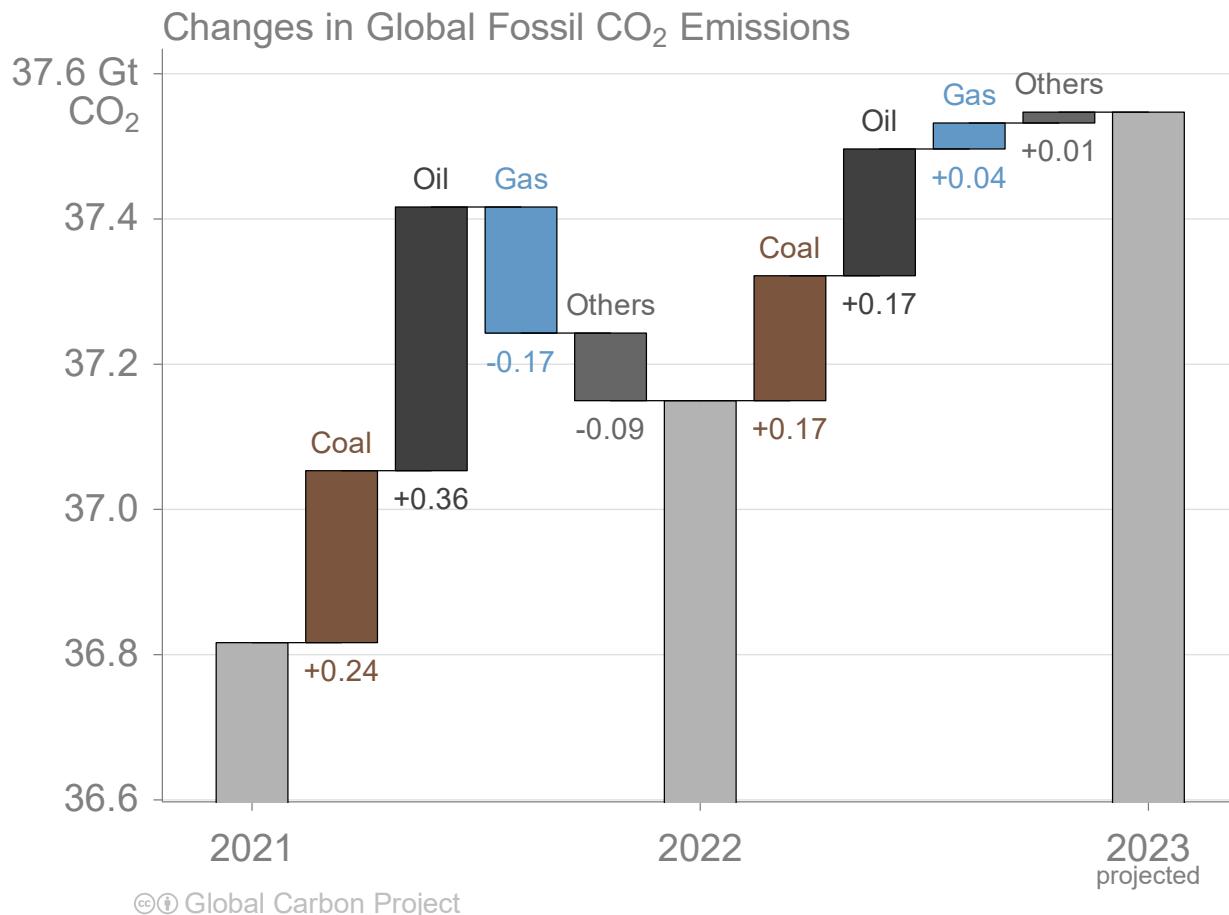
Share of global fossil CO₂ emissions in 2023: coal (41%), oil (32%), gas (21%), cement (4%), flaring and others (2%, not shown)



The 2023 projection is based on preliminary data and modelling.
Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

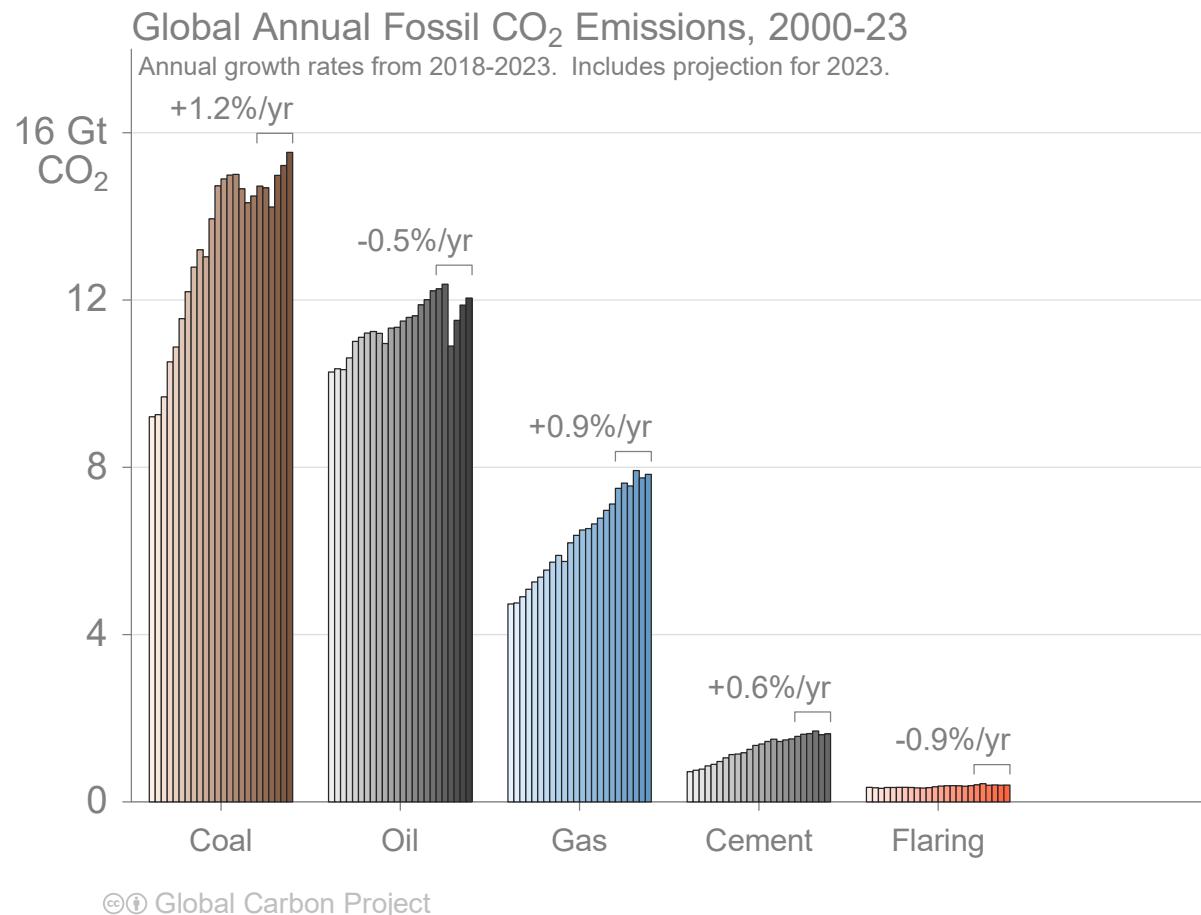
Fossil CO₂ emissions growth: 2021–2023

Global emissions from oil continued to rebound in both 2022 and 2023 with recovery of aviation. In 2022 natural gas declined because of supply constraints but returns to growth in 2023. Coal continues to climb.



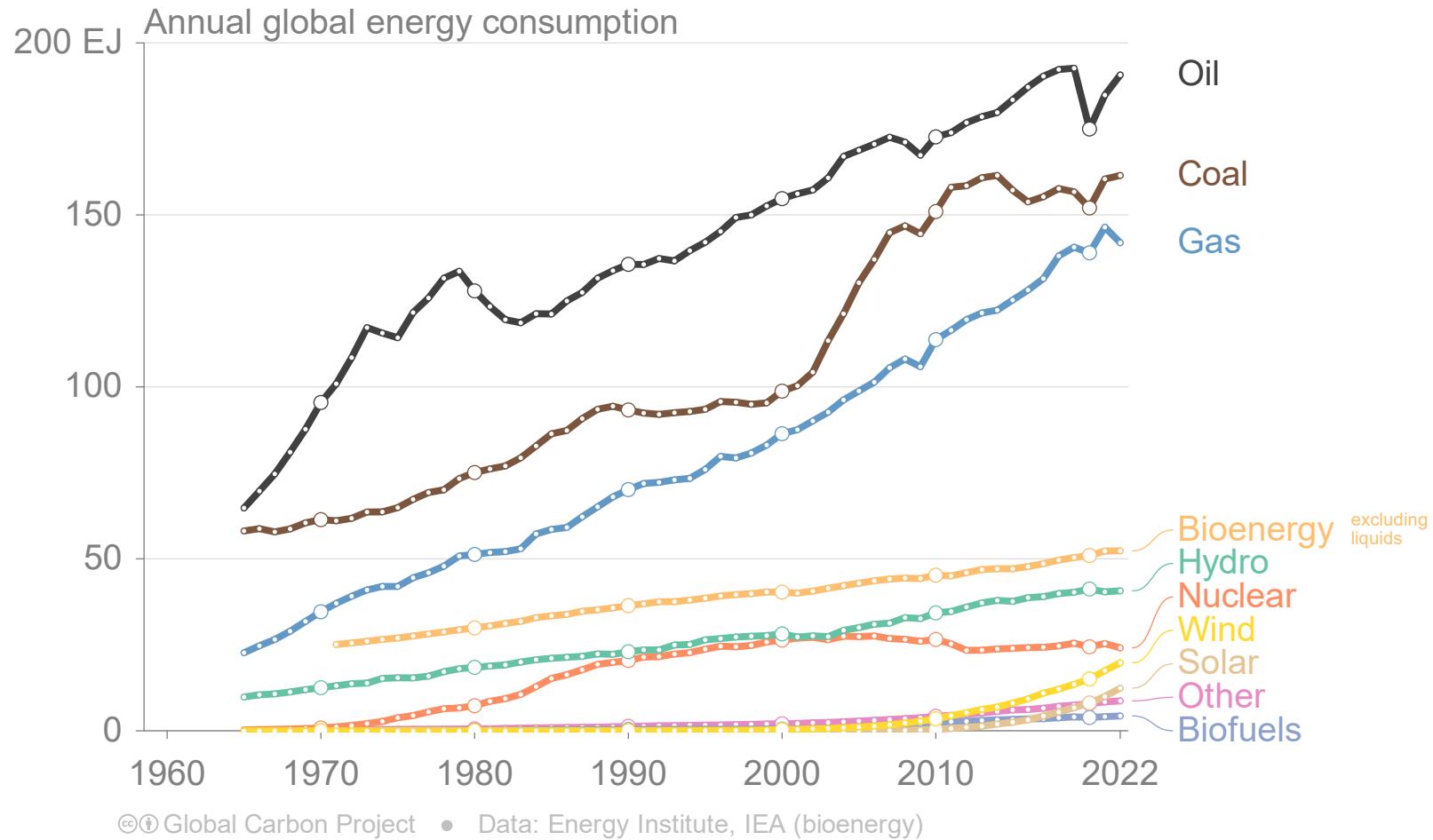
Fossil CO₂ emissions by source

Emissions by category from 2000 to 2023, with growth rates indicated for the more recent period of 2018 to 2023
Coal use has returned to growth, and both coal and oil declined sharply in the pandemic year 2020



Energy use by source

Consumption of natural gas declined in 2022, but oil recovered most of its pandemic-period losses. Renewable energy continued to grow, but needs to grow even faster to replace fossil energy consumption.



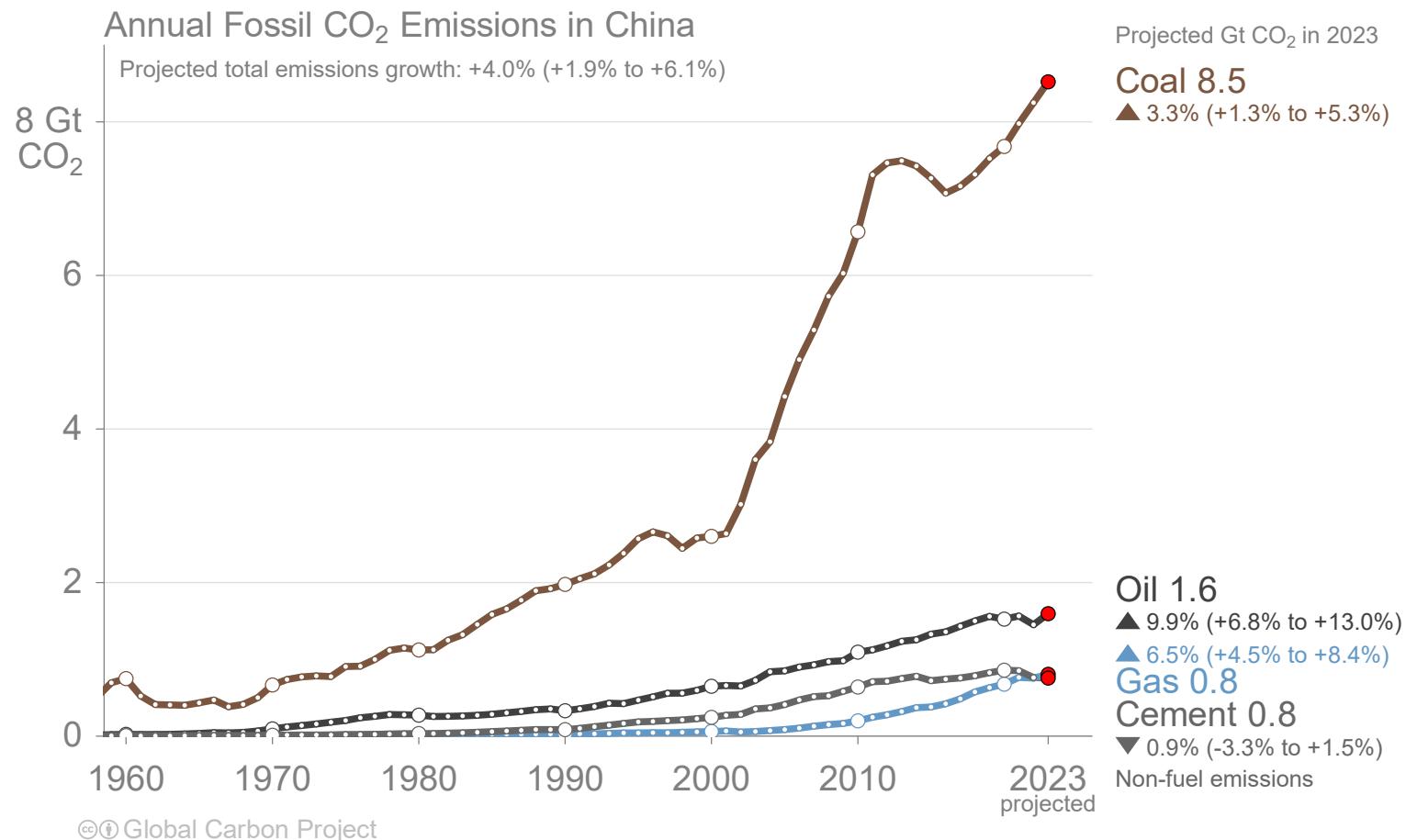
This figure shows “primary energy” using the substitution method
 (non-fossil sources are scaled up by an assumed fossil efficiency of approximately 0.38)

Source: [Energy Institute 2023](#); [Global Carbon Project 2023](#)

Fossil CO₂ emission by source for top emitters

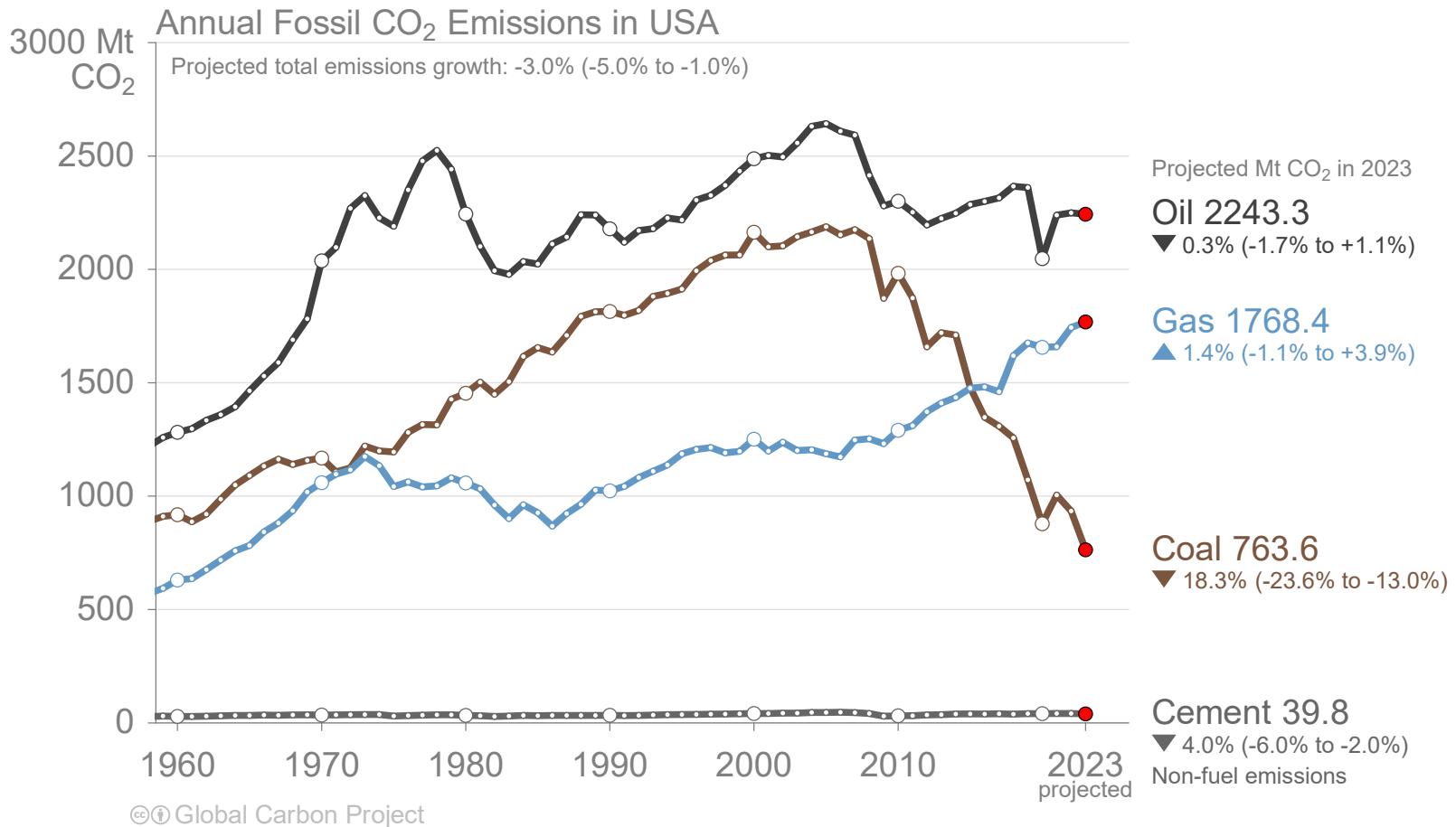
Fossil CO₂ emissions in China

China's coal consumption continued to grow strongly in 2023, while emissions from oil recovered their losses from 2022's COVID-19 lockdowns



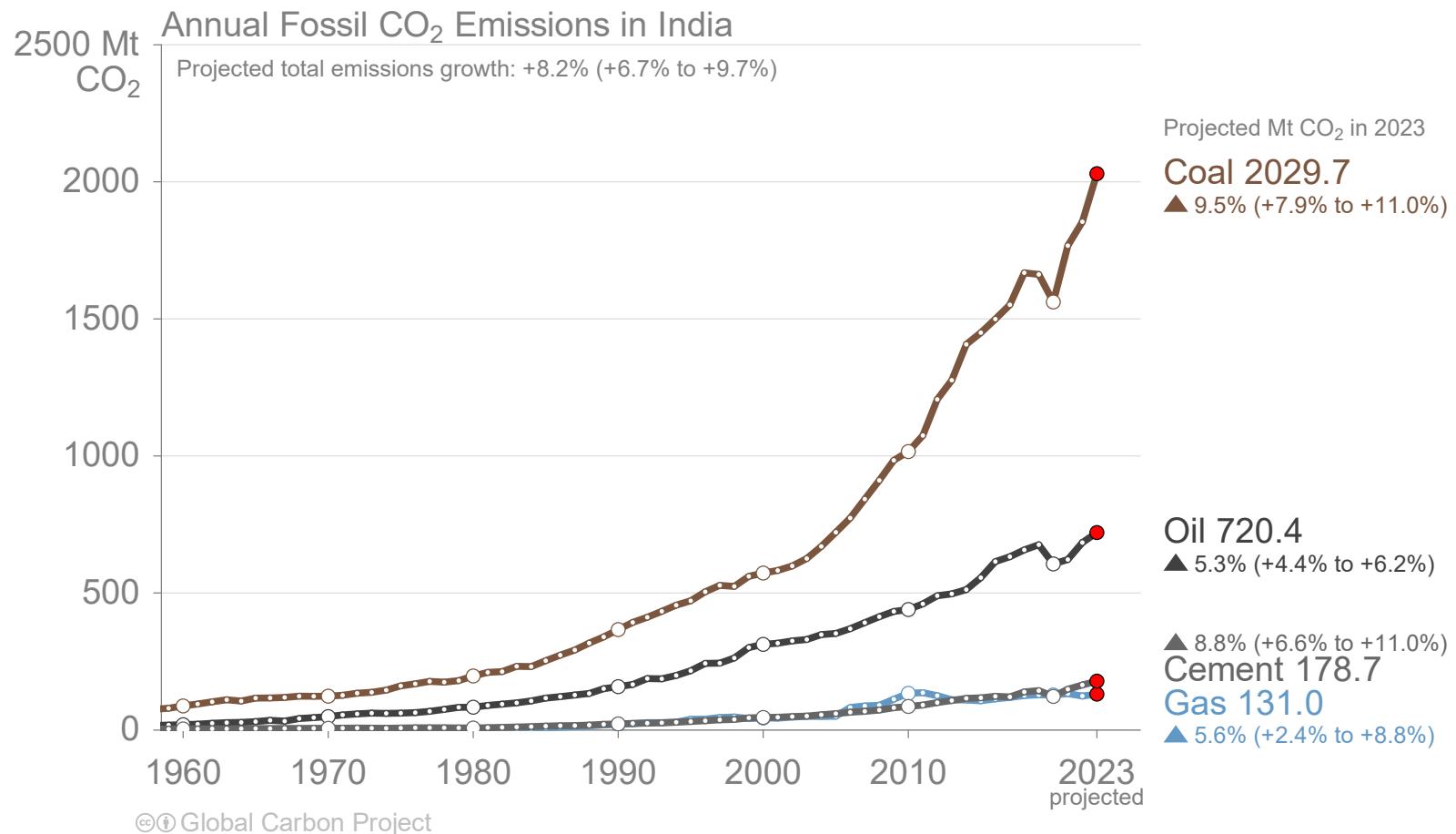
Fossil CO₂ emissions in USA

The USA's emissions from coal are expected to drop again in 2023, to their lowest level since 1903, as the transition to natural gas continues. Emissions from oil are still below 2019's level.



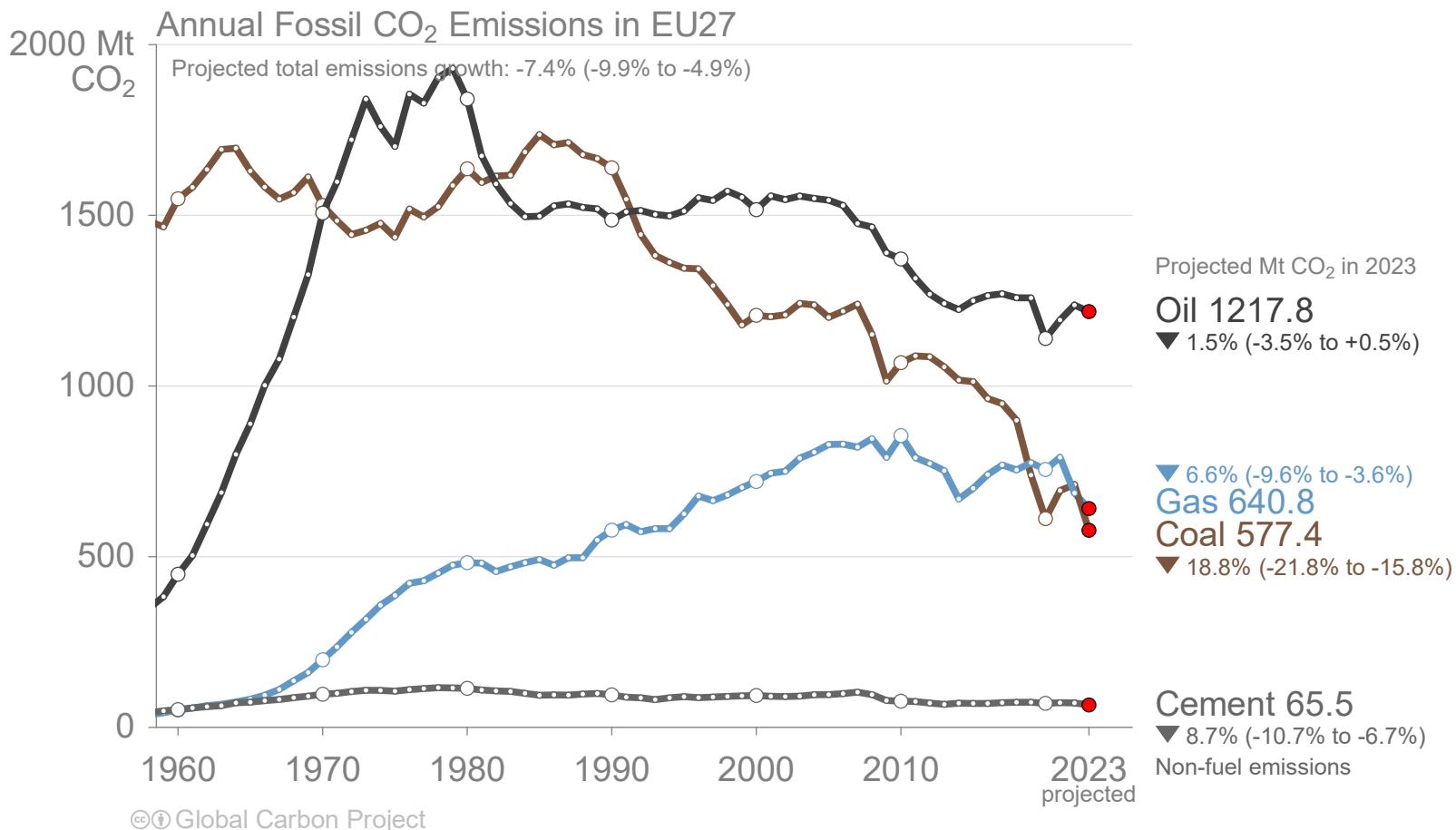
Fossil CO₂ emissions in India

India's emissions continue to grow sharply in 2023. Increases in solar and wind capacity were far from sufficient to meet a large increase in power demand as the economy grows strongly.



