GLOBAL CARBON project

GLOBAL CARBON BUDGET 2023

The GCP is a Global Research Project of futurearth Research. Innovation. Sustainability.

and a Research Partner of WCRP World Climate Research Programme

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Acknowledgements

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

Atmospheric CO_2 datasets
NOAA/GML (Lan et al., 2023)
Scripps (Keeling et al., 1976)

Atmospheric O_2 datasets
Scripps (Keeling 2023)

Fossil CO_2 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

fCO_2 based ocean flux products
CMEMS-LSCE-FFNNv2 | Jena- MLS | JMA-MLR | LDEO-HPD | MPI-SOMFFN | NIES-ML3 | OS-ETHZ-GRaCER | UoEx-Watson

Surface Ocean CO_2 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—CO_2-LR | MIROC-ES2L | MPI-ESM1-2-LR

Full references provided in Friedlingstein et al 2023

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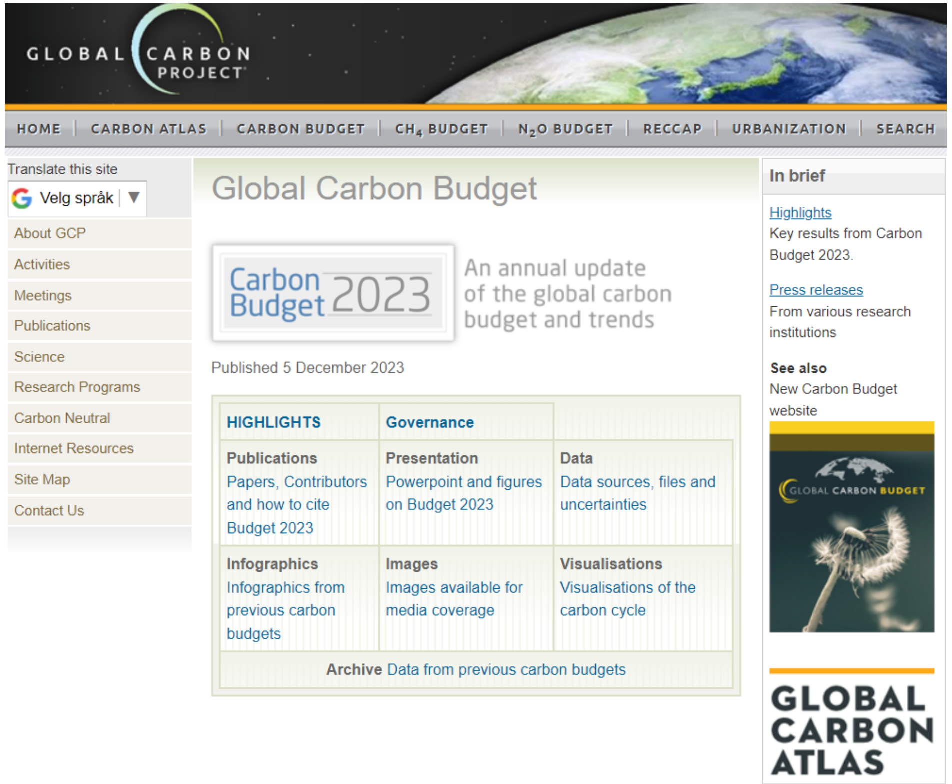
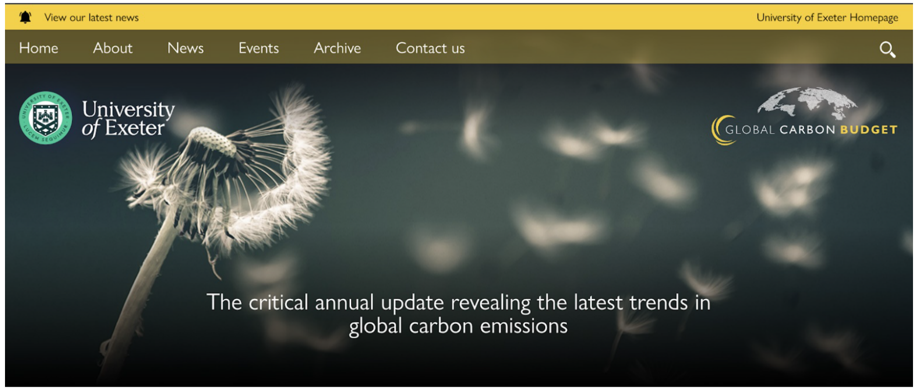
Data Access and Additional Resources



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

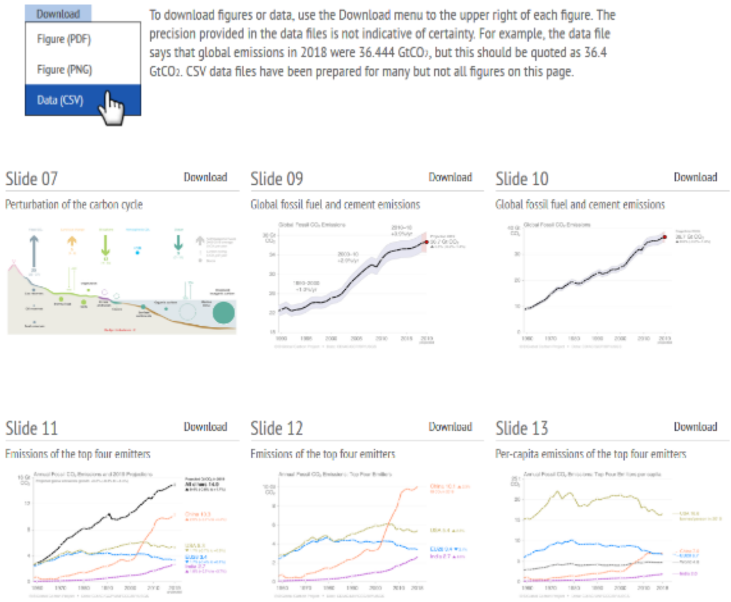


More information, data sources and data files:
https://globalcarbonbudget.org/carbonbudget

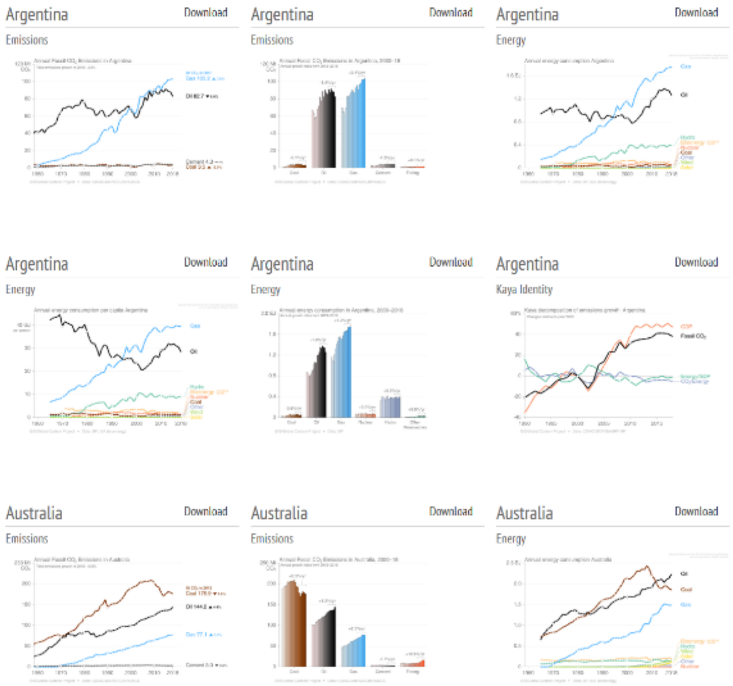
More information, data sources and data files:
www.globalcarbonatlas.org
(co-funded in part by BNP Paribas Foundation)

Download of figures and data

Global Carbon Budget



Additional country figures



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 CO_2 ($GtCO_2$)

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

1 kg carbon (C) = 3.664 kg carbon dioxide (CO_2)

1 GtC = 3.664 billion tonnes CO_2 = 3.664 $GtCO_2$

(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.

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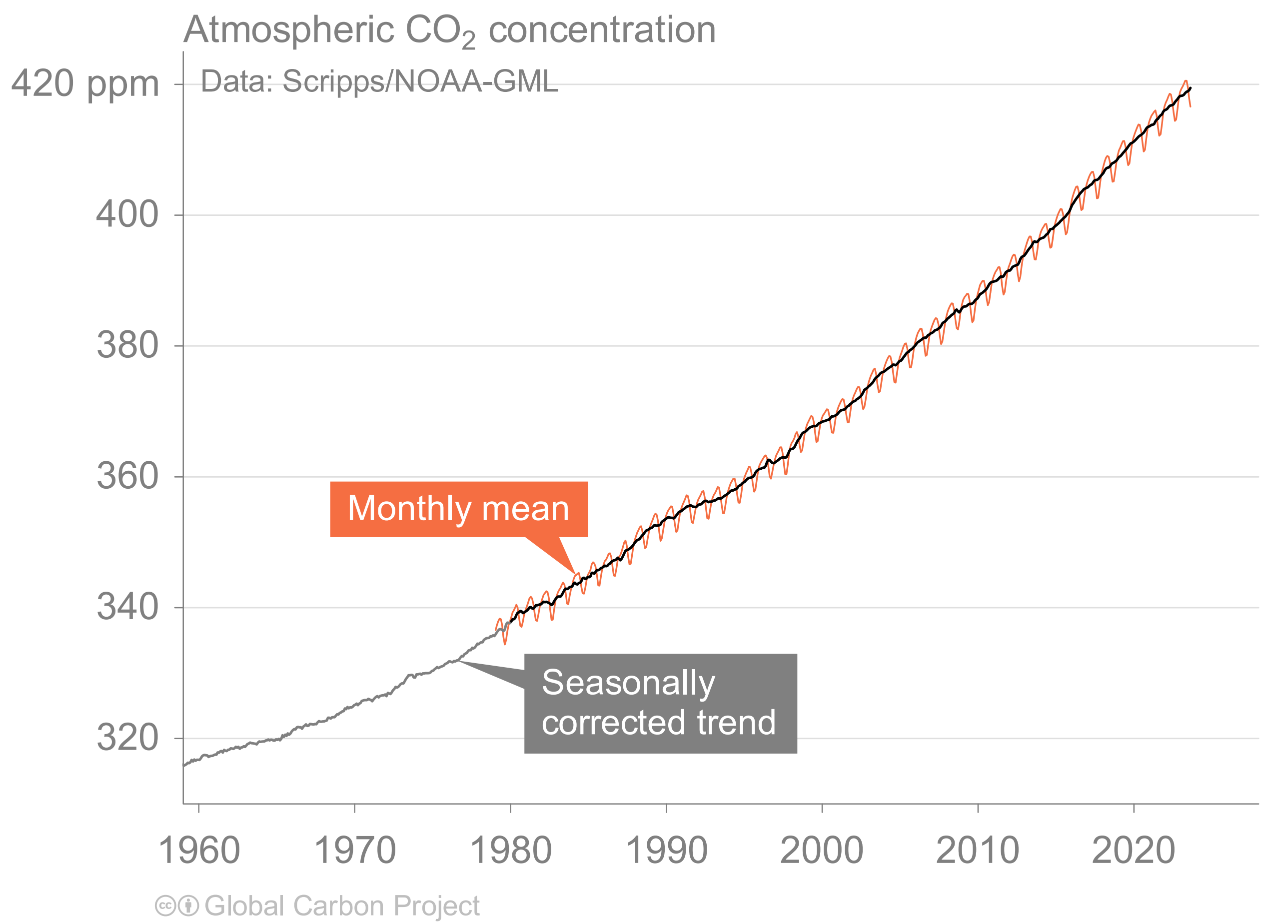
Atmospheric CO_2 concentration

The global CO_2 concentration increased from ~277 ppm in 1750 to 419.3 ppm in 2023 (up 51%)

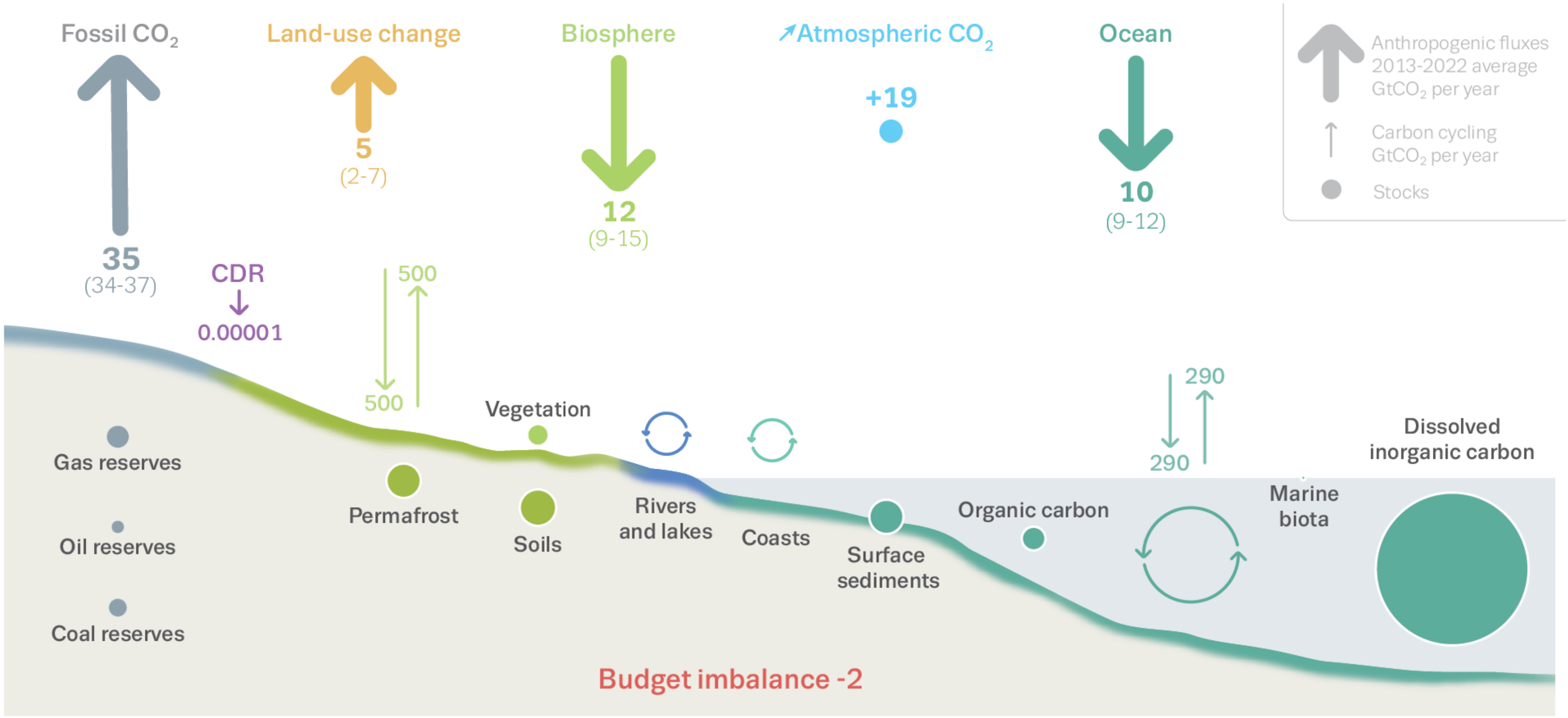


Globally averaged surface atmospheric CO_2 concentration. Data from: NOAA-GML after 1980; the Scripps Institution of Oceanography before 1980

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 ($GtCO_2$/yr)



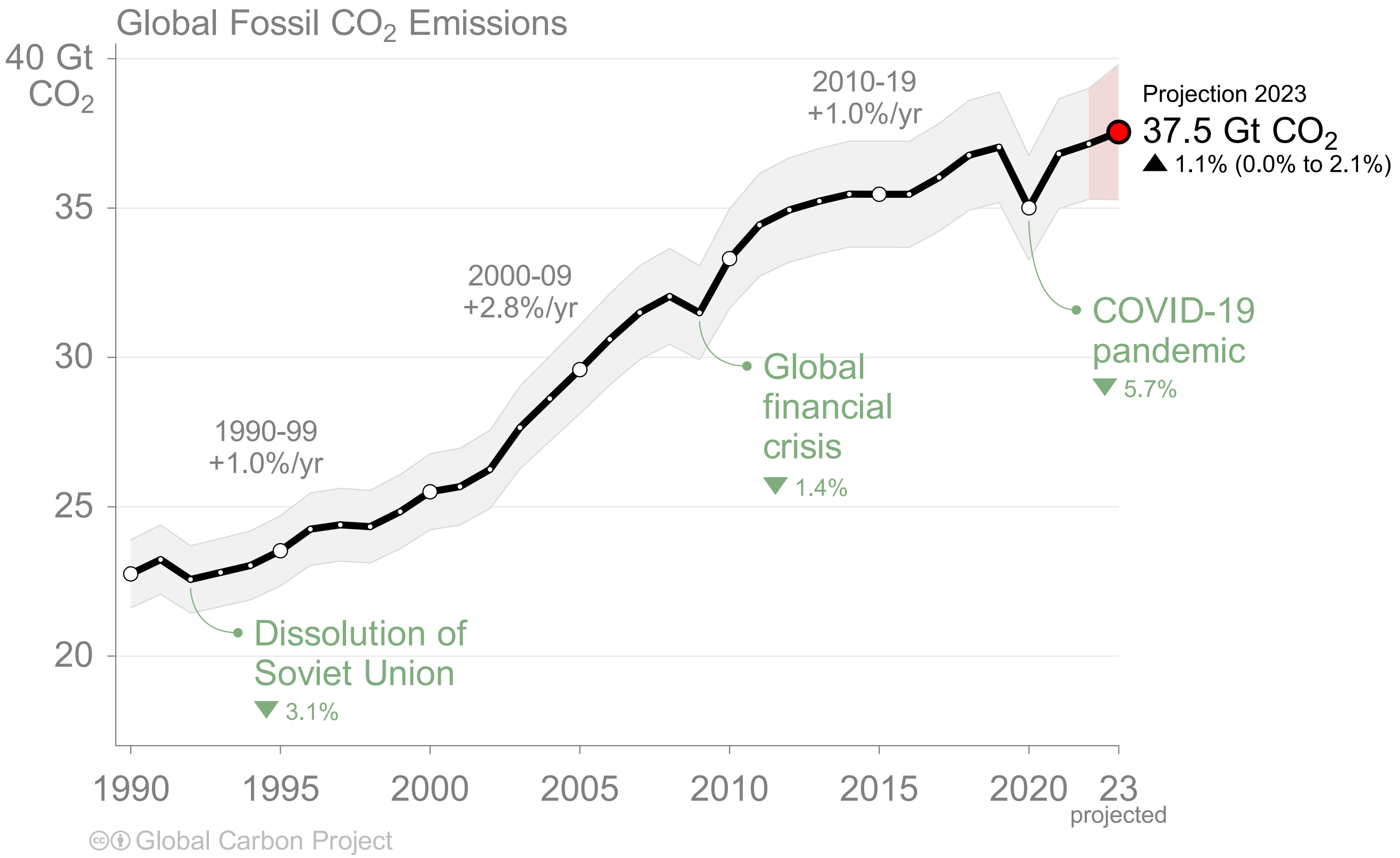
CDR here refers to Carbon Dioxide Removal besides those associated with land-use that are accounted for in the Land-use change estimate.
The budget imbalance is the difference between the estimated emissions and sinks.
Source: [NOAA-GML](); [Friedlingstein et al 2023](); [Canadell et al 2021 (IPCC AR6 WG1 Chapter 5)](); [Global Carbon Project 2023]()

Key Highlights in 2023

Global Fossil CO_2 Emissions

Global fossil CO_2 emissions: 37.1 ± 2 $GtCO_2$ in 2022, 63% over 1990

Projection for 2023: 37.5 ± 2 $GtCO_2$, 1.1% [0.0% to +2.1%] higher than 2022



Uncertainty is ±5% for one standard deviation (IPCC "likely" range)

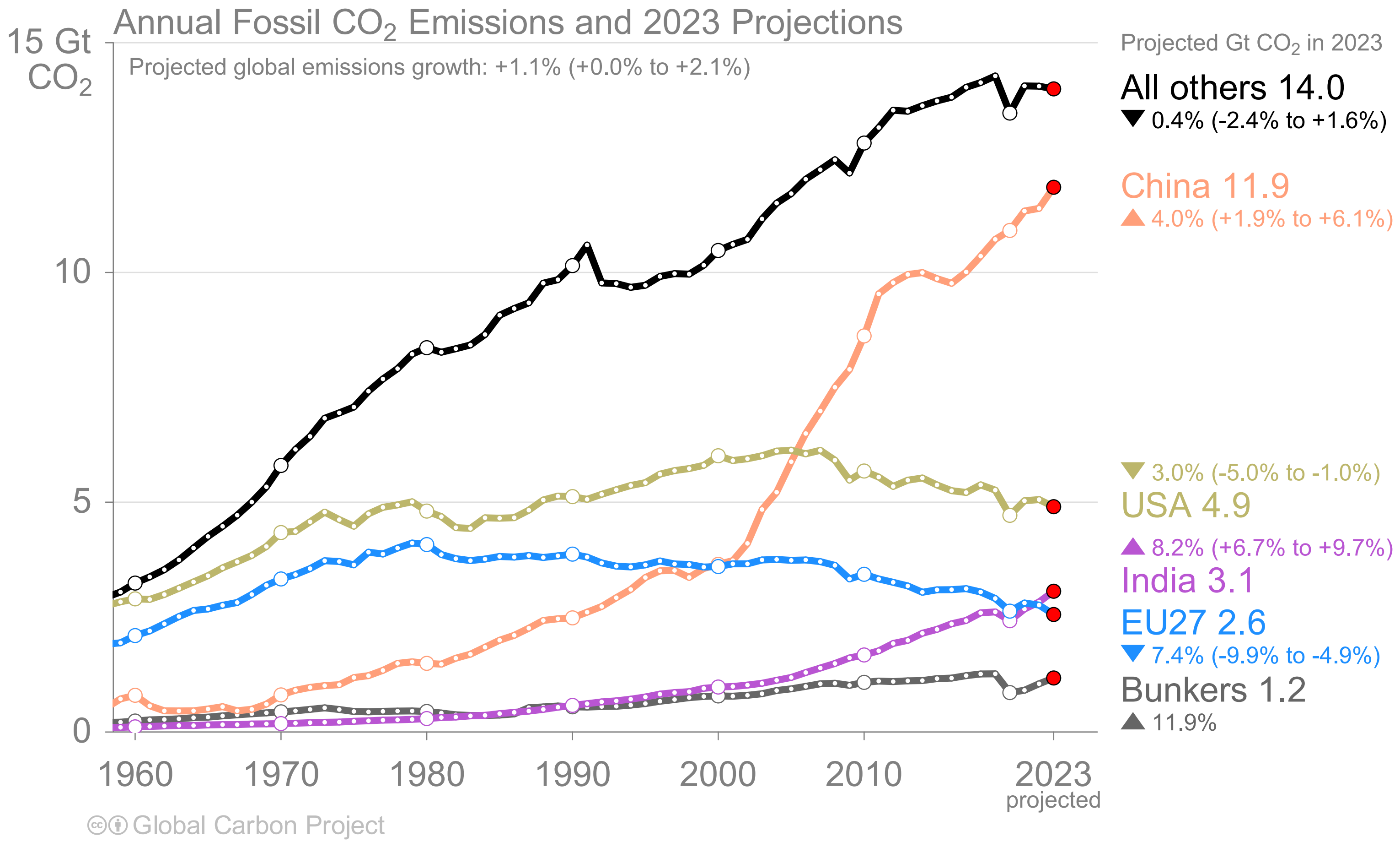
When including cement carbonation, the 2022 and 2023 estimates amount to 36.4 ± 2 $GtCO_2$ and 36.8 ± 2 $GtCO_2$ respectively

The 2023 projection is based on preliminary data and modelling.