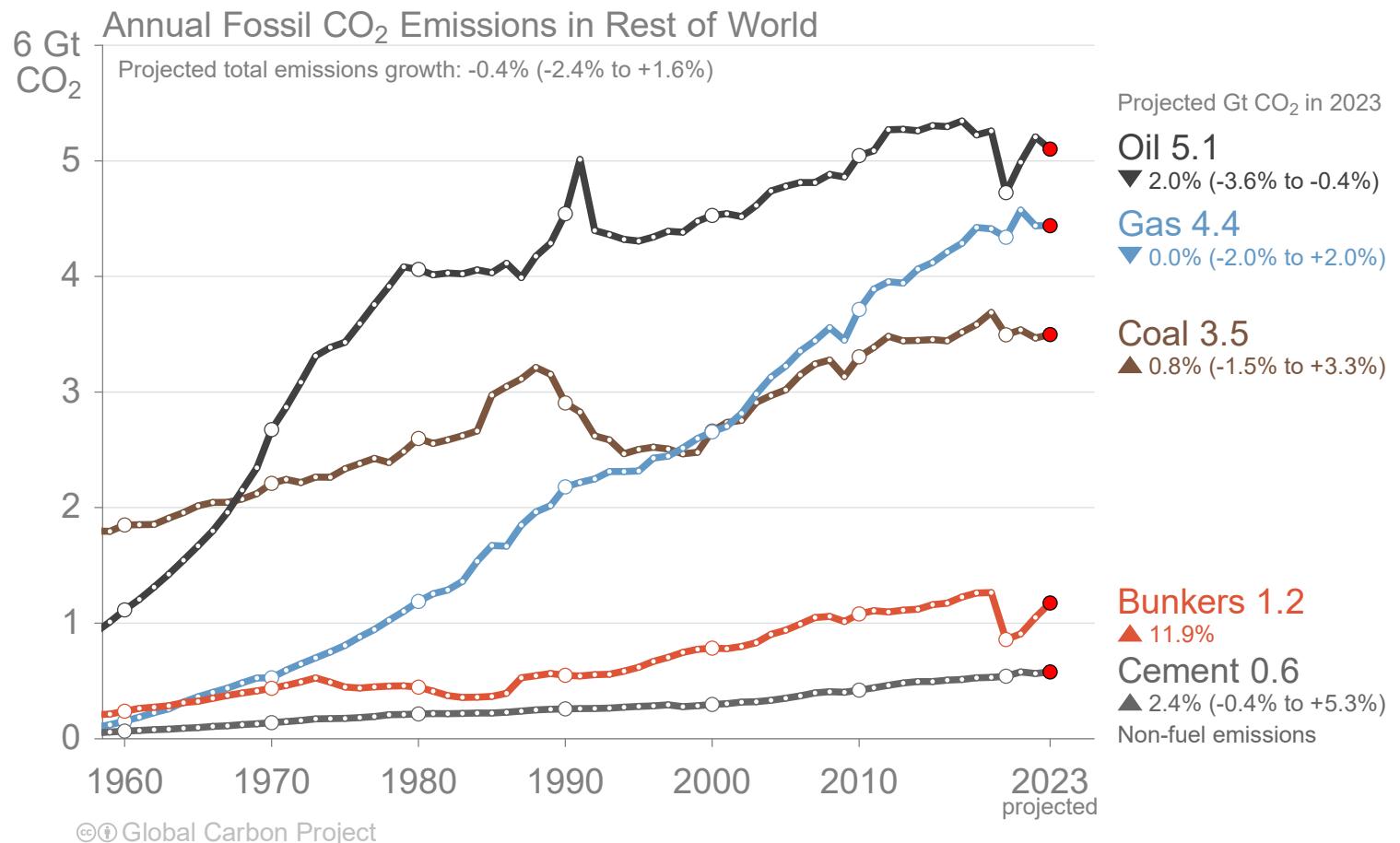
Fossil CO₂ emissions in the European Union

The EU's emissions from all three fossil fuels are expected to have declined in 2023, resulting from high prices and other economic headwinds on top of existing trends.



Fossil CO₂ emissions in Rest of World

In the Rest of the World, emissions from coal grow slightly while natural gas is flat.
 Oil in international aviation grew strongly again, but total oil in all other countries declined.



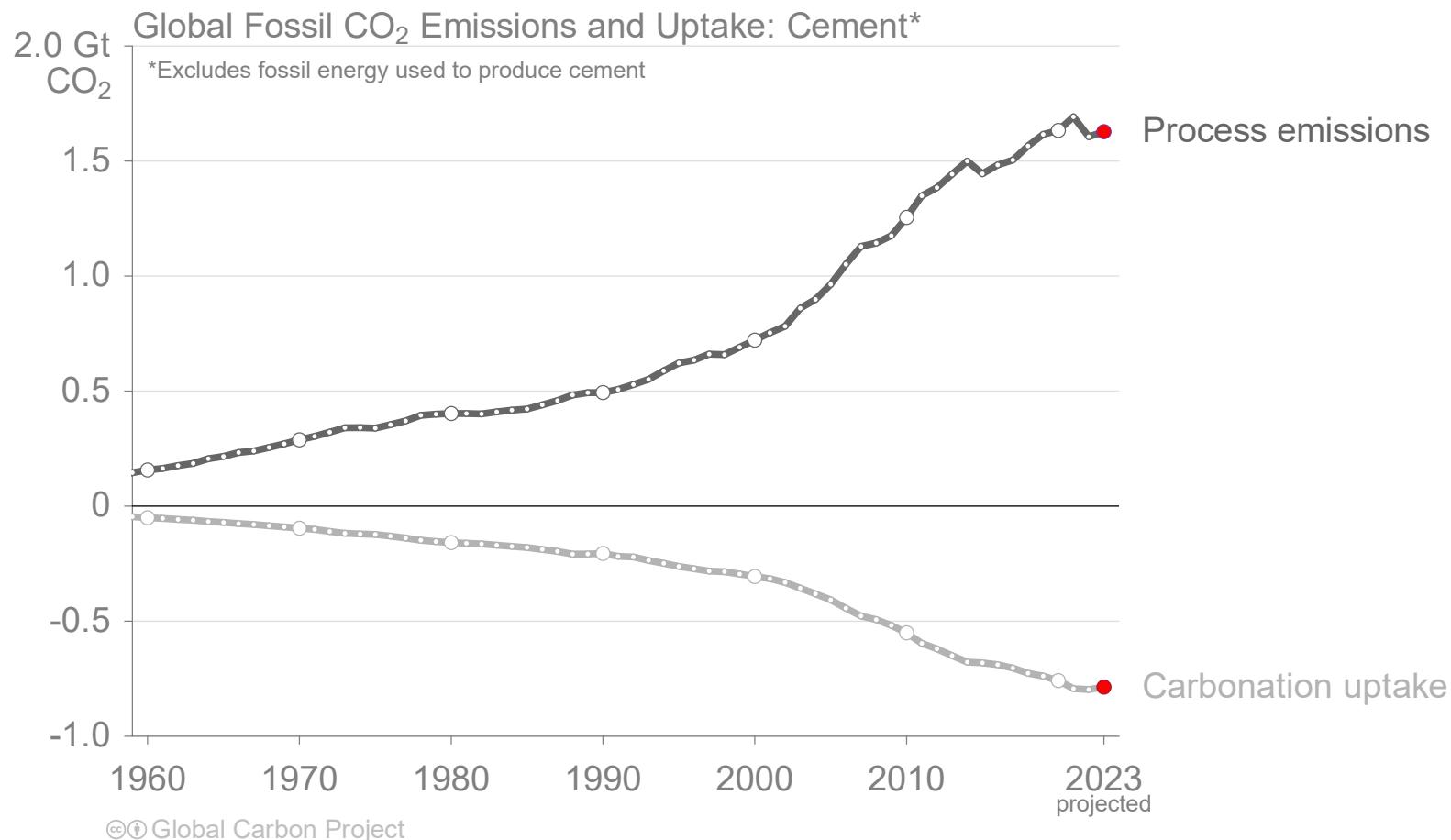
The Rest of the World is the global total less China, US, EU, and India.

Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Cement carbonation sink

Cement carbonation sink

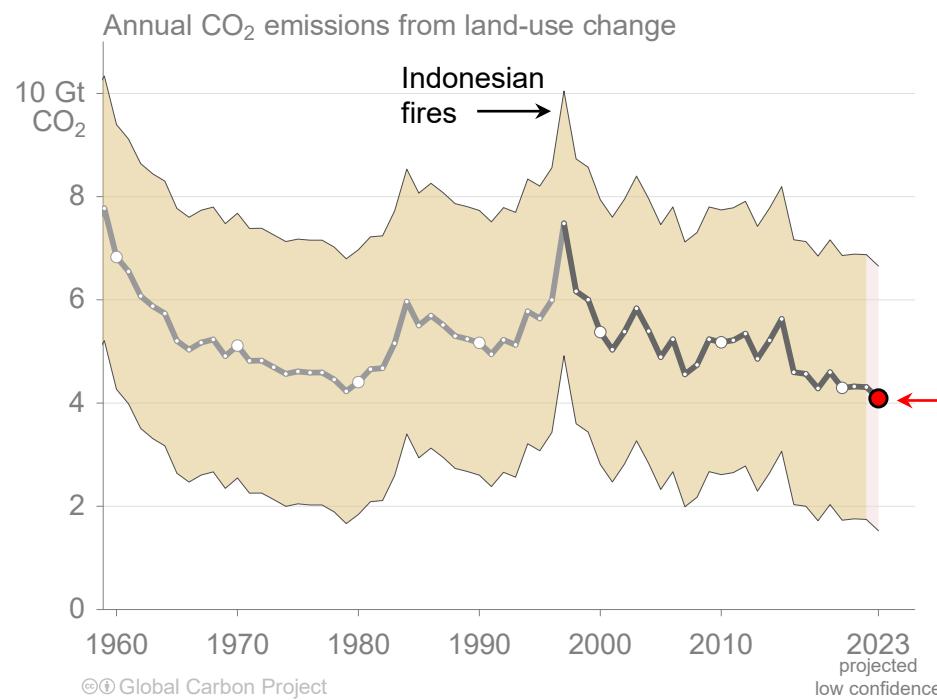
The production of cement results in ‘process’ emissions of CO₂ from the chemical decomposition of carbonates.
During its lifetime, cement re-absorbs some CO₂ from the atmosphere.



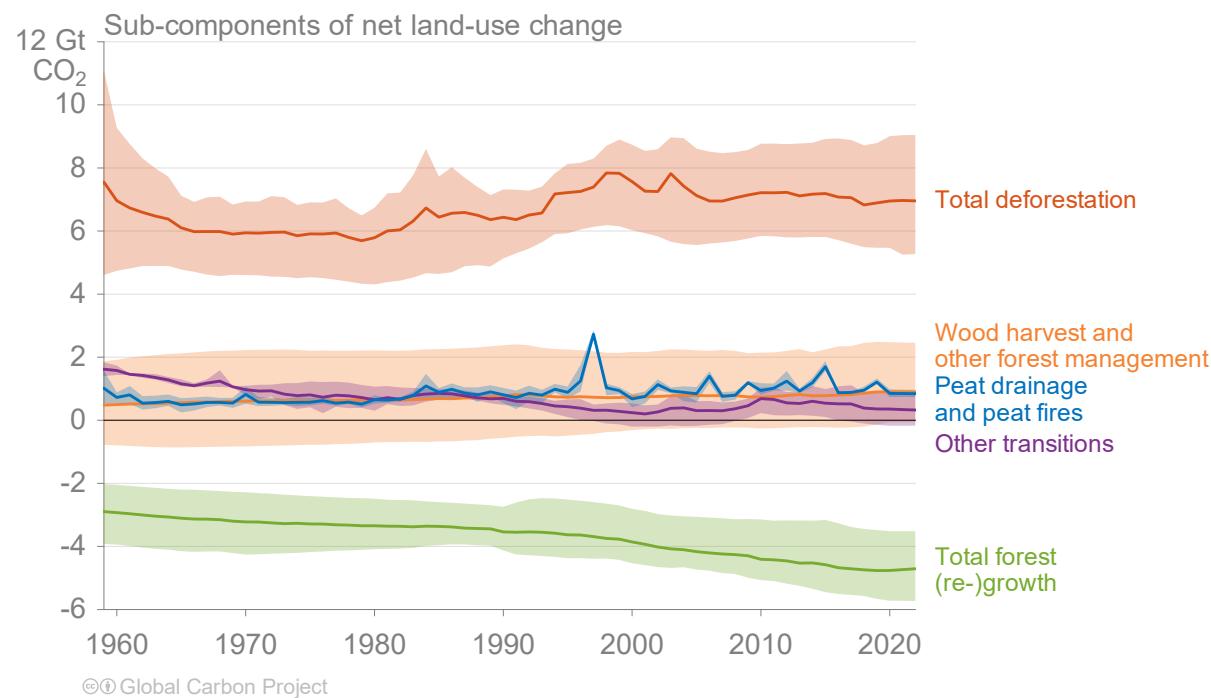
Land-use change emissions

Land-use change emissions

Land-use change emissions are $4.7 \pm 2.6 \text{ GtCO}_2$ per year for 2013–2022, and show a negative trend in the last two decades, but estimates are still highly uncertain.



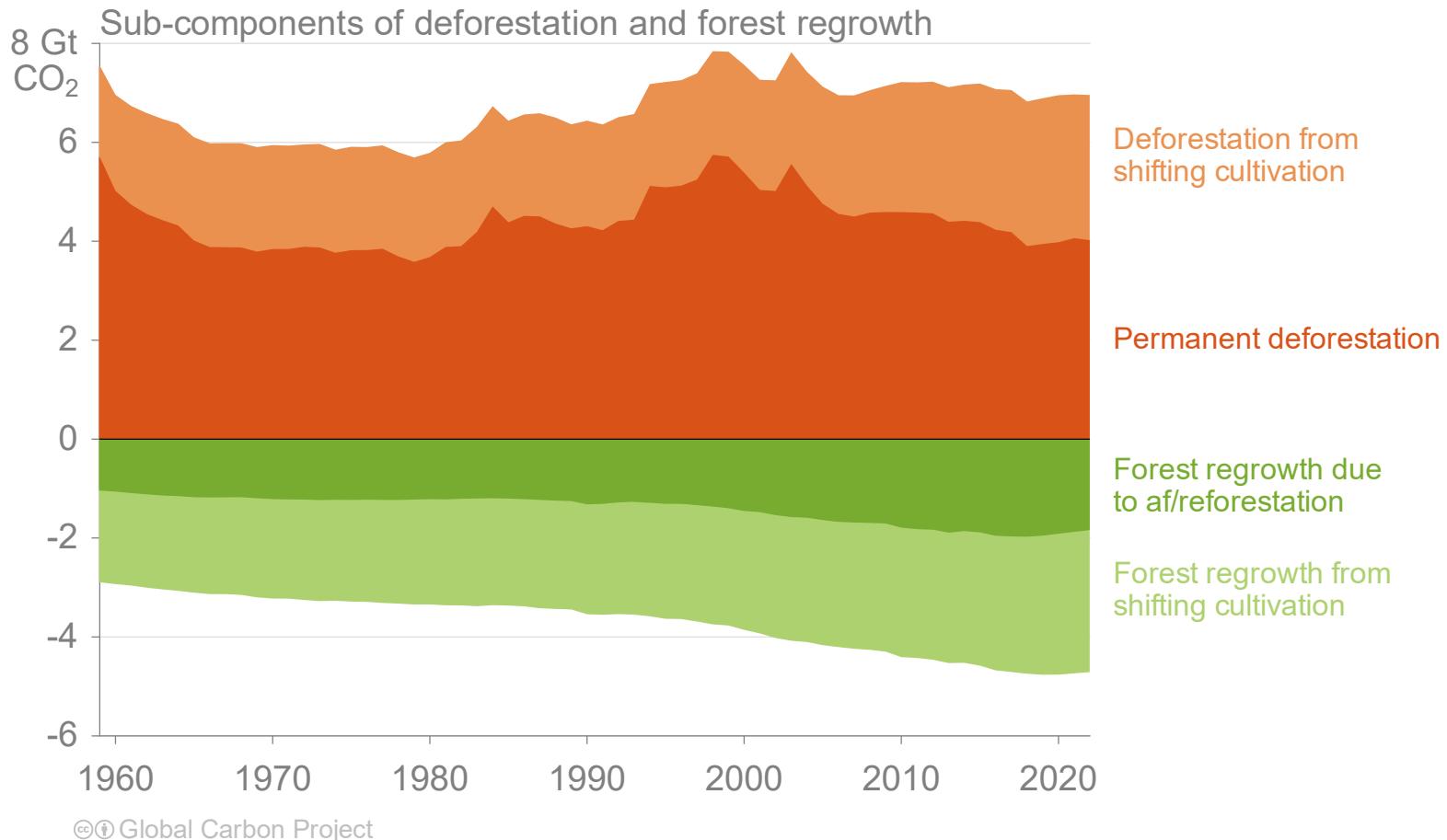
Net land use emissions are the result of multiple anthropogenic activities on land that lead to CO₂ emissions or removals



Estimates from three bookkeeping models
Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Land-use change emissions

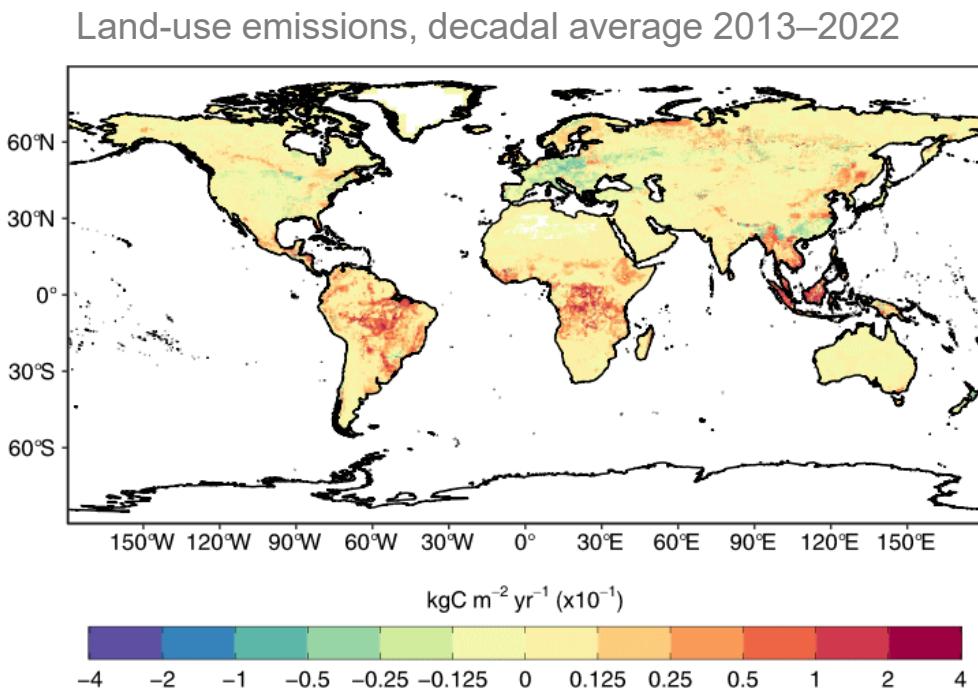
Emissions from permanent deforestation are 4.2 GtCO₂ per year for 2013–2022.
Carbon dioxide removals through permanent af/reforestation are 1.9 GtCO₂ per year over the same period.



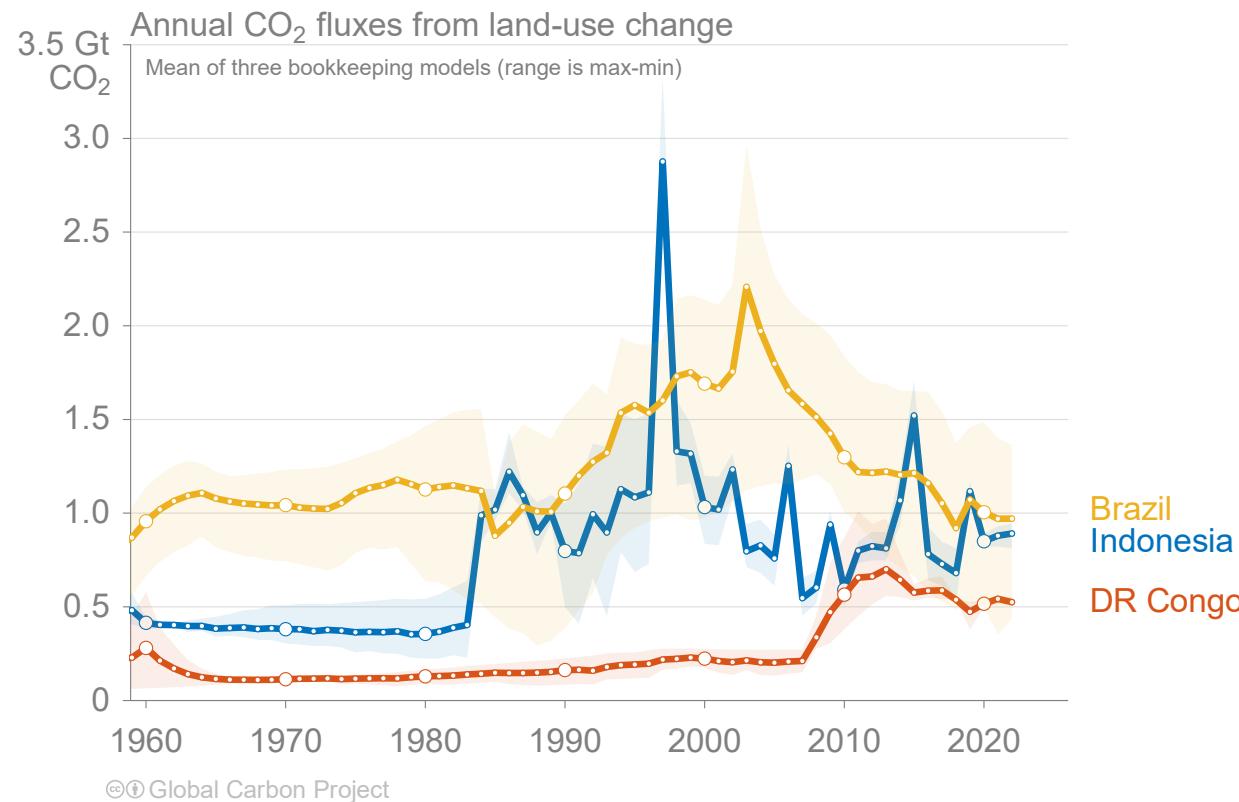
Estimates from three bookkeeping models
Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Regional patterns of land-use change emissions

Land-use emissions are high in the tropics, driven largely by deforestation. Net sinks occur in regions of re/afforestation such as parts of Europe and China.



The top three emitters over 2013–2022 – Brazil, Indonesia, and the Democratic Republic of the Congo – contribute 55% of the global net land-use emissions.

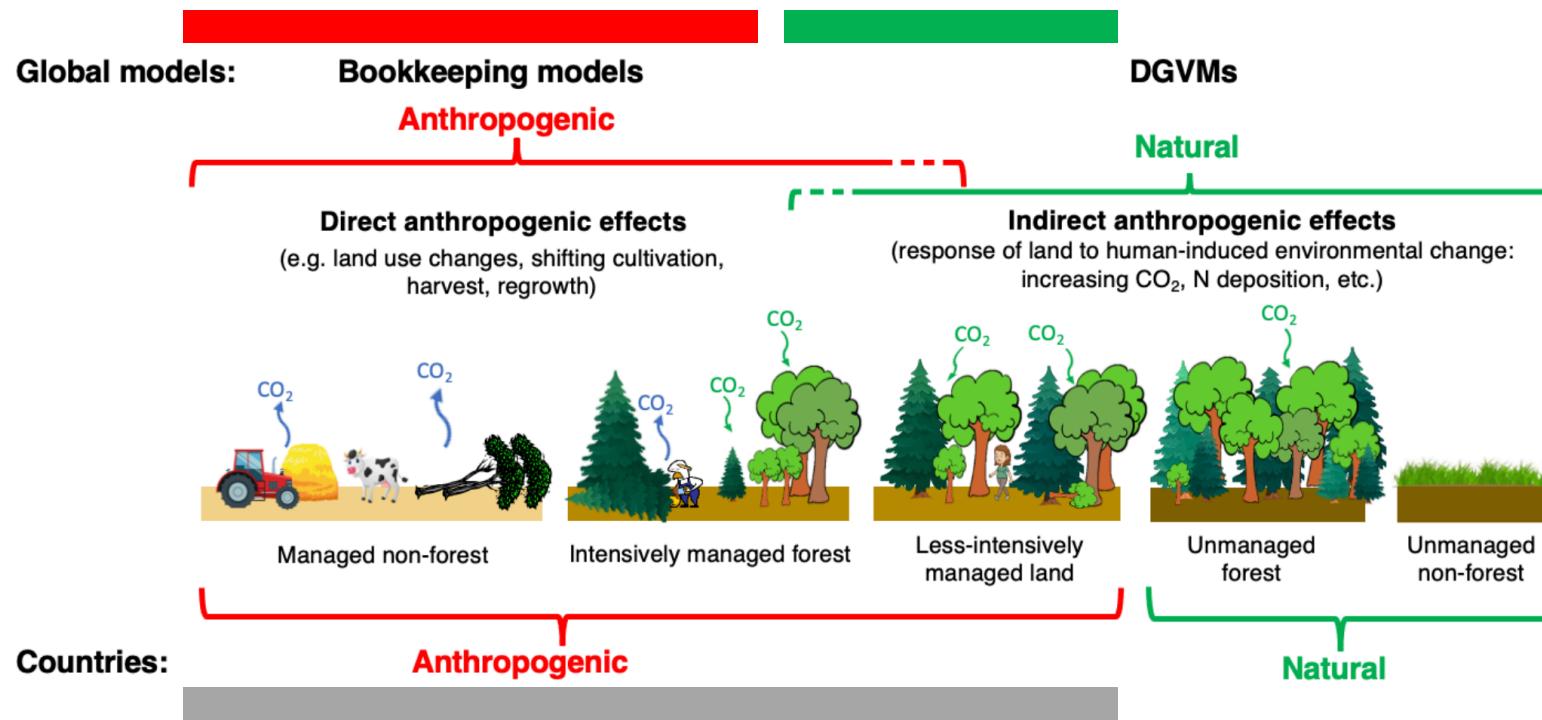


The peak in Indonesia in 1997 was the Indonesian peat fires.

Linking global models to country reports

Mapping of global carbon cycle model land flux definitions to the definition of the LULUCF net flux used in national Greenhouse Gas Inventories (NGHGI) reported to UNFCCC

When natural fluxes on managed forests (-7.5 GtCO₂ per year for 2013–2022) are added to land-use emissions (4.7 GtCO₂ per year), the GCB2023 estimates (-2.1 GtCO₂ per year) are very similar to the country-reported data (-2.0 GtCO₂ per year), linking the anthropogenic carbon budget estimates of land CO₂ fluxes directly to the Global Stocktake as part of UNFCCC Paris Agreement.

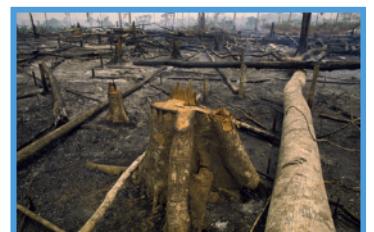
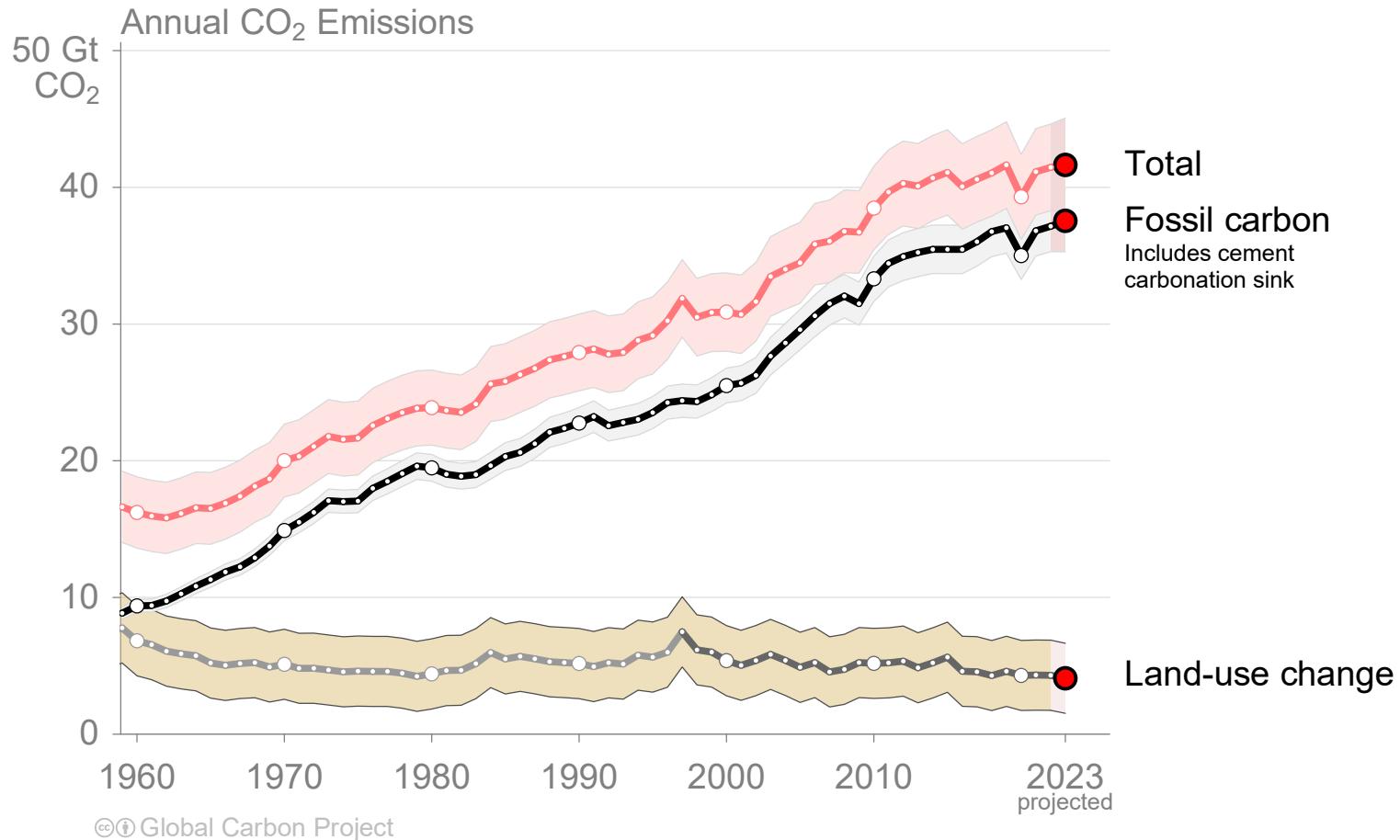


Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)
 Figure from [Grassi et al., ESSD 2023](#)

Total global emissions

Total global emissions, projected to reach $40.9 \pm 3.2 \text{ GtCO}_2$ in 2023, 47% over 1990

Percentage land-use change: 42% in 1960, 12% averaged 2013–2022

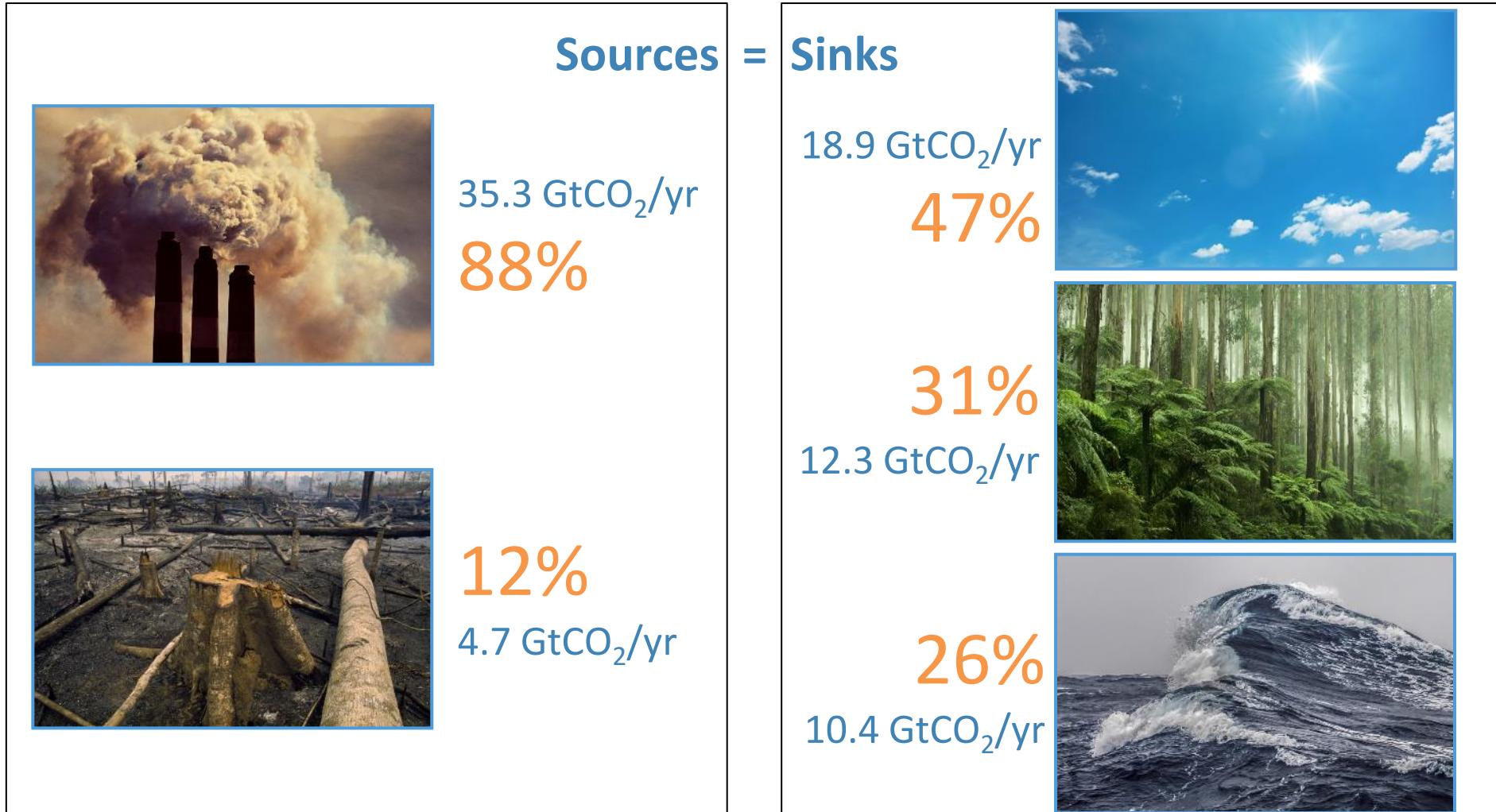


Land-use change estimates from three bookkeeping models, using fire-based variability from 1997

Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Closing the Global Carbon Budget

Fate of anthropogenic CO₂ emissions (2013–2022)

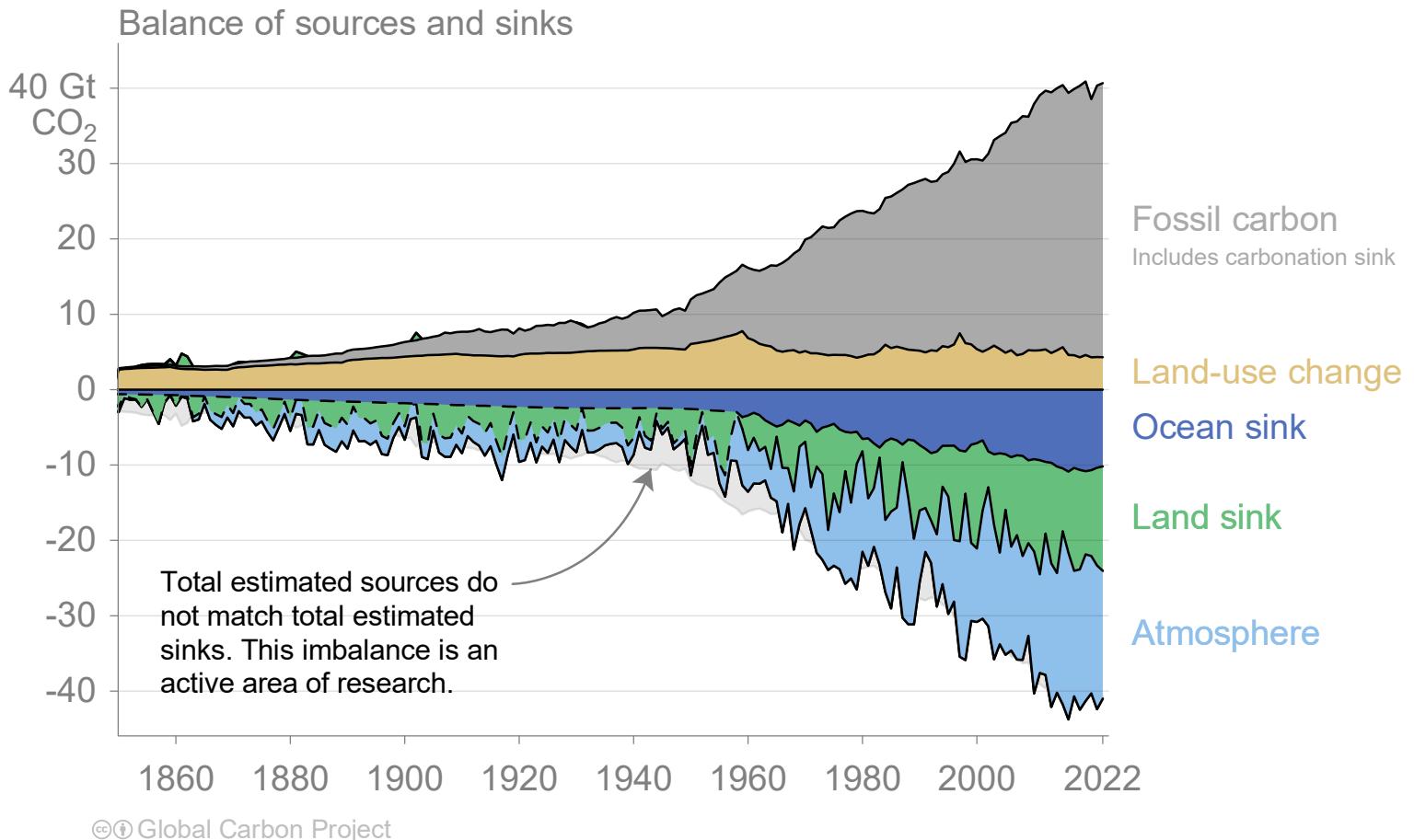


Budget Imbalance:
(the difference between estimated sources & sinks)

4%
-1.6 GtCO₂/yr

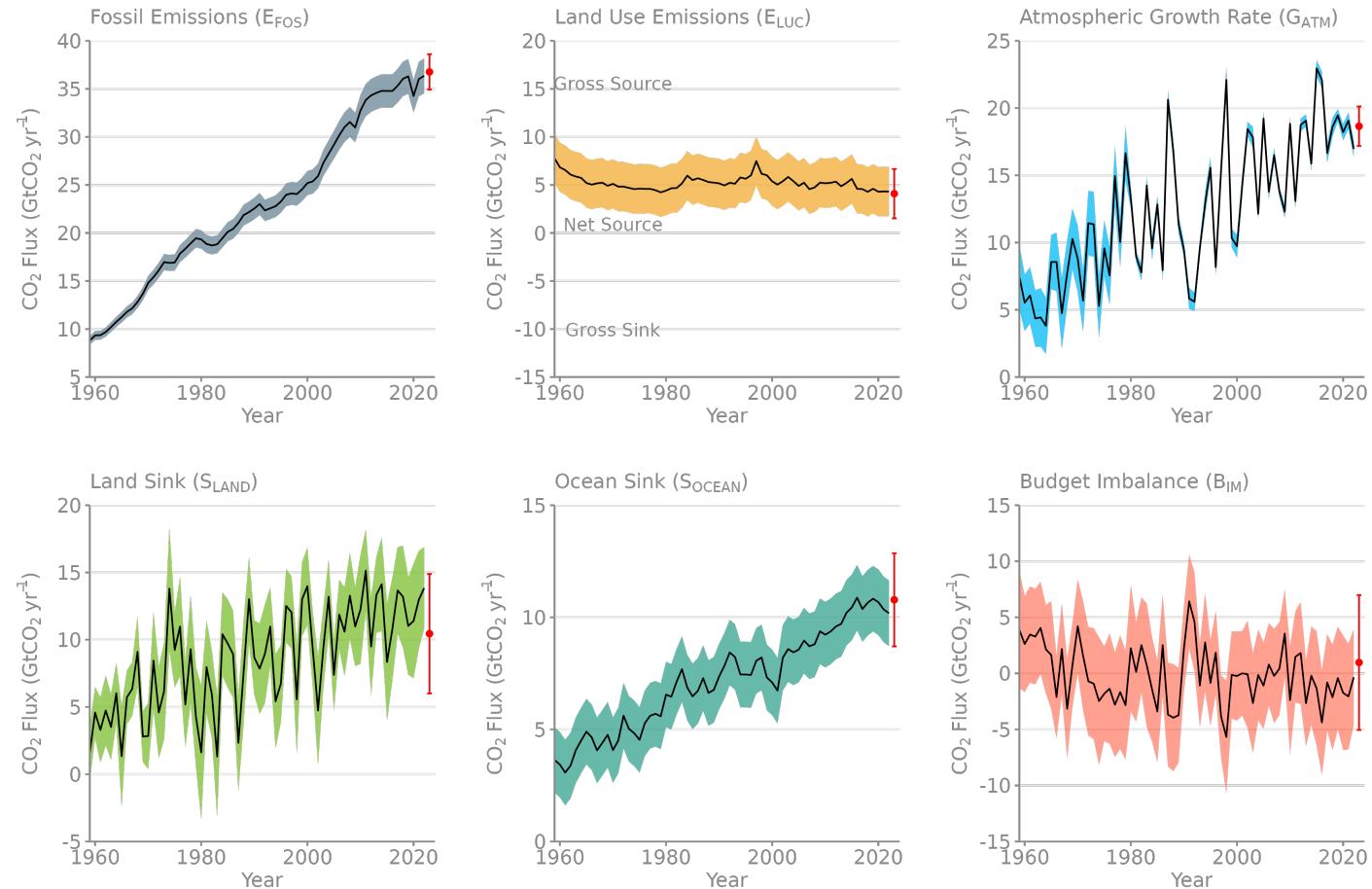
Global carbon budget

Carbon emissions are partitioned among the atmosphere and carbon sinks on land and in the ocean
The “imbalance” between total emissions and total sinks is an active area of research



Changes in the budget over time

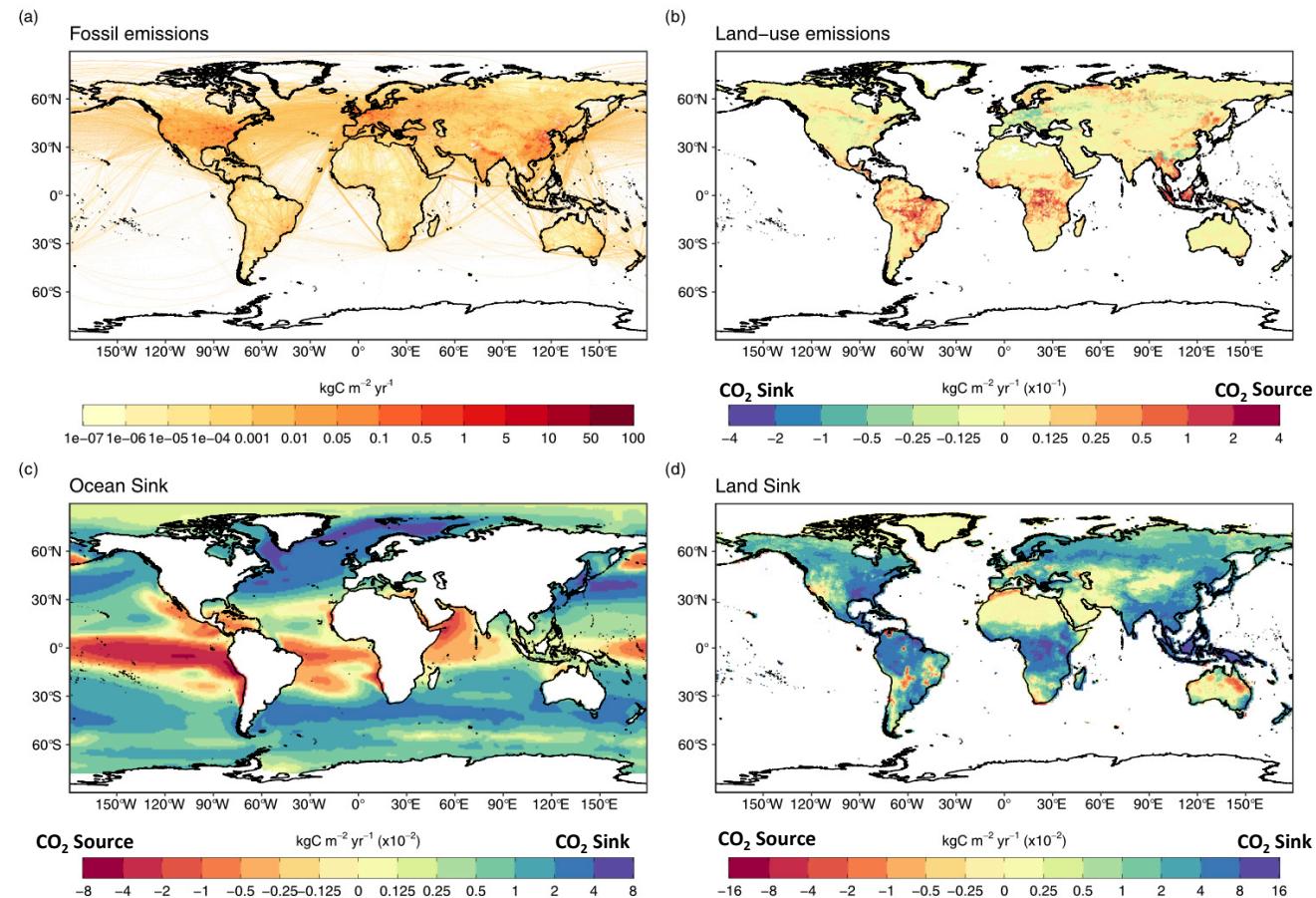
The sinks have continued to grow with increasing emissions, but climate change will affect carbon cycle processes in a way that will exacerbate the increase of CO₂ in the atmosphere



The budget imbalance is the total emissions minus the estimated growth in the atmosphere, land and ocean.
It reflects the limits of our understanding of the carbon cycle.
Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Global carbon budget

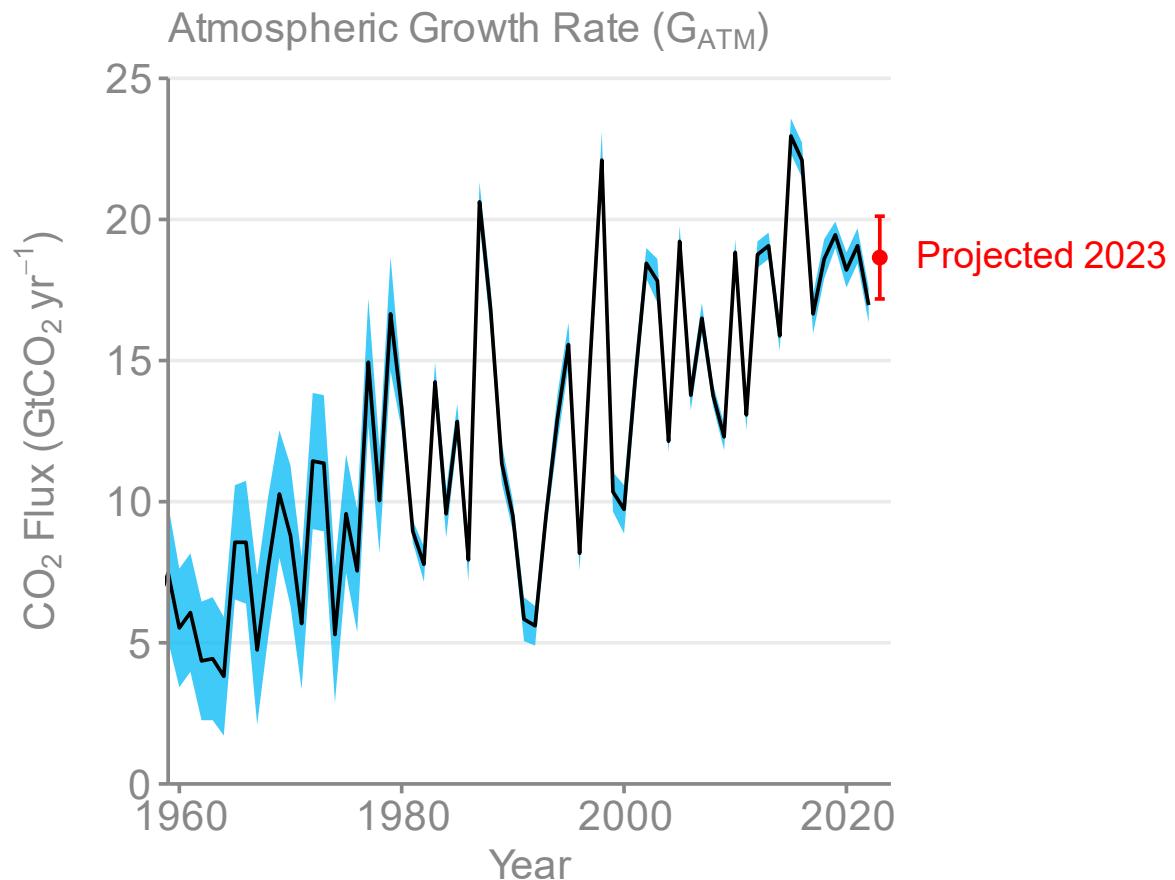
Fossil emissions dominate in the Northern Hemisphere, while land-use emissions are important in the tropics.
 The North Atlantic and Southern Ocean are carbon sinks while the tropical ocean is a source of CO₂.
 Tropical, temperate and boreal forest are the main terrestrial carbon sinks



Atmospheric concentration

The atmospheric concentration growth rate has increased steadily.