Source: Friedlingstein et al 2023; Global Carbon Project 2023

Emissions Projections for 2023

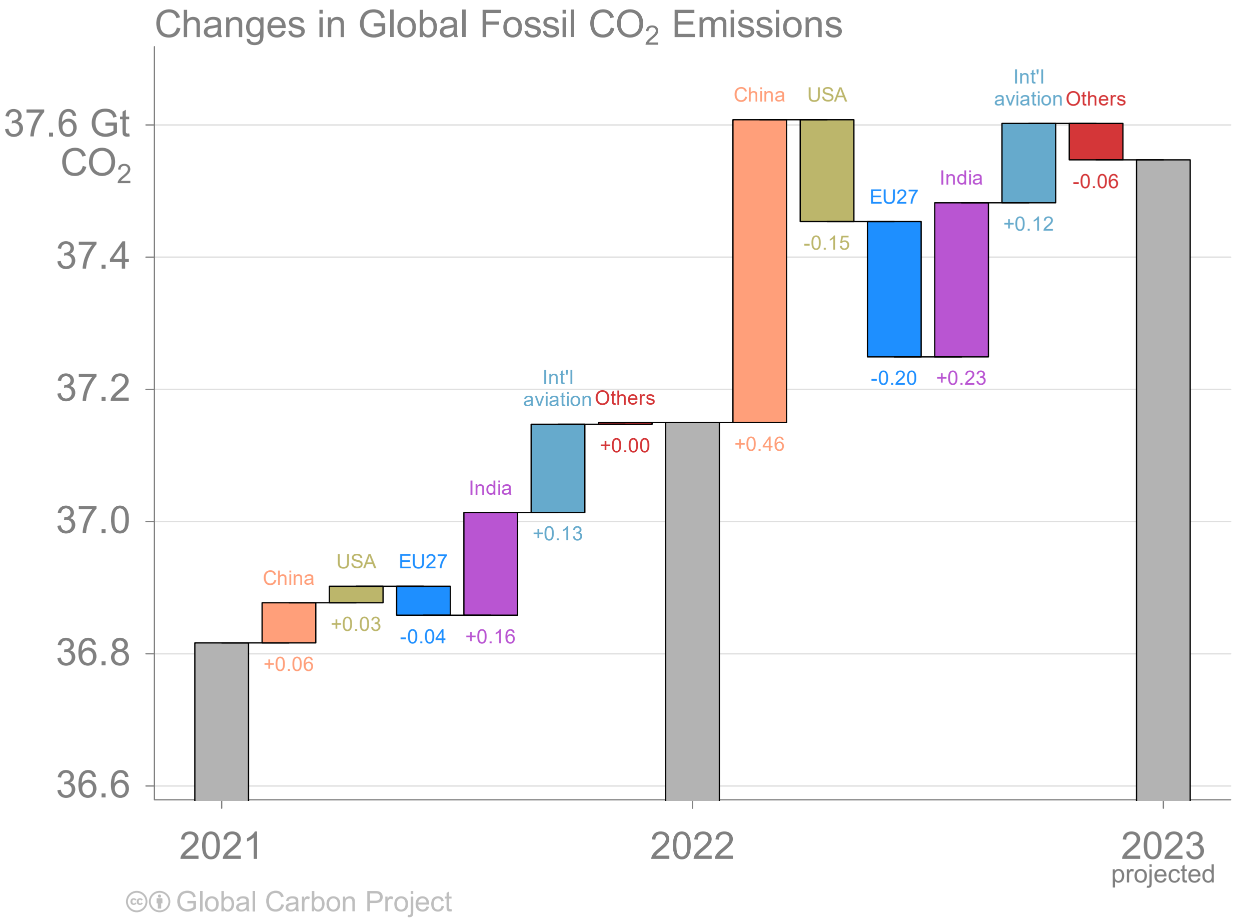
There are sharp contrasts between the projected emissions changes for the top emitters



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 CO_2 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

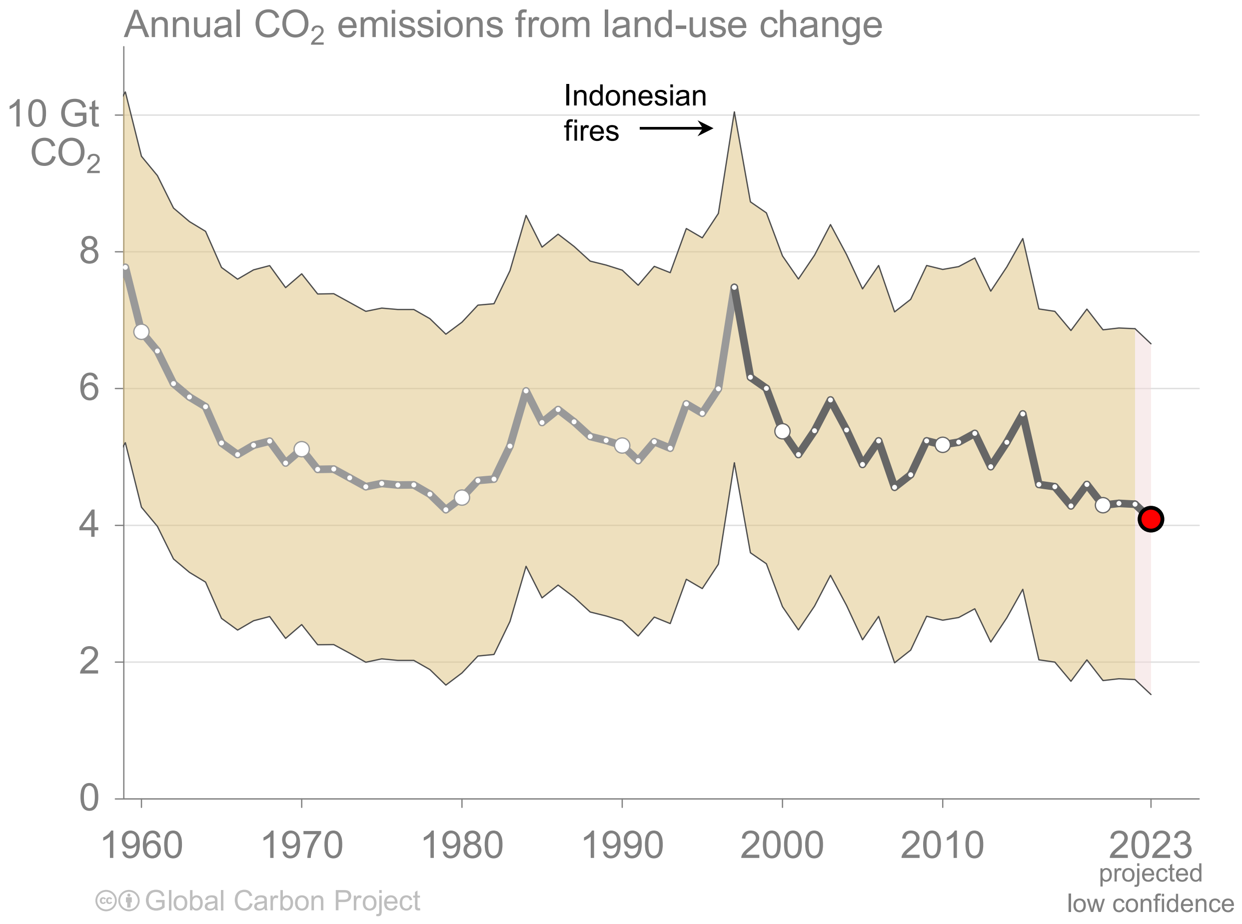
Summary of fossil CO_2 emissions in 2022 and 2023

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 $GtCO_2$ 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 $GtCO_2$

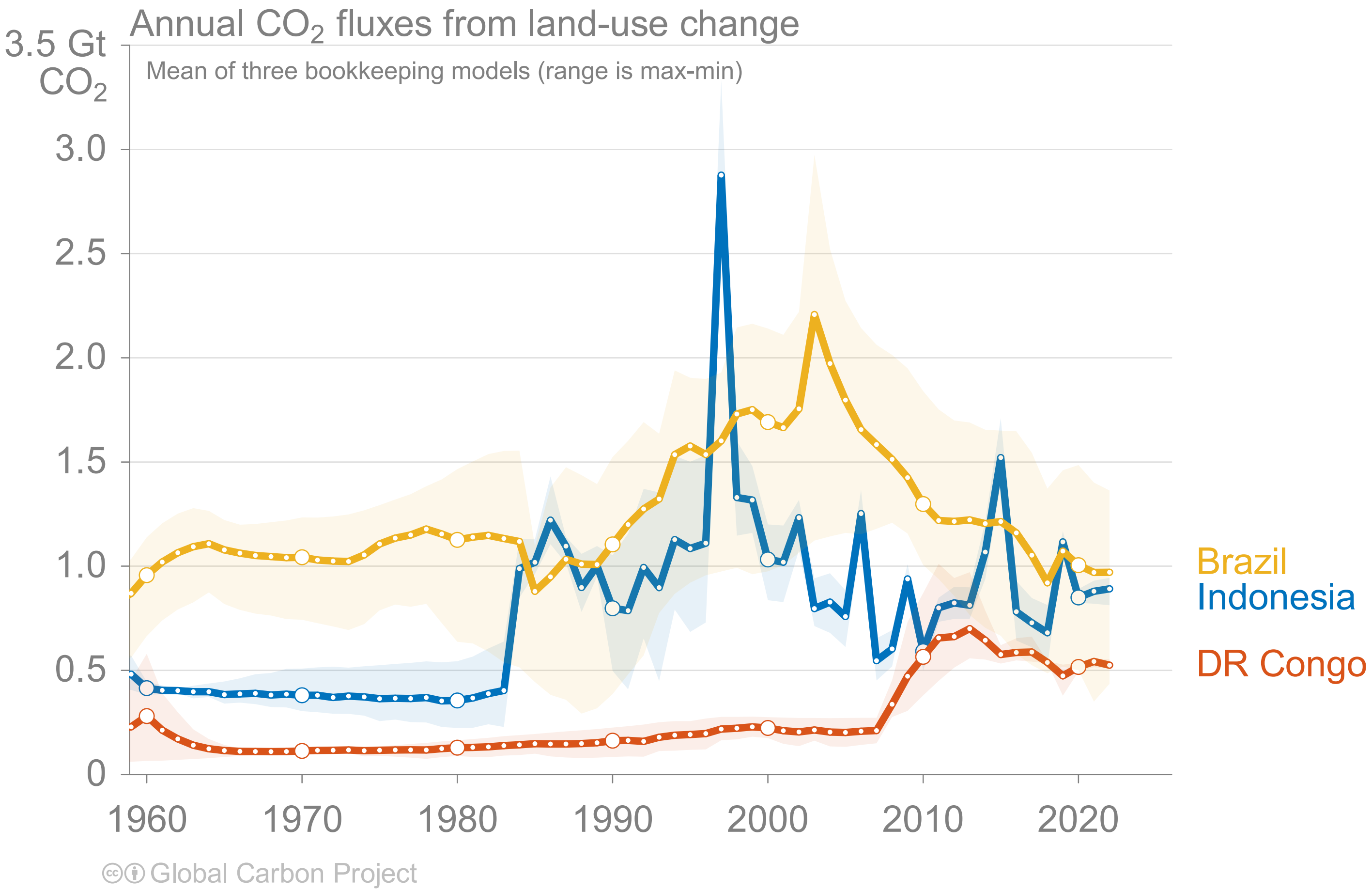


Estimates from three bookkeeping models

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

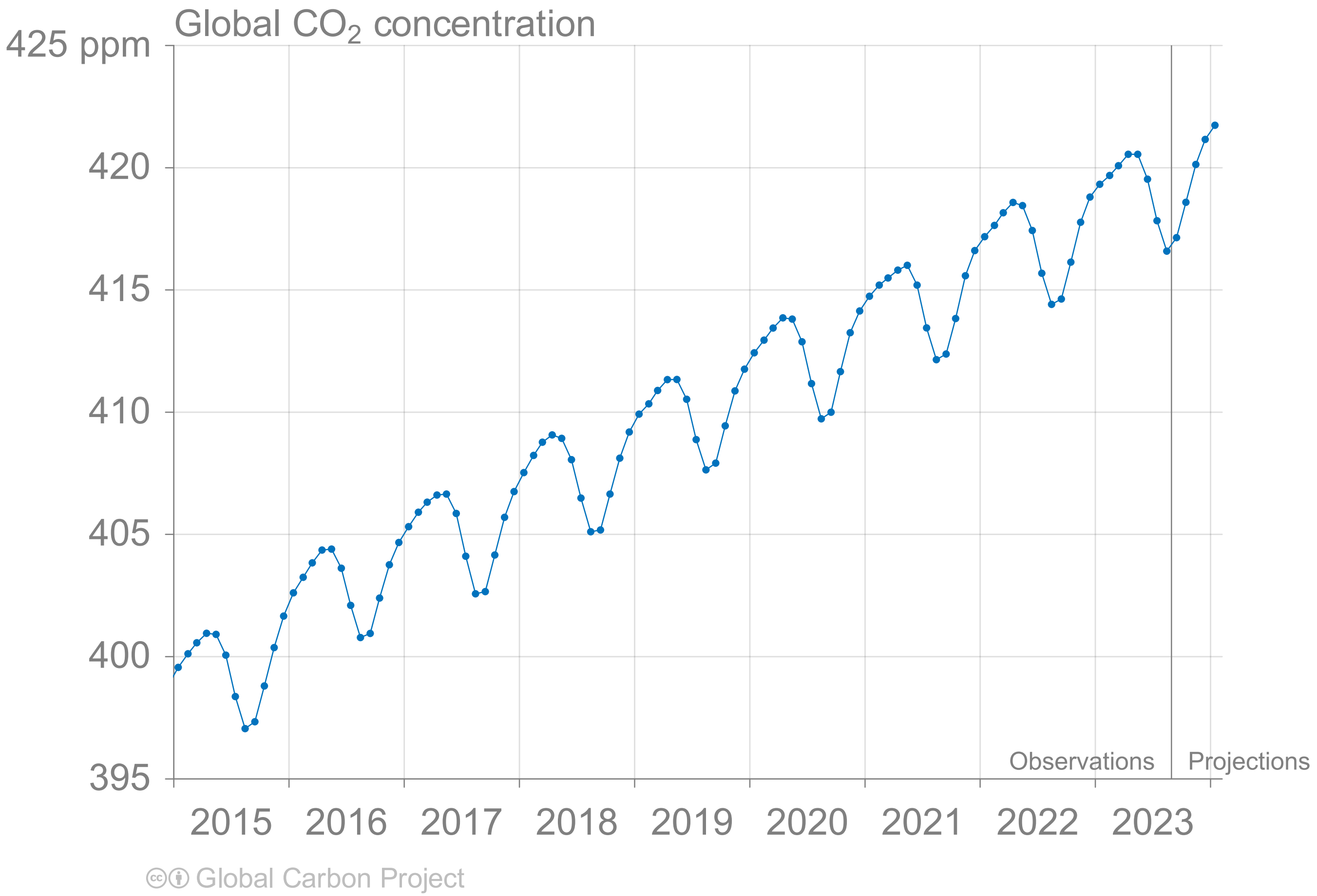


Estimates from three bookkeeping models

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

Forecast of global atmospheric CO_2 concentration

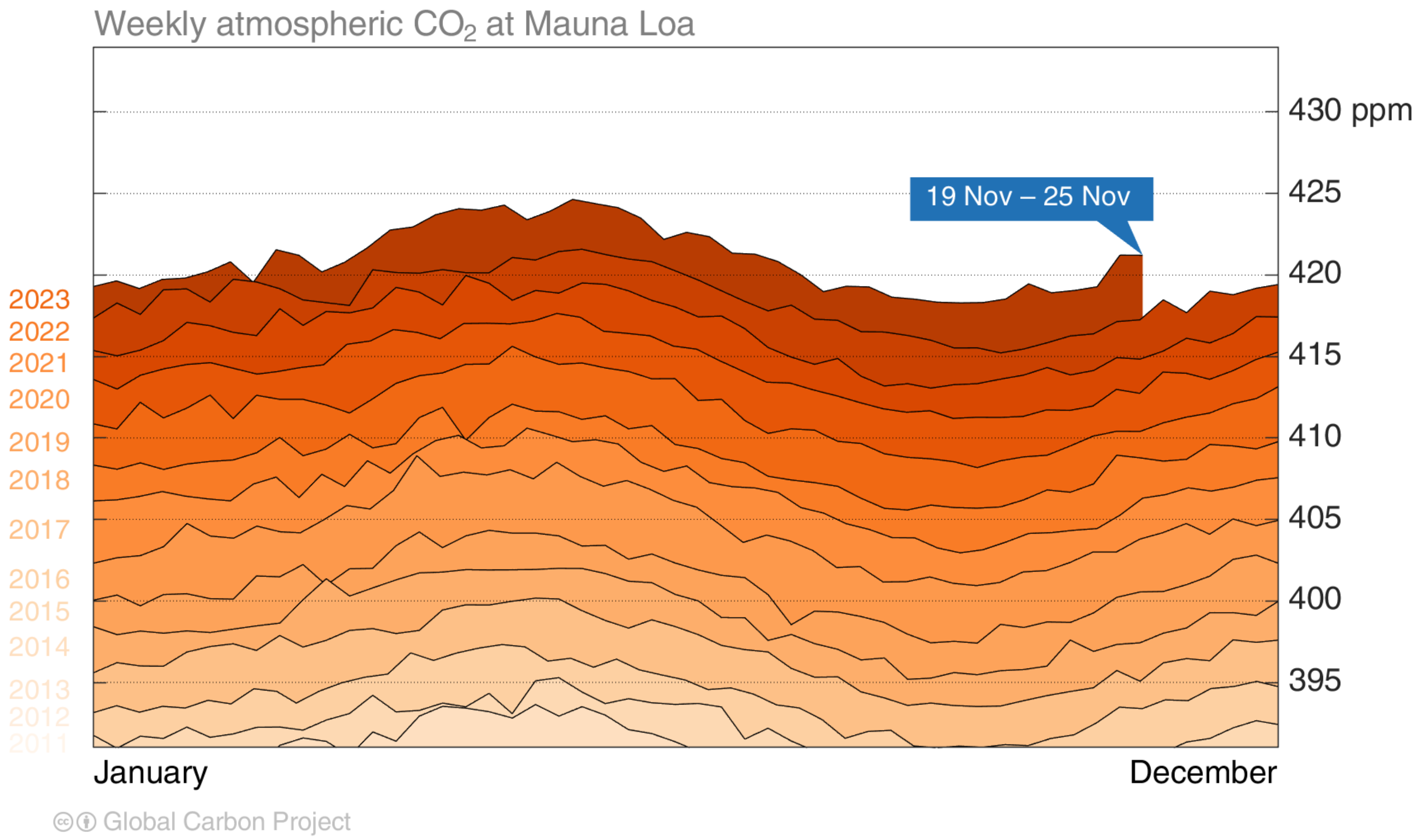
The global atmospheric CO_2 concentration is forecast to average 419.3 parts per million (ppm) in 2023, increasing by 2.4 ppm.
A bigger increase is expected in 2024 when the current El Niño has full effect.



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

Mauna Loa atmospheric CO_2

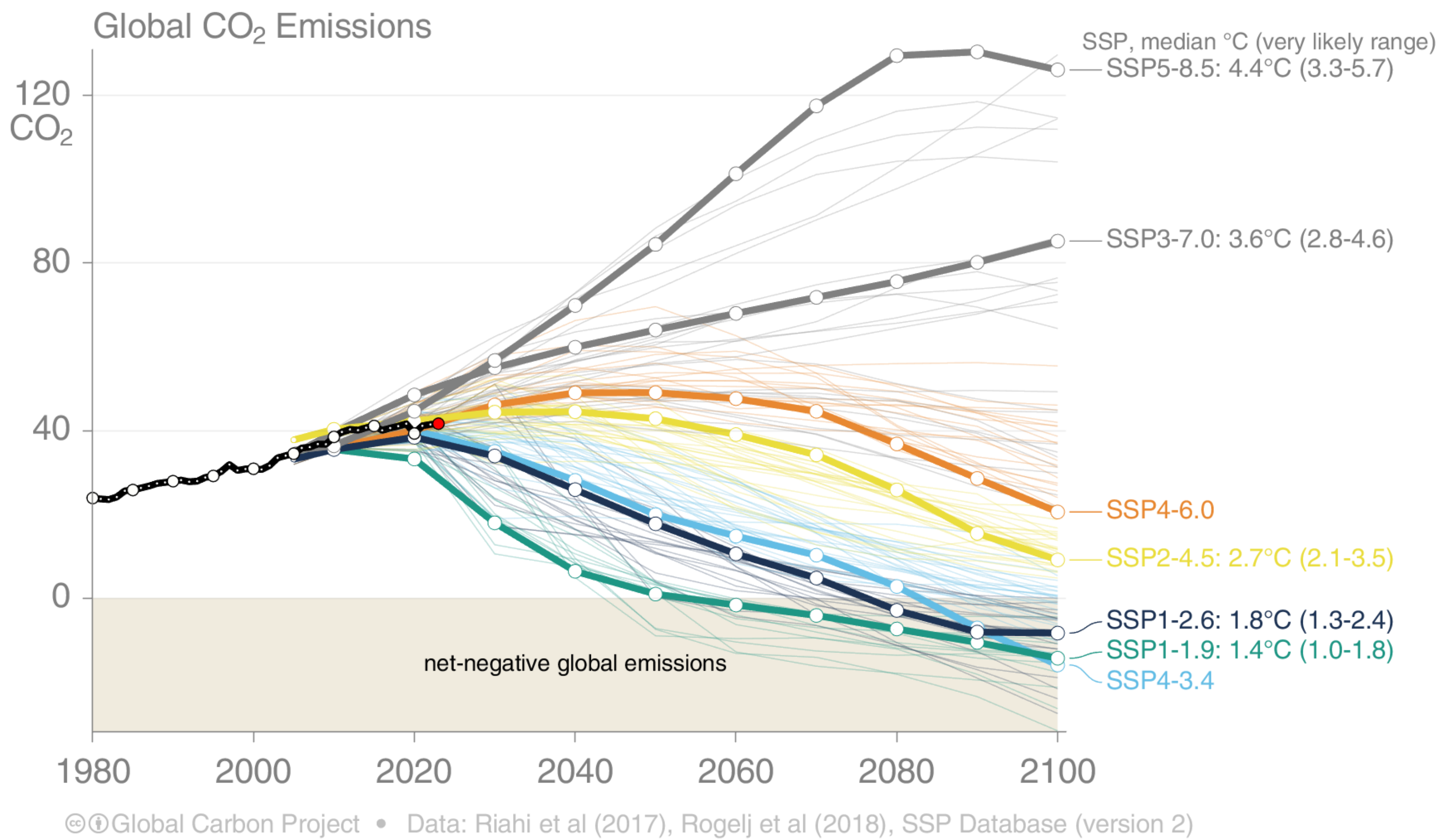
Atmospheric CO_2 concentration has increased every single year,
including in 2020 – despite the drop in fossil CO_2 emissions – because of continued emissions



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

Shared Socioeconomic Pathways (SSPs)

The SSPs were designed to span the range of potential outcomes. Total CO_2 emissions are currently tracking in the middle of the range. The temperature outcomes are based on assessed scenarios in IPCC AR6 Working Group I.

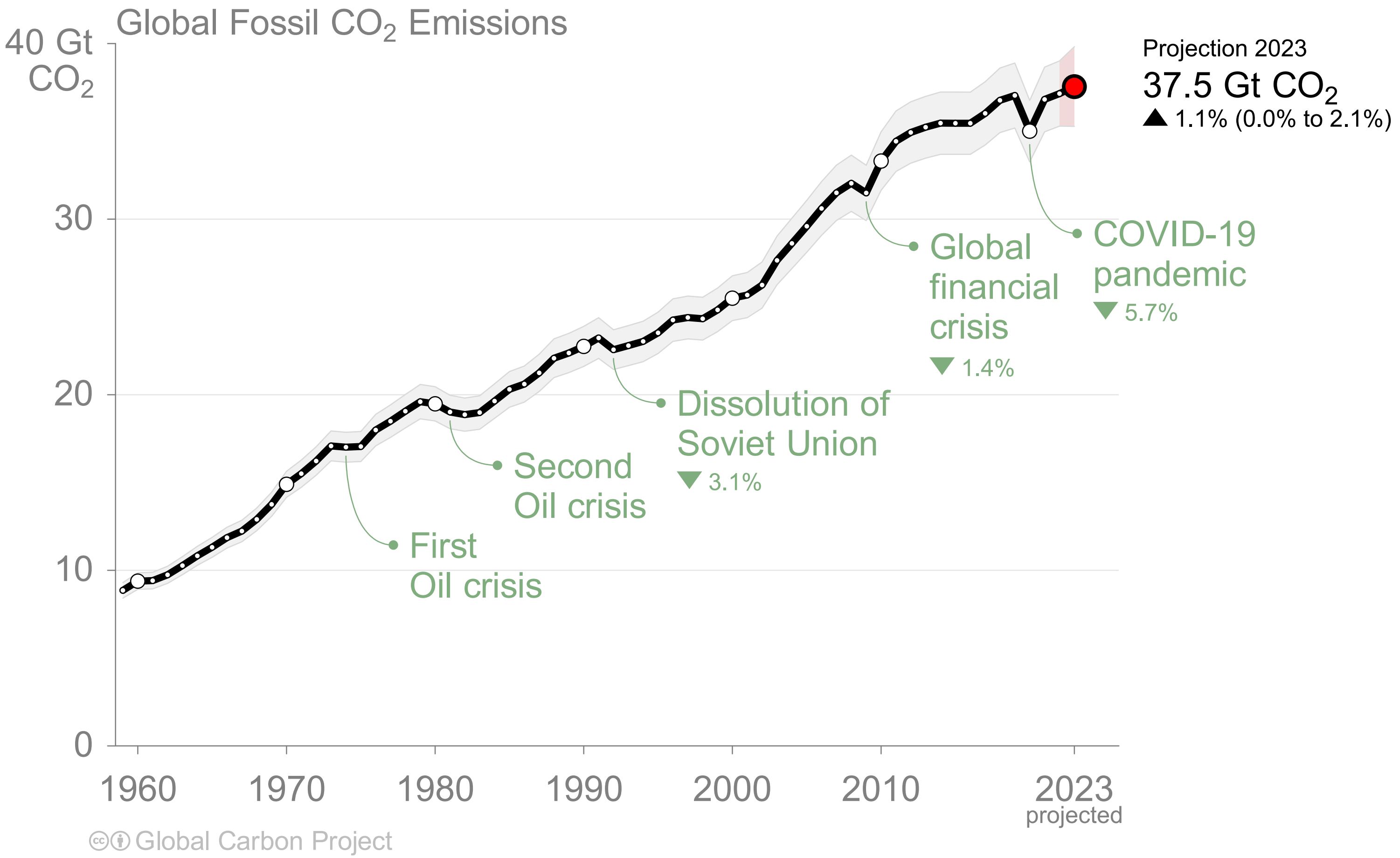


This set of quantified SSPs are based on the output of six Integrated Assessment Models (AIM/CGE, GCAM, IMAGE, MESSAGE, REMIND, WITCH).
Net emissions include those from land-use change and bioenergy with CCS.
Source: [Riahi et al. 2016](); [Rogelj et al. 2018](); [IIASA SSP Database](); [IAMC](); [Global Carbon Project 2023]()