The high growth in 1987, 1998, & 2015–16 reflect a strong El Niño, which weakens the land sink.
The effects of the currently emerging El Niño are expected to be most visible in the growth rate in 2024.

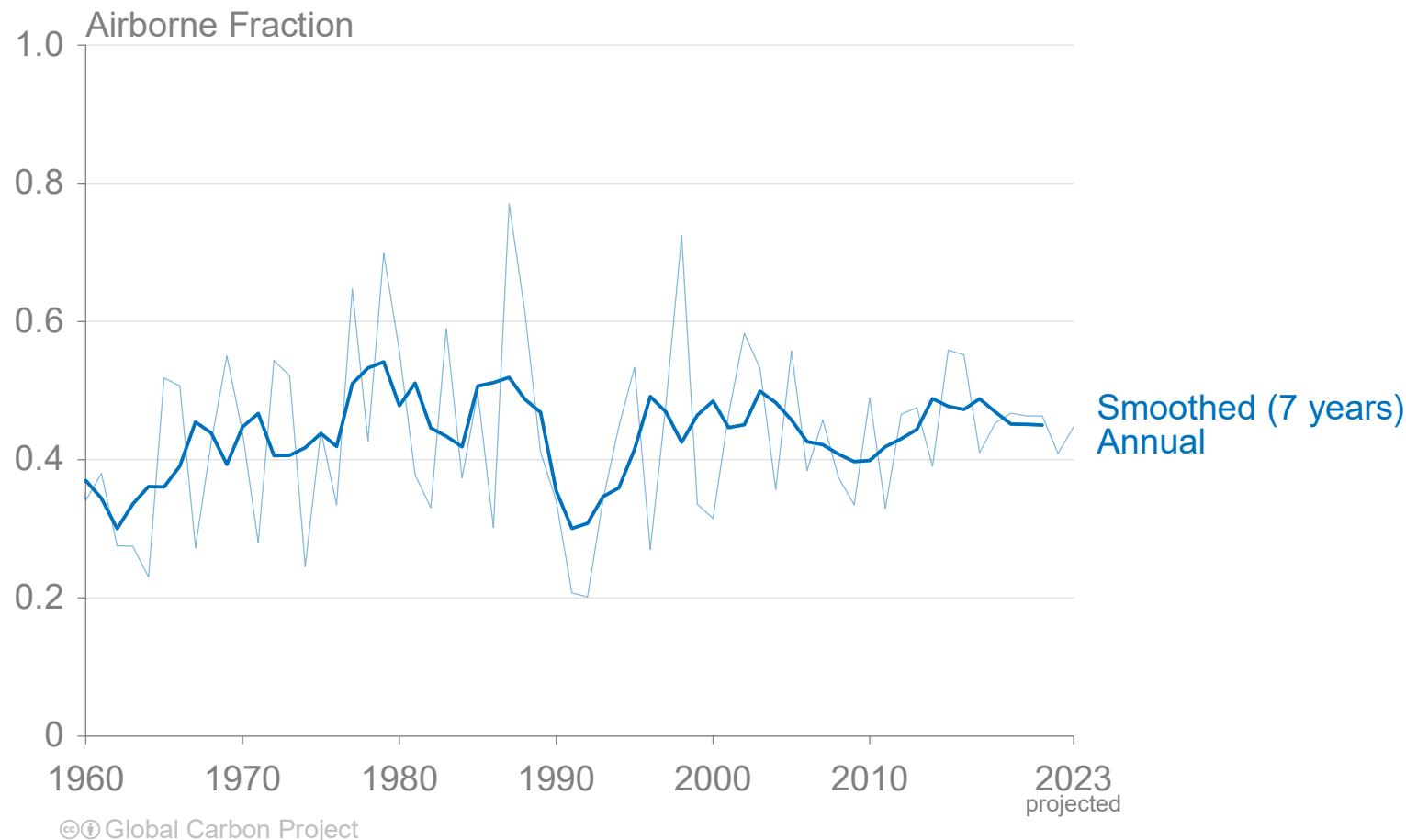


Airborne Fraction

The airborne fraction is the proportion of the total annual CO₂ emissions that remains in the atmosphere.

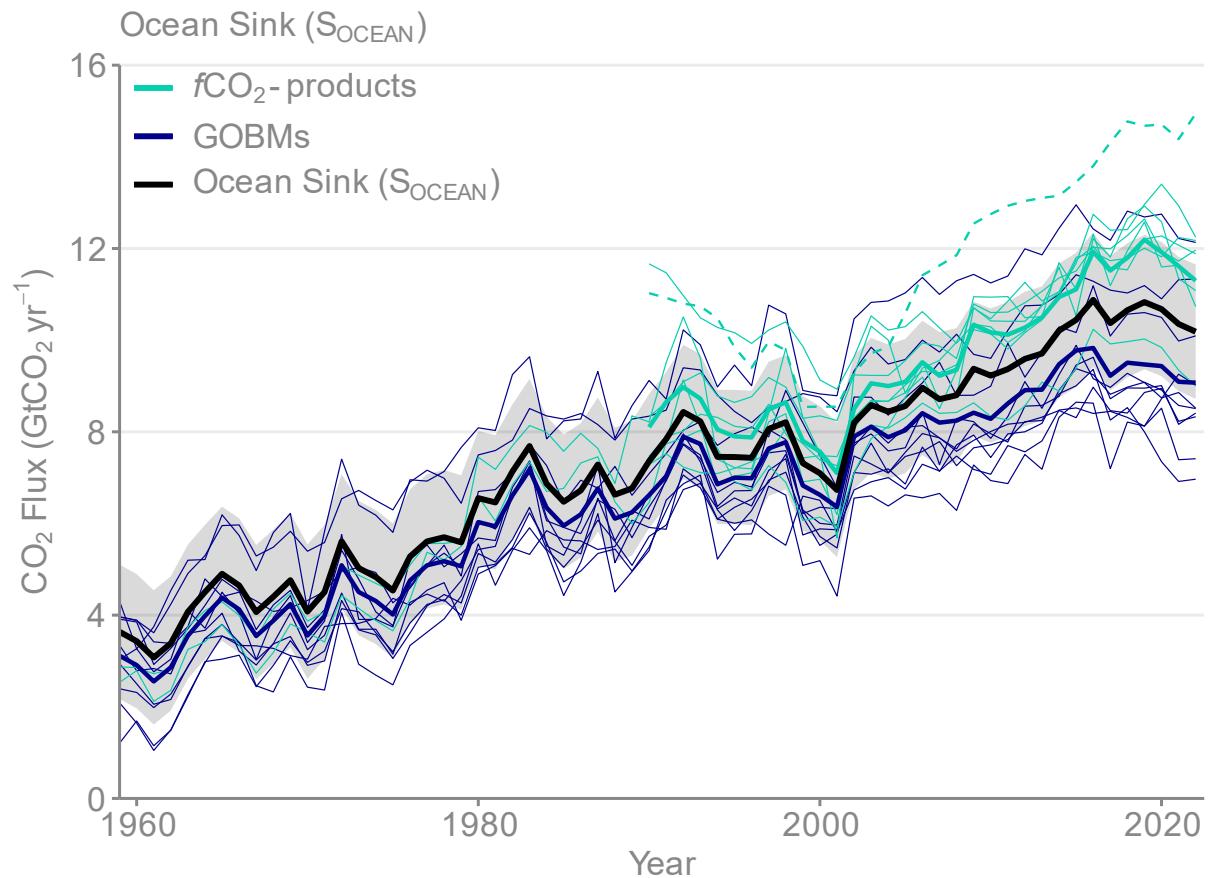
The rest of the CO₂ emissions are removed by the land and ocean sinks.

Around 45% of CO₂ emissions remain in the atmosphere despite sustained growth in CO₂ emissions.



Ocean sink

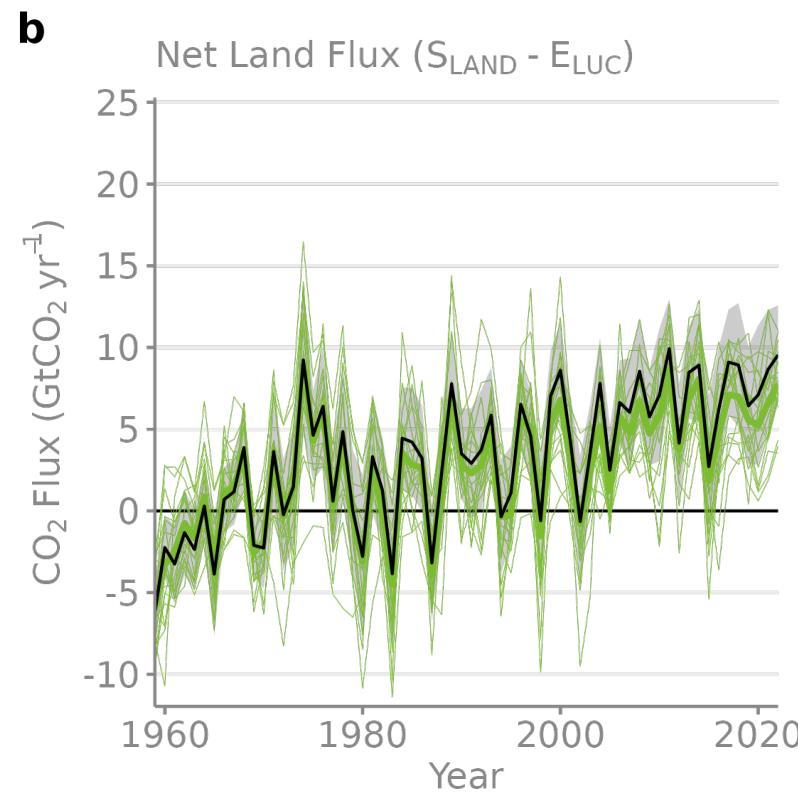
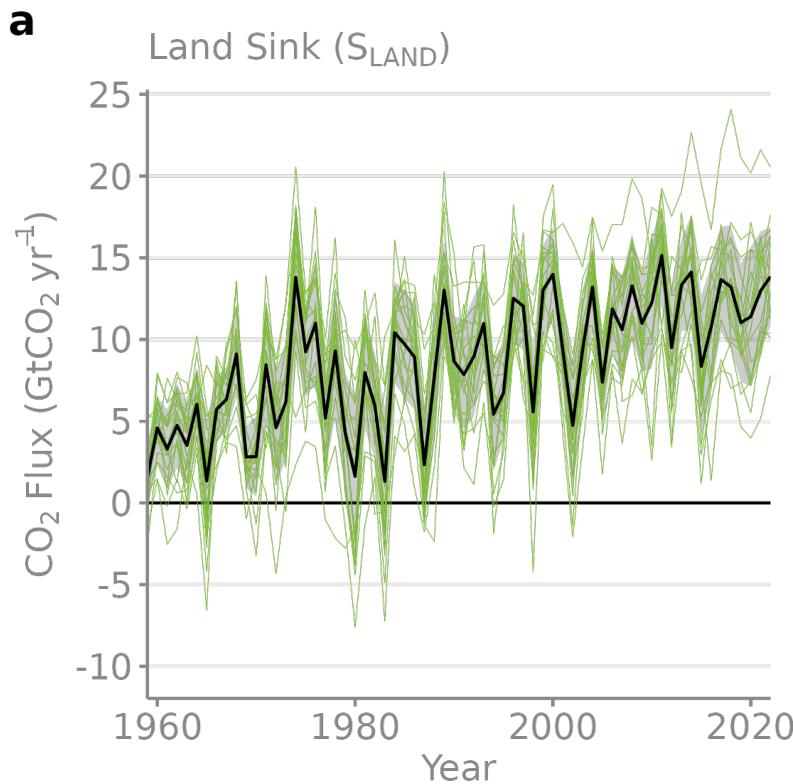
The ocean carbon sink, estimated by Global Ocean Biogeochemical Models and observation-based data products, amounts to $10.4 \pm 1.5 \text{ GtCO}_2/\text{yr}$ for 2013–2022 and $10.2 \pm 1.5 \text{ GtCO}_2/\text{yr}$ in 2022.
The ocean CO_2 sink has not grown since 2019 due to a triple La Niña event during 2020–2022.



Terrestrial sink

The land carbon sink, estimated by Dynamic Global Vegetation Models, was $12.3 \pm 3.1 \text{ GtCO}_2/\text{yr}$ during 2013–2022 and $13.9 \pm 3.0 \text{ GtCO}_2/\text{yr}$ in 2022.

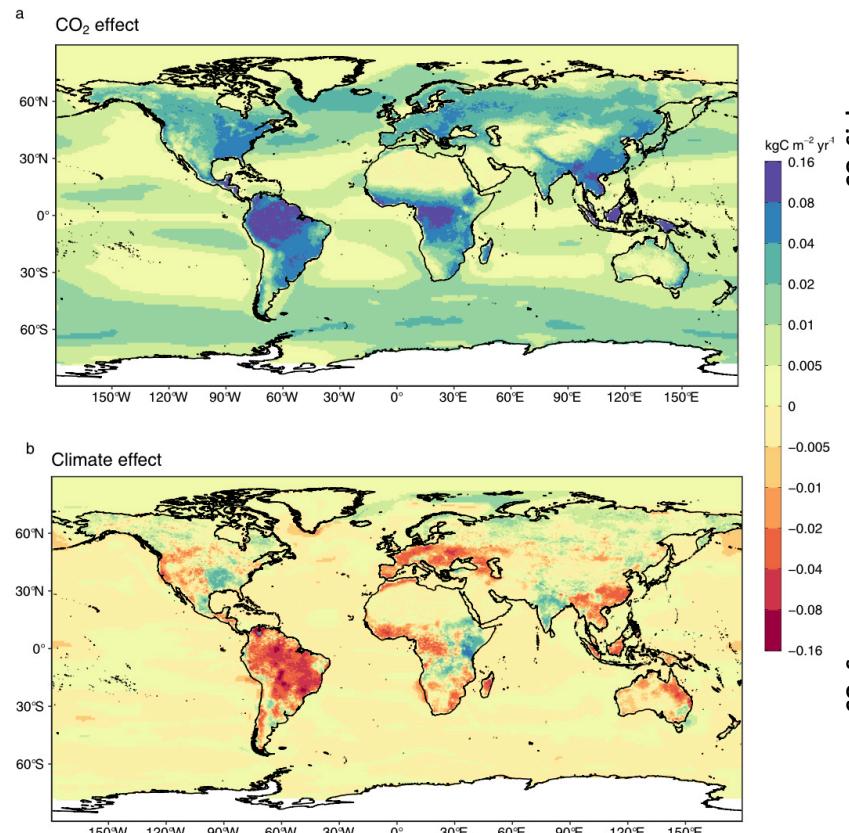
The total CO₂ fluxes on land (including land-use change) are also constrained by atmospheric inversions.



Land and ocean sinks — Effects of CO₂ vs climate change

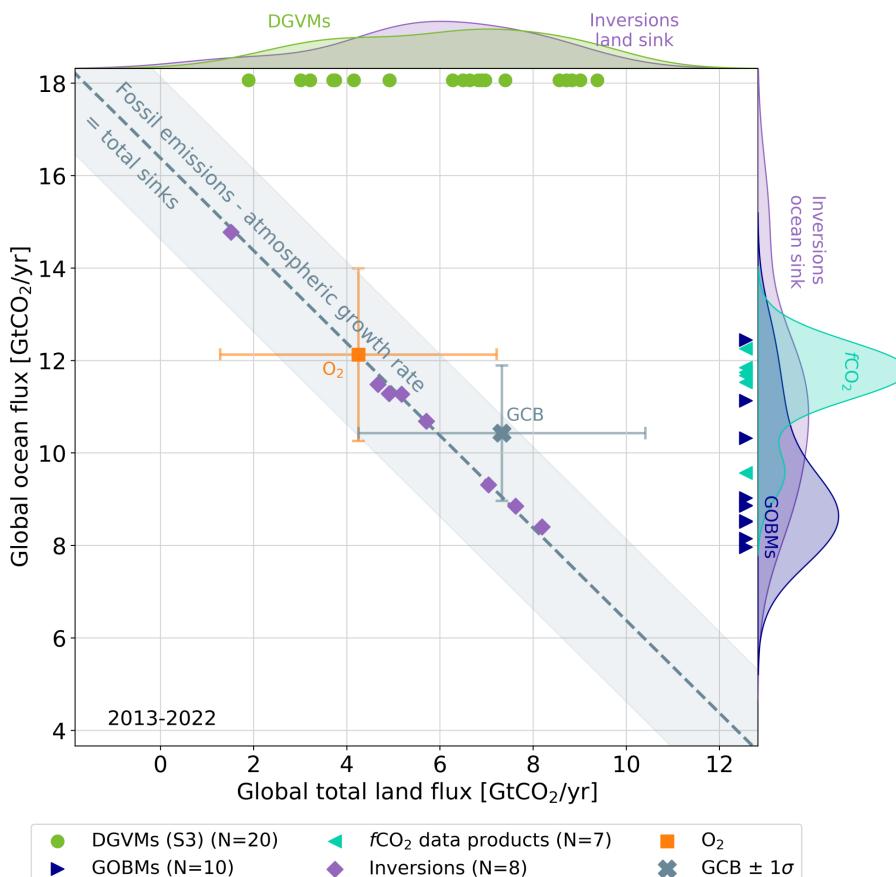
Process models suggest that increasing atmospheric CO₂ drives the land and ocean sinks while climate change reduces the carbon sinks; the climate effect is largest in tropical and semi-arid land ecosystems.

Globally during the 2013–2022 decade, climate change reduced the land sink by ~20% and the ocean sink by ~7%.



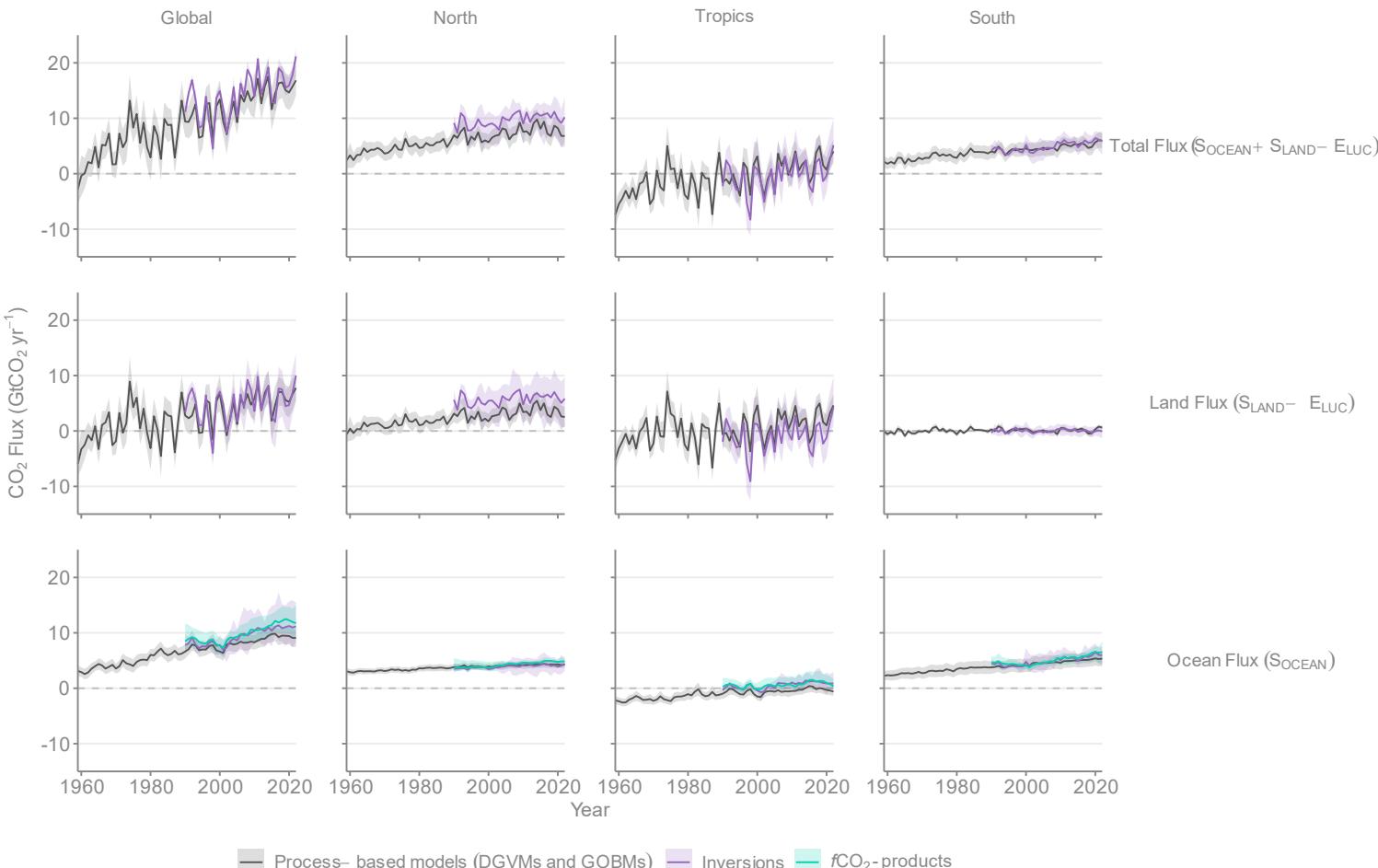
Land and ocean sinks — Estimates from atmospheric inversions

Both atmospheric CO₂ inversions and atmospheric oxygen allow to estimate the land and ocean carbon fluxes, independently from the land and ocean process-based models, confirming the global carbon budget estimates of the land and ocean partitioning of anthropogenic CO₂



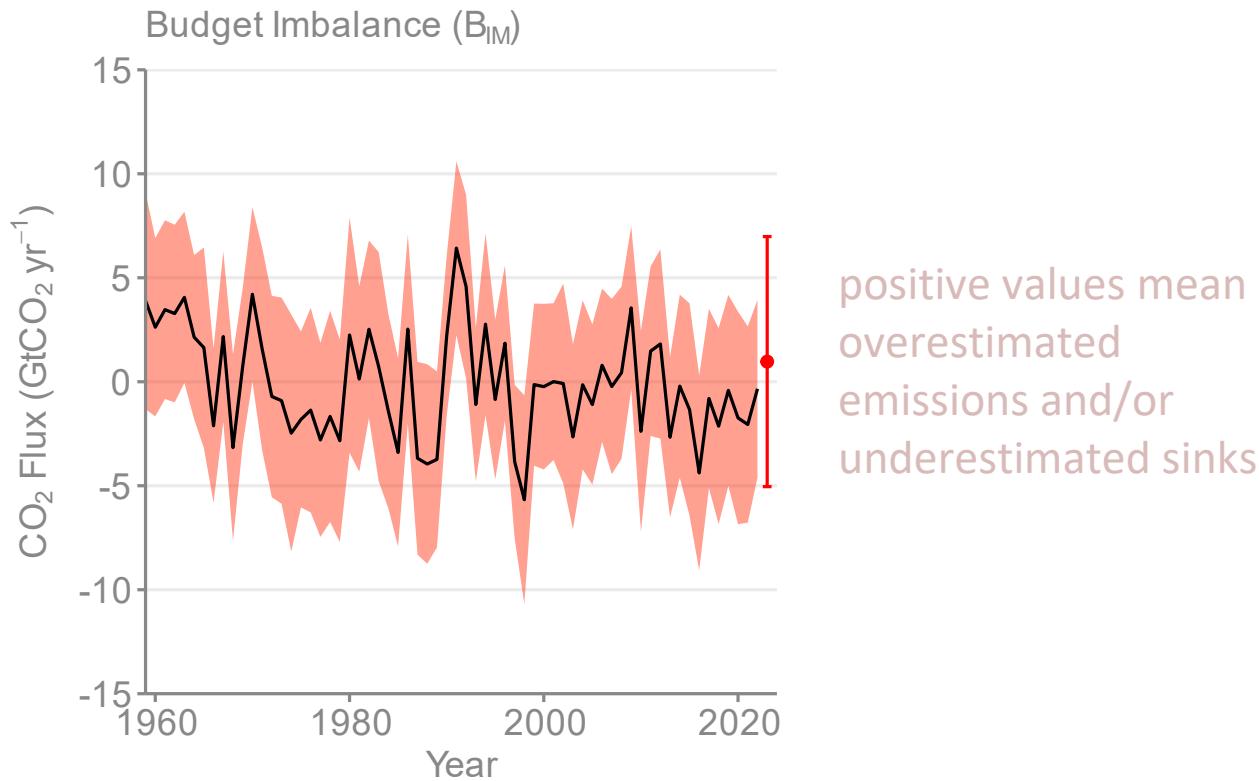
Total land and ocean fluxes

Total land and ocean fluxes show more interannual variability in the tropics



Remaining carbon budget imbalance

Large and unexplained variability in the global carbon balance caused by uncertainty and understanding hinder independent verification of reported CO₂ emissions

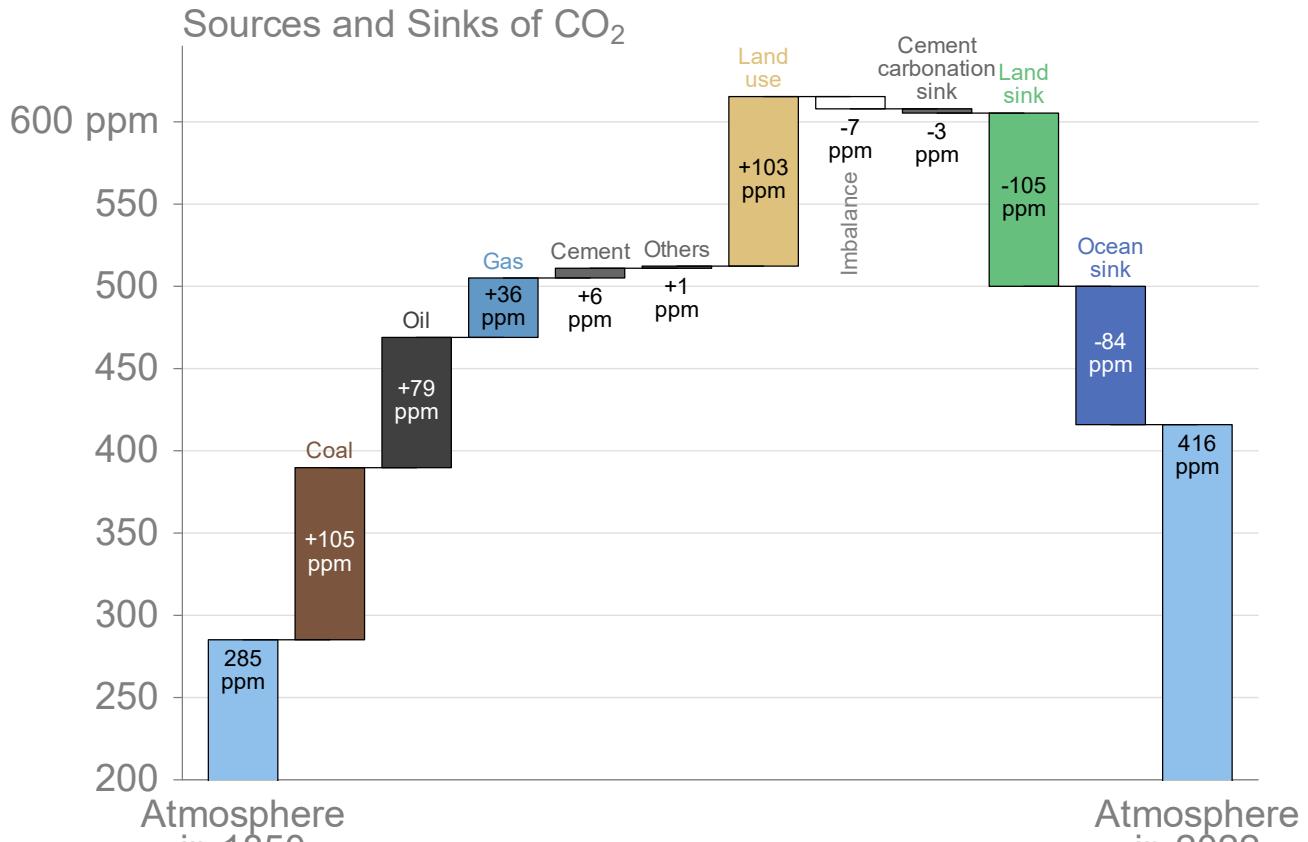


The budget imbalance is the carbon left after adding independent estimates for total emissions, minus the atmospheric growth rate and estimates for the land and ocean carbon sinks using models constrained by observations

Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Global carbon budget

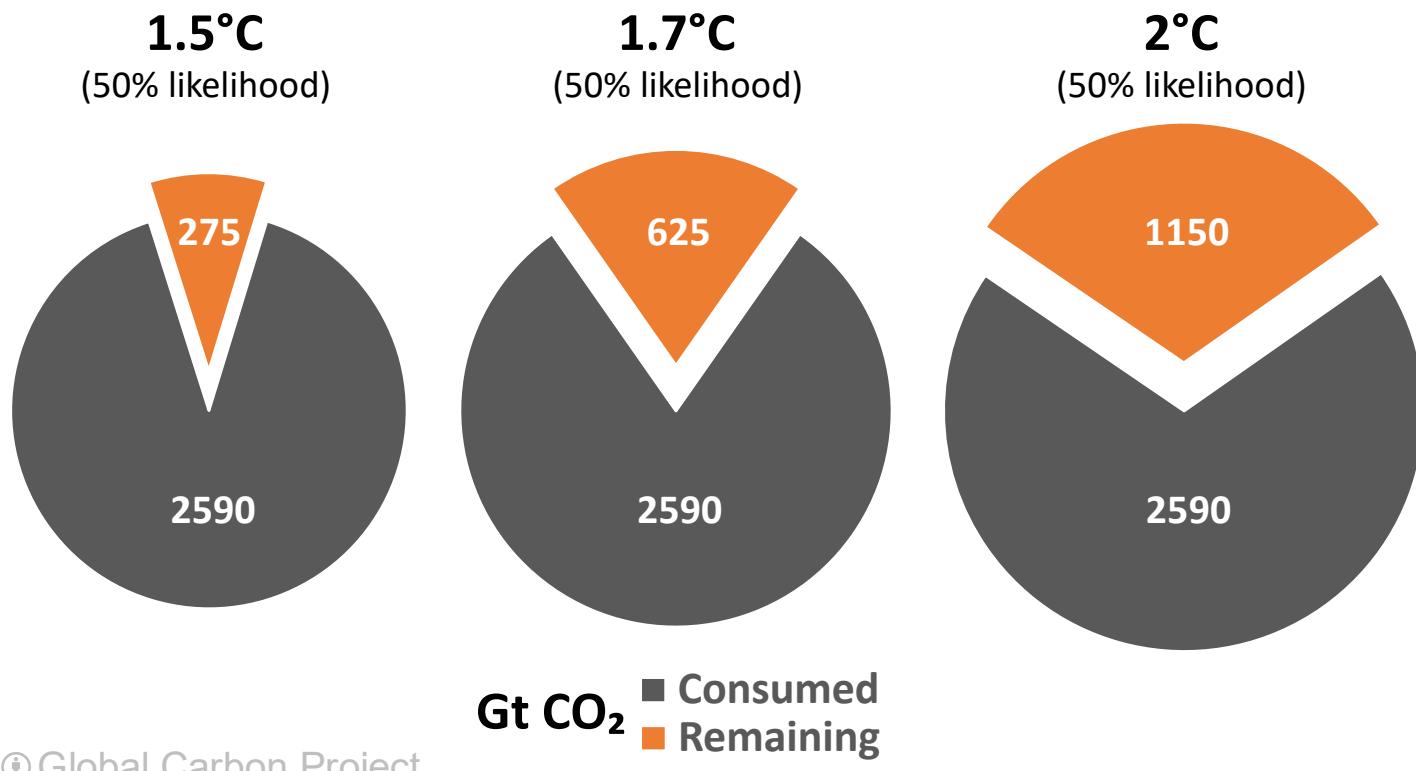
The cumulative contributions to the global carbon budget from 1850
The carbon imbalance represents the gap in our current understanding of sources & sinks



© Global Carbon Project

Remaining carbon budget

The remaining carbon budget to limit global warming to 1.5°C, 1.7°C and 2°C is 275 GtCO₂, 625 GtCO₂, and 1150 GtCO₂ respectively, equivalent to 7, 15 and 28 years from 2024. 2590 GtCO₂ have been emitted since 1850



cc Global Carbon Project

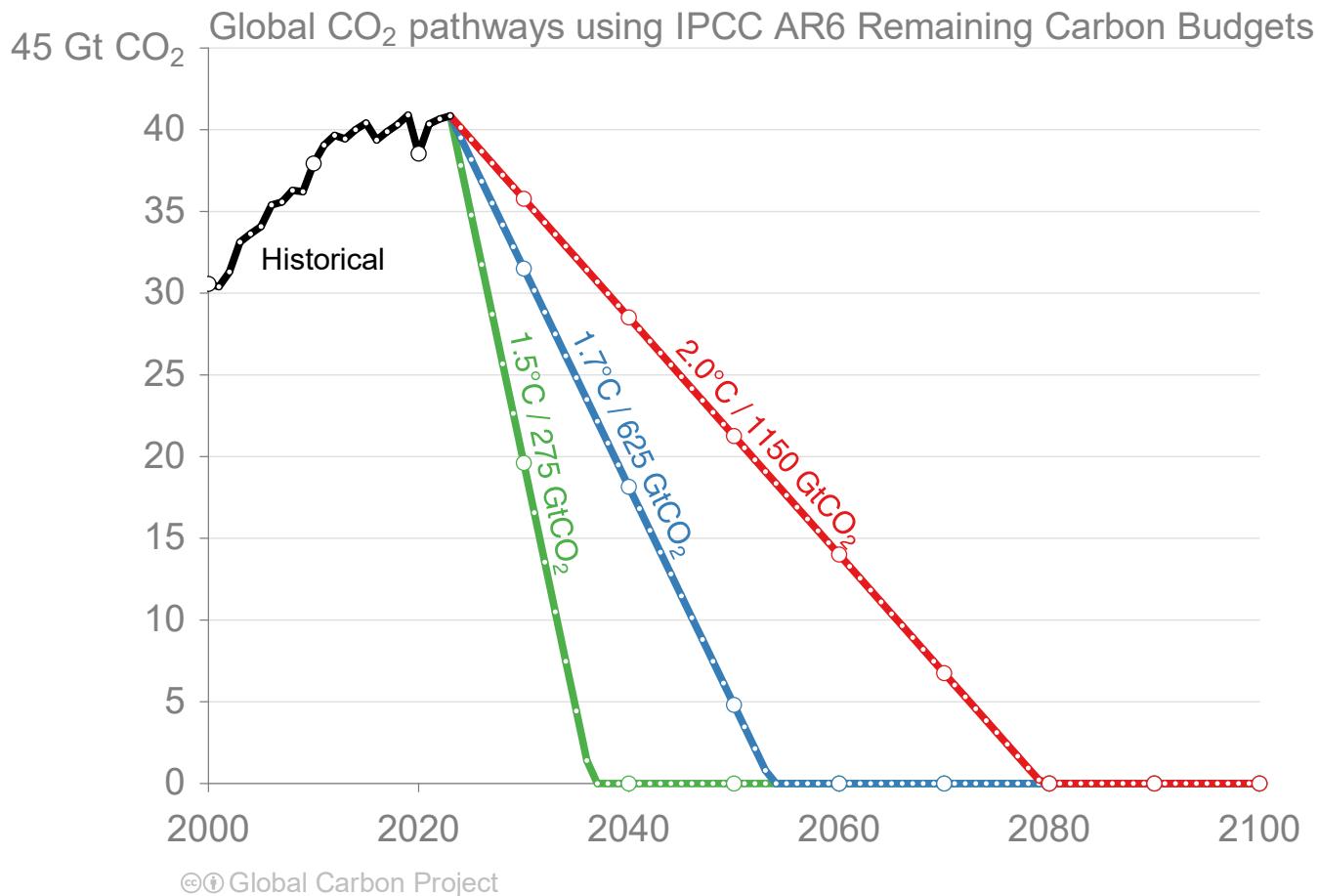
The remaining carbon budgets is the average of two estimates (IPCC AR6 and Forster et al., 2023), both updated by removing the most recent emissions.

Quantities are subject to additional uncertainties e.g., future mitigation choices of non-CO₂ emissions

Source: IPCC AR6 WG1; [Forster et al., 2023](#); [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Remaining carbon budget

Global CO₂ emissions must reach zero to limit global warming



Acknowledgements

Acknowledgements

The work presented in the **Global Carbon Budget 2023** has been possible thanks to the contributions of **hundreds of people** involved in observational networks, modeling, and synthesis efforts.

We thank the institutions and agencies that provide support for individuals and funding that enable the collaborative effort of bringing all components together in the carbon budget effort.

We thank the sponsors of the GCP and GCP support and liaison offices.



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<https://doi.org/10.5194/essd-15-5301-2023>

We also thank the Fondation BNP Paribas for supporting the Global Carbon Atlas and the Integrated Carbon Observation System (ICOS) for hosting our data.

This presentation was created by Robbie Andrew and Pierre Friedlingstein with Pep Canadell, Glen Peters and Corinne Le Quéré in support of the international carbon research community.

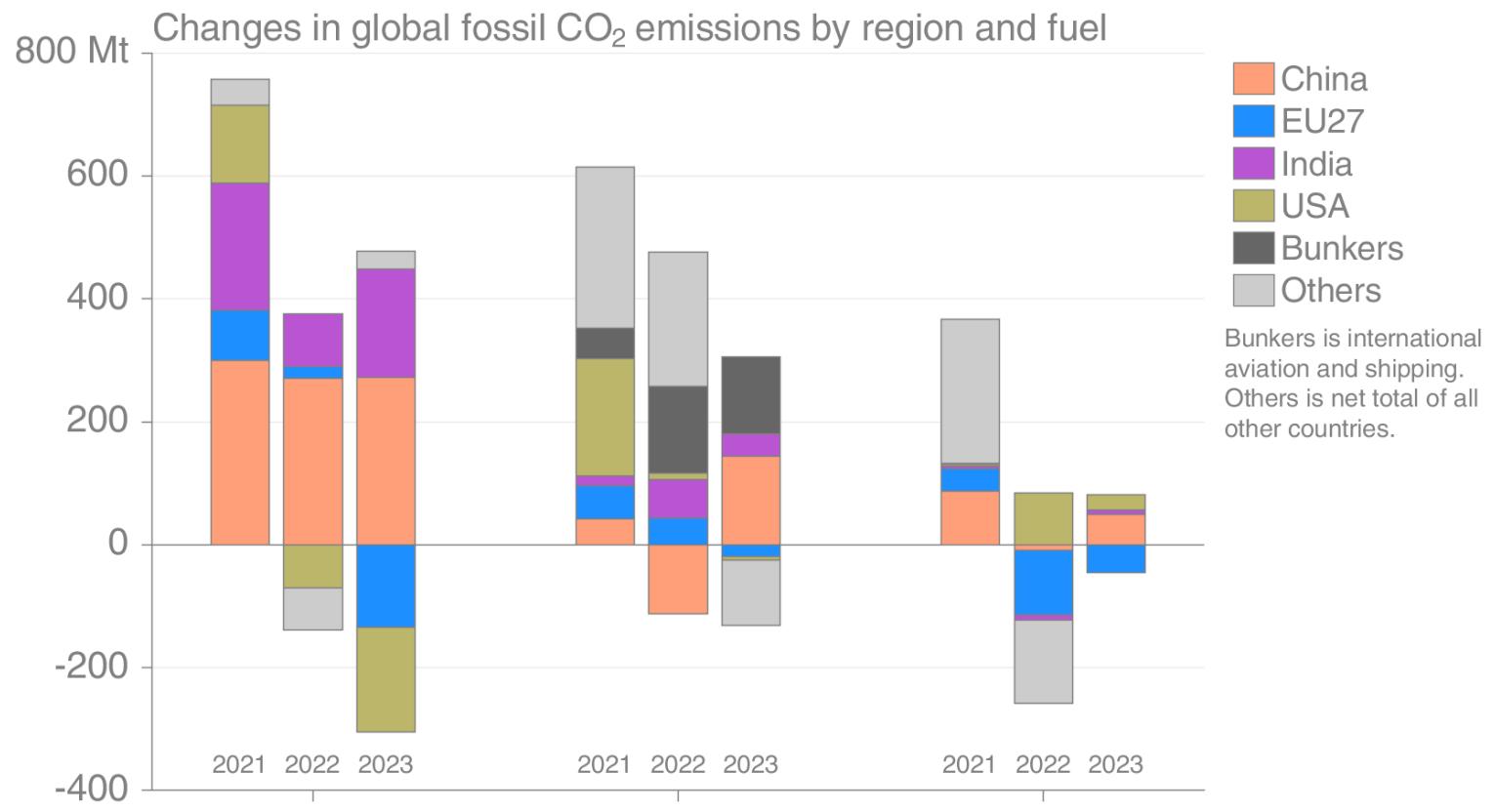
Additional Figures

Additional Figures

Fossil CO₂

Emissions changes 2021–2023

Emissions from coal in China and India have been a core reason for global growth. Both 2022 and 2023 were marked by post-pandemic recovery in international aviation (bunkers).

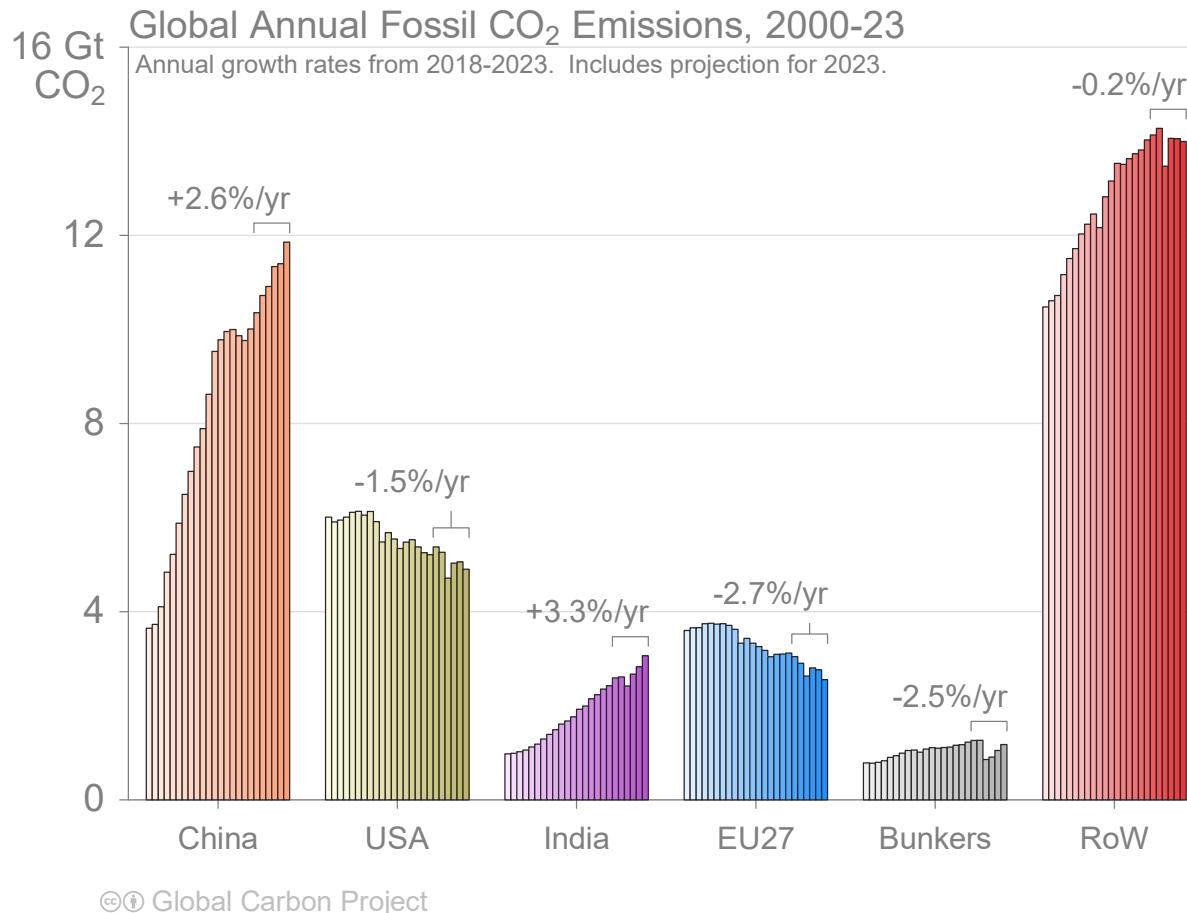


© Global Carbon Project

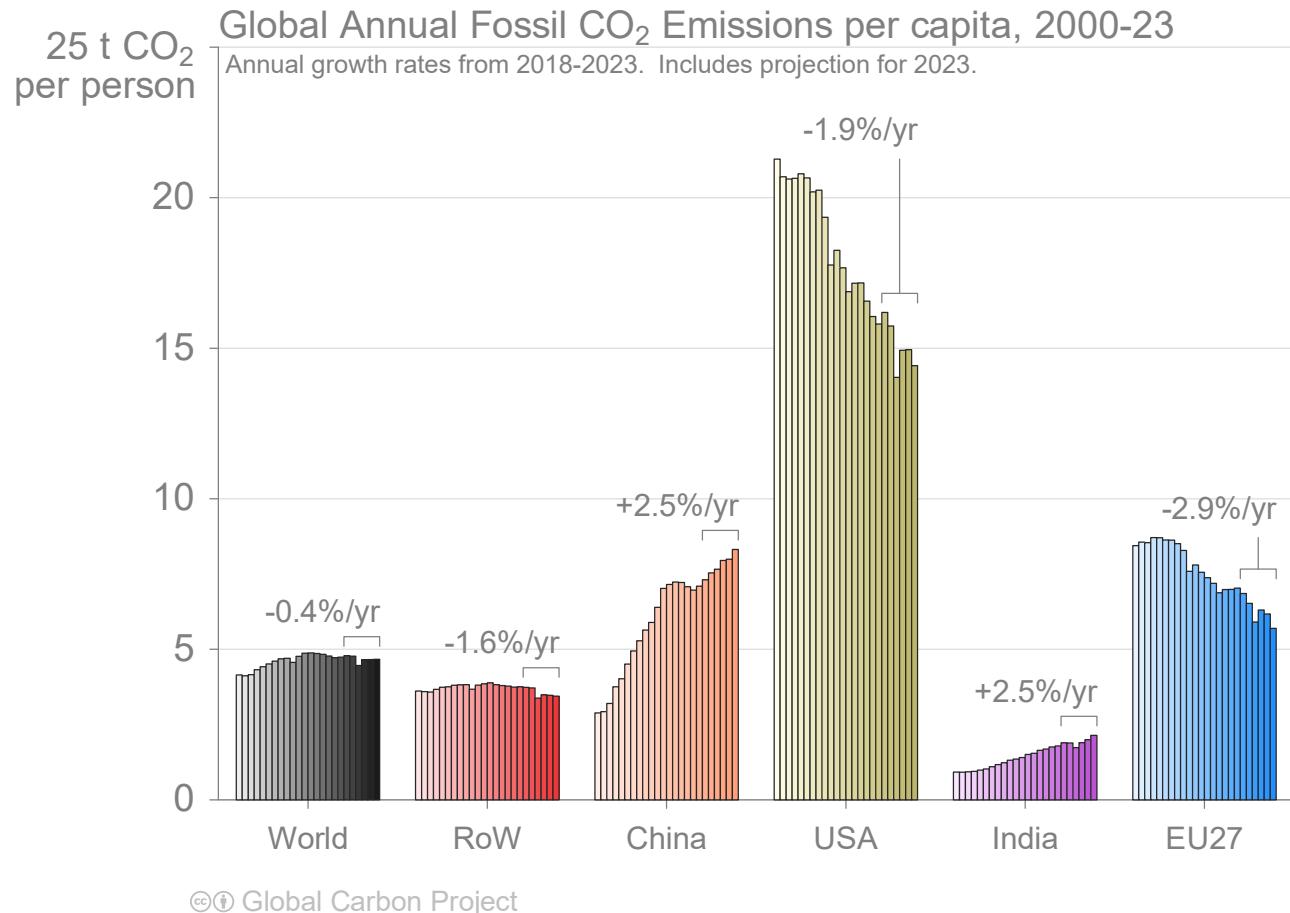
Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Top emitters: Fossil CO₂ Emissions

Emissions by country from 2000 to 2023, with the growth rates indicated for the more recent period of 2018 to 2023

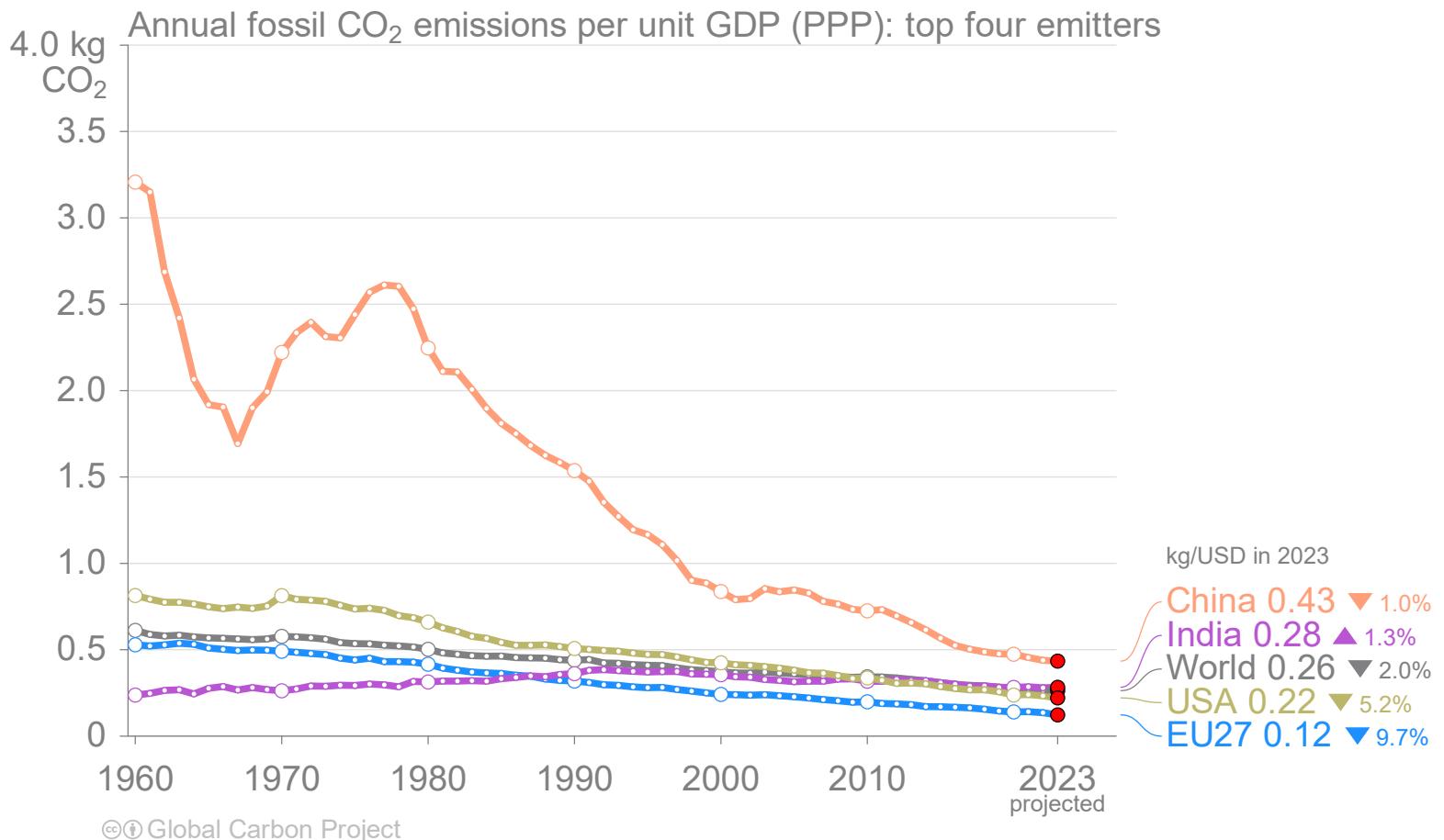


Per capita CO₂ emissions



Top emitters: Fossil CO₂ Emission Intensity

Emission intensity (emission per unit economic output) generally declines over time.
In many countries, these declines are insufficient to overcome economic growth.