Global fossil CO_2 emissions

Global fossil CO_2 emissions

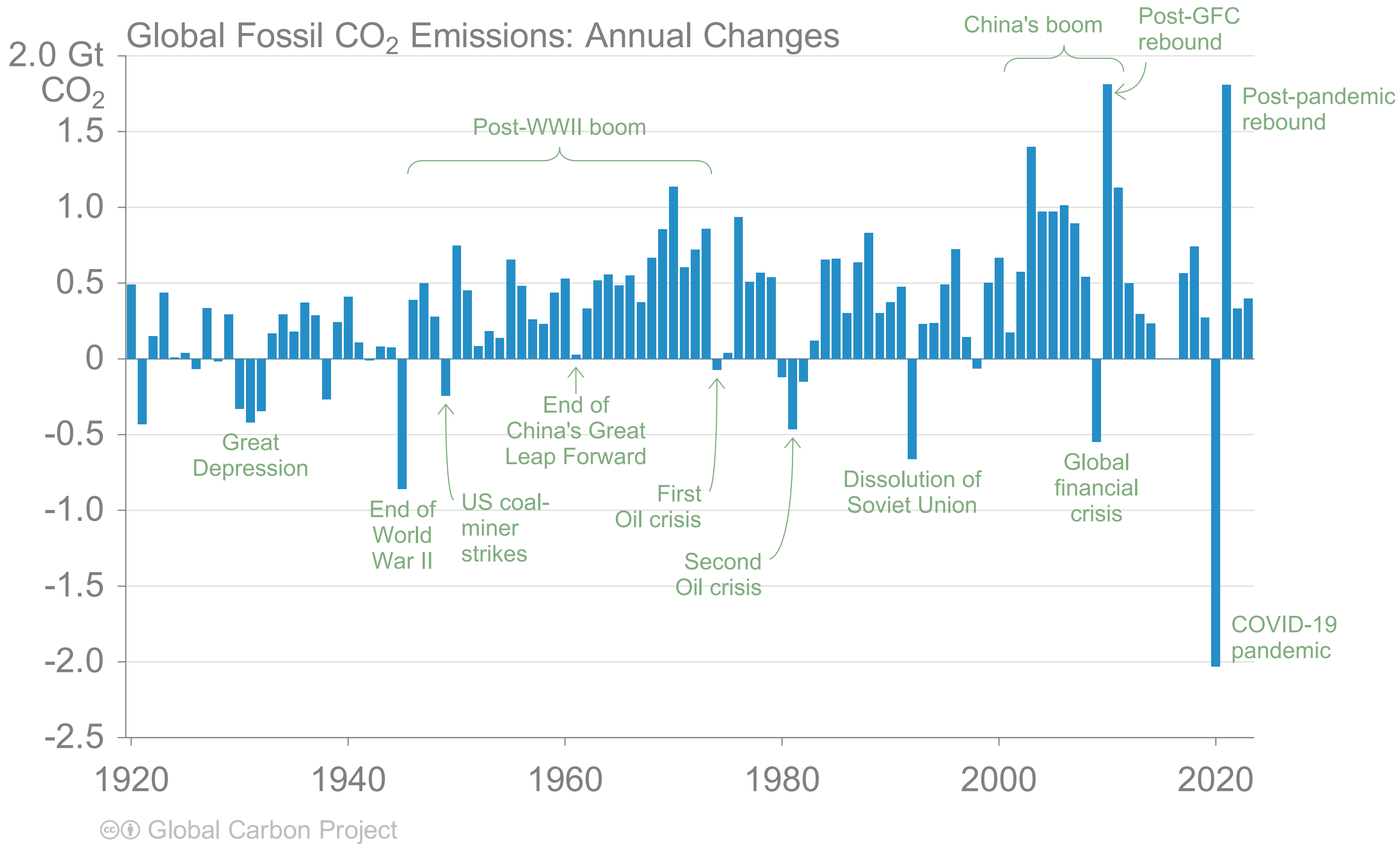
Global fossil CO_2 emissions have risen steadily over the last decades.
Emissions are set to grow again in 2023.



When including cement carbonation, the 2023 estimate is 36.8 ± 2 $GtCO_2$.
The 2023 projection is based on preliminary data and modelling.
Source: [Friedlingstein et al 2023](); [Global Carbon Project 2023]()

Global fossil CO_2 emissions

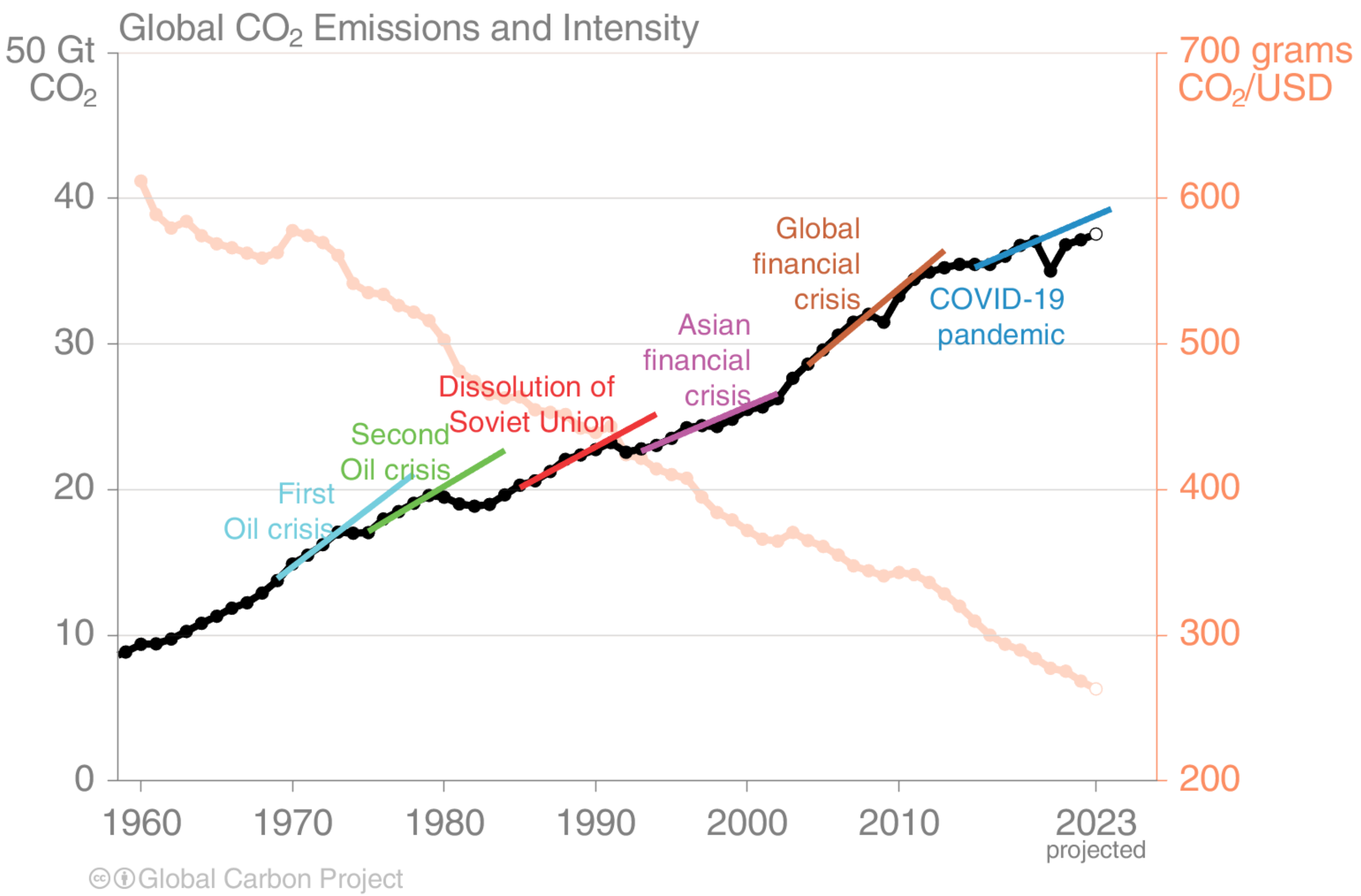
For the last 100 years, it has generally taken a crisis to drive global emissions reductions.
To stabilise temperatures, intentional, planned, sustained global reductions must begin.



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

Fossil CO_2 emission intensity

Global CO_2 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

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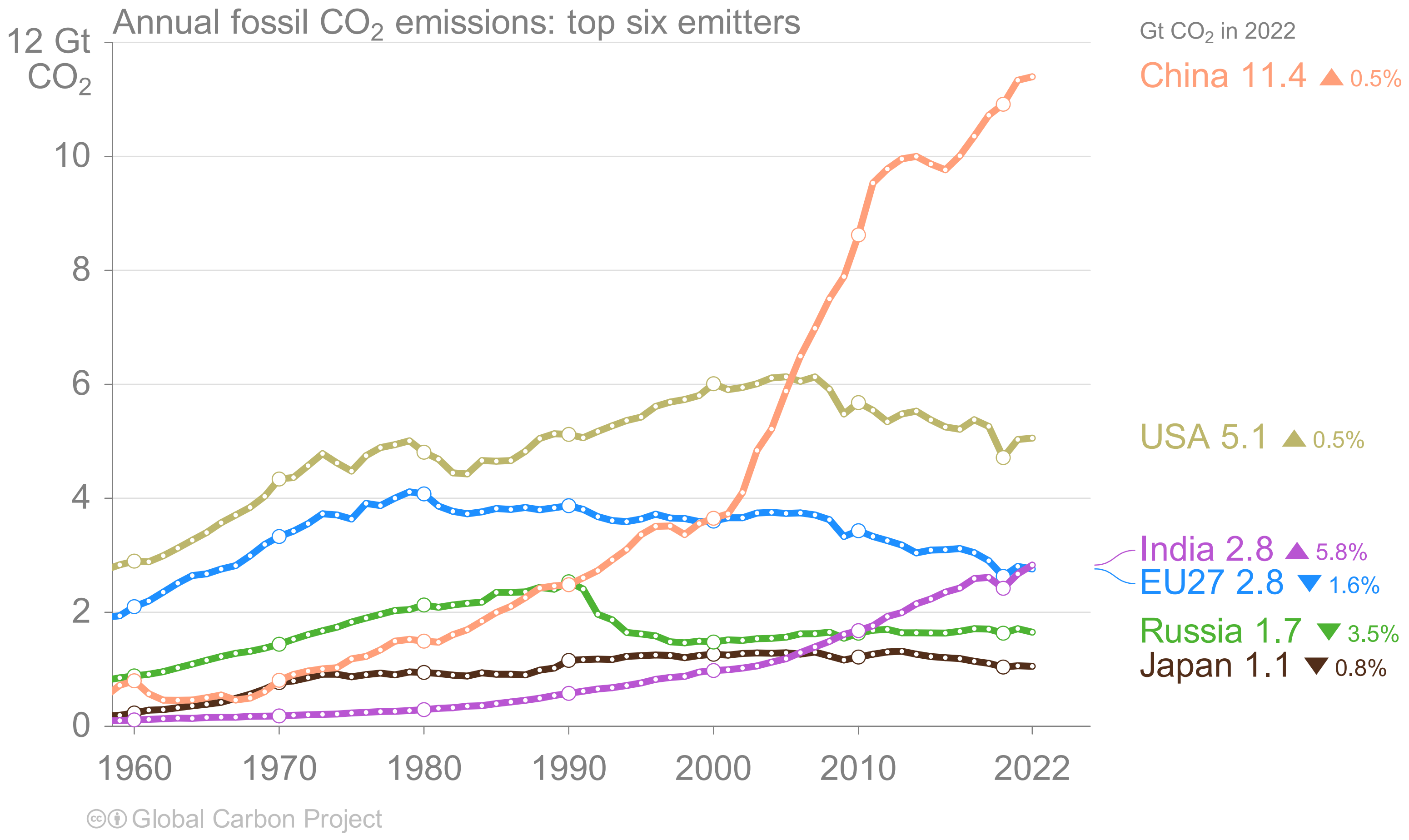
Fossil CO_2 emissions by country

Top emitters: Fossil CO_2 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

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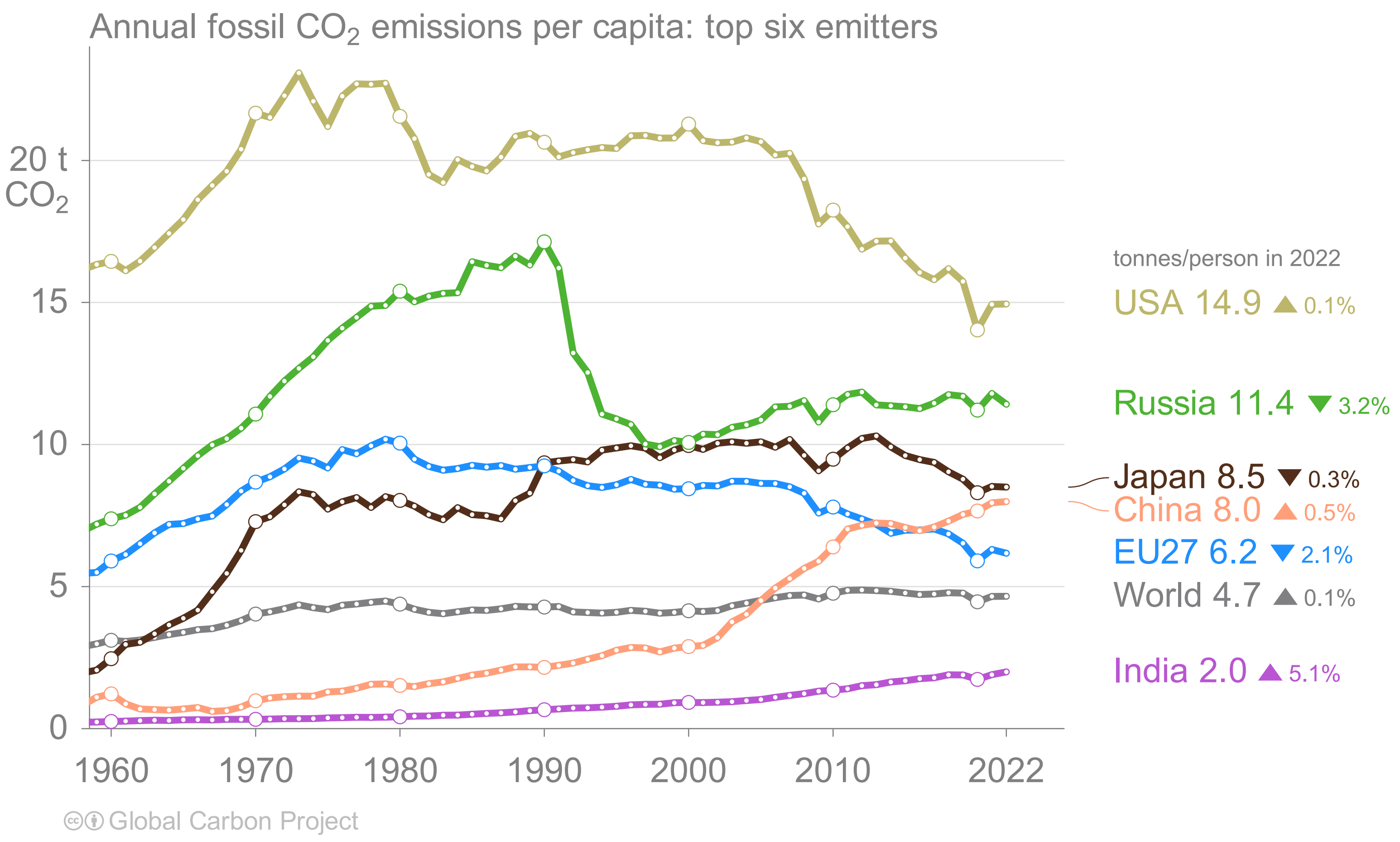
Top emitters: Fossil CO_2 emissions per capita to 2022

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

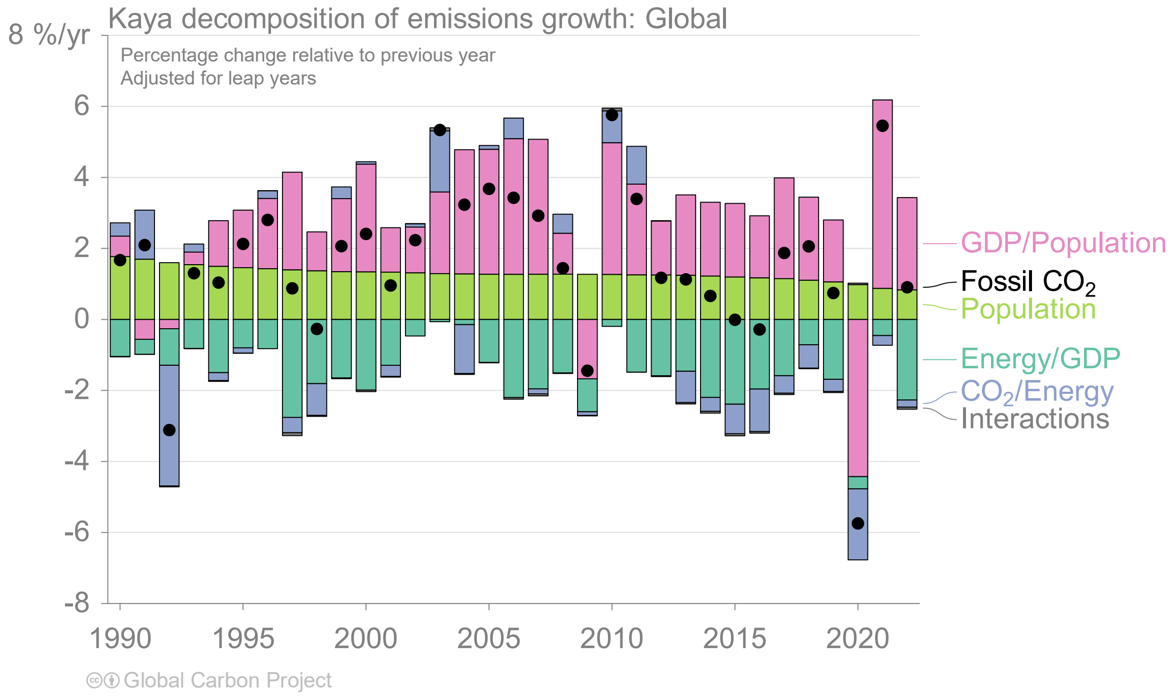


International aviation and maritime shipping (bunker fuels) contributed 2.8% of global emissions in 2022.

Source: Friedlingstein et al 2023; Global Carbon Project 2023

Fossil CO_2 emissions — Kaya decomposition

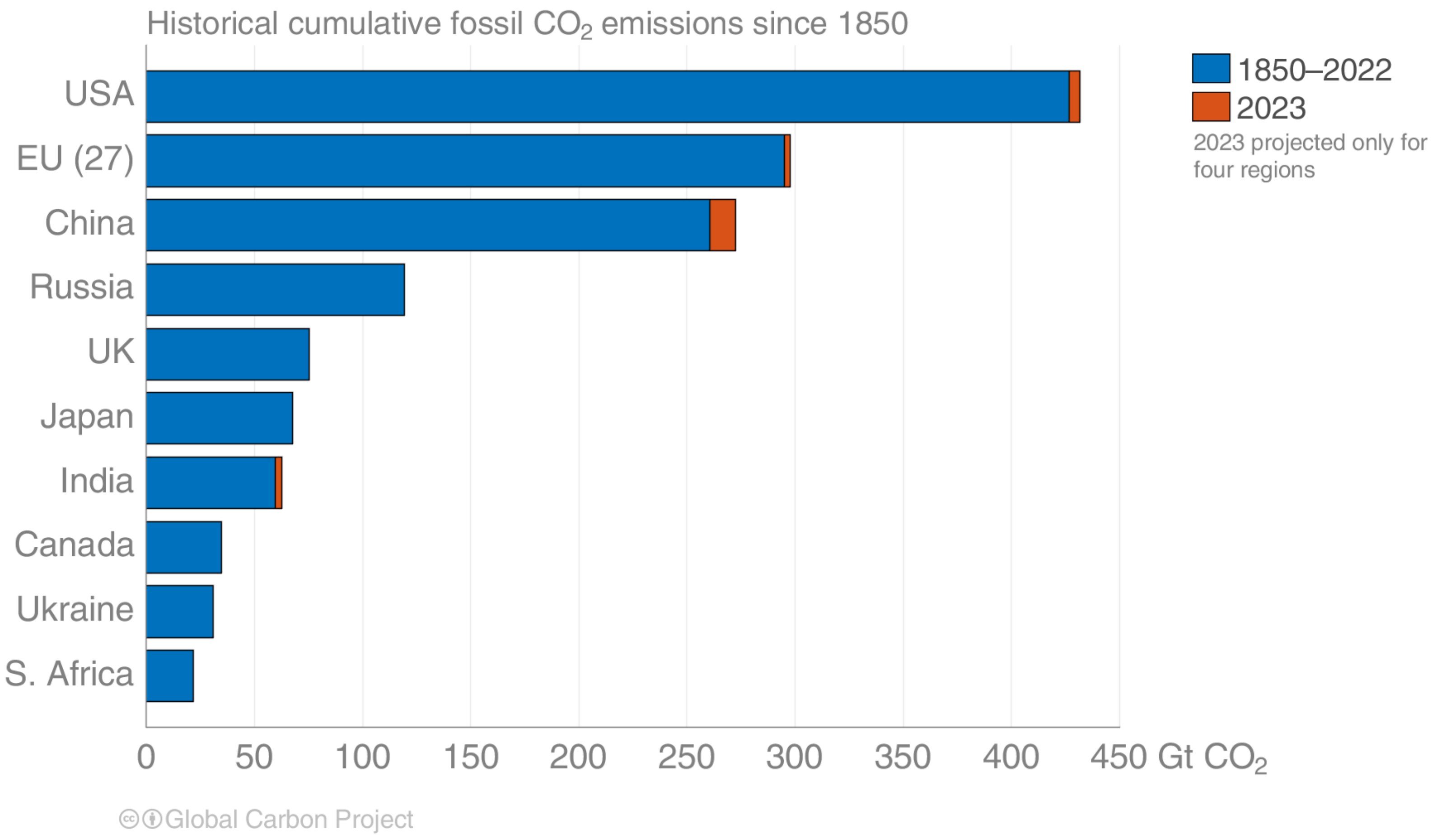
Globally, decarbonisation and declines in energy per GDP are largely responsible for the reduced growth rate in emissions over the last decade. 2020 was a clear outlier with a sharp decline in GDP.



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

Historical cumulative fossil CO_2 emissions

The USA and EU have the highest accumulated fossil CO_2 emissions since 1850, but China is a close third.



Calculated using territorial emissions.

Source: Friedlingstein et al 2023; Global Carbon Project 2023

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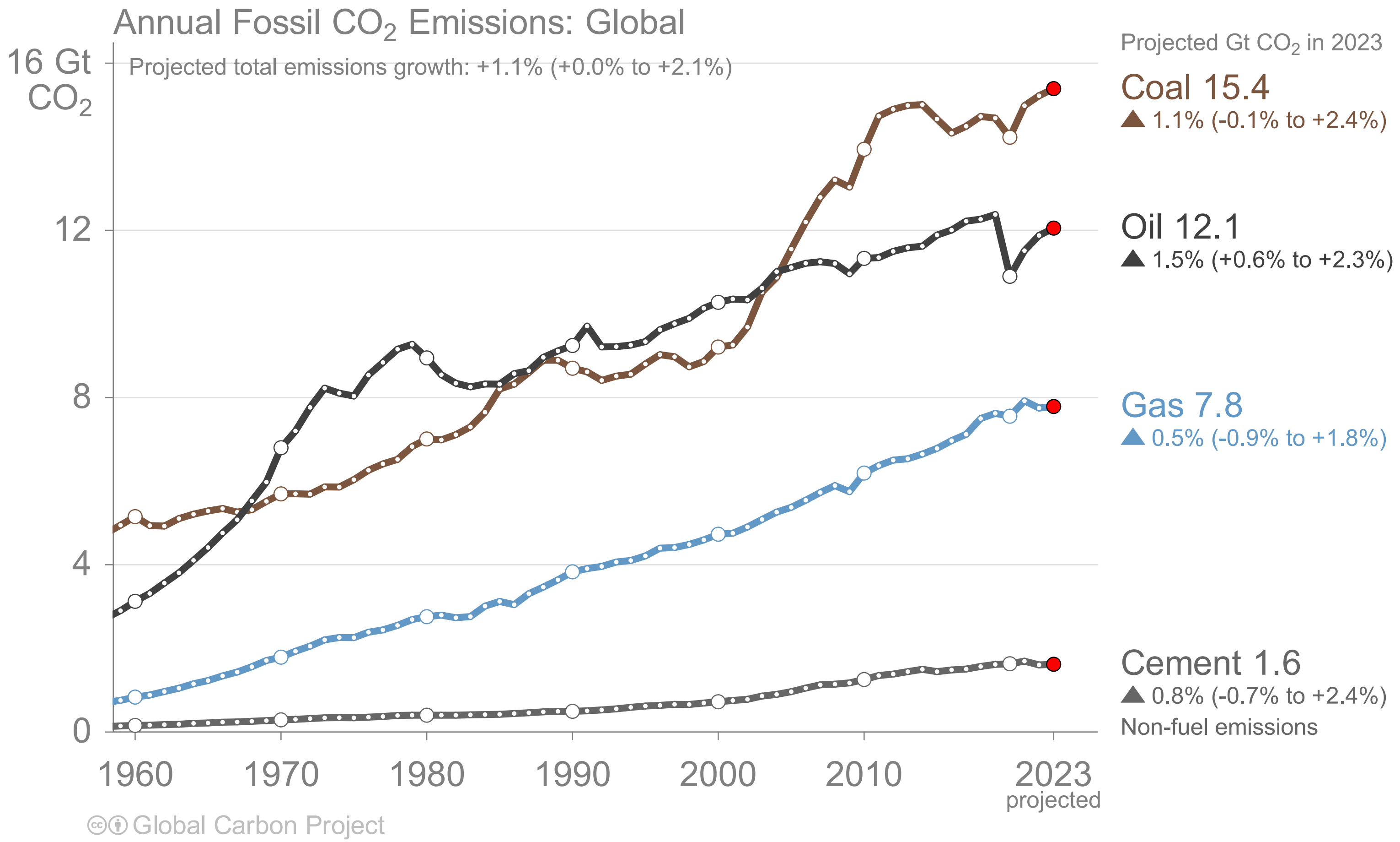
Fossil CO_2 emissions by source

Fossil CO_2 emissions by source

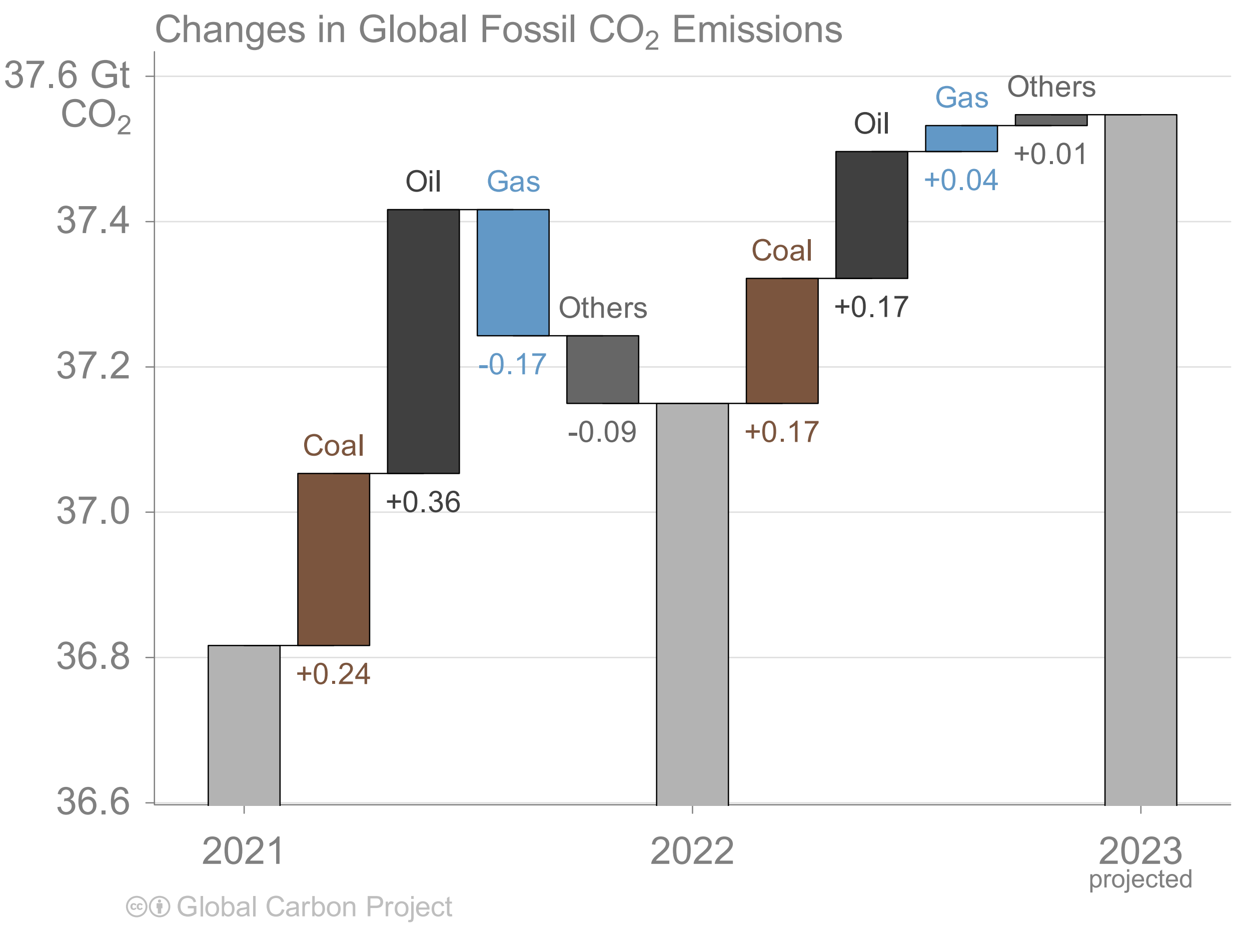
Share of global fossil CO_2 emissions in 2023: coal (41%), oil (32%), gas (21%), cement (4%), flaring and others (2%, not shown)



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

Fossil CO_2 emissions growth: 2021–2023

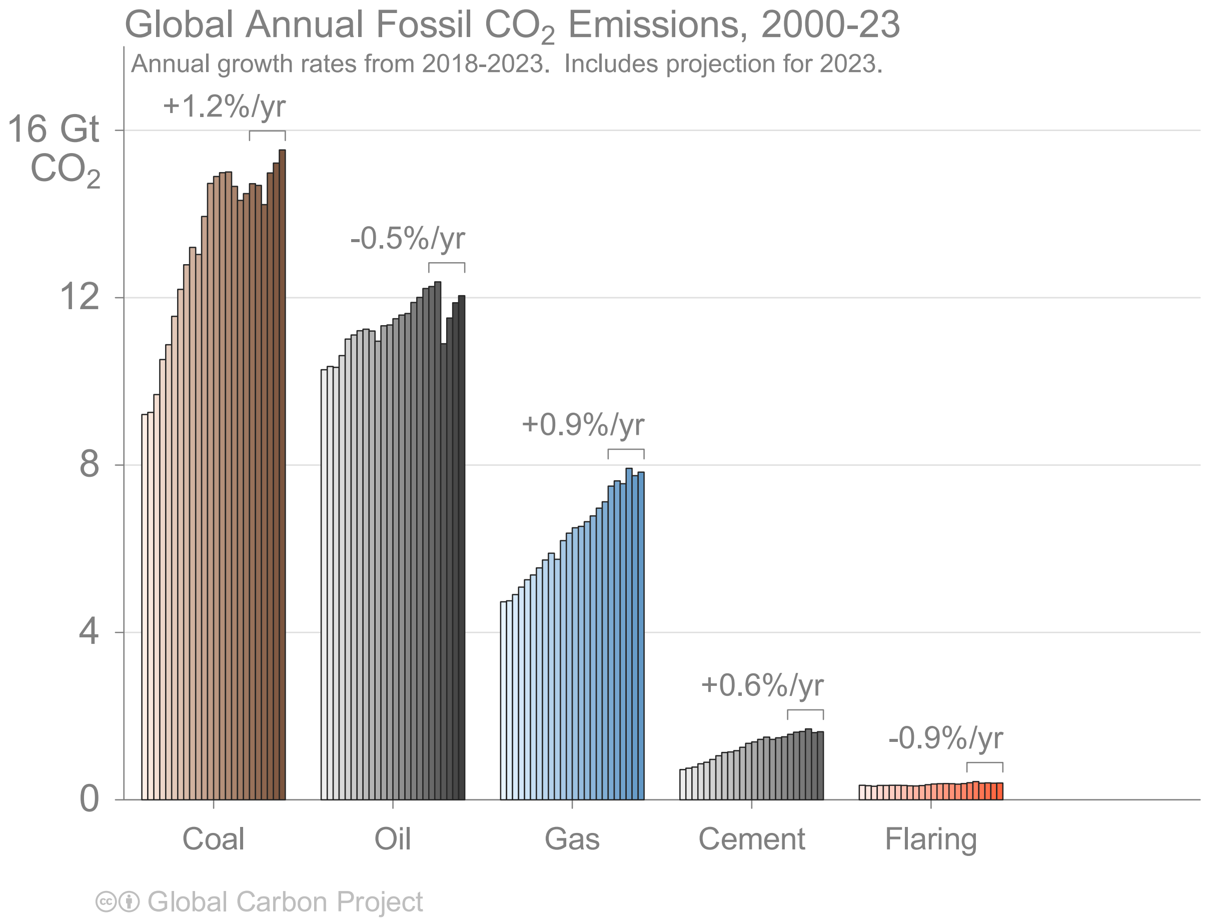
Global emissions from oil continued to rebound in both 2022 and 2023 with recovery of aviation.
In 2022 natural gas declined because of supply constraints but returns to growth in 2023. Coal continues to climb.



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

Fossil CO_2 emissions by source

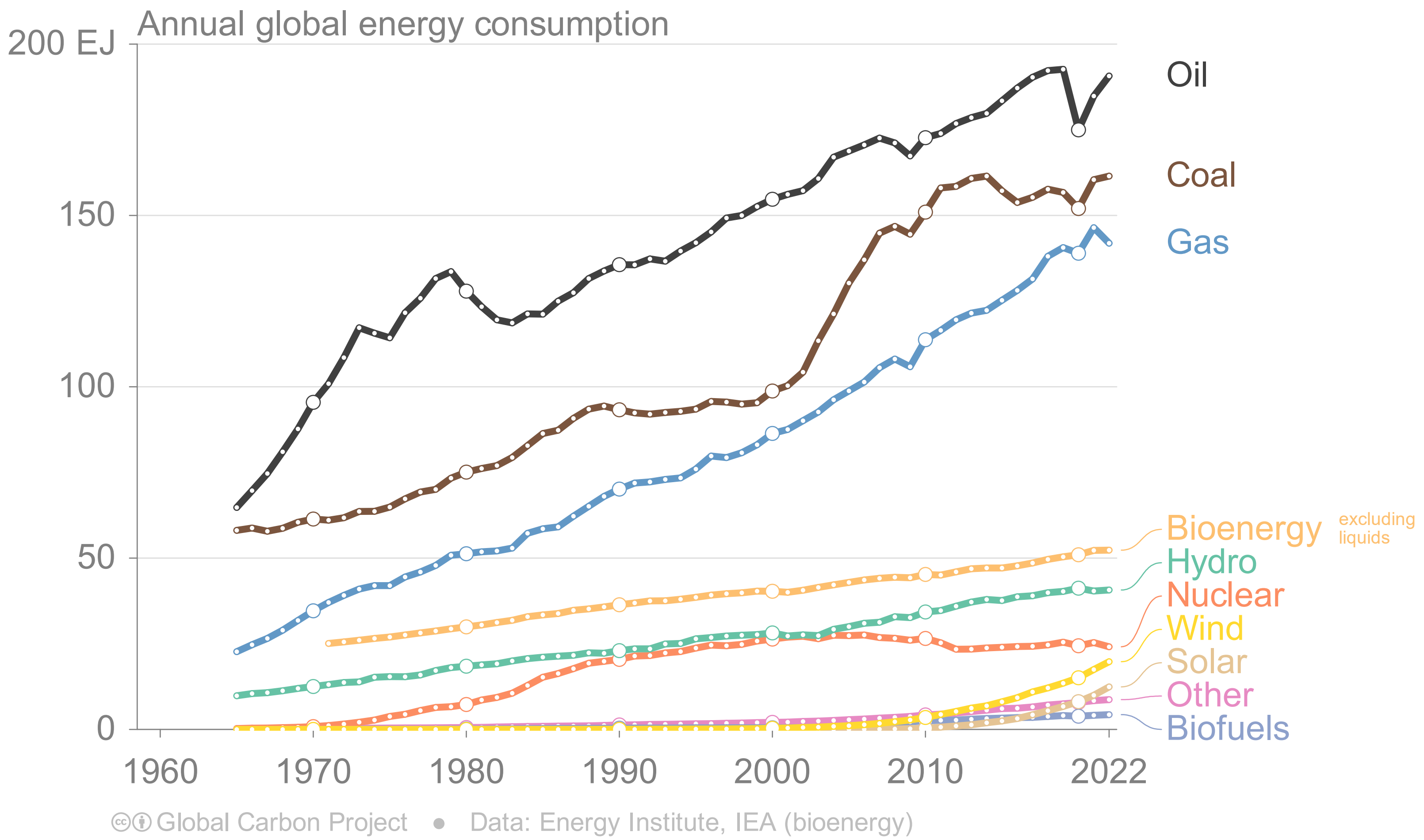
Emissions by category from 2000 to 2023, with growth rates indicated for the more recent period of 2018 to 2023
Coal use has returned to growth, and both coal and oil declined sharply in the pandemic year 2020



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

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.

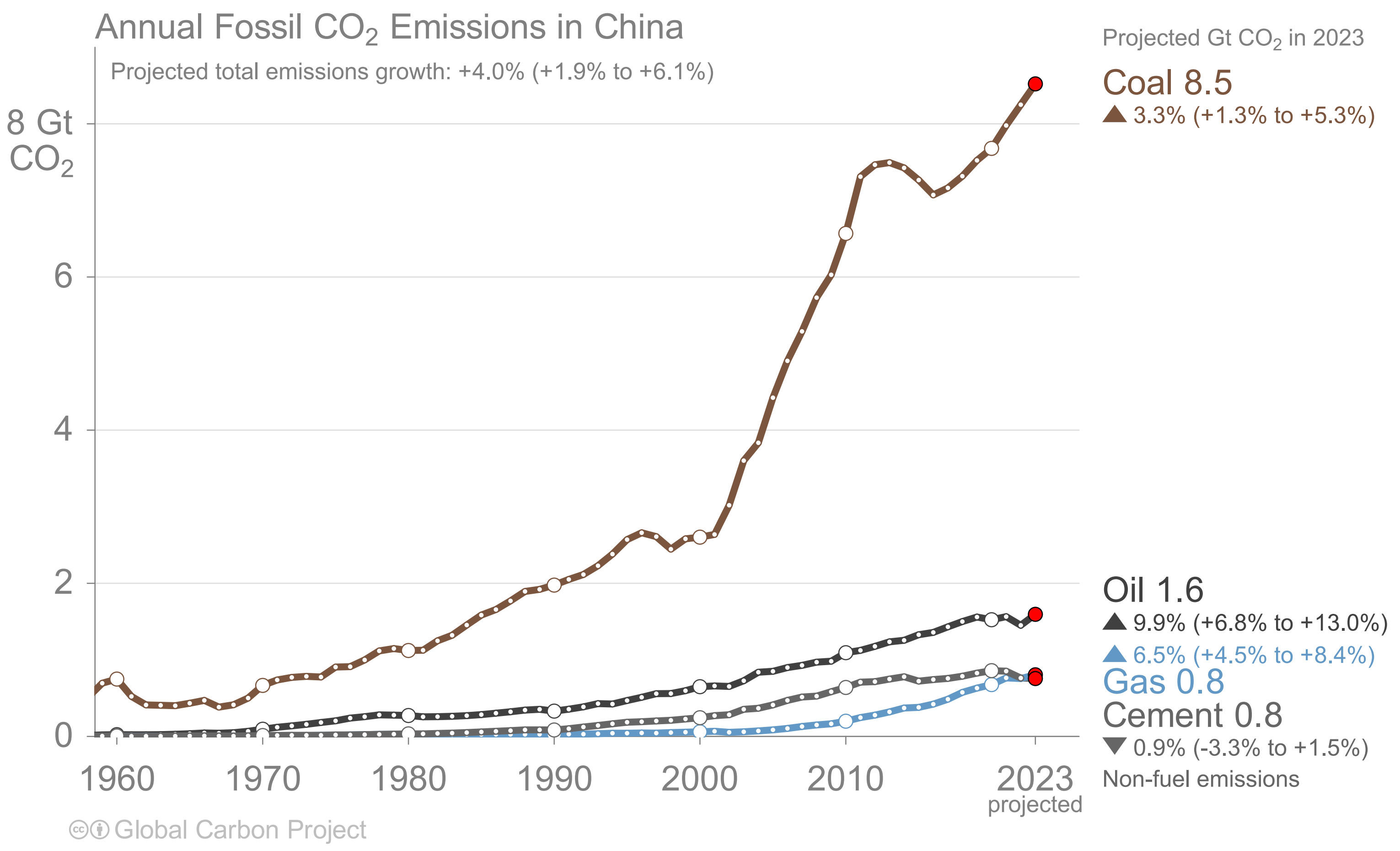


This figure shows "primary energy" using the substitution method
(non-fossil sources are scaled up by an assumed fossil efficiency of approximately 0.38)
Source: [Energy Institute 2023]; [Global Carbon Project 2023]

Fossil CO_2 emission by source for top emitters

Fossil CO_2 emissions in China

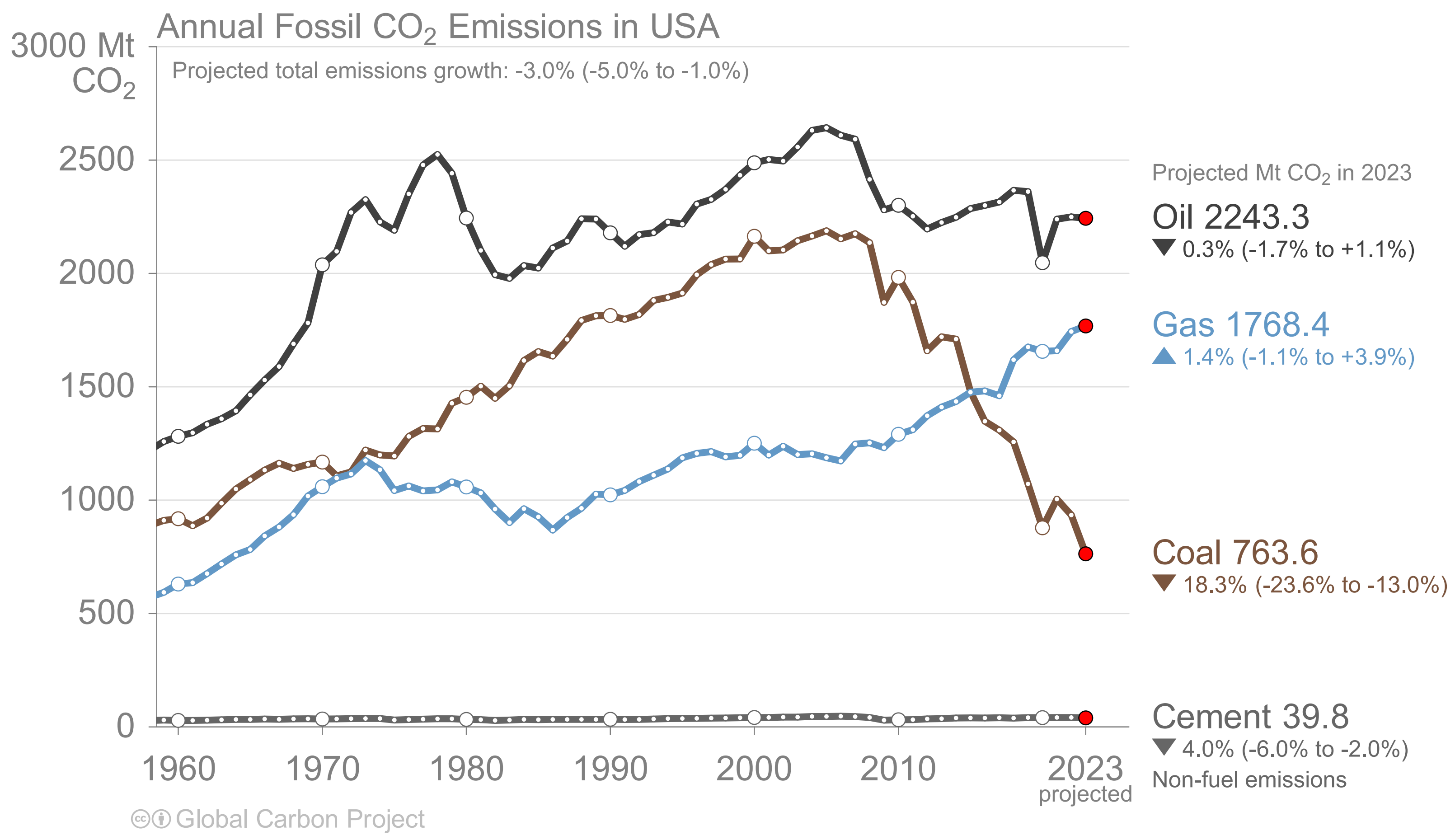
China's coal consumption continued to grow strongly in 2023,
while emissions from oil recovered their losses from 2022's COVID-19 lockdowns



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

Fossil CO_2 emissions in USA

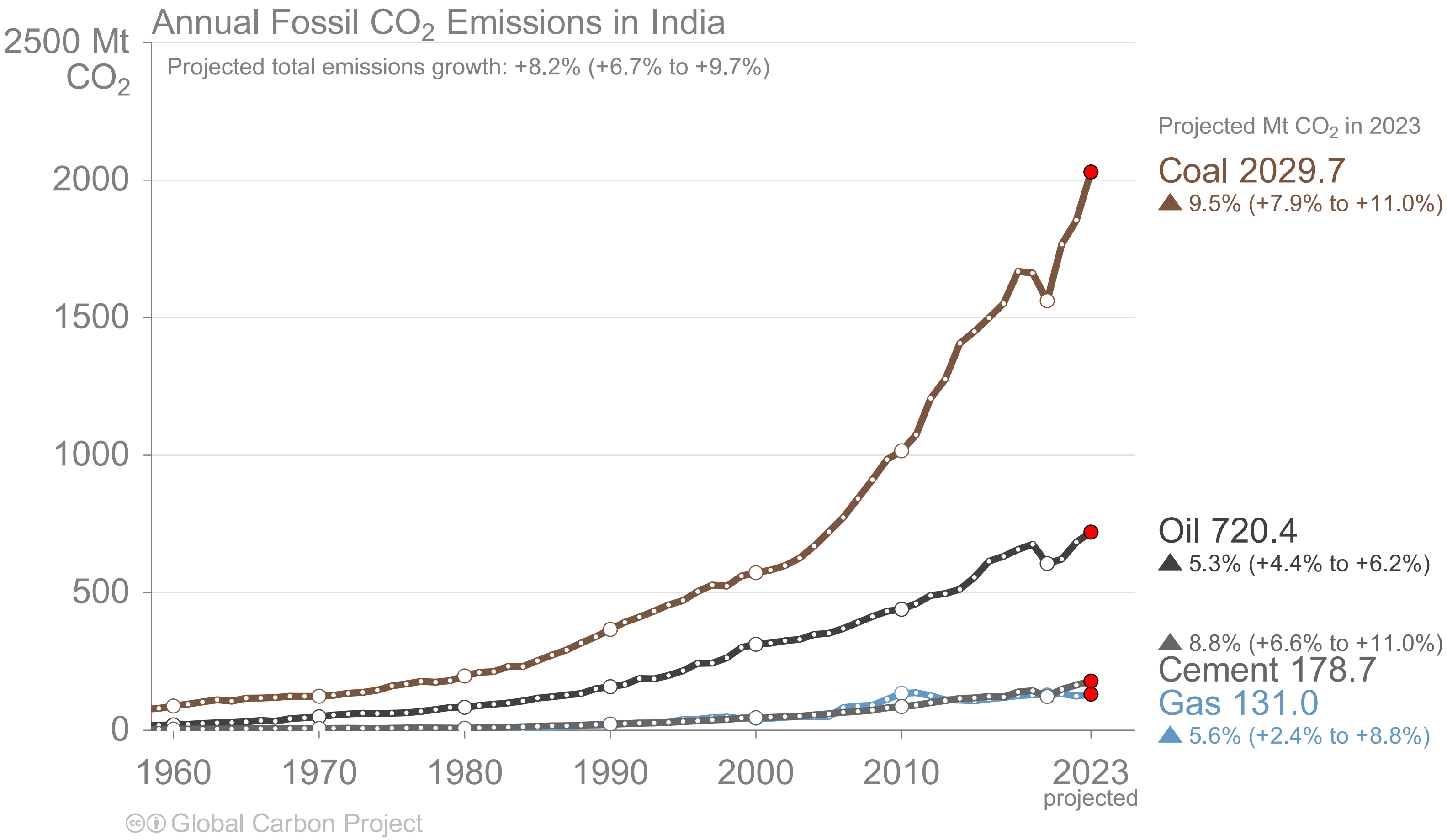
The USA's emissions from coal are expected to drop again in 2023, to their lowest level since 1903, as the transition to natural gas continues. Emissions from oil are still below 2019's level.