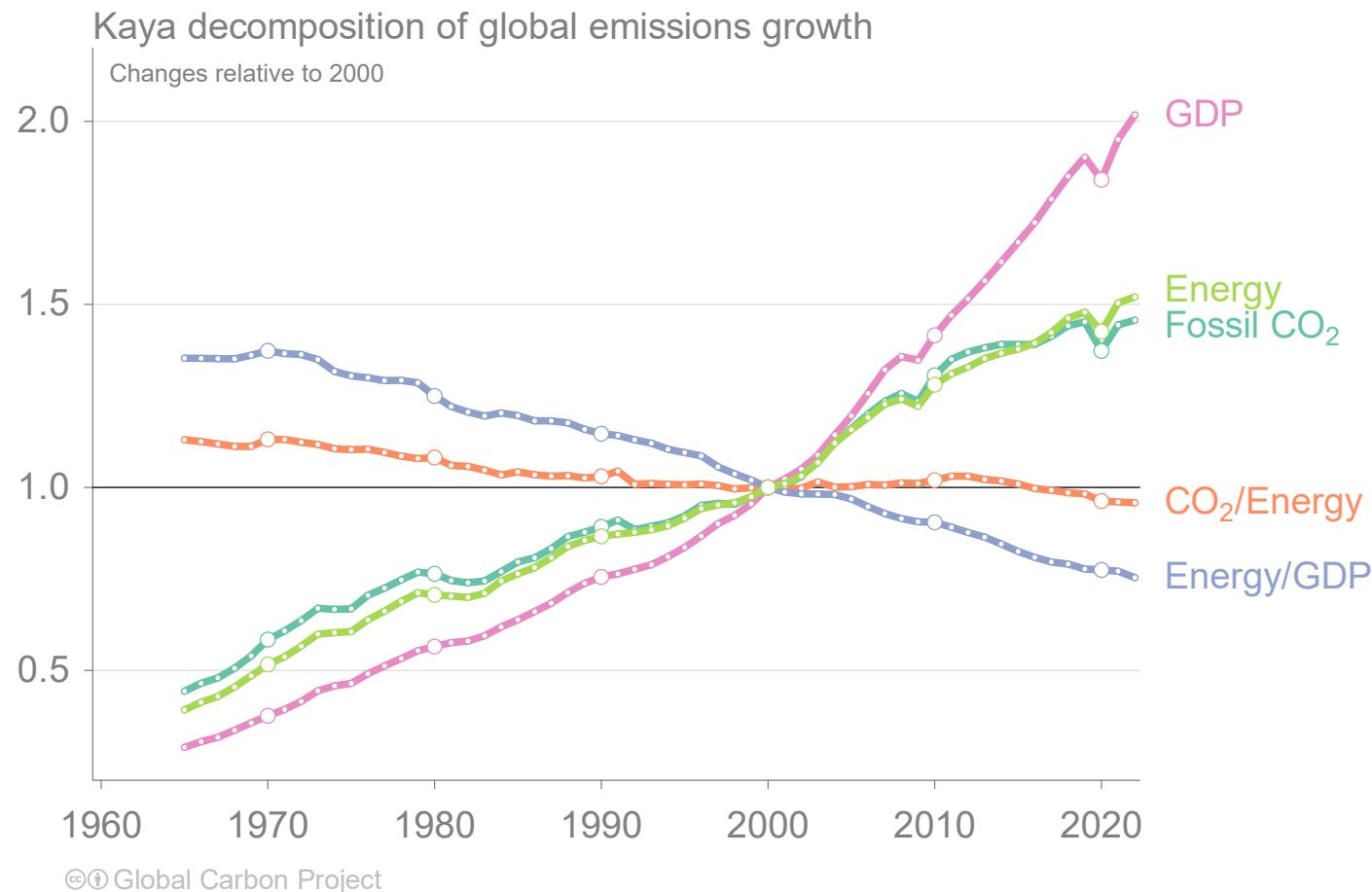


GDP is measured in purchasing power parity (PPP) terms in 2017 US dollars.

Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Kaya decomposition

The Kaya decomposition illustrates that relative decoupling of economic growth from CO₂ emissions is driven by improved energy intensity (Energy/GDP) and, recently, carbon intensity of energy (CO₂/Energy)

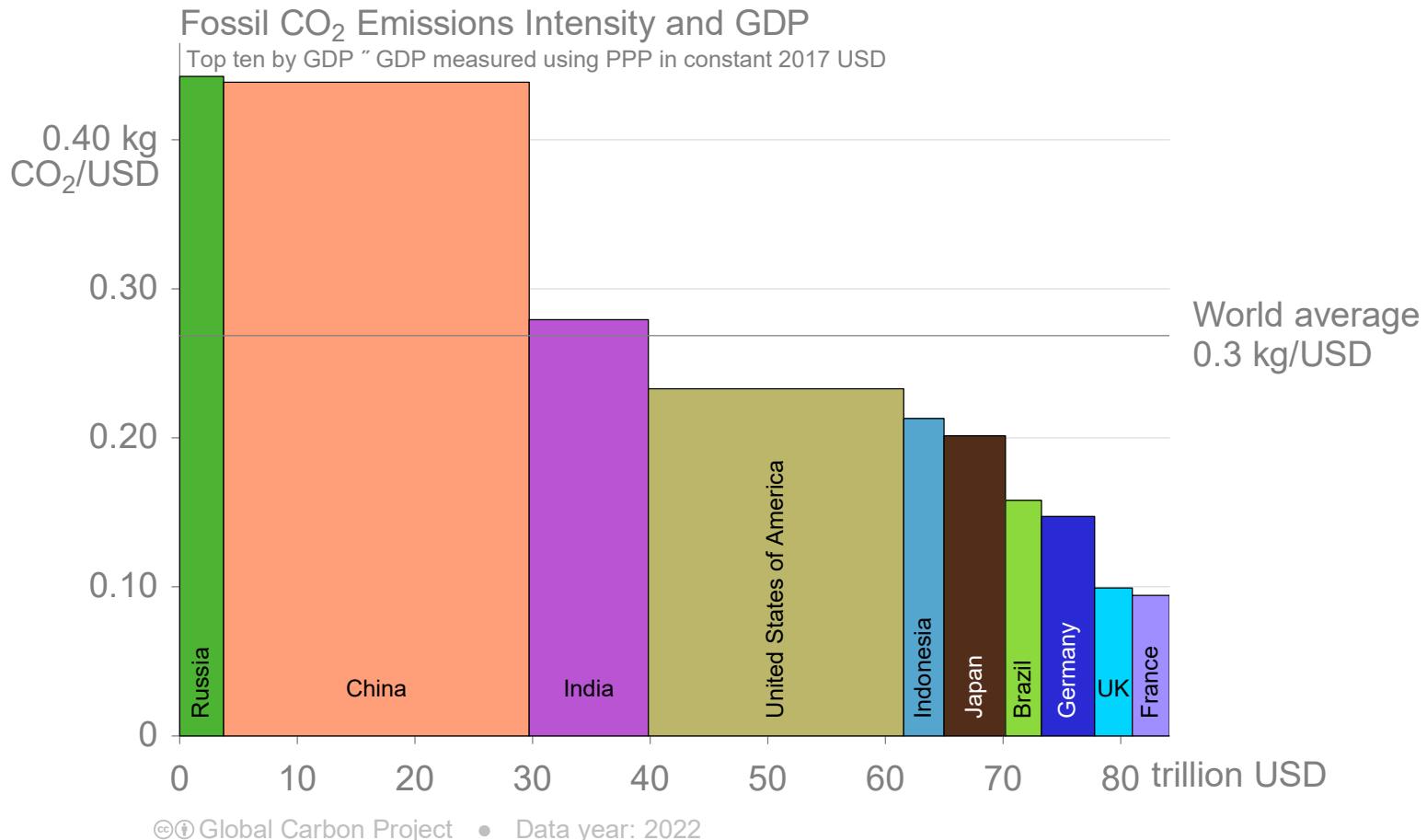


GDP: Gross Domestic Product (economic activity)

Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Fossil CO₂ emission intensity

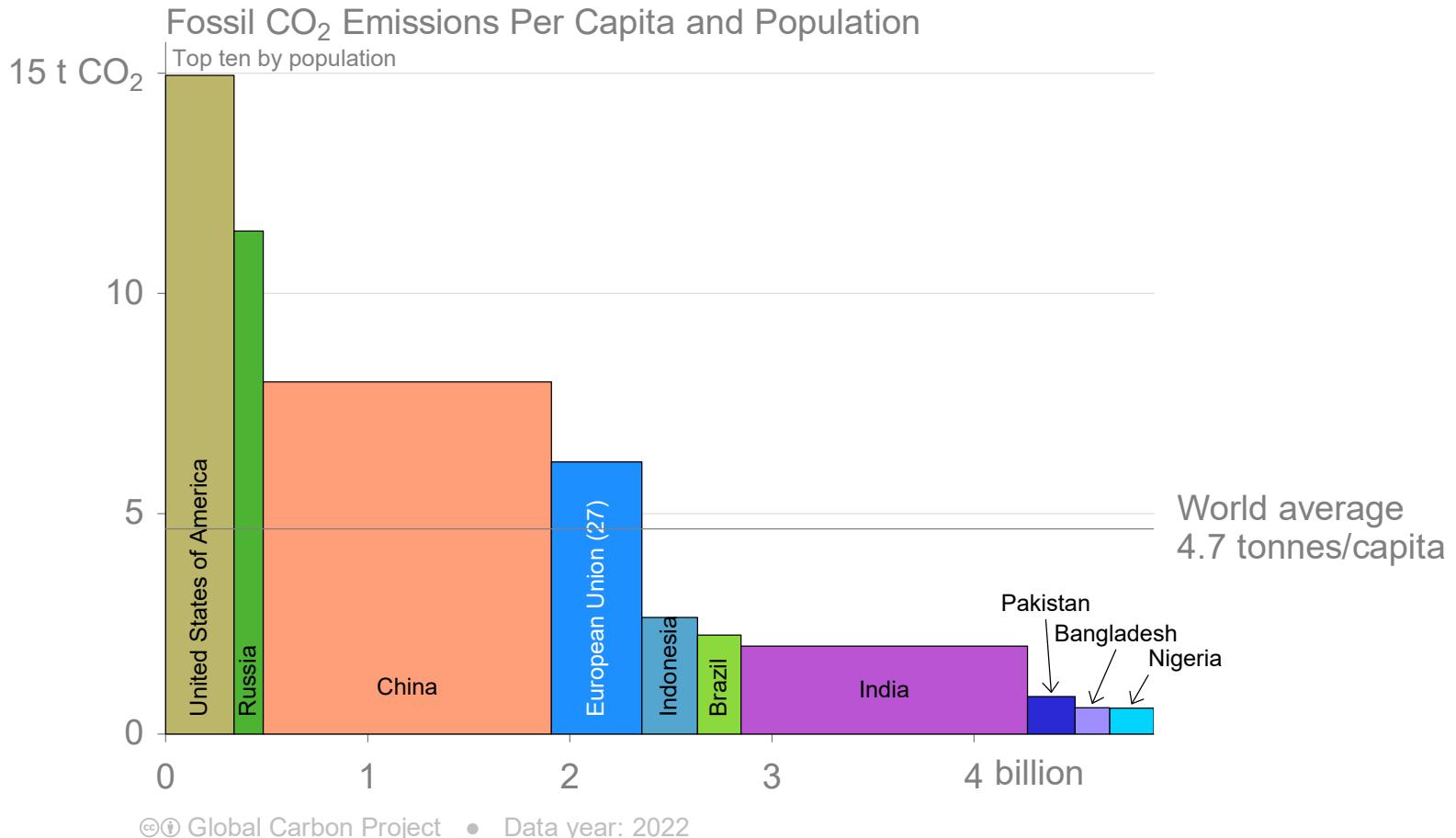
The 10 largest economies have a wide range of emission intensity of economic activity



Emission intensity: Fossil CO₂ emissions divided by Gross Domestic Product (GDP)
Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Fossil CO₂ Emissions per capita

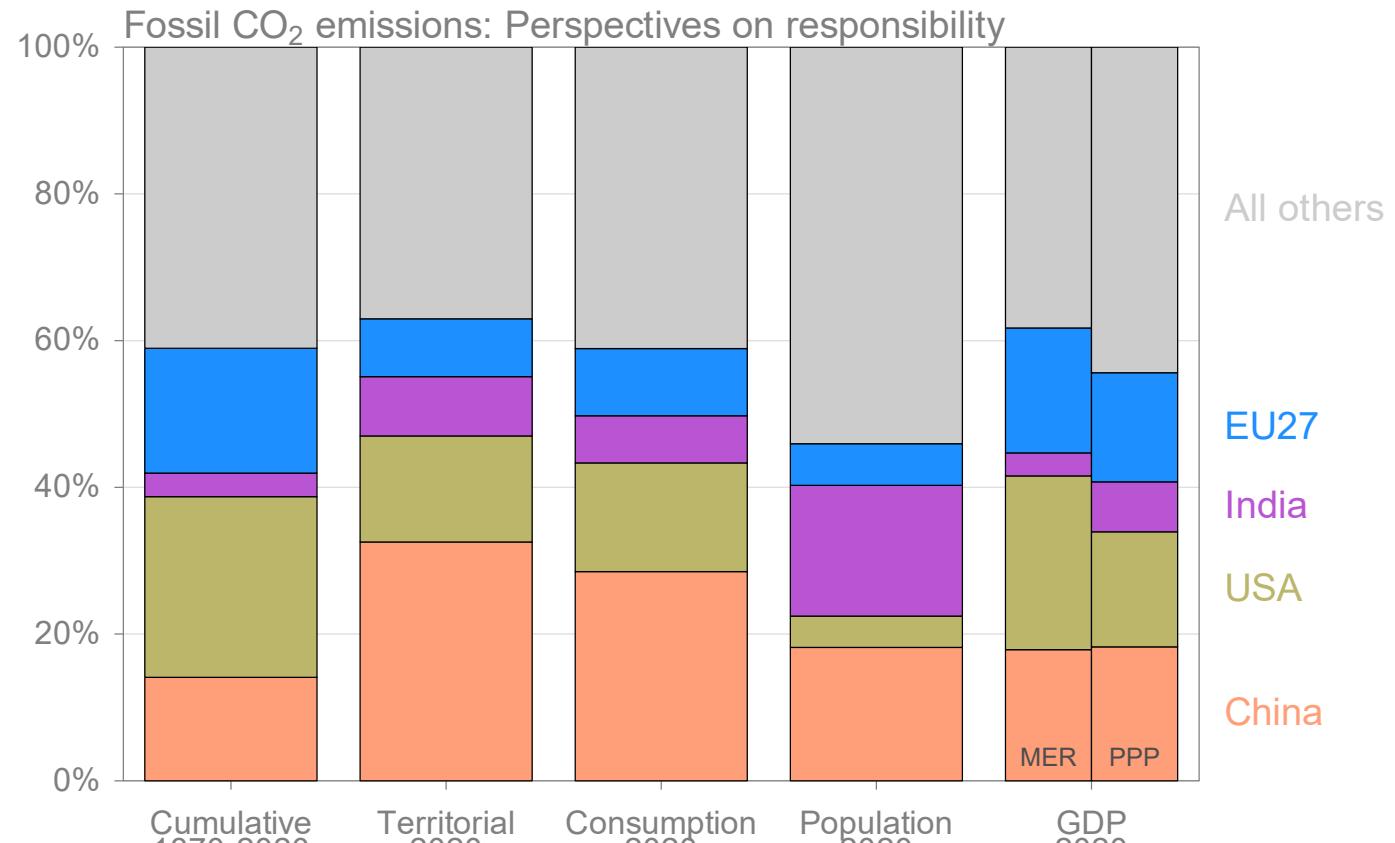
The 10 most populous countries span a wide range of development and emissions per capita



Emission per capita: Fossil CO₂ emissions divided by population
Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Alternative rankings of countries

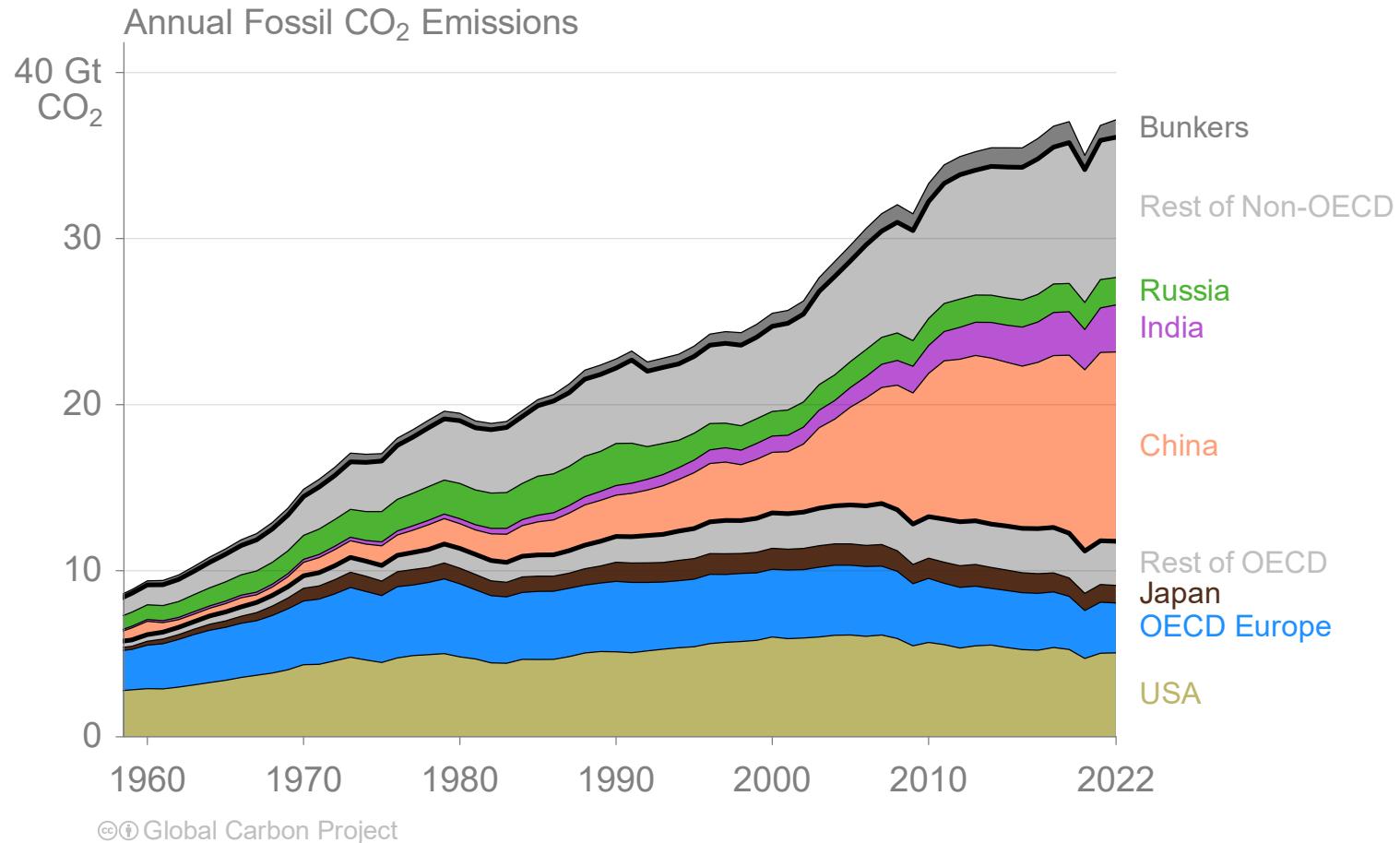
The responsibility of individual countries depends on perspective.
Bars indicate fossil CO₂ emissions, population, and GDP.