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

Fossil CO_2 emissions in India

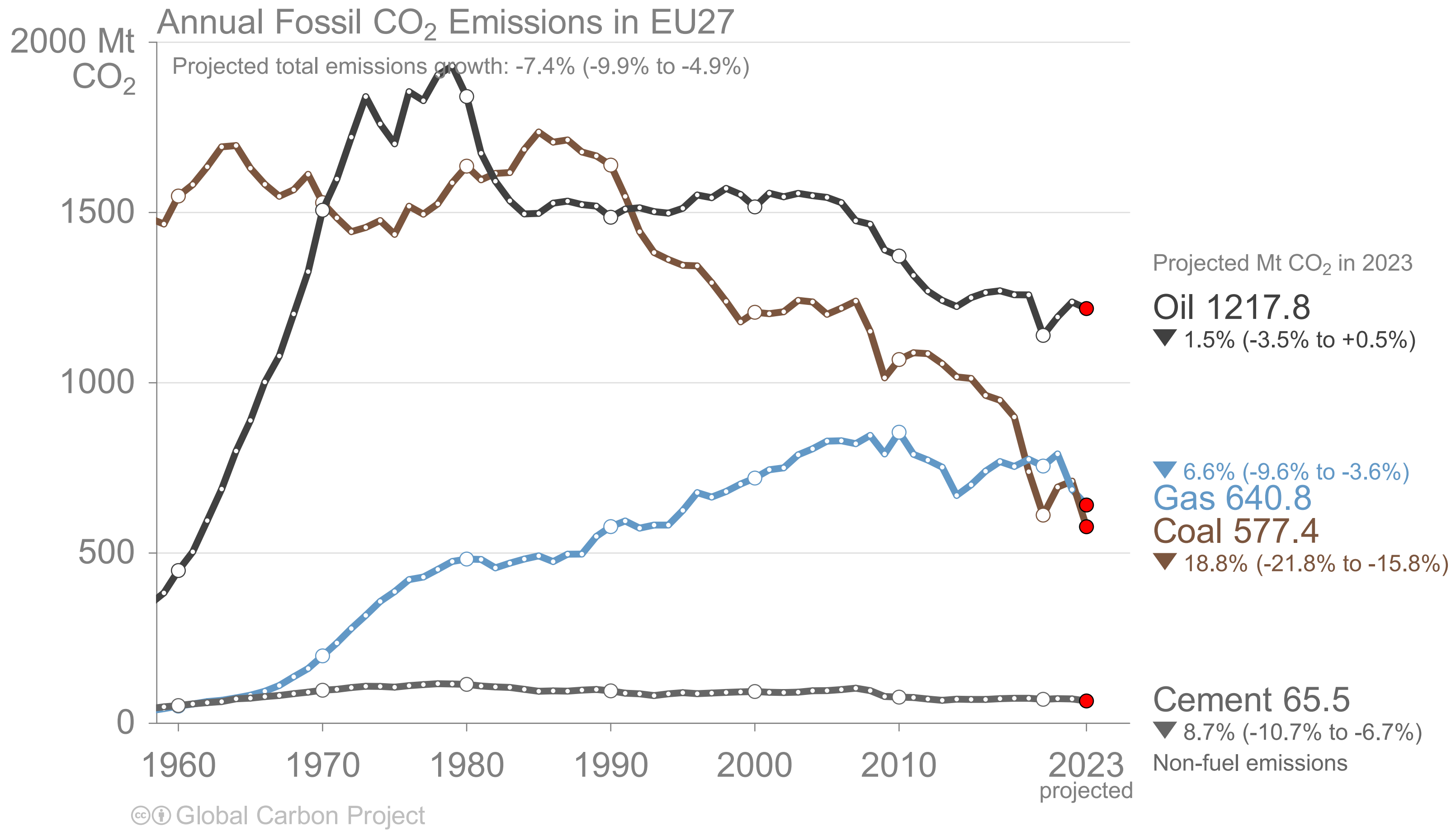
India's emissions continue to grow sharply in 2023. Increases in solar and wind capacity were far from sufficient to meet a large increase in power demand as the economy grows strongly.



Source: Friedlingstein et al 2023; Global Carbon Project 2023

Fossil CO_2 emissions in the European Union

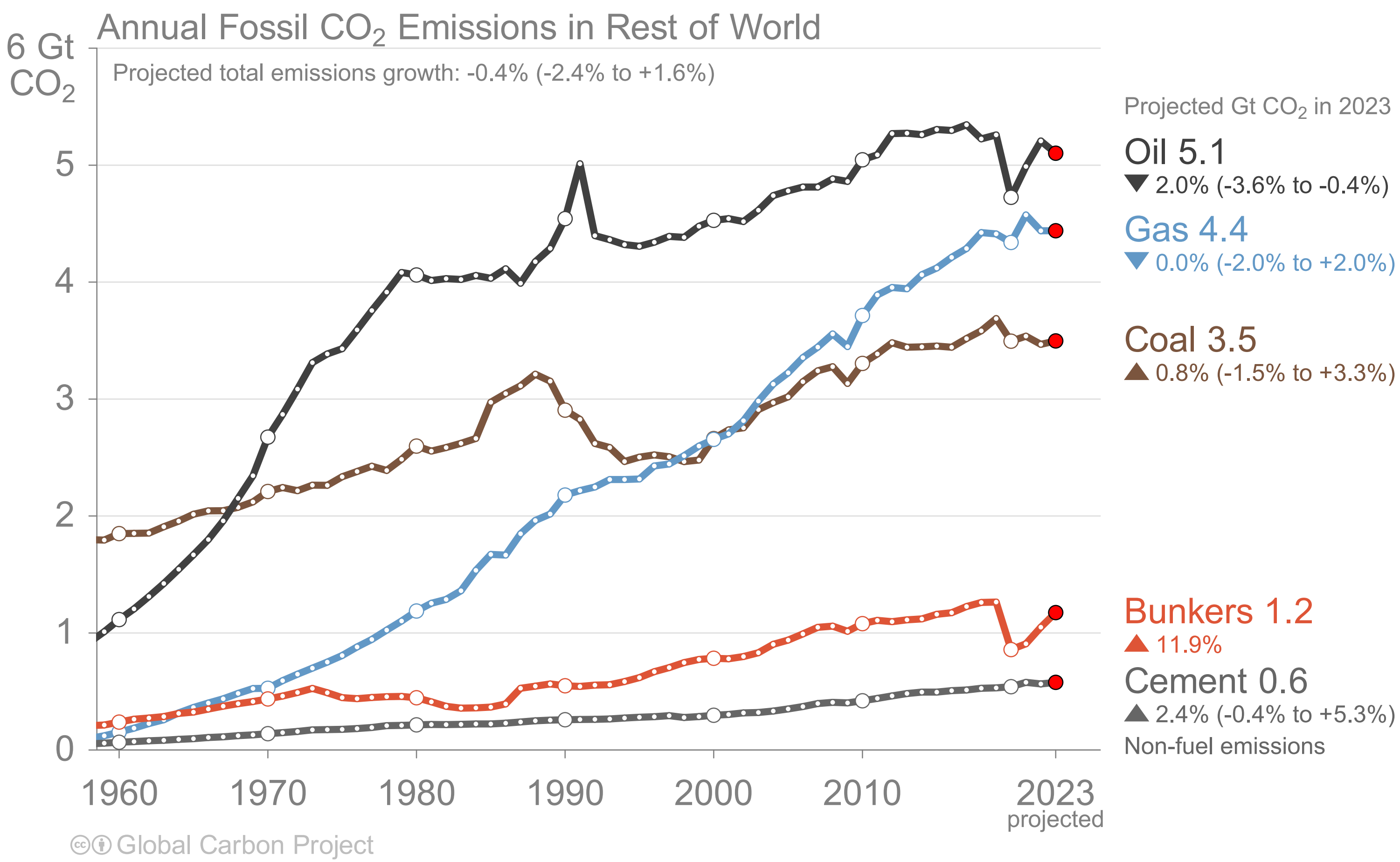
The EU's emissions from all three fossil fuels are expected to have declined in 2023, resulting from high prices and other economic headwinds on top of existing trends.



Source: Friedlingstein et al 2023; Global Carbon Project 2023

Fossil CO_2 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.

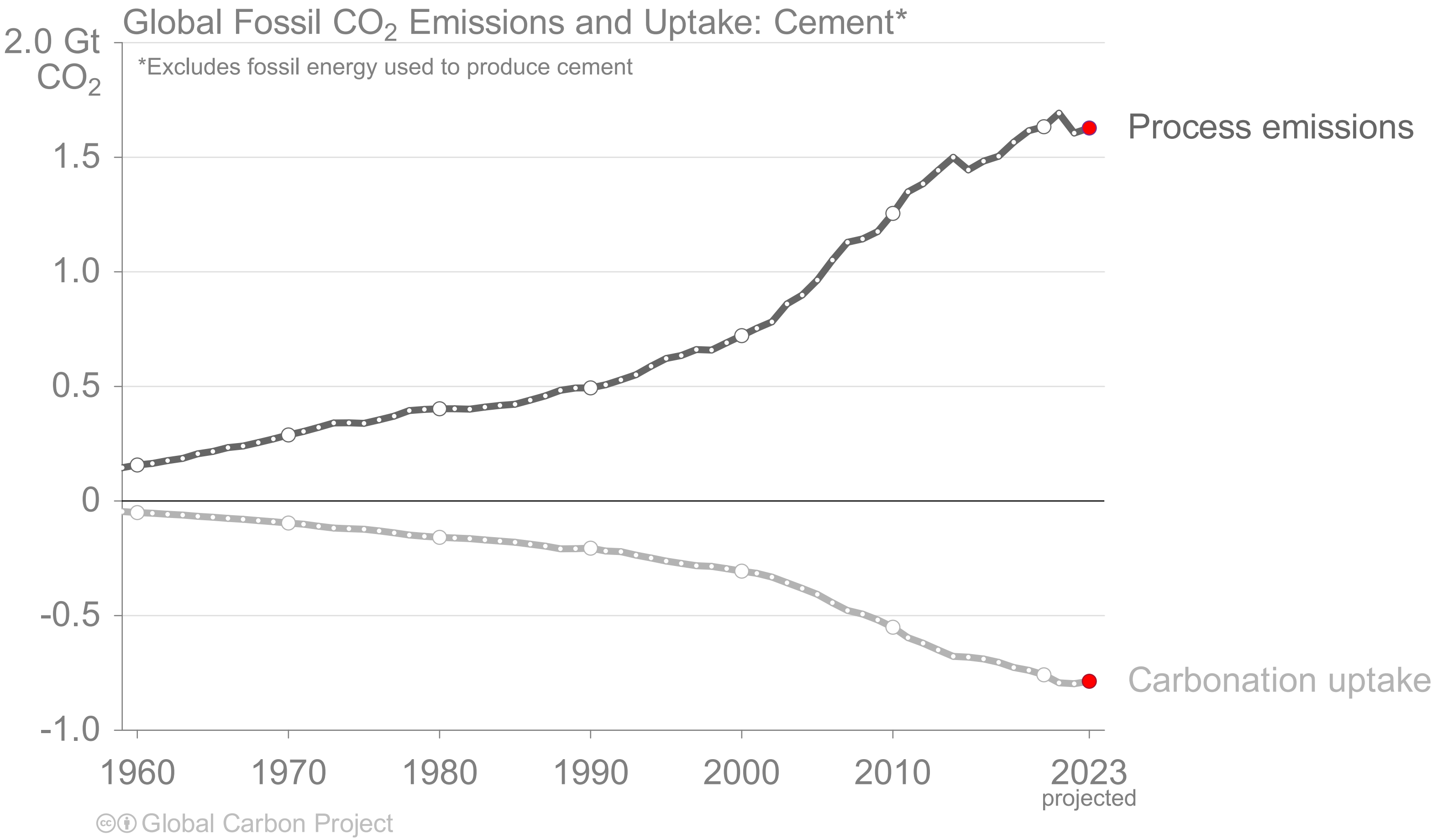


The Rest of the World is the global total less China, US, EU, and India.
Source: Friedlingstein et al 2023; Global Carbon Project 2023

Cement carbonation sink

Cement carbonation sink

The production of cement results in 'process' emissions of CO_2 from the chemical decomposition of carbonates. During its lifetime, cement re-absorbs some CO_2 from the atmosphere.



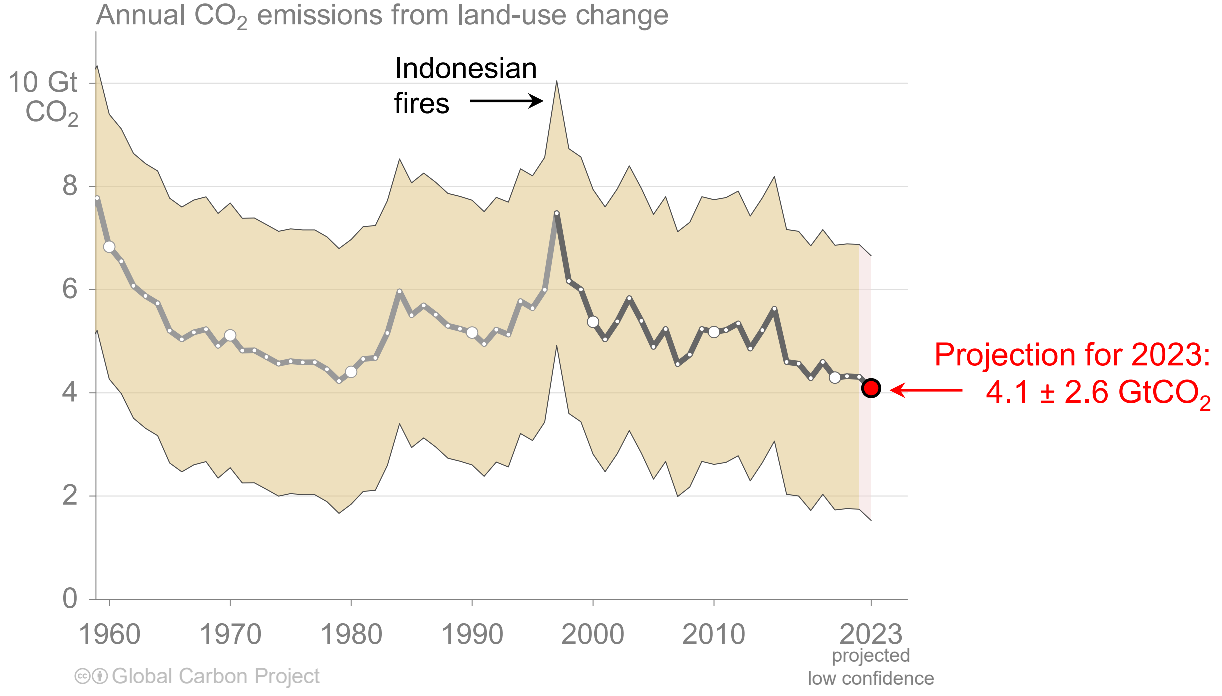
Source: [Friedlingstein et al 2023]; [Global Carbon Project 2023]

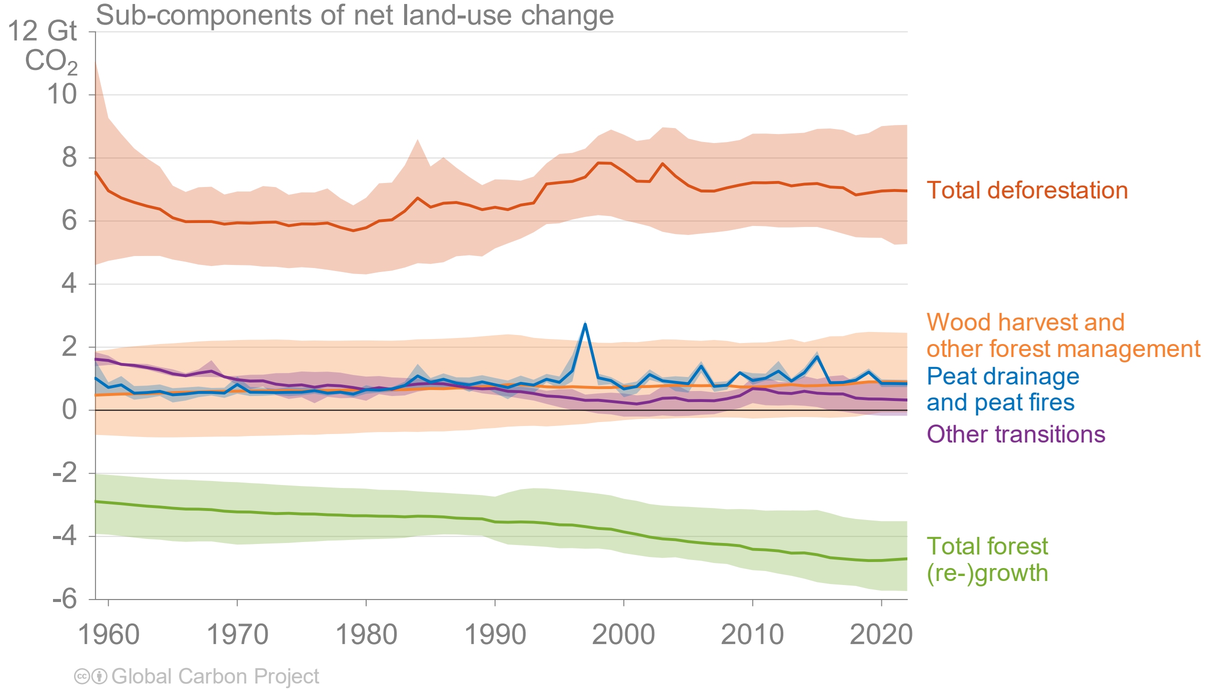
Land-use change emissions

Land-use change emissions

Land-use change emissions are 4.7 ± 2.6 $GtCO_2$ 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 CO_2 emissions or removals



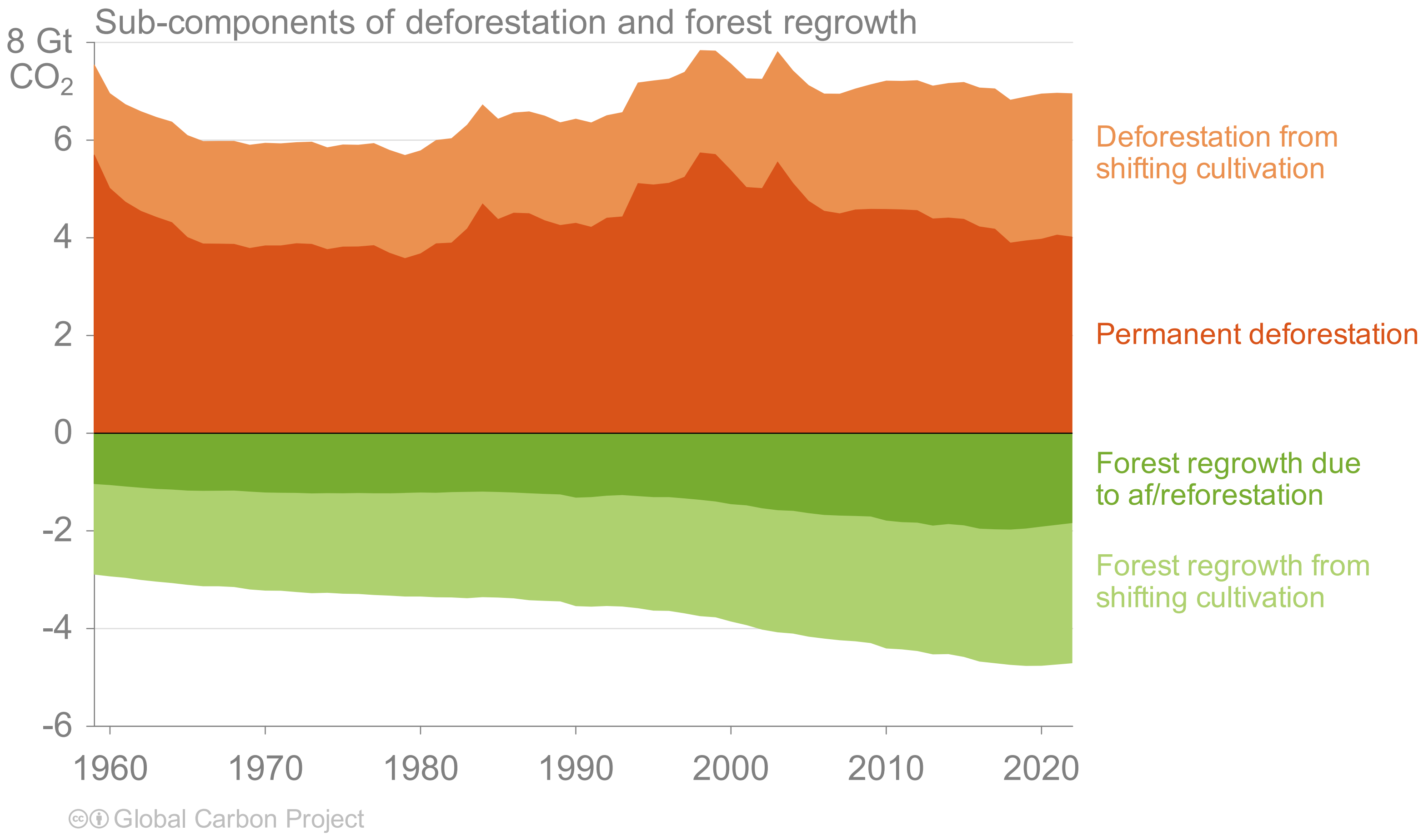


Estimates from three bookkeeping models

Source: Friedlingstein et al 2023; Global Carbon Project 2023

Land-use change emissions

Emissions from permanent deforestation are 4.2 $GtCO_2$ per year for 2013–2022.
Carbon dioxide removals through permanent af/reforestation are 1.9 $GtCO_2$ per year over the same period.

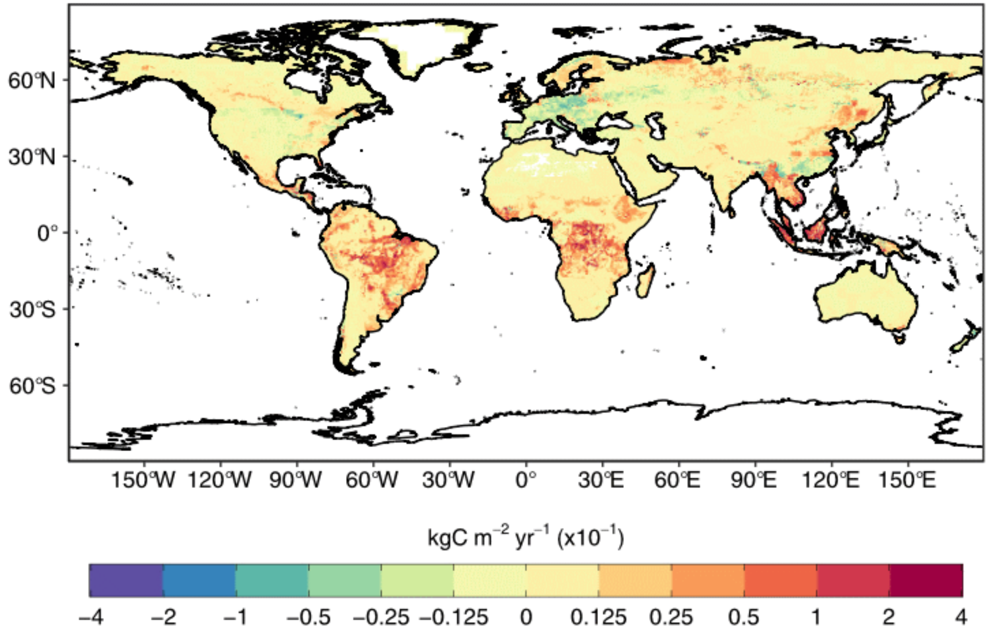


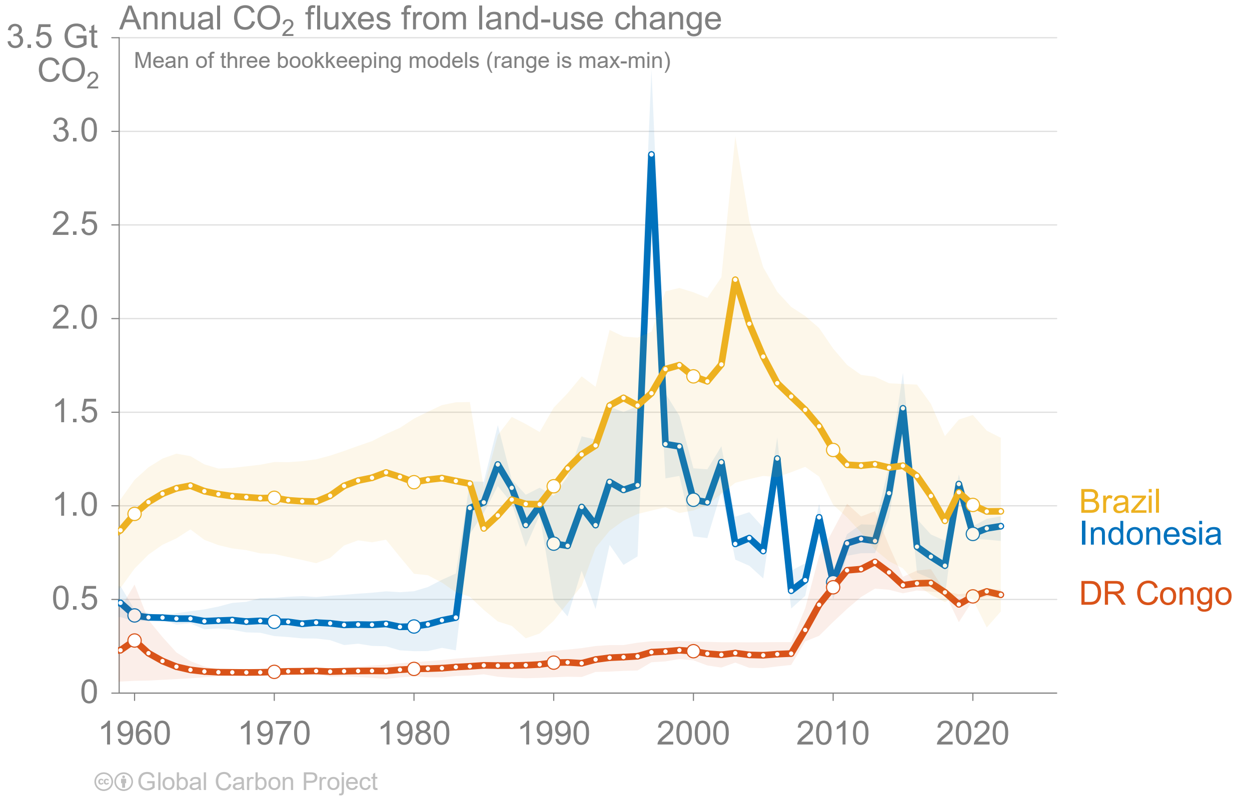
Estimates from three bookkeeping models
Source: Friedlingstein et al 2023; Global Carbon Project 2023

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.

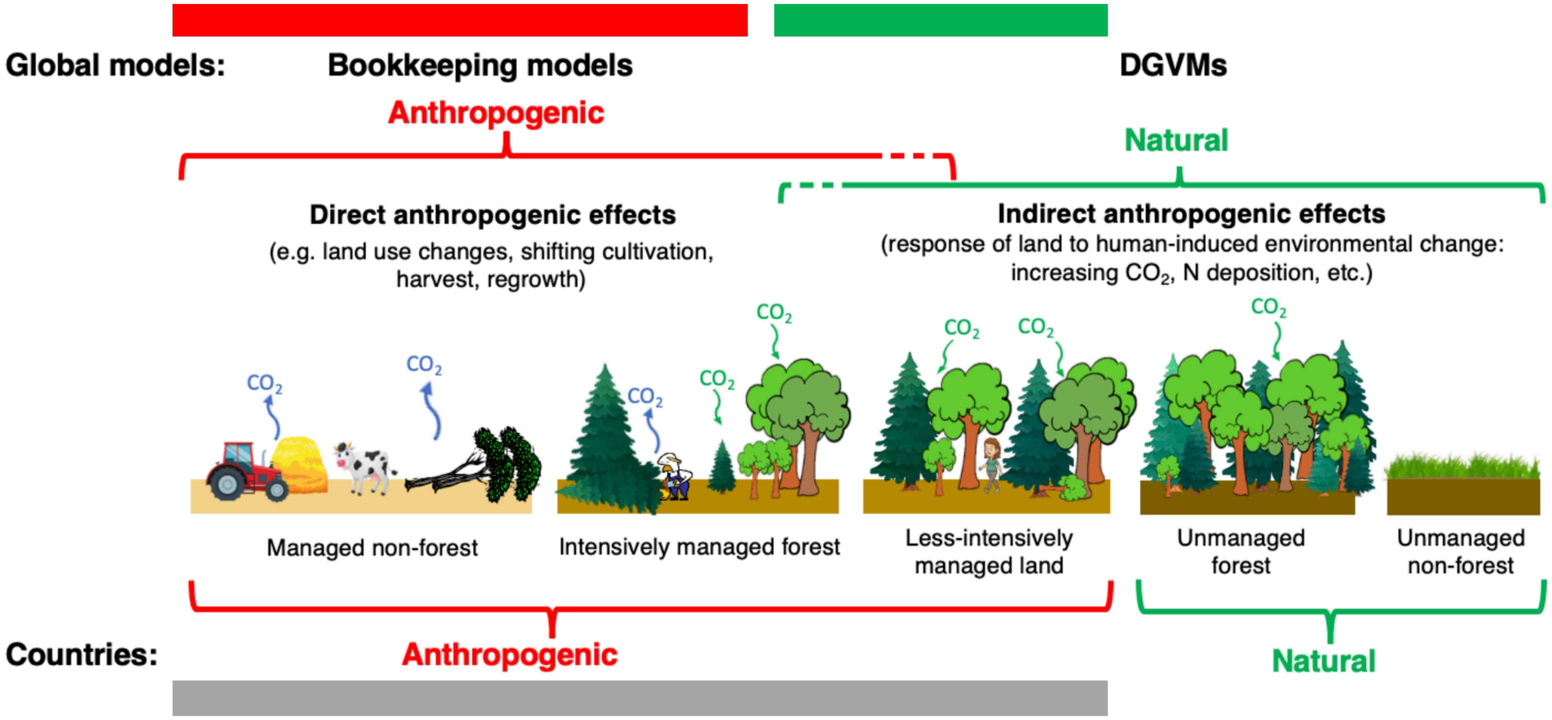
Estimates from three bookkeeping models

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

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 $GtCO_2$ per year for 2013–2022) are added to land-use emissions (4.7 $GtCO_2$ per year), the GCB2023 estimates (-2.1 $GtCO_2$ per year) are very similar to the country-reported data (-2.0 $GtCO_2$ per year), linking the anthropogenic carbon budget estimates of land CO_2 fluxes directly to the Global Stocktake as part of UNFCCC Paris Agreement.

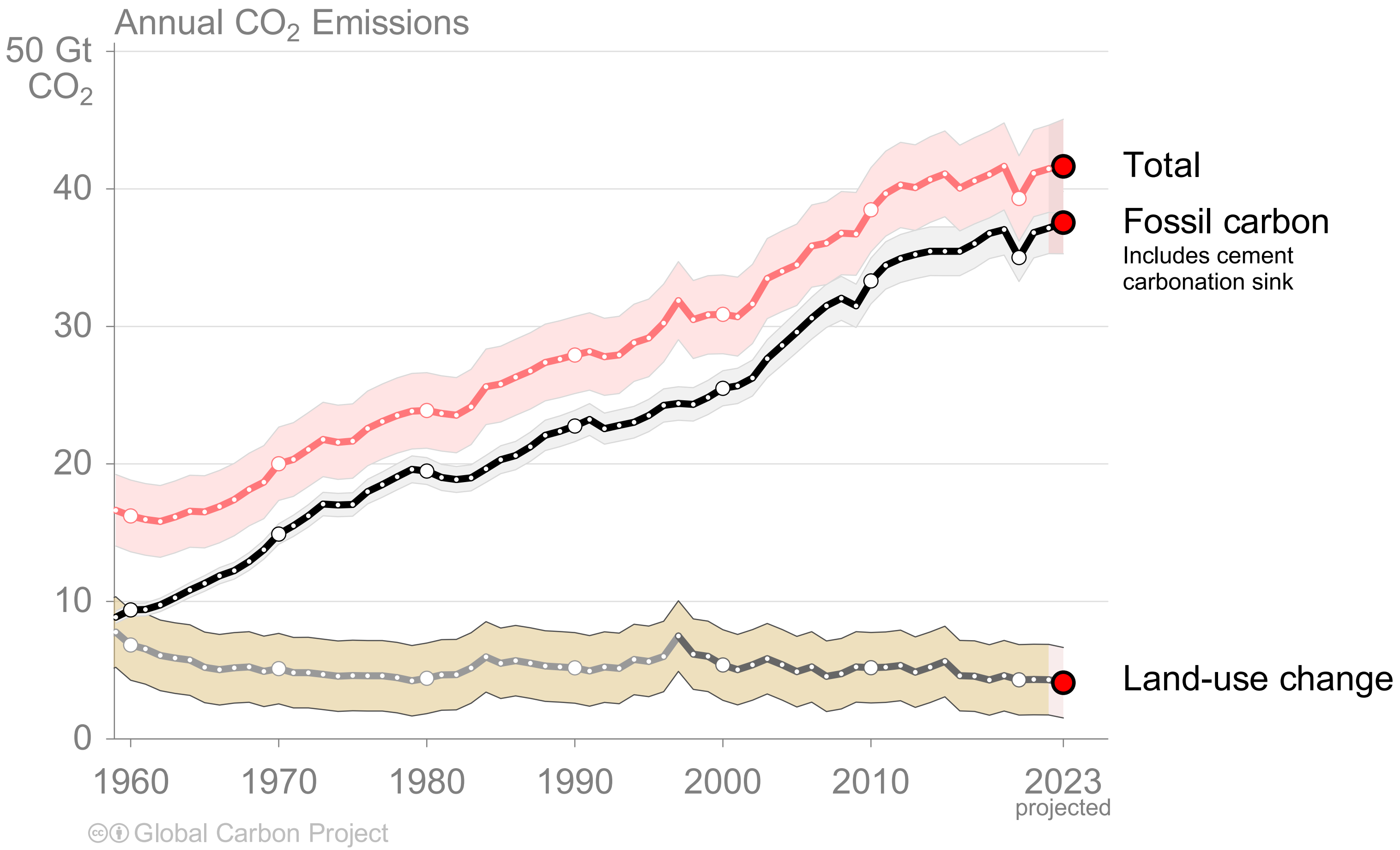


Source: Friedlingstein et al 2023; Global Carbon Project 2023
Figure from Grassi et al., ESSD 2023

Total global emissions

Total global emissions, projected to reach 40.9 ± 3.2 $GtCO_2$ 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

GLOBAL CARBON project

Fate of anthropogenic CO_2 emissions (2013–2022)

Sources = **Sinks**

35.3 $GtCO_2/yr$

88%

12%

4.7 $GtCO_2/yr$

18.9 $GtCO_2/yr$

47%

31%

12.3 $GtCO_2/yr$

26%

10.4 $GtCO_2/yr$

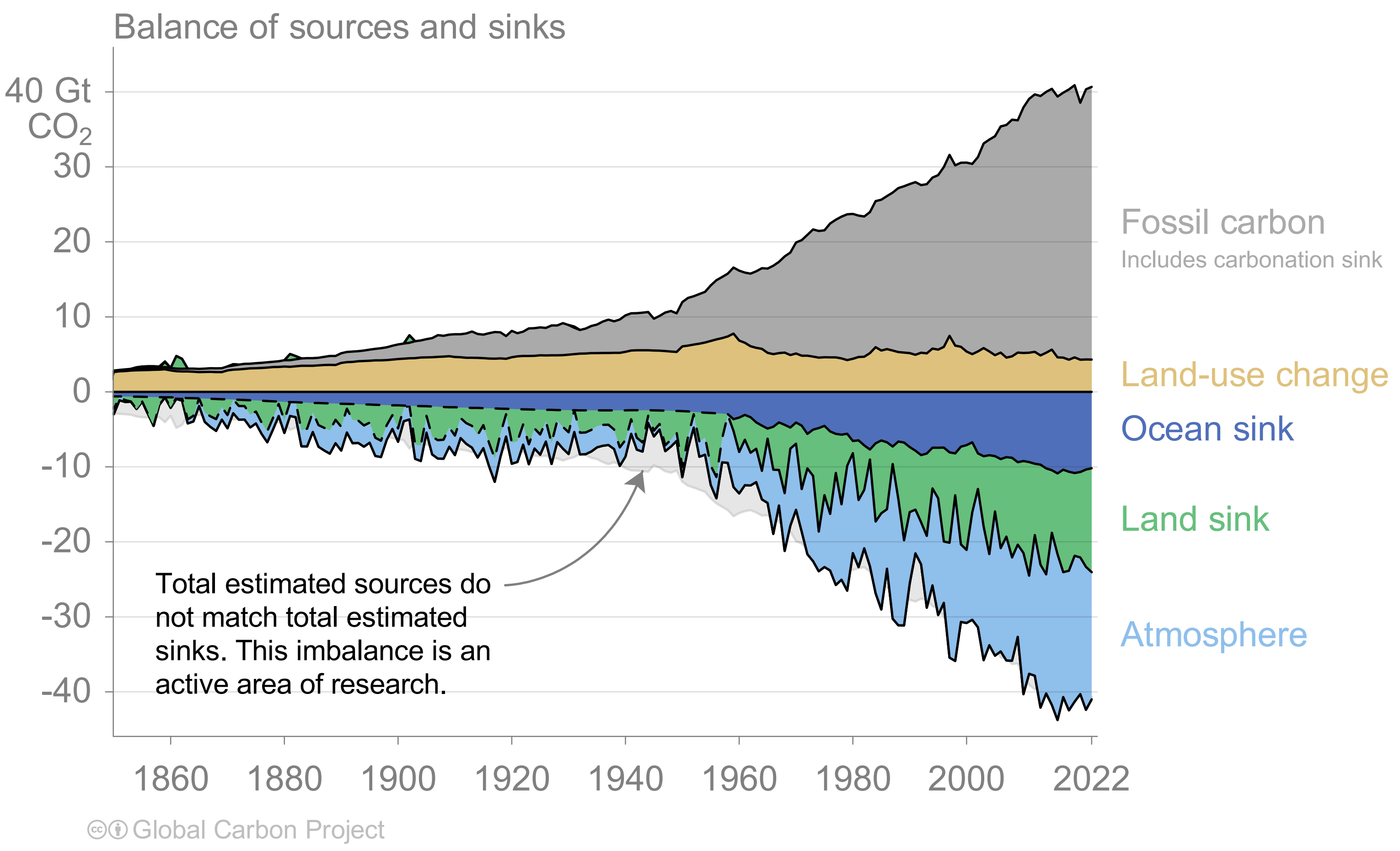
Budget Imbalance:
(the difference between estimated sources & sinks)

4%
-1.6 $GtCO_2/yr$

Source: Friedlingstein et al 2023; Global Carbon Project 2023

Global carbon budget

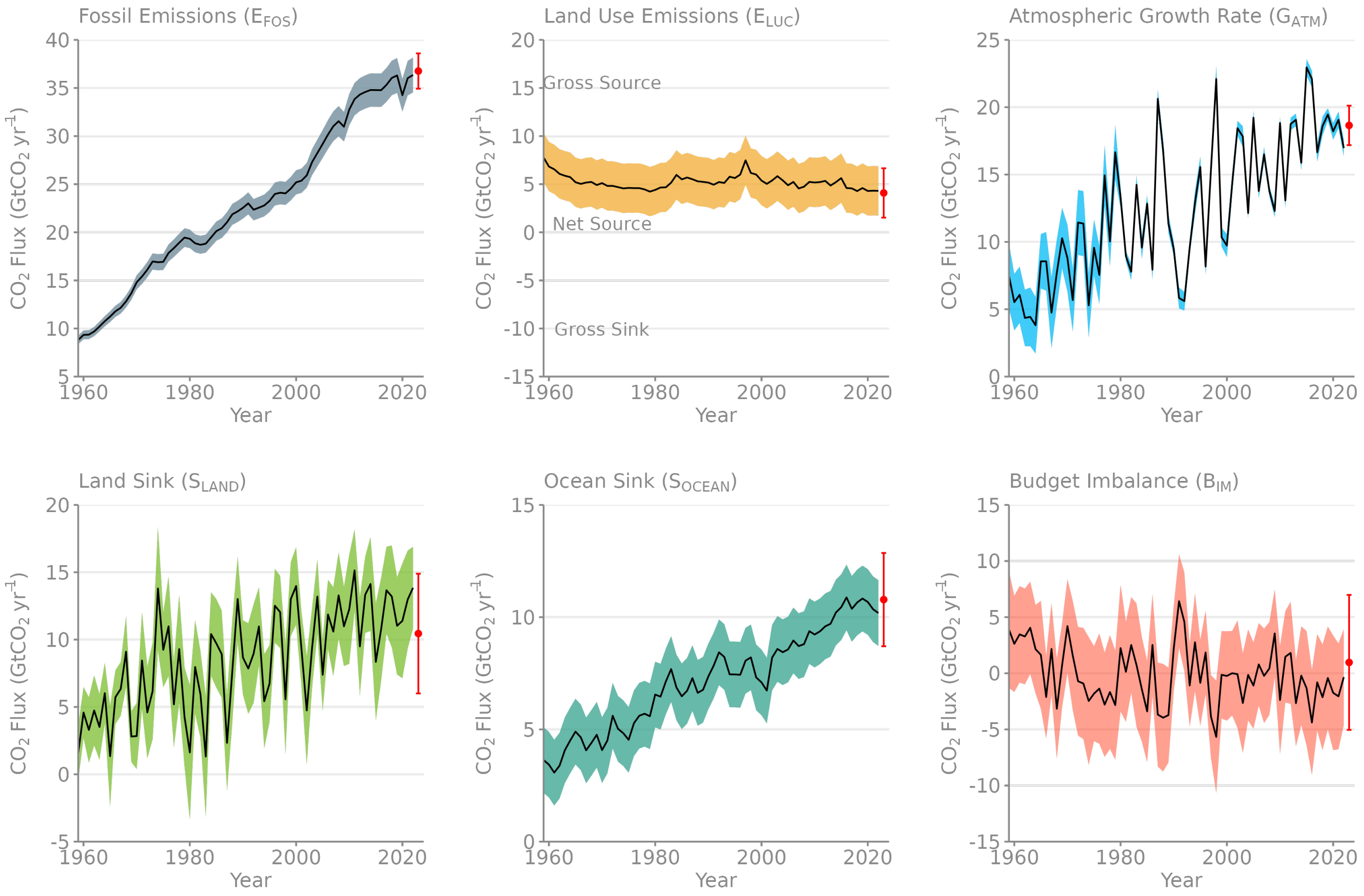
Carbon emissions are partitioned among the atmosphere and carbon sinks on land and in the ocean
The “imbalance” between total emissions and total sinks is an active area of research



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

Changes in the budget over time

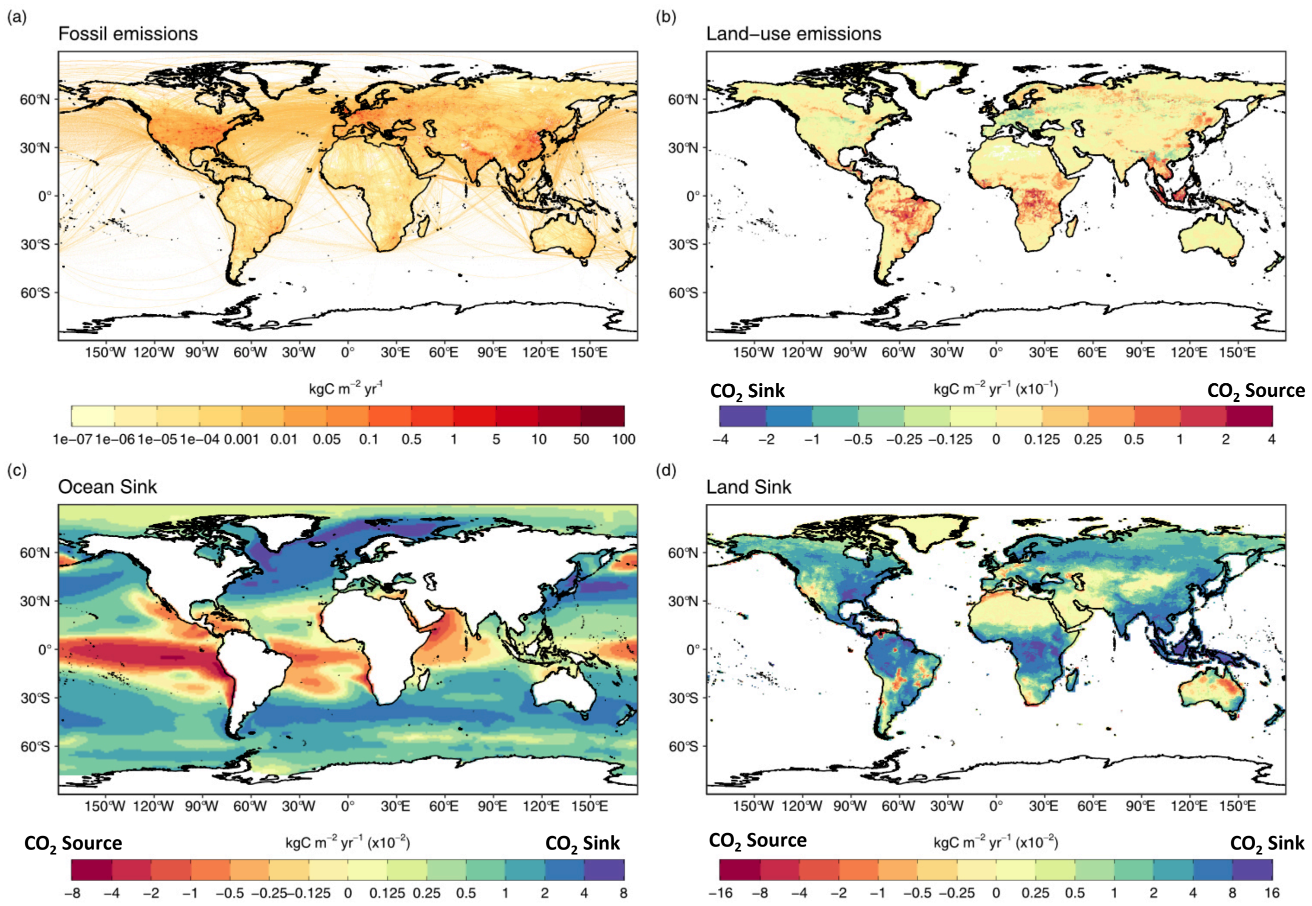
The sinks have continued to grow with increasing emissions, but climate change will affect carbon cycle processes in a way that will exacerbate the increase of CO_2 in the atmosphere



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

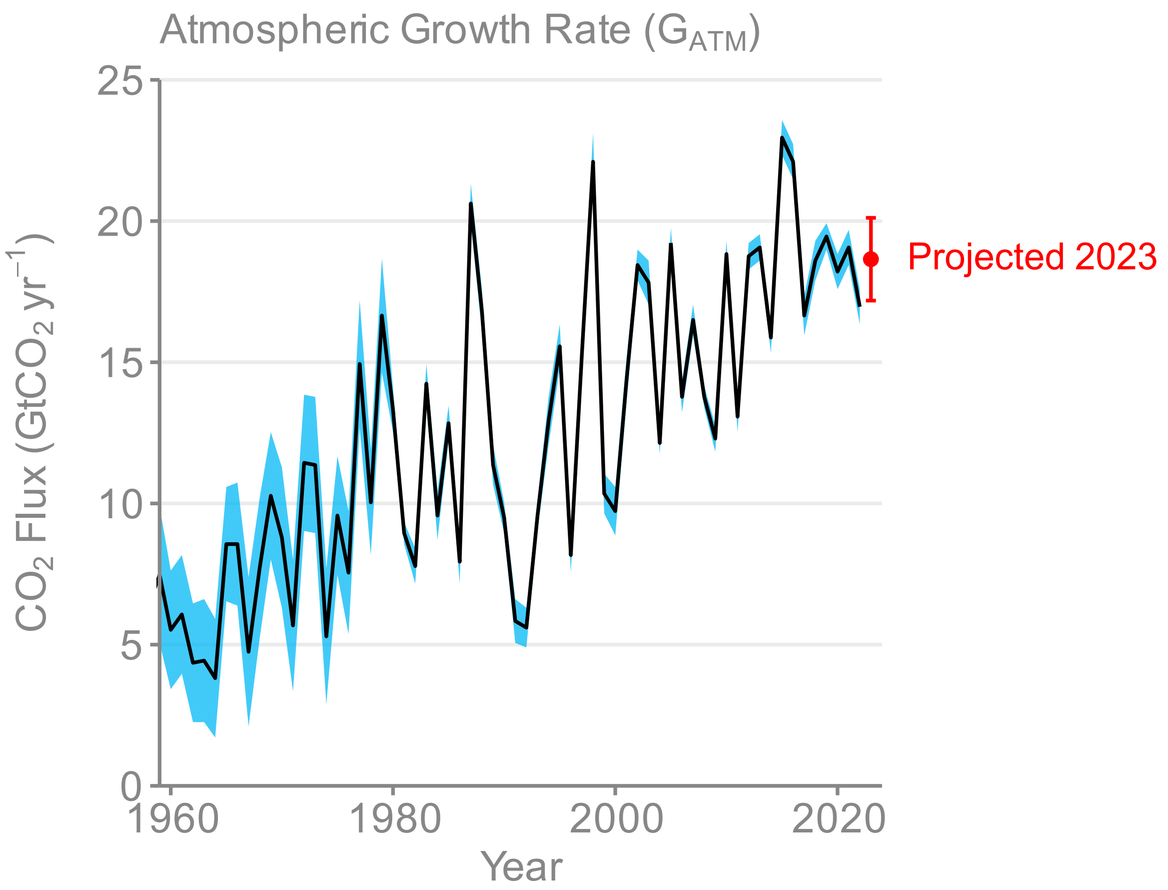
Fossil emissions dominate in the Northern Hemisphere, while land-use emissions are important in the tropics.
The North Atlantic and Southern Ocean are carbon sinks while the tropical ocean is a source of CO_2.
Tropical, temperate and boreal forest are the main terrestrial carbon sinks



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

Atmospheric concentration

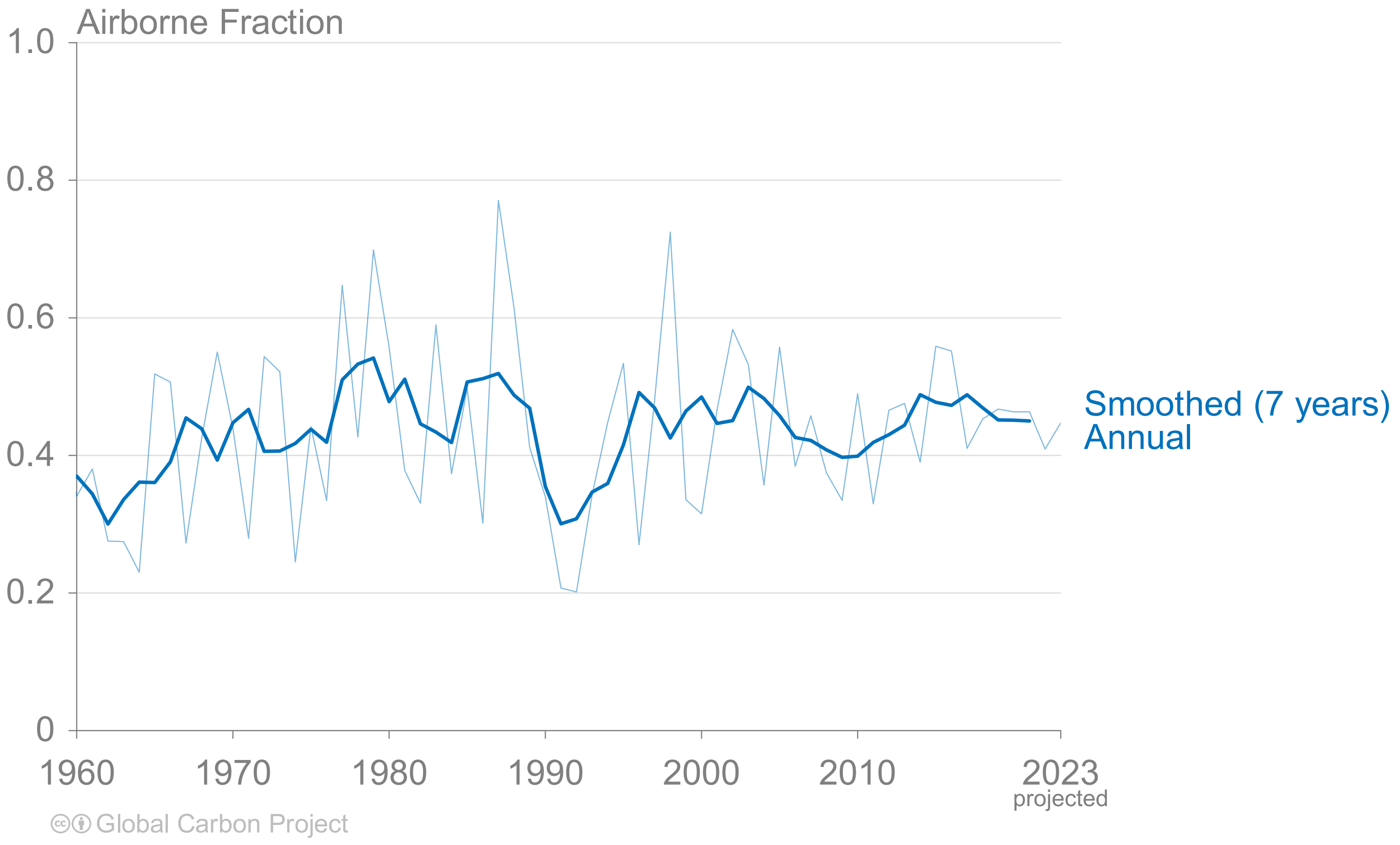
The atmospheric concentration growth rate has increased steadily.
The high growth in 1987, 1998, & 2015–16 reflect a strong El Niño, which weakens the land sink.
The effects of the currently emerging El Niño are expected to be most visible in the growth rate in 2024.