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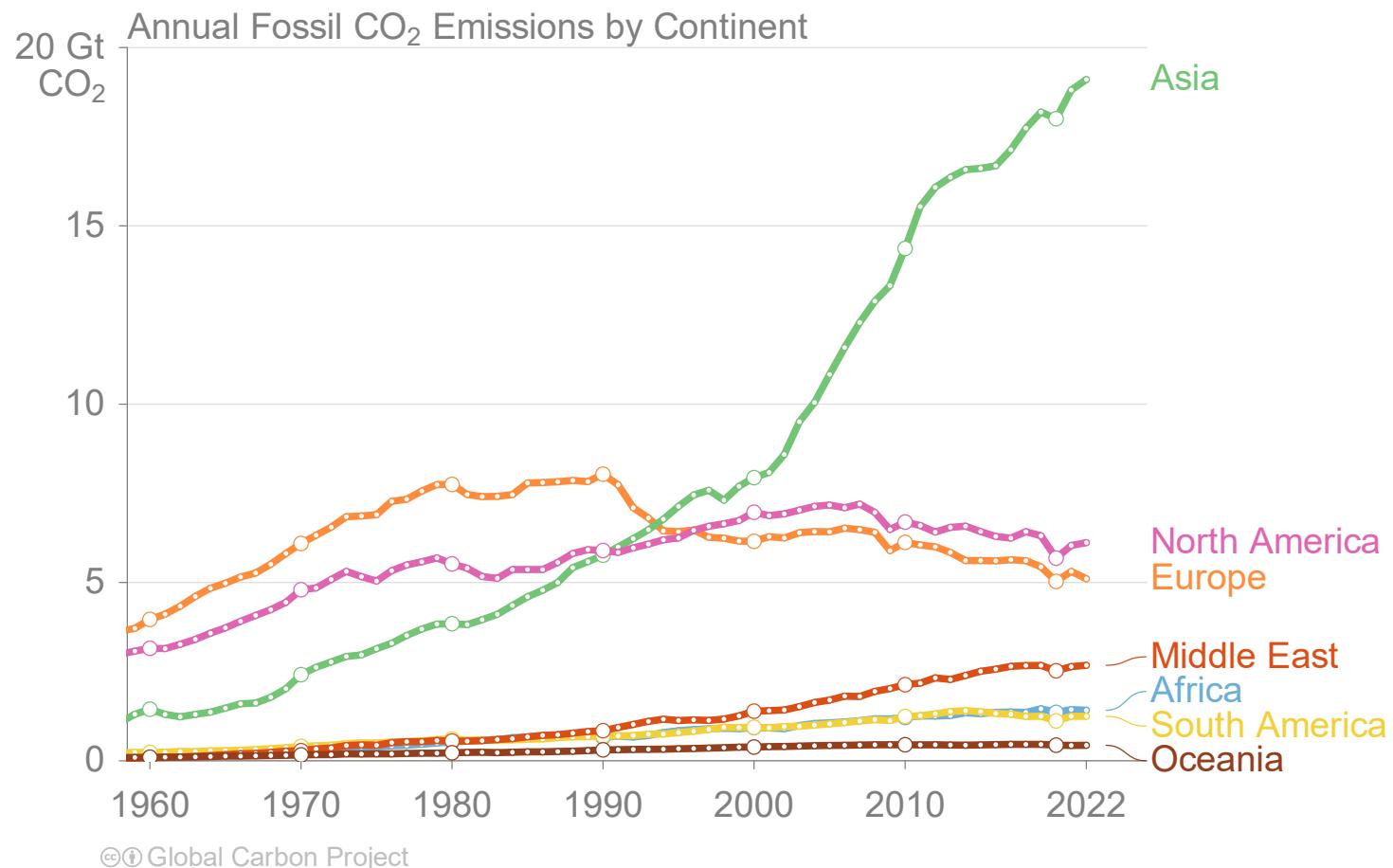
GDP: Gross Domestic Product in Market Exchange Rates (MER) and Purchasing Power Parity (PPP)
Source: [United Nations](#); [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Breakdown of global fossil CO₂ emissions by country



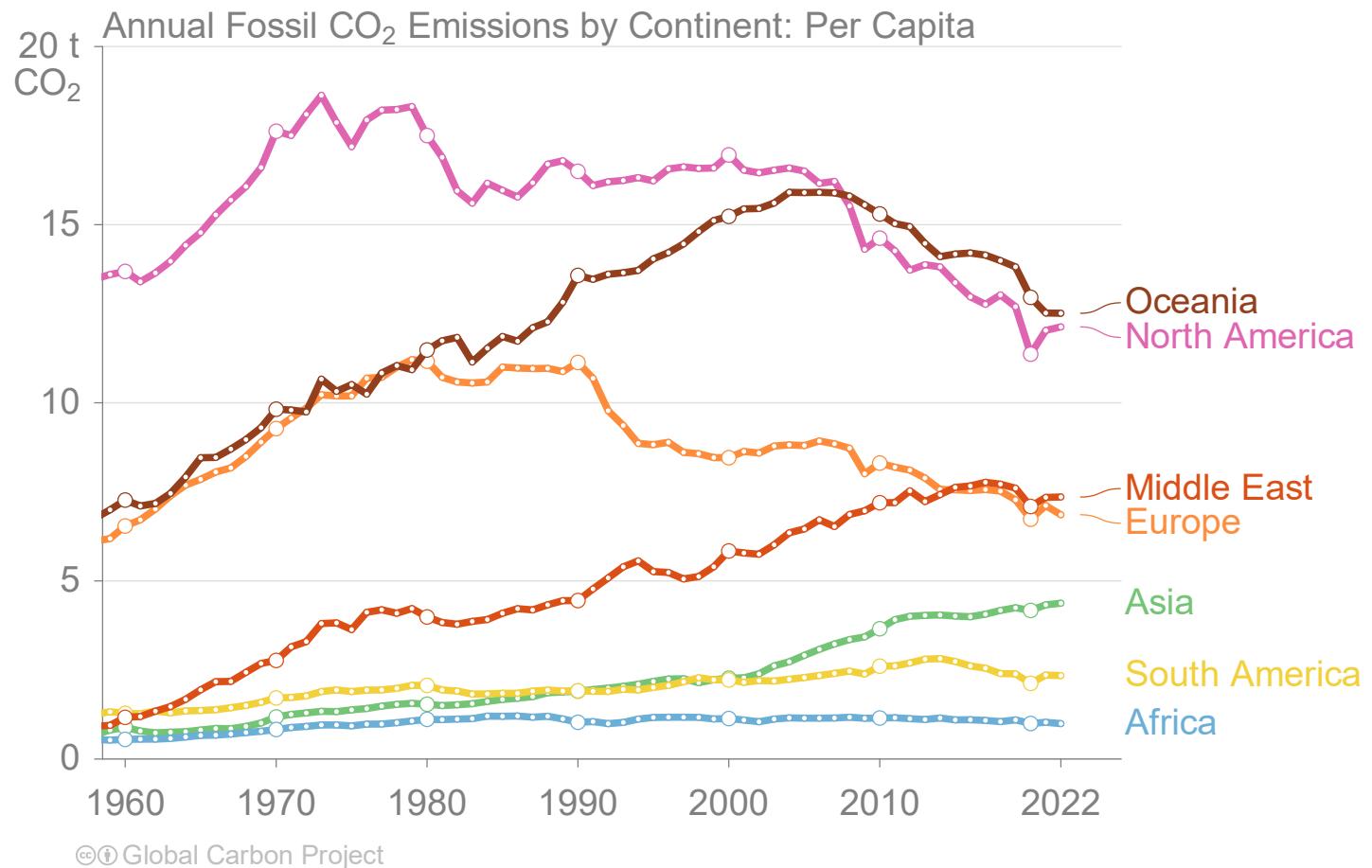
Fossil CO₂ emissions by continent

Asia dominates global fossil CO₂ emissions, while emissions in North America are of similar size to those in Europe, and the Middle East is growing rapidly.



Fossil CO₂ emissions by continent: per capita

Oceania and North America have the highest per capita emissions, while the Middle East has recently overtaken Europe.
Africa has by far the lowest emissions per capita.



Additional Figures

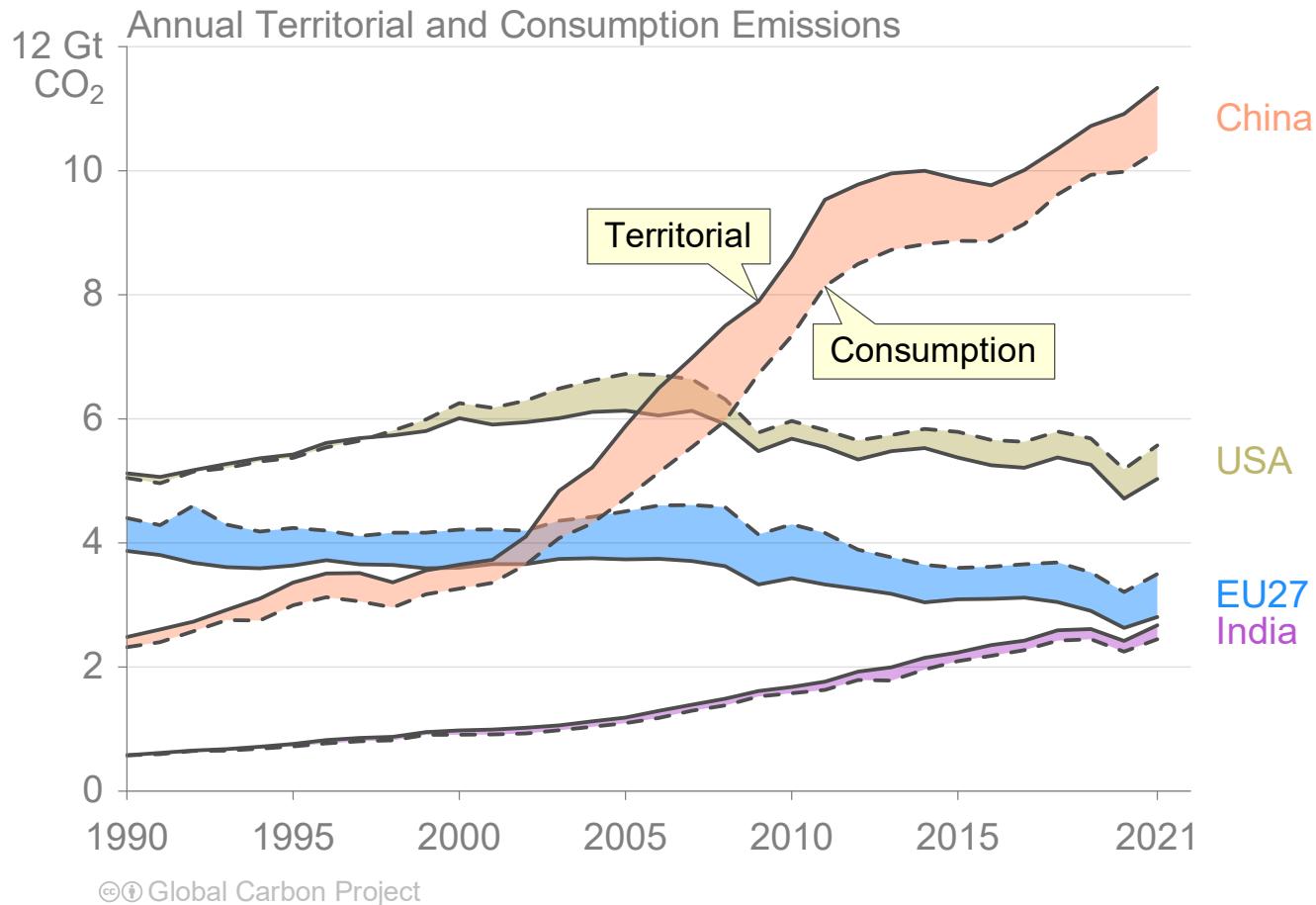
Consumption-based Emissions

Consumption-based emissions allocate emissions to the location that goods and services are consumed

Consumption-based emissions = Production/Territorial-based emissions minus emissions embodied in exports plus the emissions embodied in imports

Consumption-based emissions (carbon footprint)

Allocating fossil CO₂ emissions to consumption provides an alternative perspective.
USA and EU are net importers of embodied emissions, China and India are net exporters.

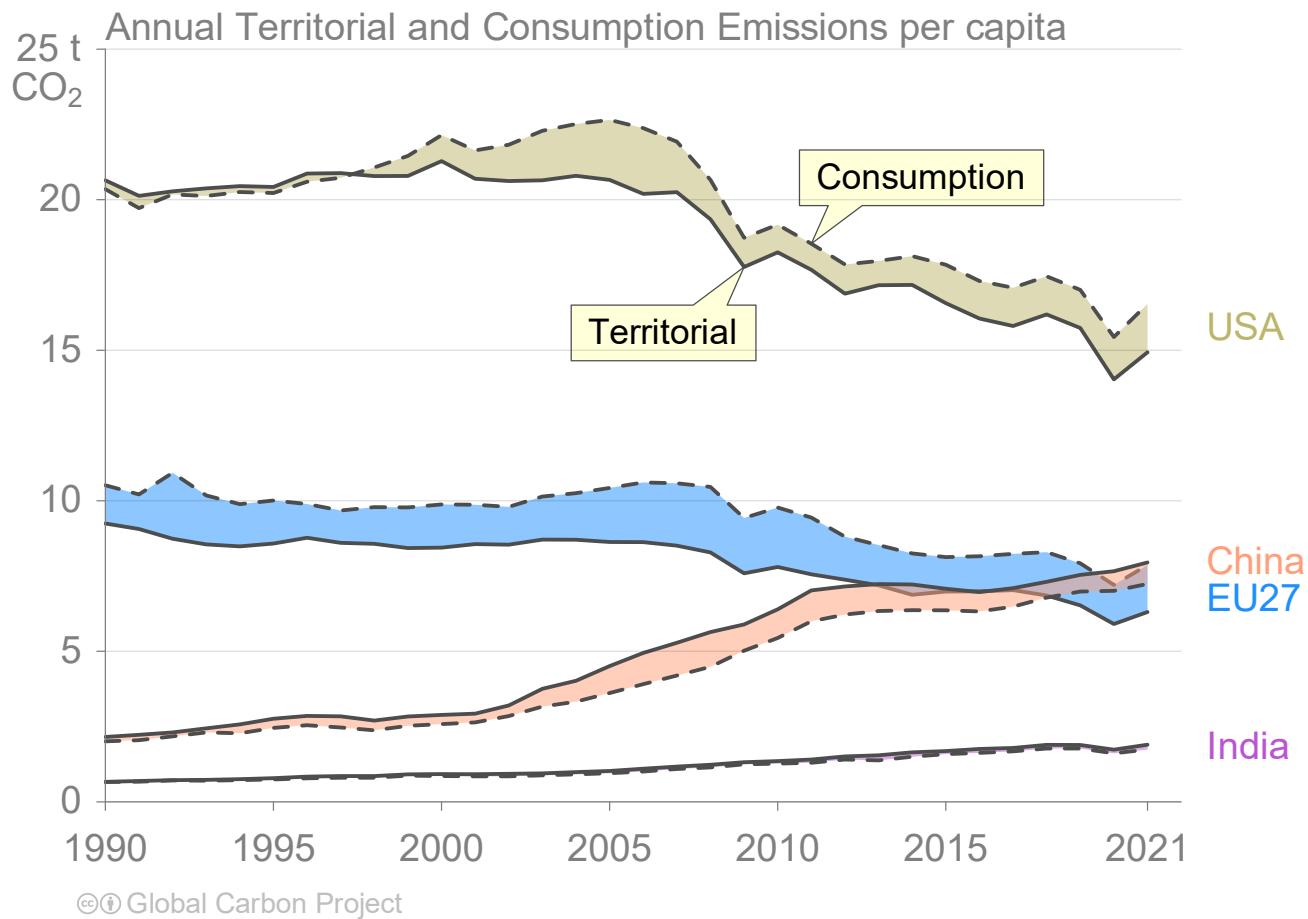


Consumption-based emissions are calculated by adjusting the standard emissions estimates to account for international trade

Source: [Peters et al 2011](#); [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Consumption-based emissions per person

The differences between fossil CO₂ emissions per capita is larger than the differences between consumption and territorial emissions.

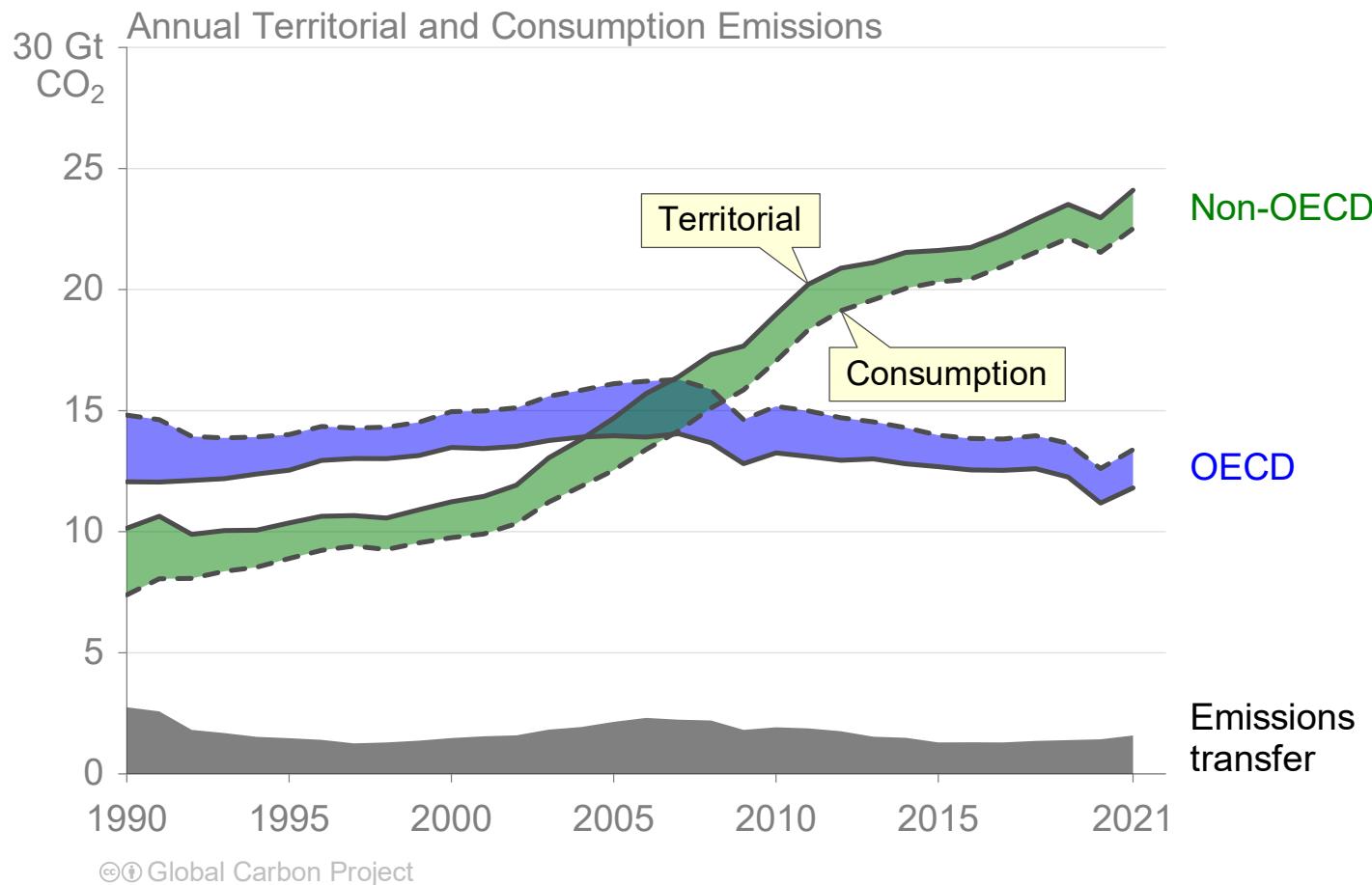


Consumption-based emissions are calculated by adjusting the standard emissions estimates to account for international trade

Source: [Peters et al 2011](#); [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

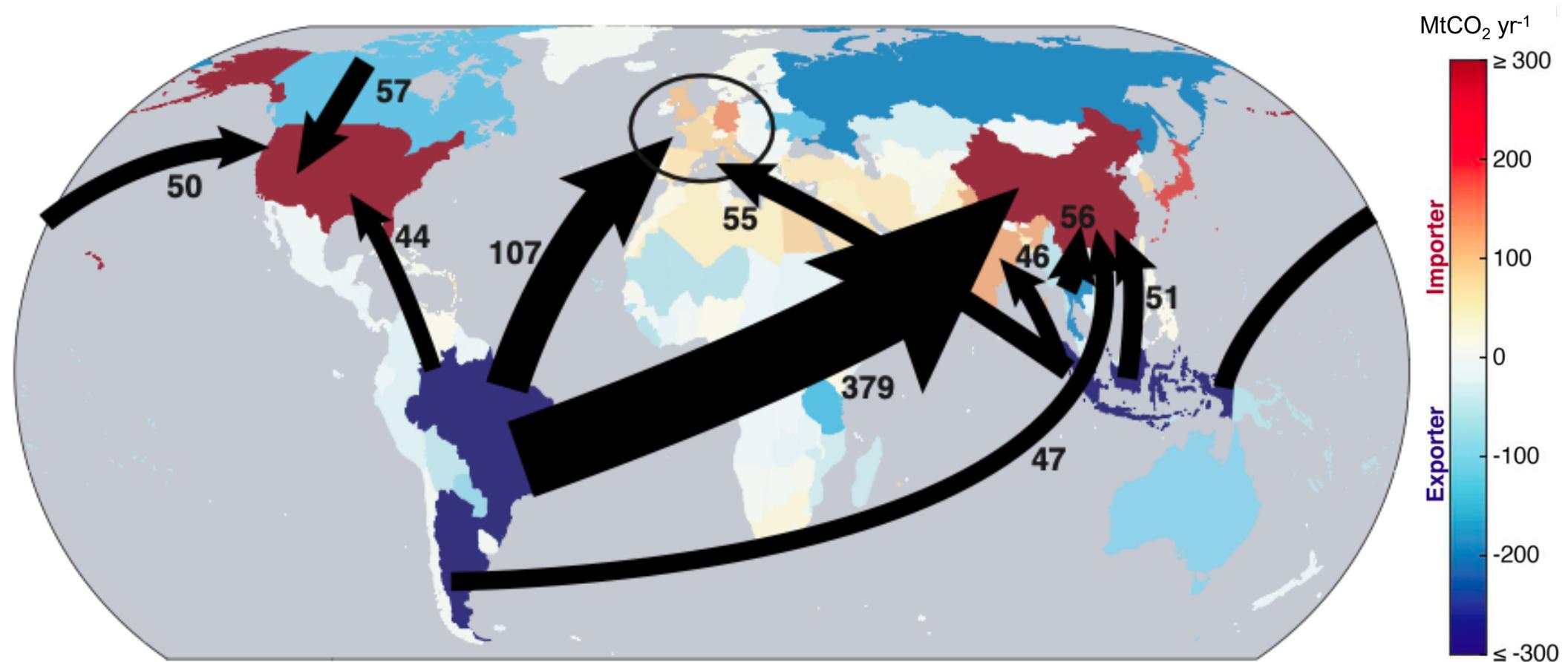
Consumption-based emissions (carbon footprint)

Transfers of emissions embodied in trade between OECD and non-OECD countries grew slowly during the 2000's, declined to 2015 and have been relatively flat since then.



Major flows from production to consumption (2017) — Land Use Change CO₂

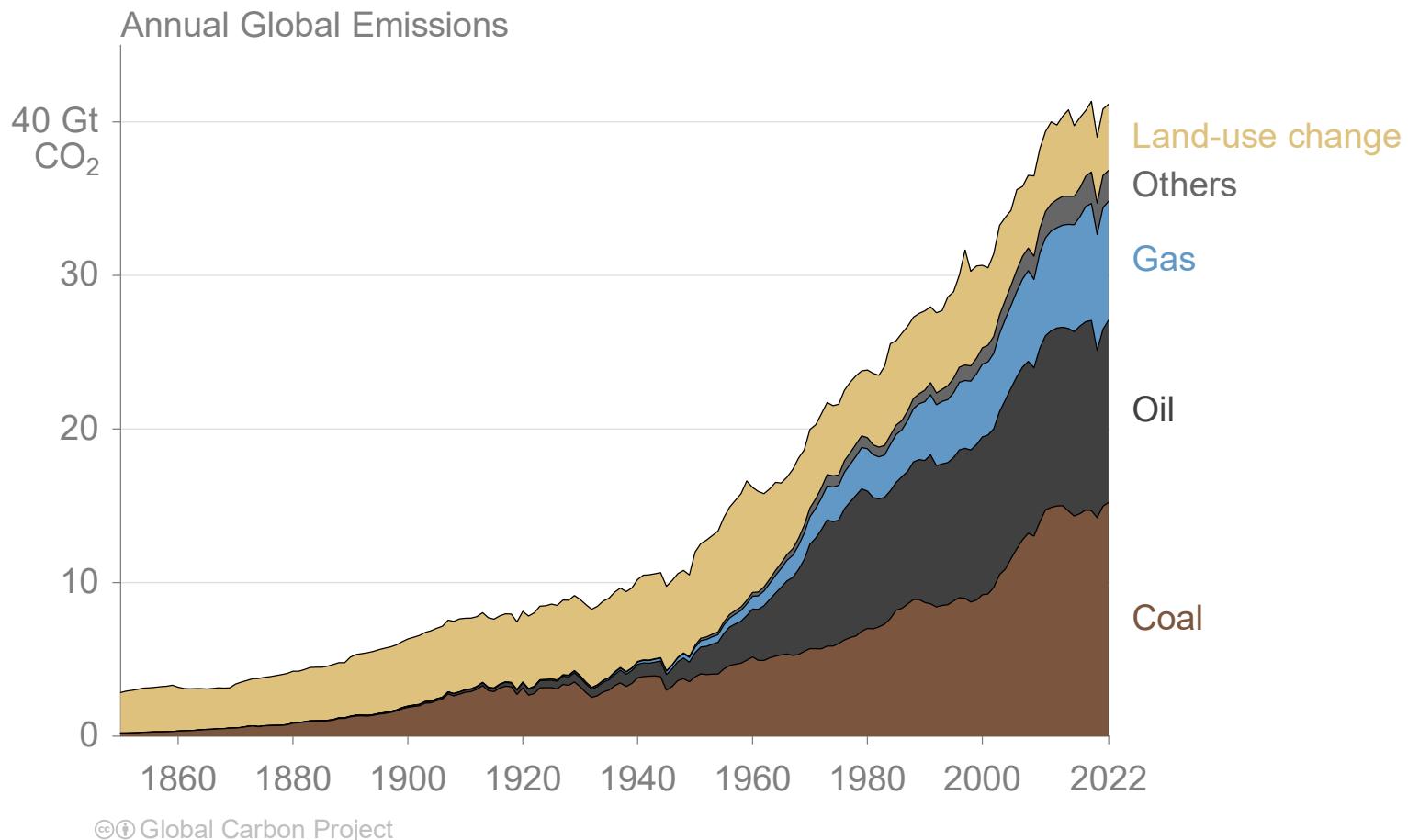
Global distribution of land-use change emissions embodied in trade: Arrows show largest flows from location of generation of emissions to location of consumption of agricultural and forestry goods.