Source: [NOAA-GML](); [Friedlingstein et al 2023](); [Global Carbon Project 2023]()

Airborne Fraction

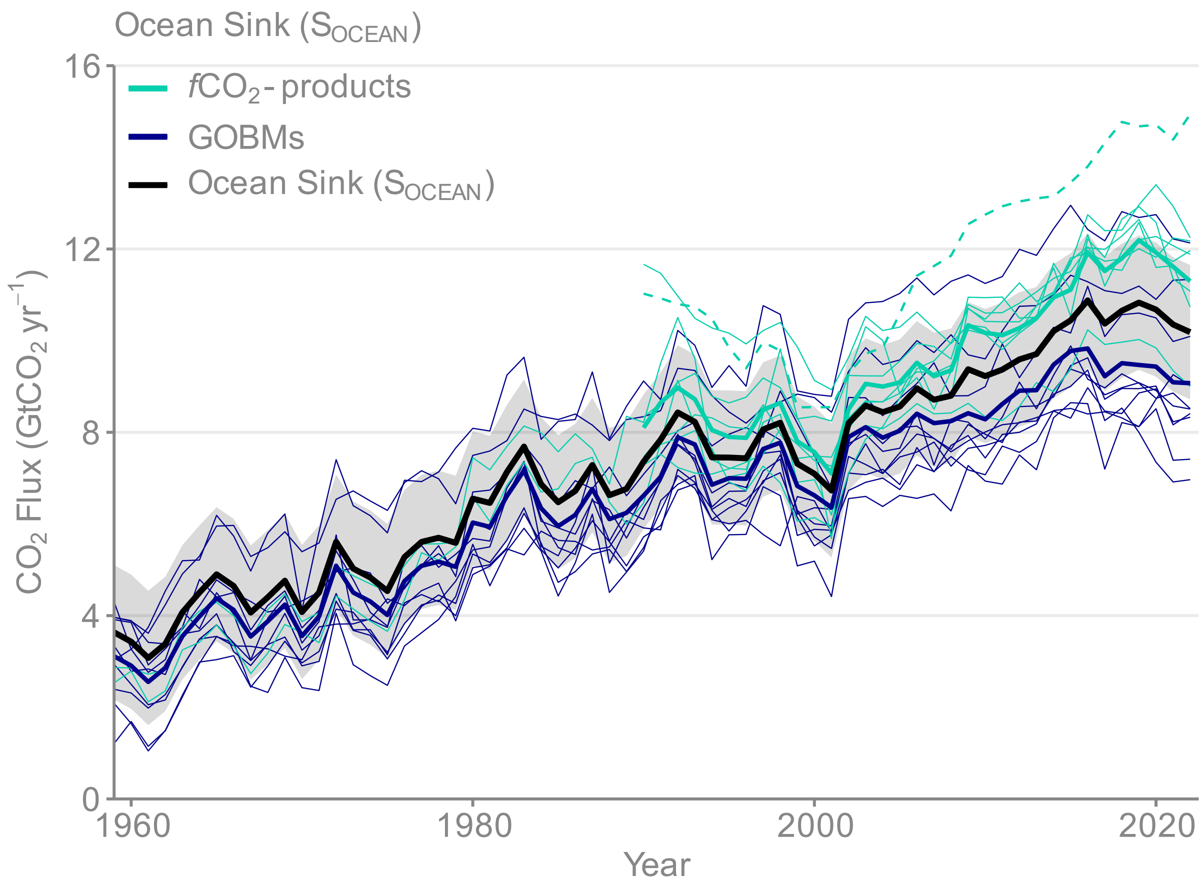
The airborne fraction is the proportion of the total annual CO_2 emissions that remains in the atmosphere.
The rest of the CO_2 emissions are removed by the land and ocean sinks.
Around 45% of CO_2 emissions remain in the atmosphere despite sustained growth in CO_2 emissions.



Source: Friedlingstein et al 2023; Global Carbon Project 2023

Ocean sink

The ocean carbon sink, estimated by Global Ocean Biogeochemical Models and observation-based data products, amounts to 10.4 ± 1.5 $GtCO_2$/yr for 2013–2022 and 10.2 ± 1.5 $GtCO_2$/yr in 2022.
The ocean CO_2 sink has not grown since 2019 due to a triple La Niña event during 2020–2022.



Source: SOCATv2023; Bakker et al 2016; Friedlingstein et al 2023; Global Carbon Project 2023

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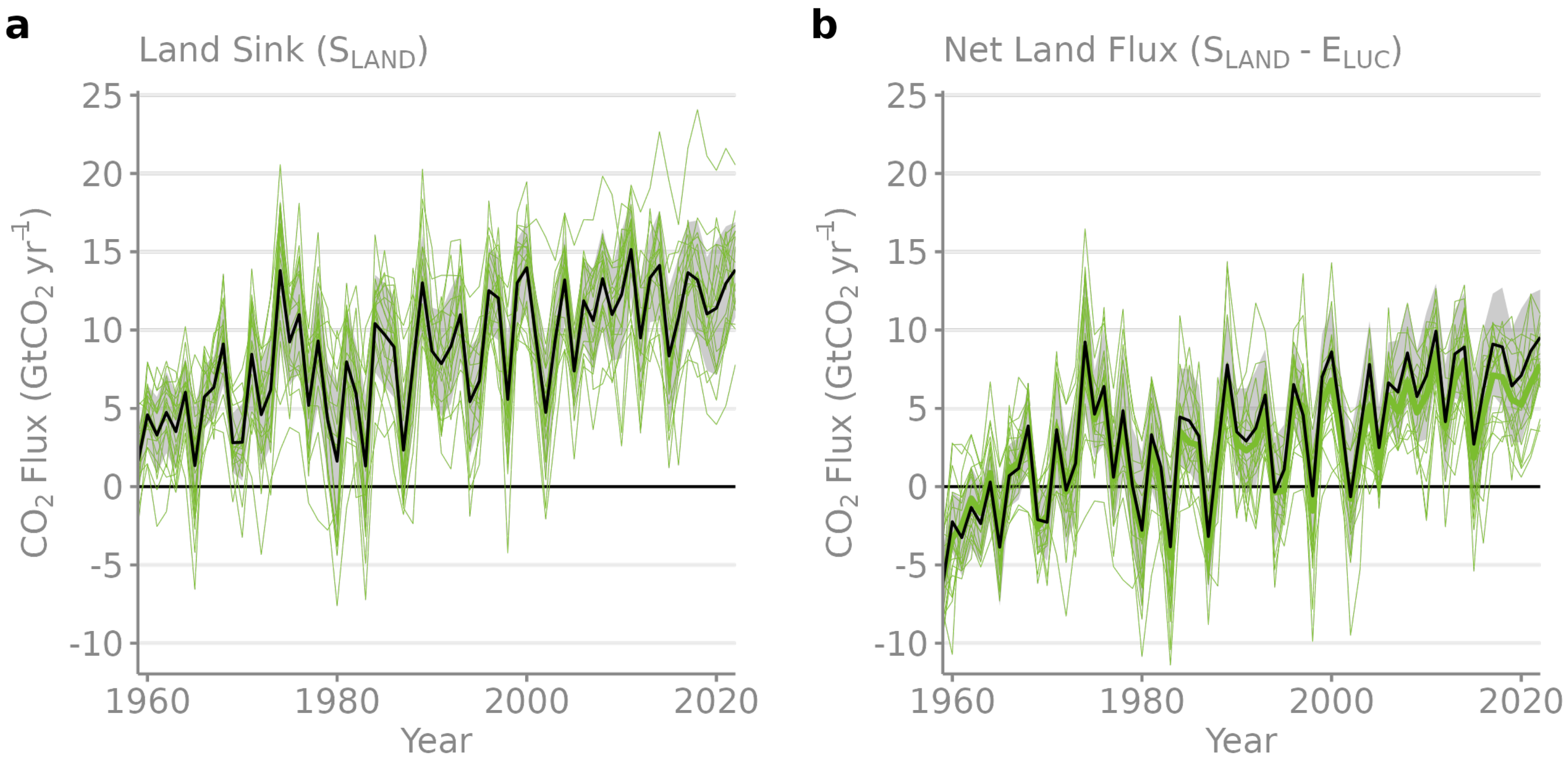
Terrestrial sink

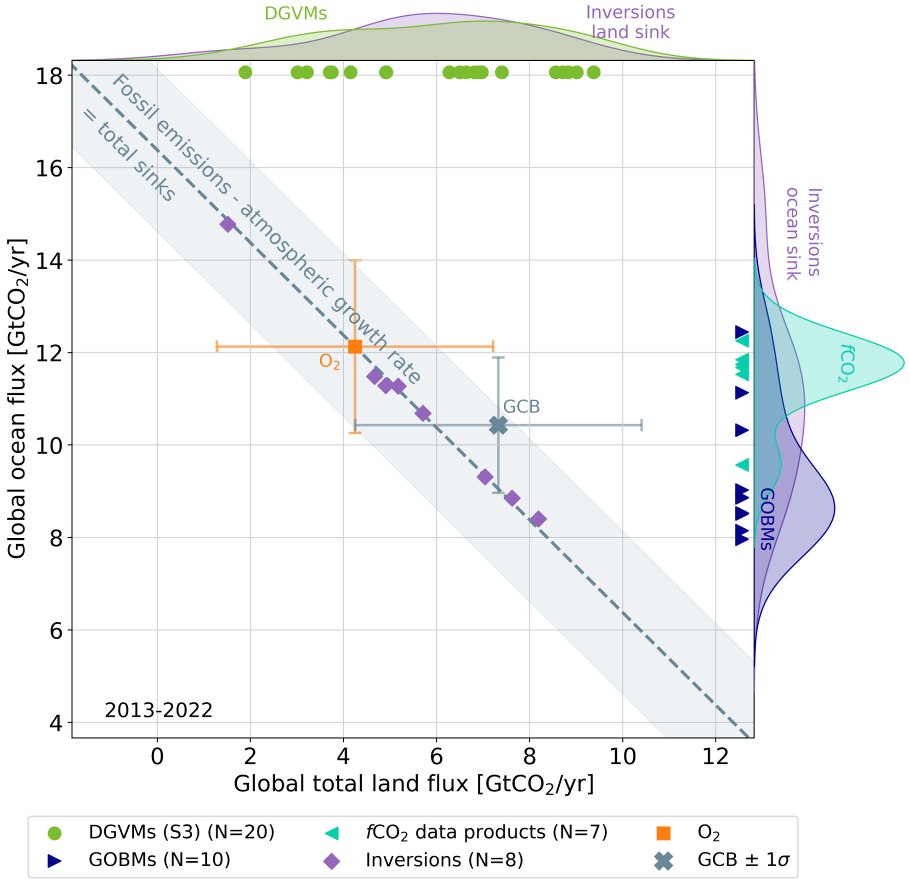
The land carbon sink, estimated by Dynamic Global Vegetation Models, was 12.3 ± 3.1 $GtCO_2$/yr during 2013–2022 and 13.9 ± 3.0 $GtCO_2$/yr in 2022.
The total CO_2 fluxes on land (including land-use change) are also constrained by atmospheric inversions.



Source: Friedlingstein et al 2023; Global Carbon Project 2023

Land and ocean sinks — Estimates from atmospheric inversions

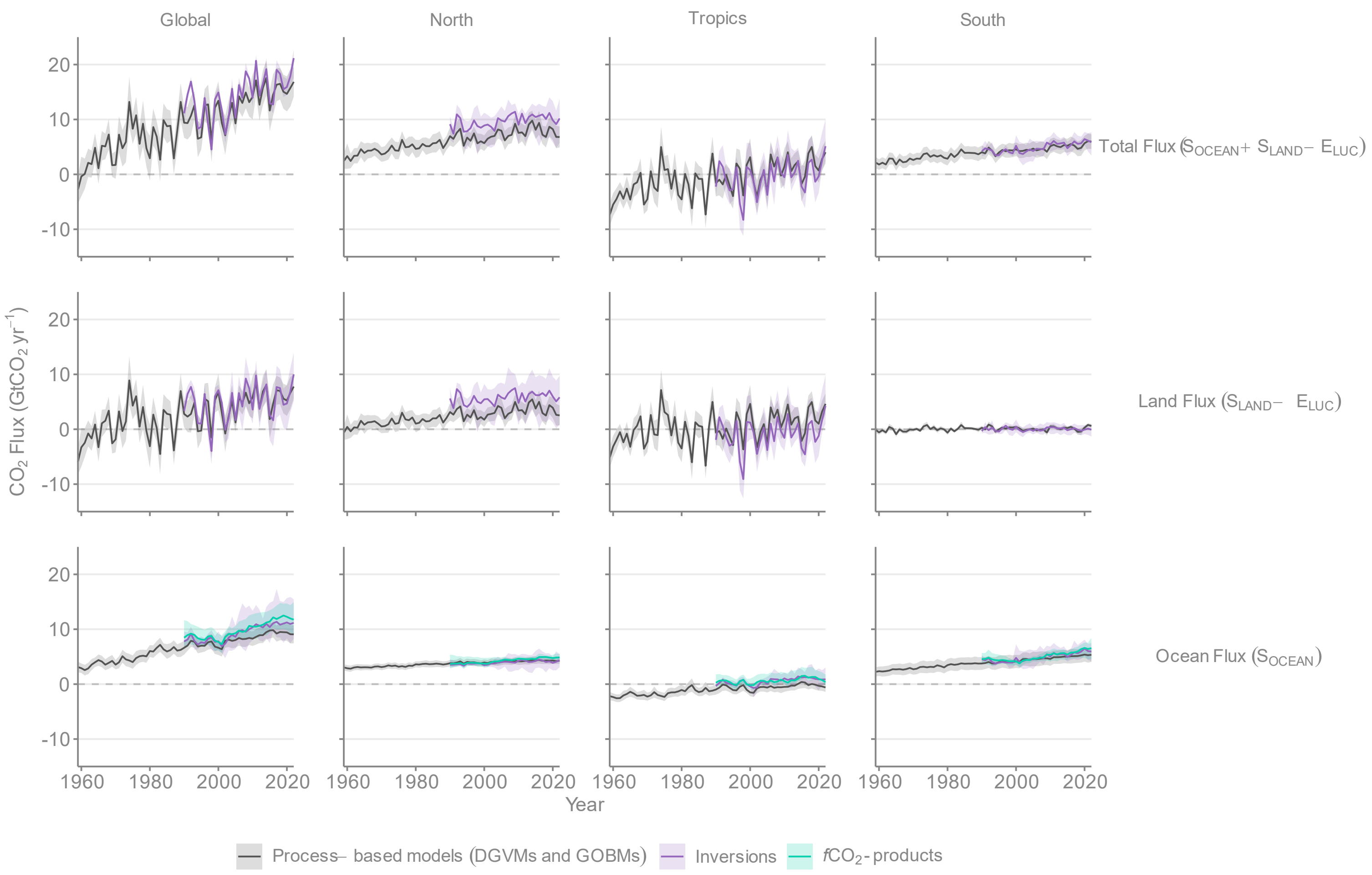
Both atmospheric CO_2 inversions and atmospheric oxygen allow to estimate the land and ocean carbon fluxes, independently from the land and ocean process-based models, confirming the global carbon budget estimates of the land and ocean partitioning of anthropogenic CO_2



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

Total land and ocean fluxes

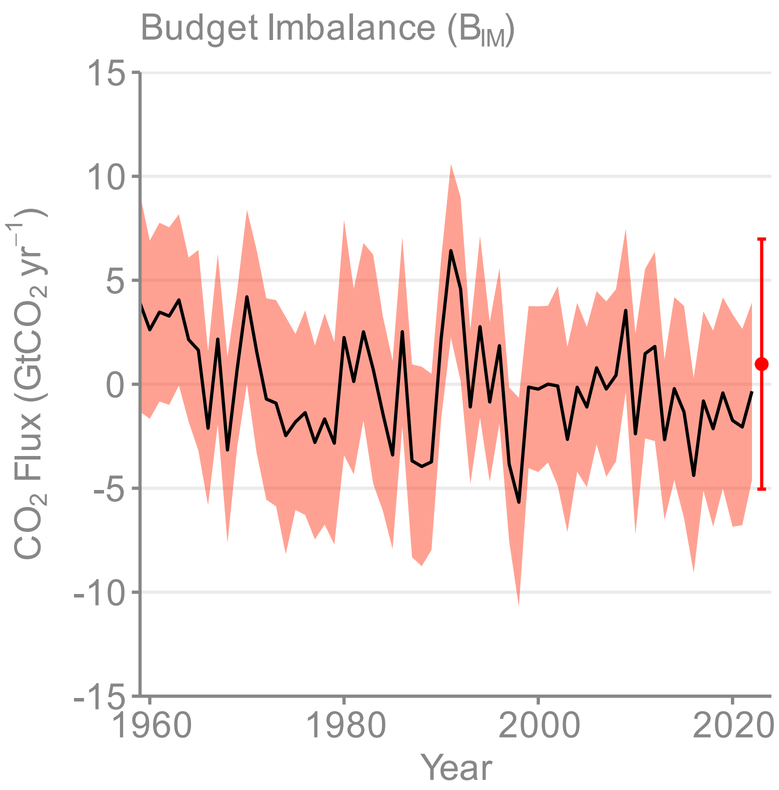
Total land and ocean fluxes show more interannual variability in the tropics



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

Remaining carbon budget imbalance

Large and unexplained variability in the global carbon balance caused by uncertainty and understanding hinder independent verification of reported CO_2 emissions



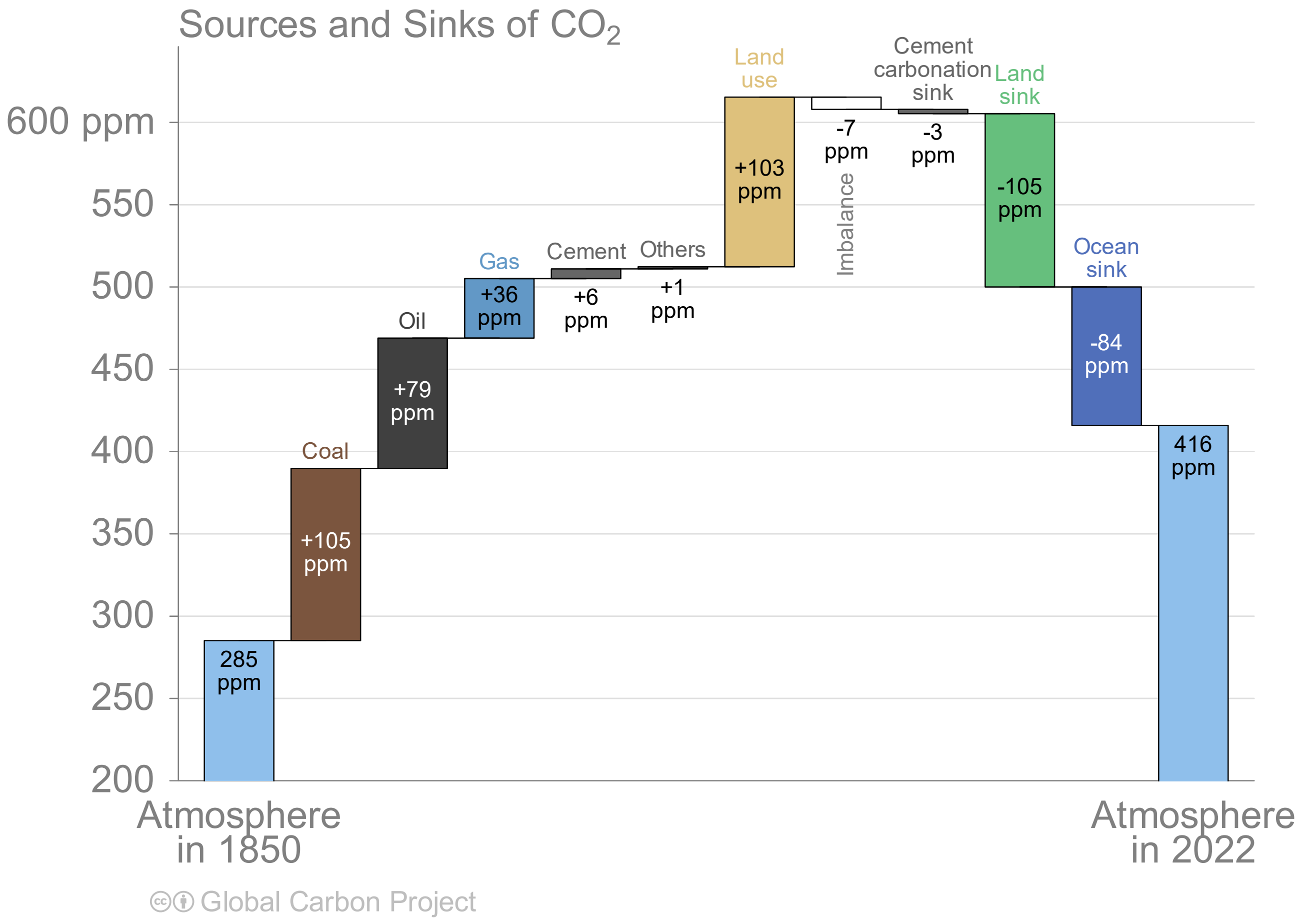
positive values mean overestimated emissions and/or underestimated sinks