Additional Figures Historical Emissions

Total global emissions by source

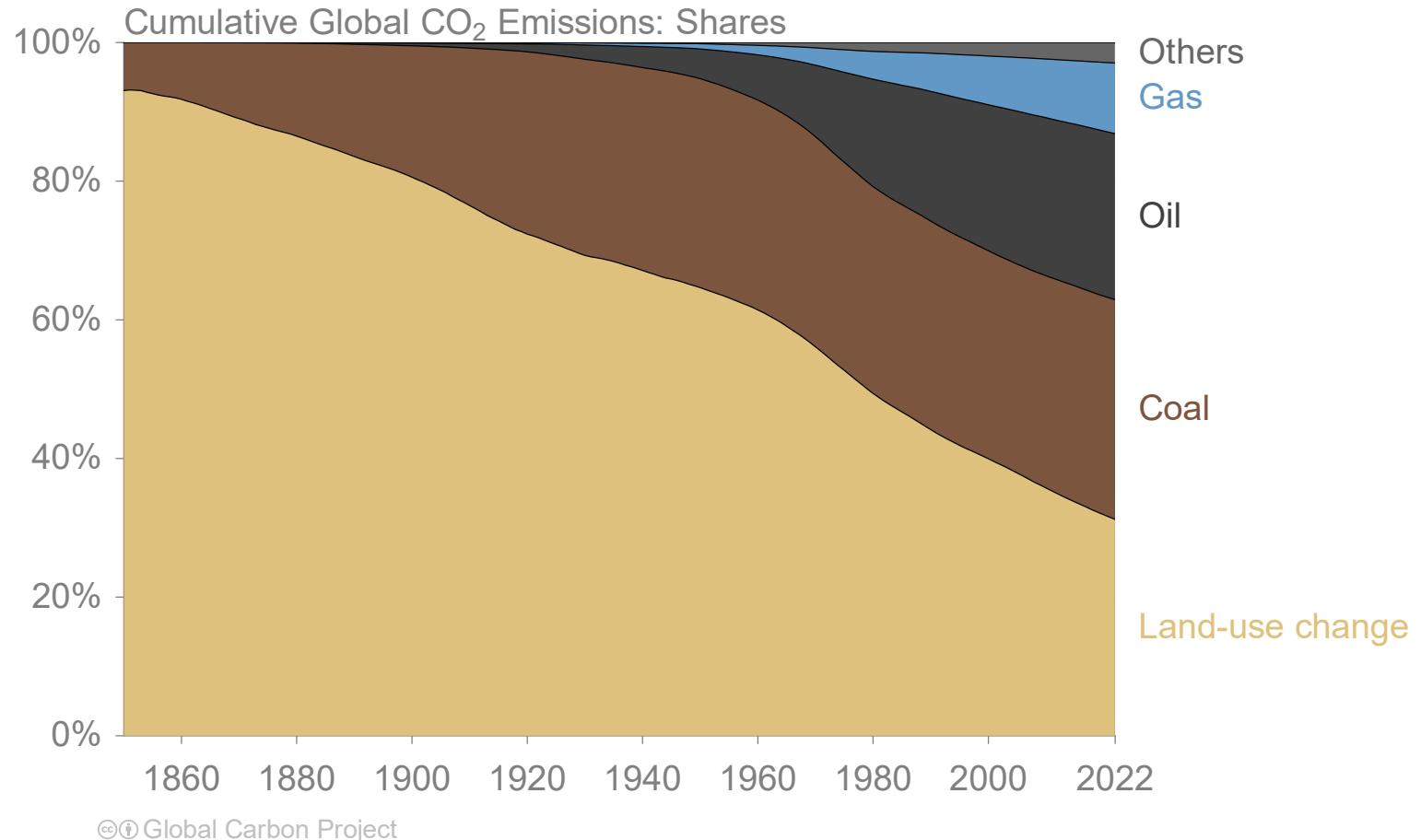
Land-use change was the dominant source of annual CO₂ emissions until around 1950.
Fossil CO₂ emissions now dominate global changes.



Others: Emissions from cement production, gas flaring and carbonate decomposition

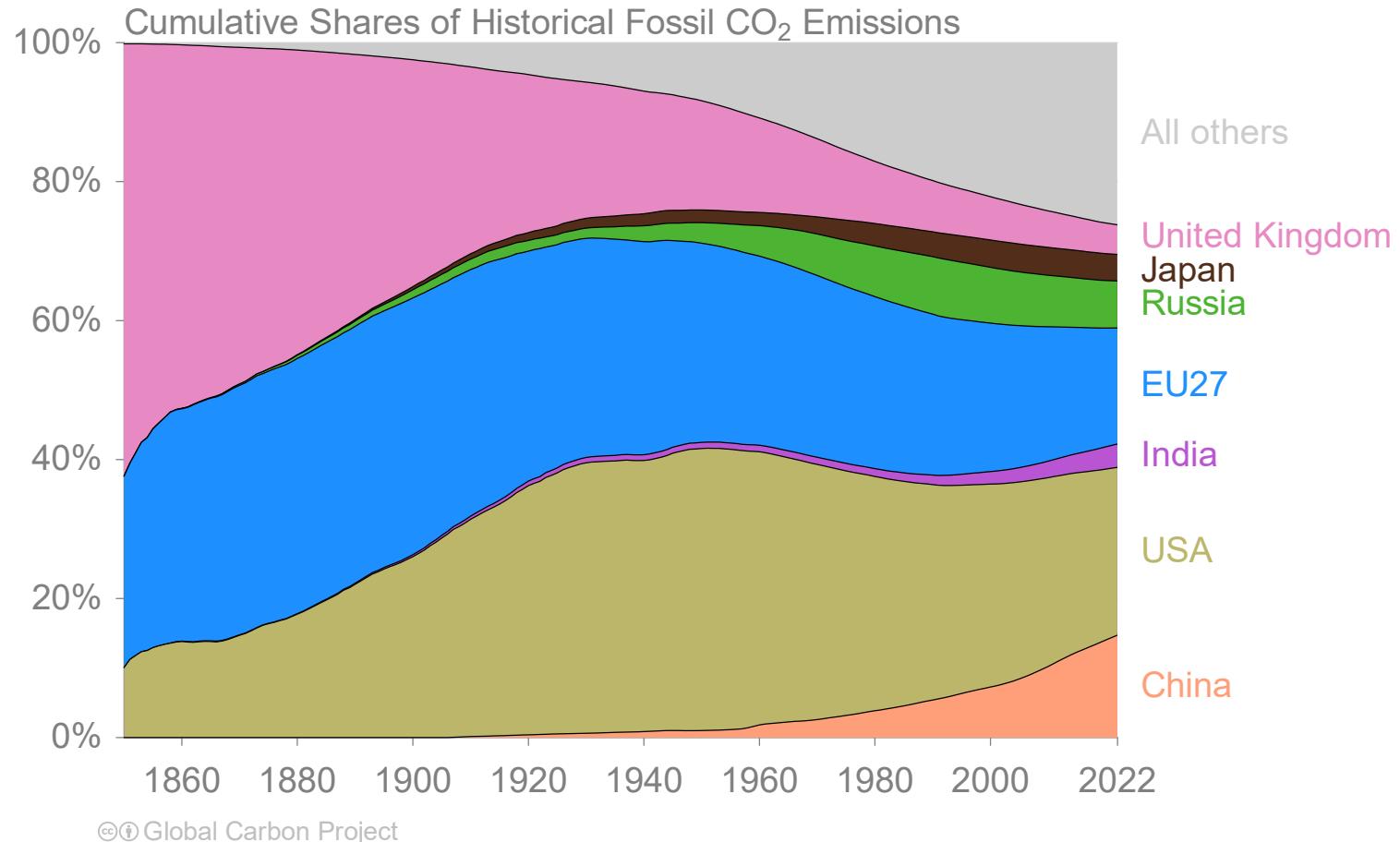
Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Historical cumulative emissions by source



Others: Emissions from cement production, gas flaring and carbonate decomposition
Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

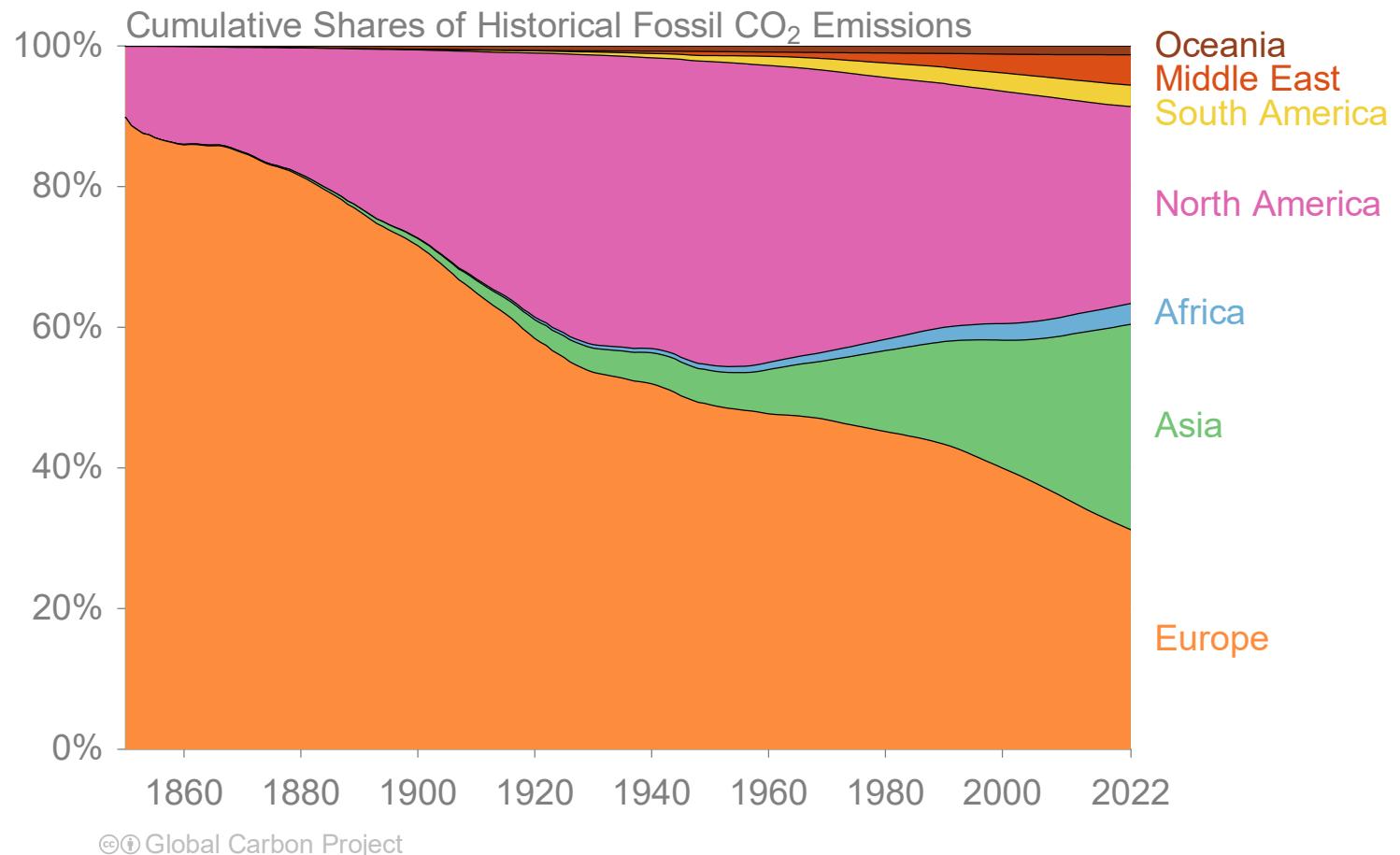
Historical cumulative fossil CO₂ emissions by country



'All others' includes all other countries along with emissions from international aviation and maritime shipping
Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Historical cumulative emissions by continent

Cumulative fossil CO₂ emissions (1850–2022). North America and Europe have contributed the most cumulative emissions, but Asia is growing fast



The figure excludes emissions from international aviation and maritime shipping

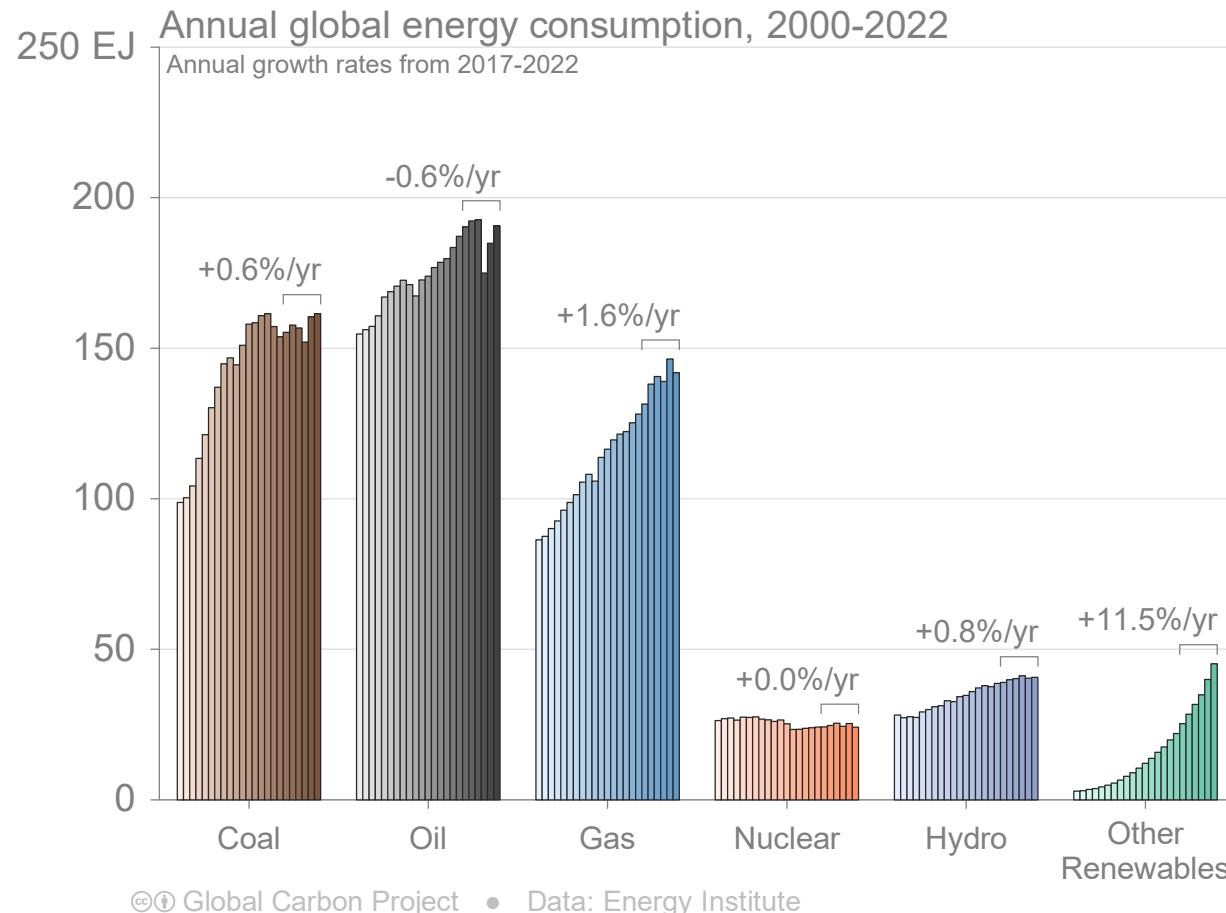
Source: [Friedlingstein et al 2023](#); [Global Carbon Project 2023](#)

Additional Figures

Energy Use

Energy use by source

Energy consumption by fuel source from 2000 to 2022, with growth rates indicated for the more recent period of 2017 to 2022

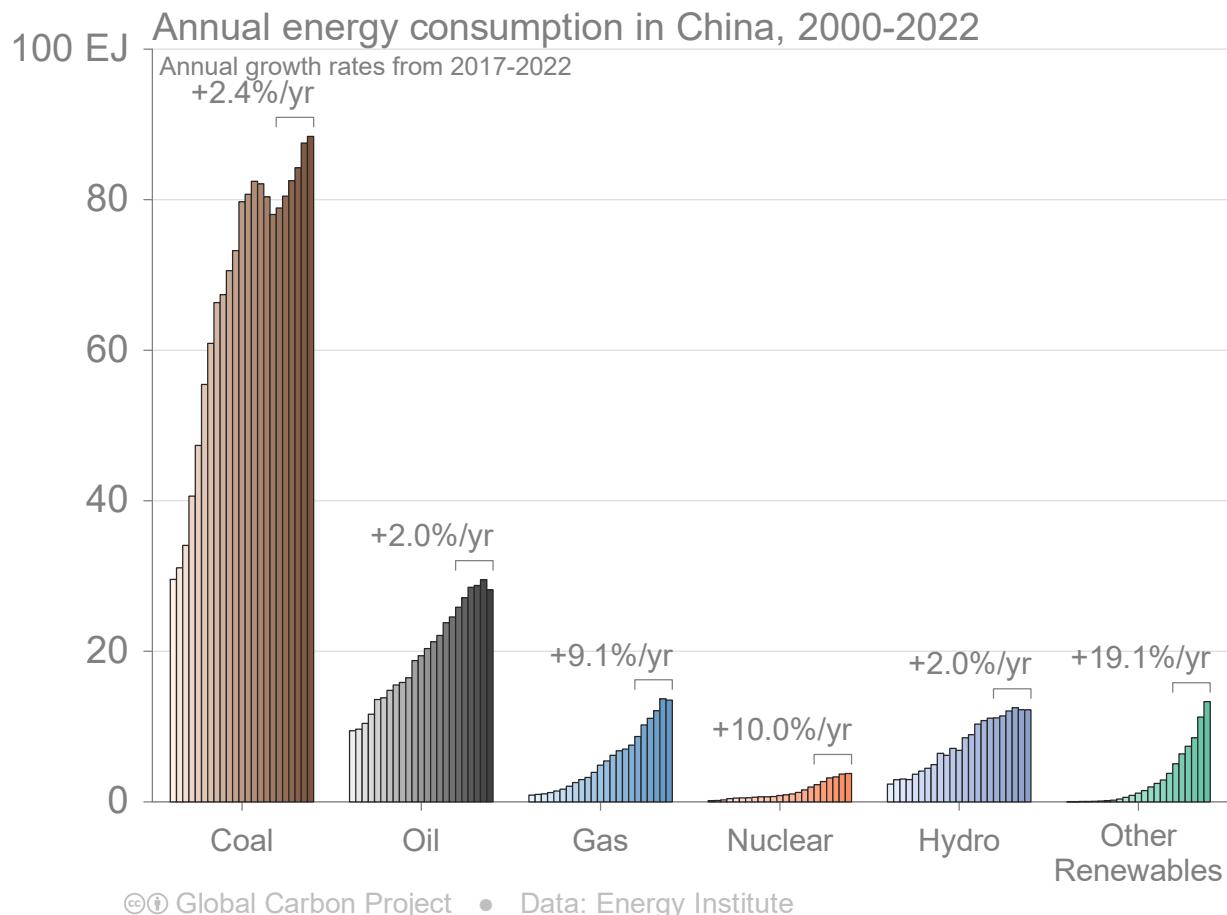


This figure shows “primary energy” using the BP substitution method
(non-fossil sources are scaled up by an assumed fossil efficiency of approximately 0.38)

Source: [Energy Institute, 2023](#); [Global Carbon Project 2023](#)

Energy use by source: China

Coal consumption in energy units has returned to peak levels,
while consumption of all other energy sources is growing strongly

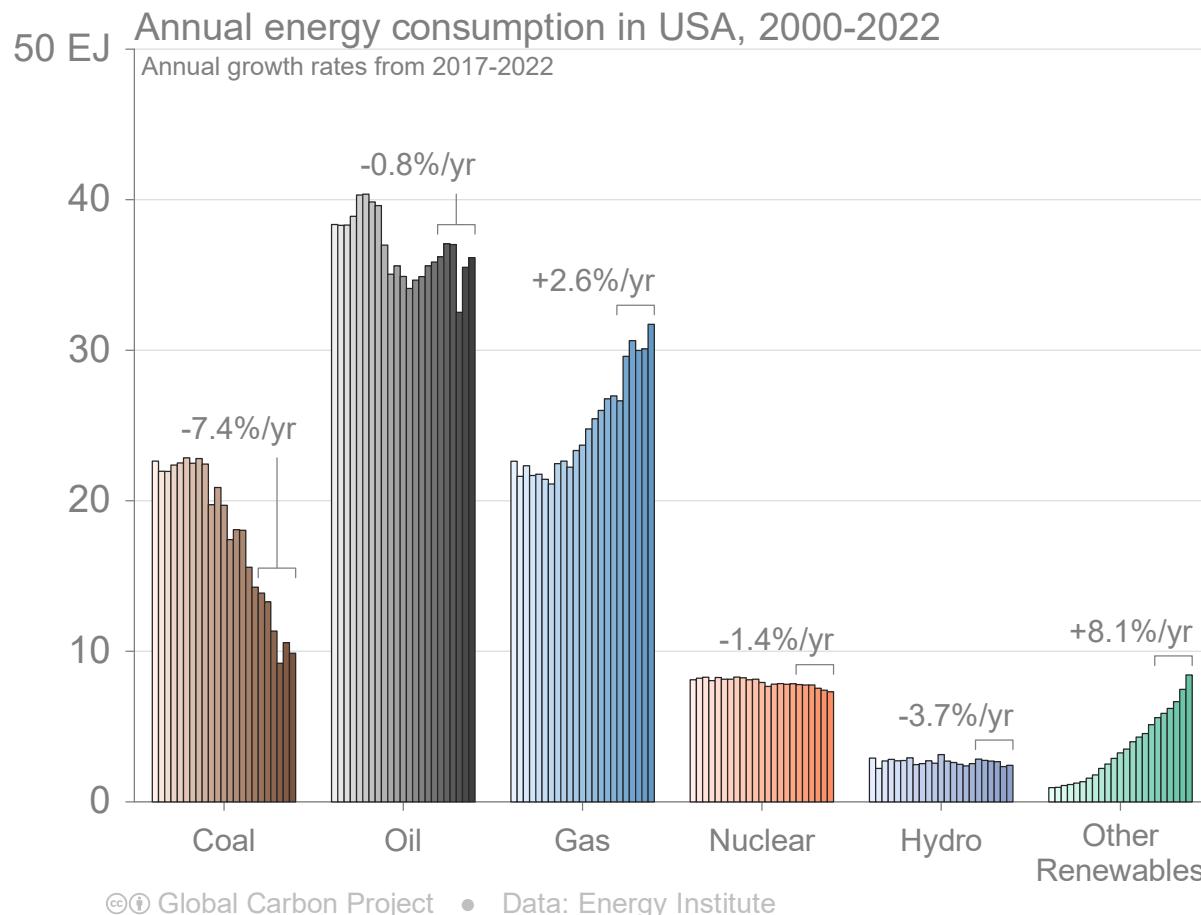


This figure shows “primary energy” using the BP substitution method
(non-fossil sources are scaled up by an assumed fossil efficiency of approximately 0.38)

Source: [Energy Institute, 2023](#); [Global Carbon Project 2023](#)

Energy use by source: USA

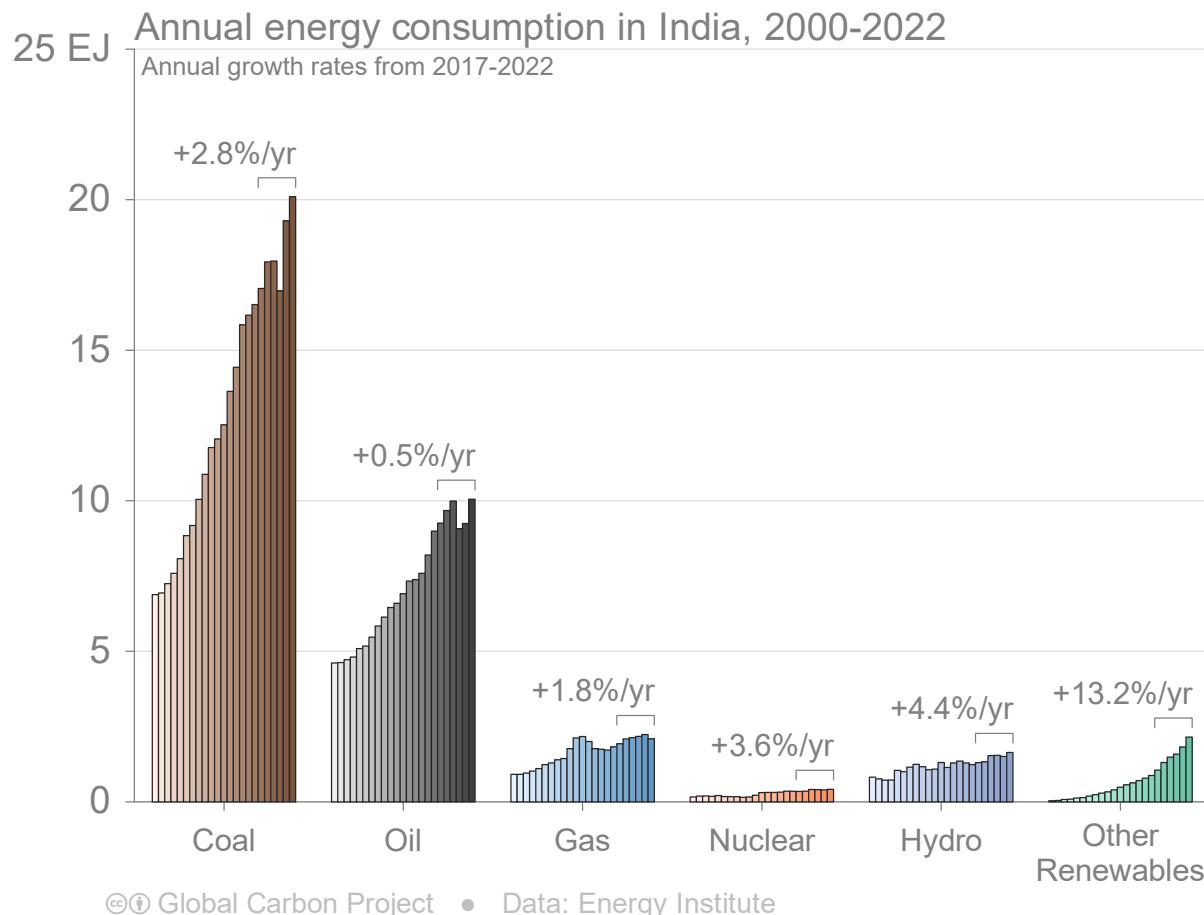
Coal consumption has declined sharply in recent years with the shale gas boom and strong renewables growth. Output from nuclear power is slowly declining as stations are retired.



This figure shows “primary energy” using the BP substitution method
(non-fossil sources are scaled up by an assumed fossil efficiency of approximately 0.38)
Source: [Energy Institute, 2023](#); [Global Carbon Project 2023](#)

Energy use by source: India

Pandemic year 2020 temporarily interrupted India's strong growth in energy consumption.
Consumption of coal and oil dominate.



This figure shows “primary energy” using the BP substitution method
(non-fossil sources are scaled up by an assumed fossil efficiency of approximately 0.38)

Source: [Energy Institute, 2023](#); [Global Carbon Project 2023](#)

Energy use by source: EU

Consumption of both oil and gas has rebounded in recent years, while coal continues to decline.
Renewables are growing strongly, now providing more energy than nuclear power.