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

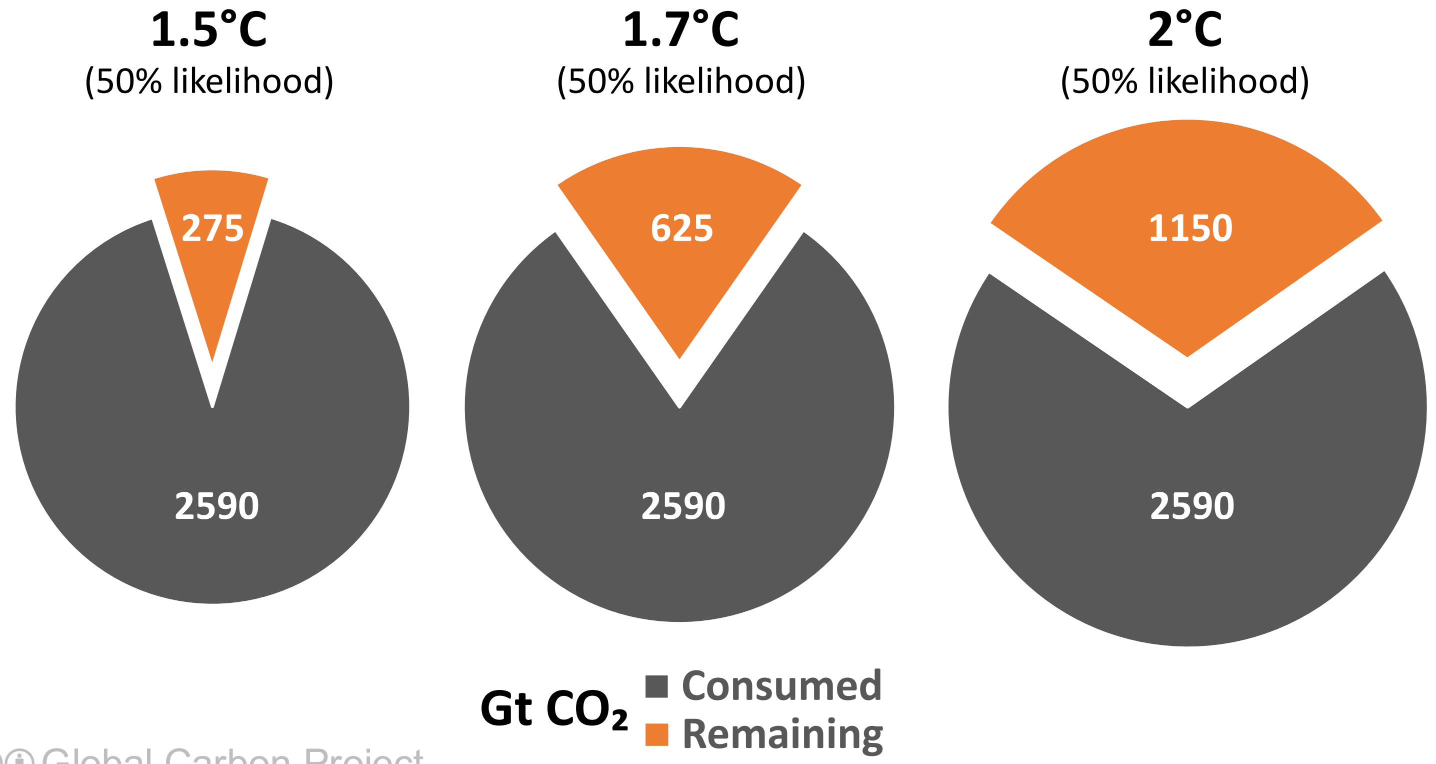
The cumulative contributions to the global carbon budget from 1850
The carbon imbalance represents the gap in our current understanding of sources & sinks



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

Remaining carbon budget

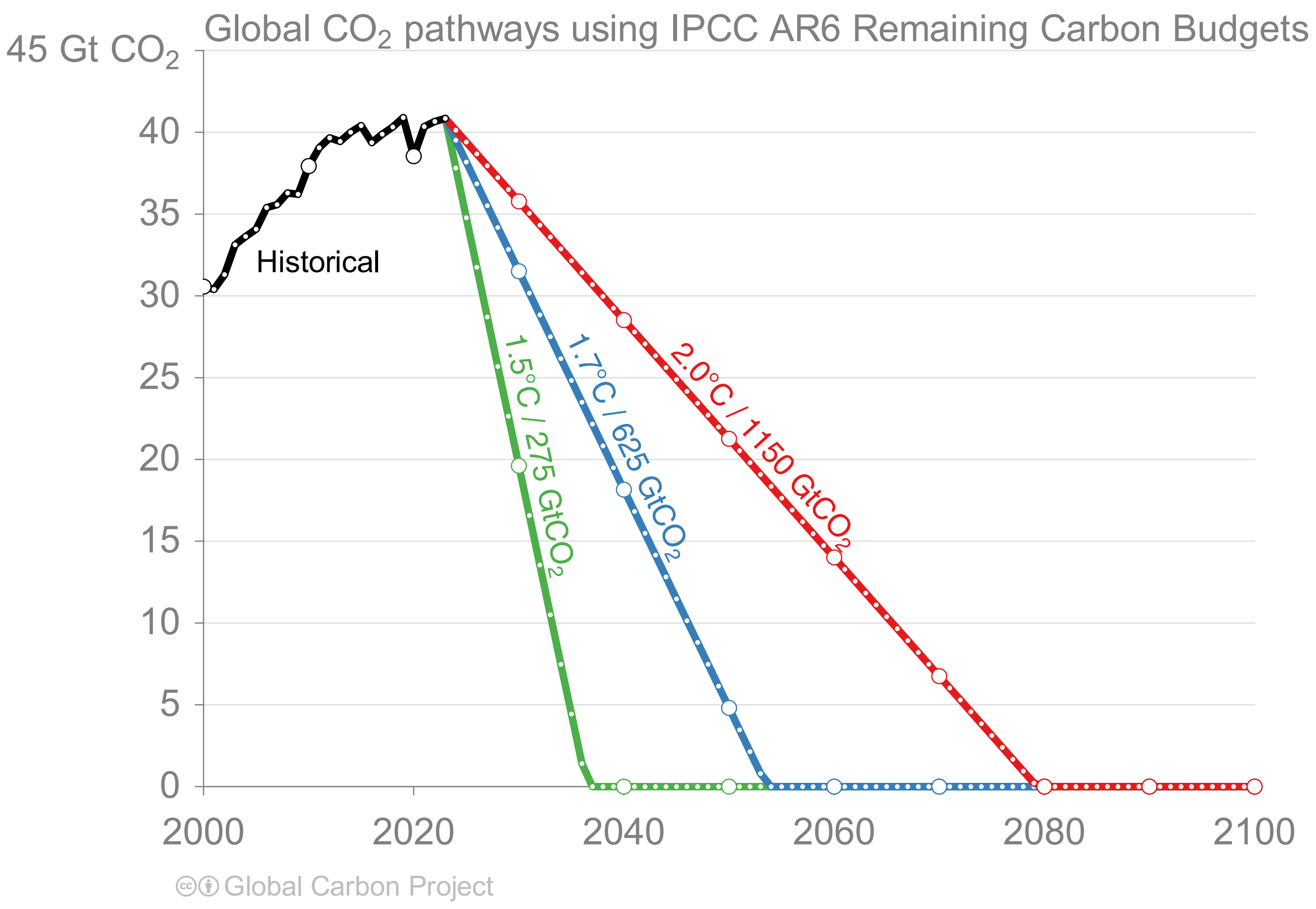
The remaining carbon budget to limit global warming to 1.5°C , 1.7°C and 2°C is
275 $GtCO_2$, 625 $GtCO_2$, and 1150 $GtCO_2$ respectively, equivalent to 7, 15 and 28 years from 2024.
2590 $GtCO_2$ have been emitted since 1850



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-CO_2 emissions
Source: IPCC AR6 WG1; Forster et al., 2023; Friedlingstein et al 2023; Global Carbon Project 2023

Remaining carbon budget

Global CO_2 emissions must reach zero to limit global warming



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

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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We also thanks 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.

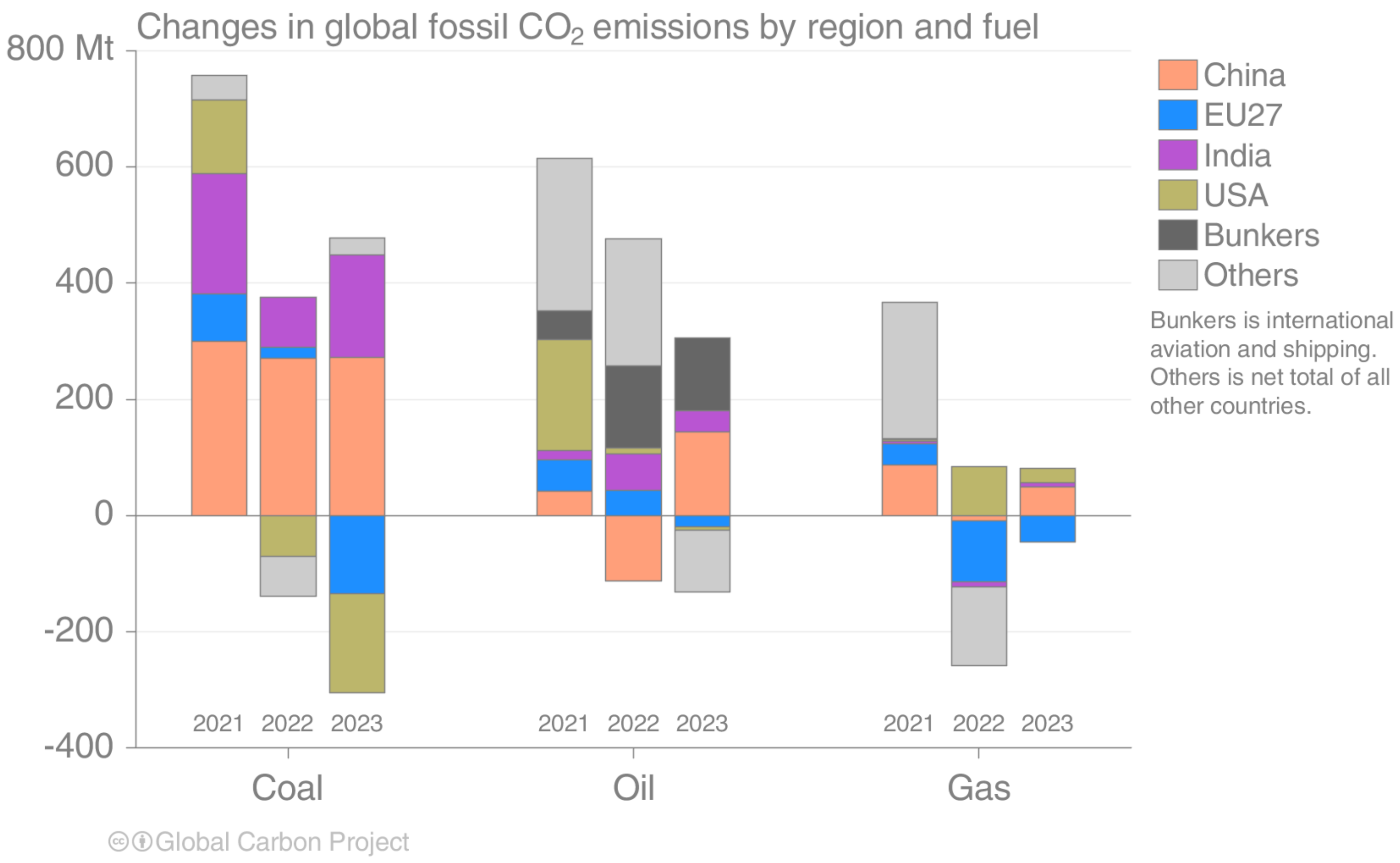
Additional Figures

GLOBAL CARBON project

Additional Figures
Fossil CO_2

Emissions changes 2021–2023

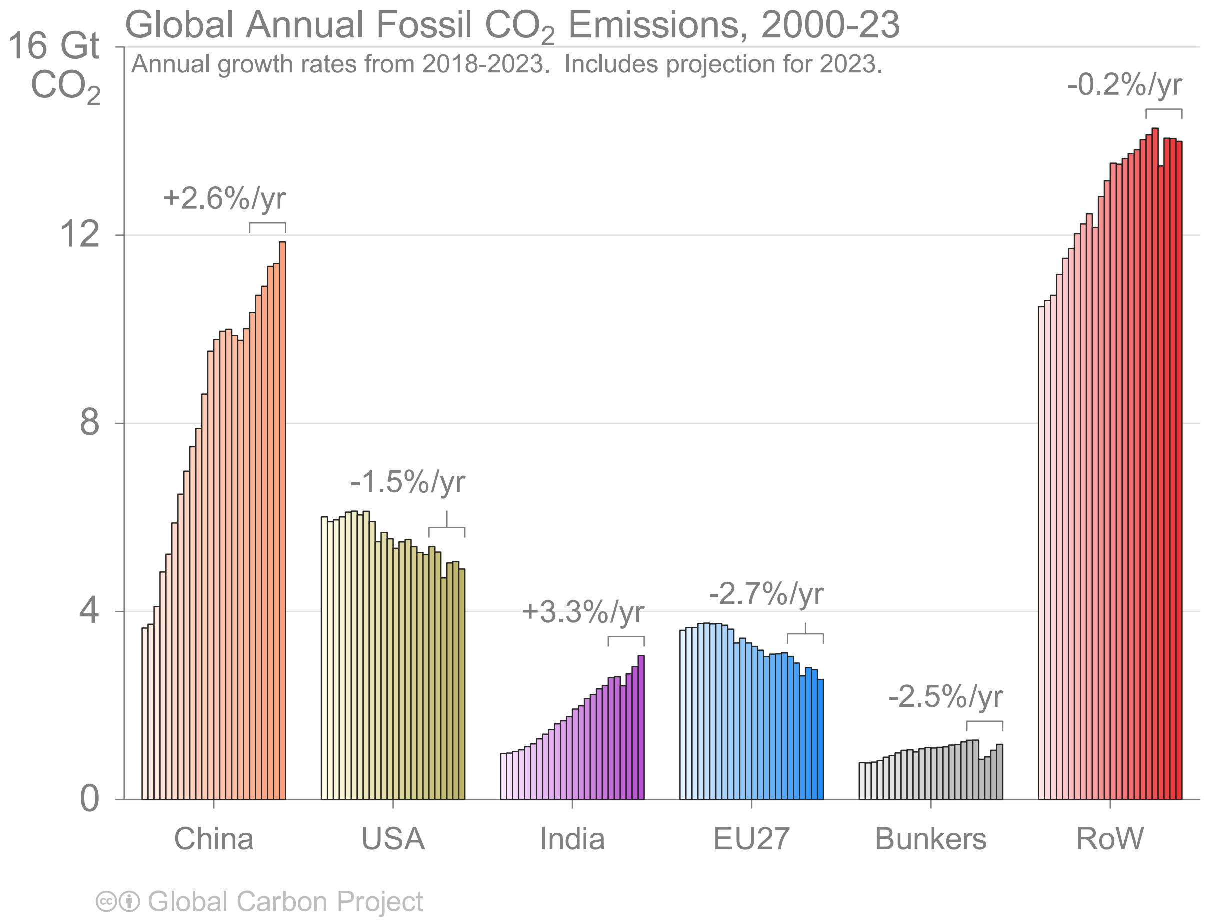
Emissions from coal in China and India have been a core reason for global growth. Both 2022 and 2023 were marked by post-pandemic recovery in international aviation (bunkers).



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

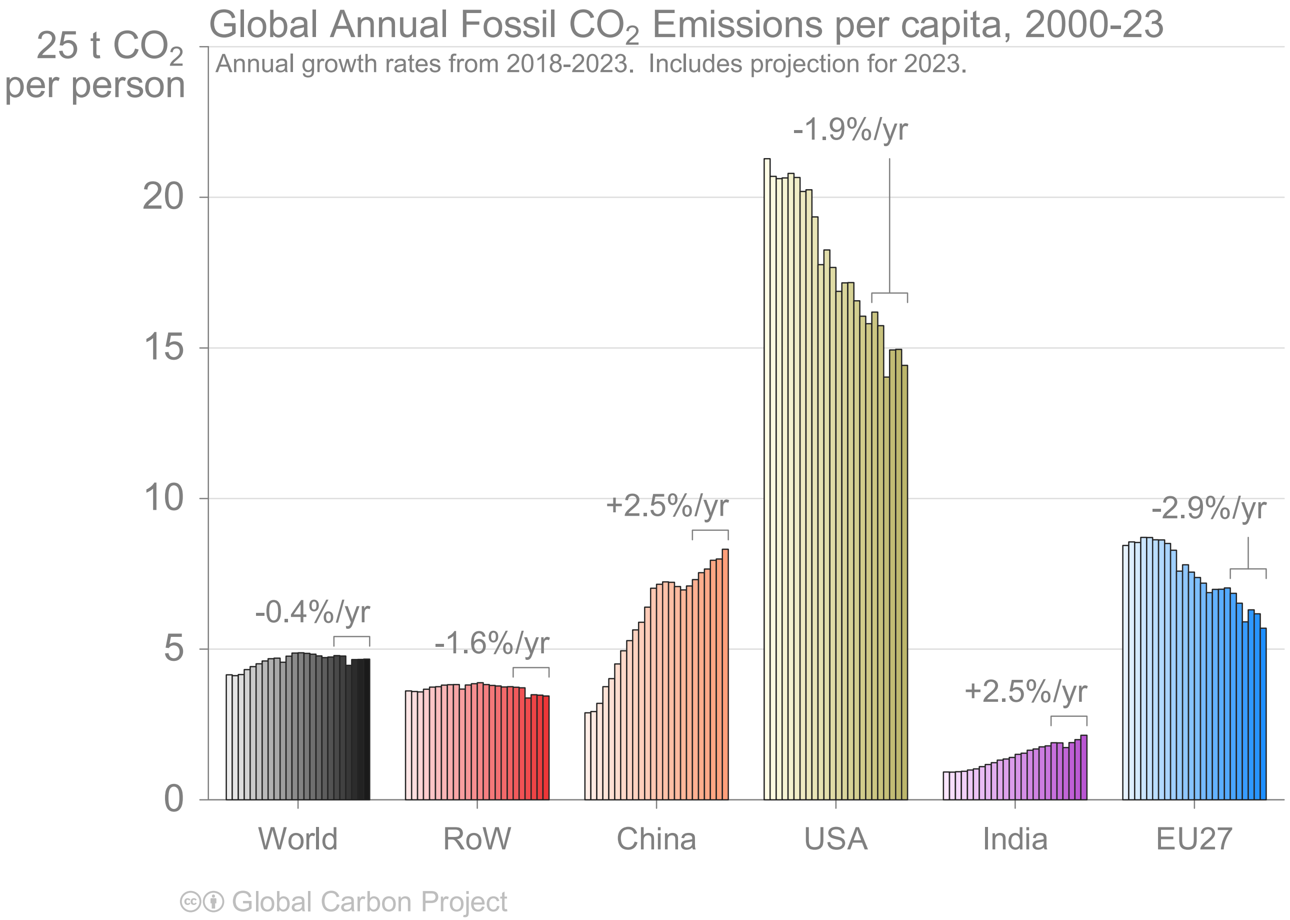
Top emitters: Fossil CO_2 Emissions

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



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

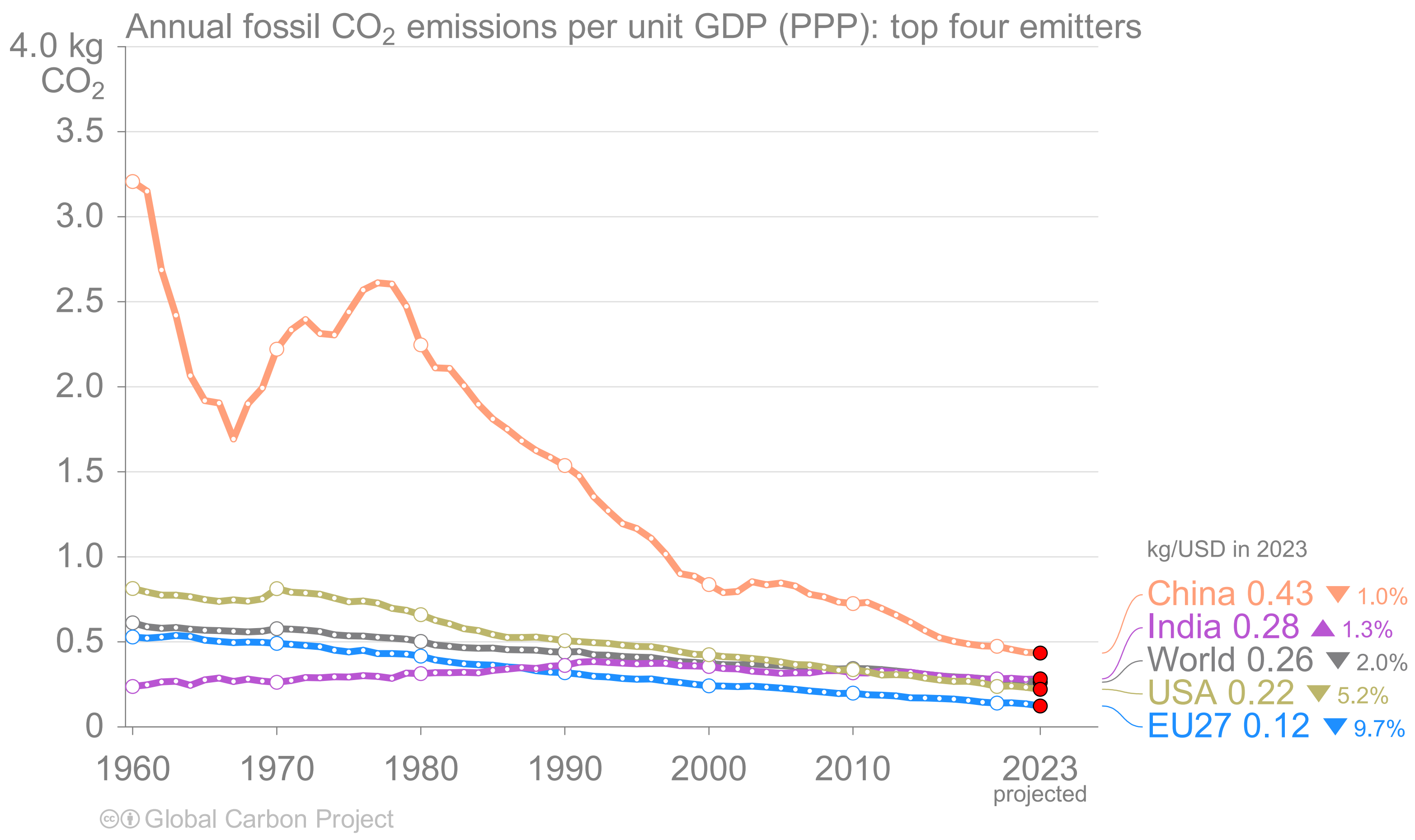
Per capita CO_2 emissions



Source: Friedlingstein et al 2023; Global Carbon Project 2023

Top emitters: Fossil CO_2 Emission Intensity

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

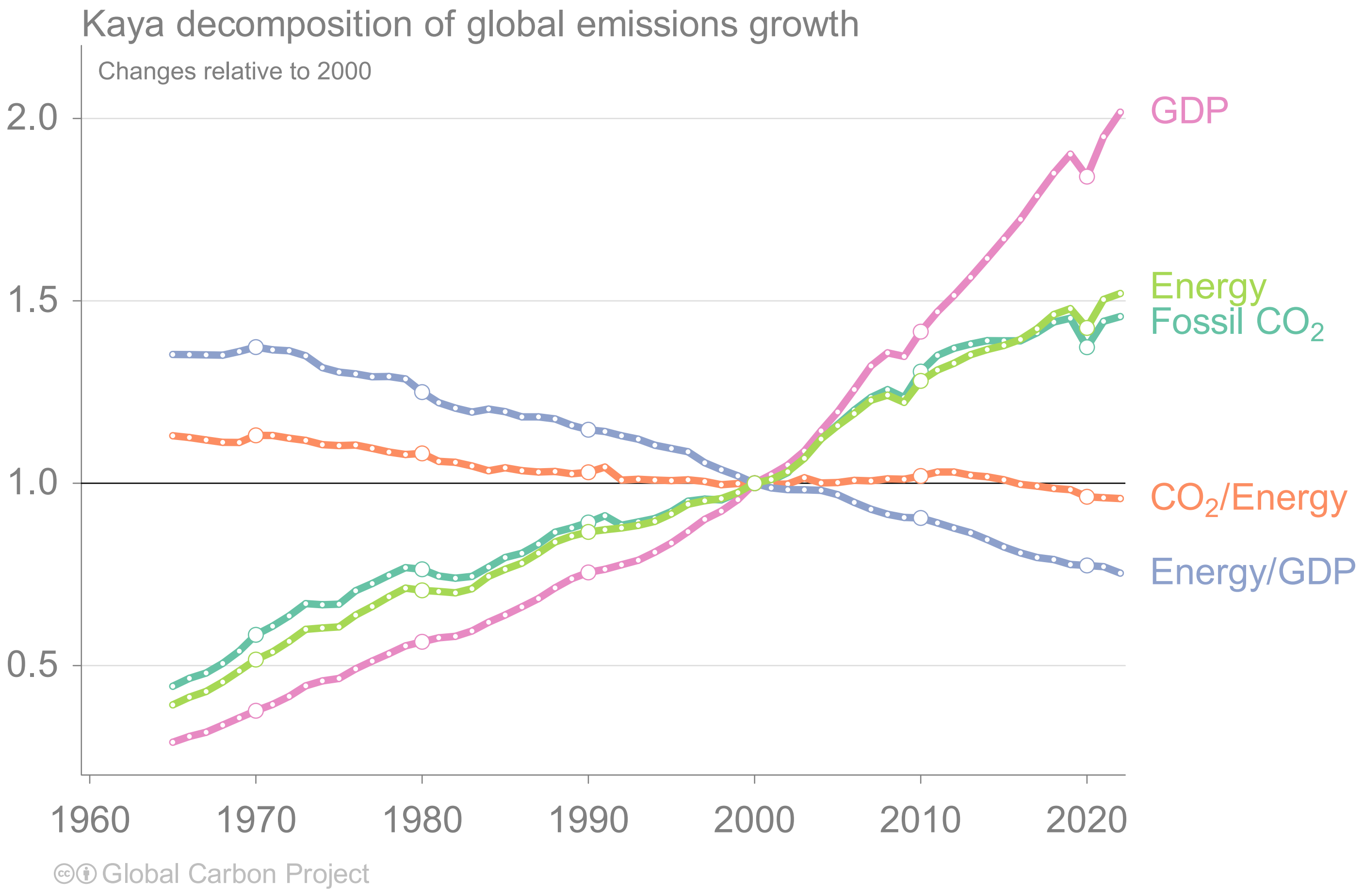


GDP is measured in purchasing power parity (PPP) terms in 2017 US dollars.

Source: Friedlingstein et al 2023; Global Carbon Project 2023

Kaya decomposition

The Kaya decomposition illustrates that relative decoupling of economic growth from CO_2 emissions is driven by improved energy intensity (Energy/GDP) and, recently, carbon intensity of energy (CO_2/Energy)

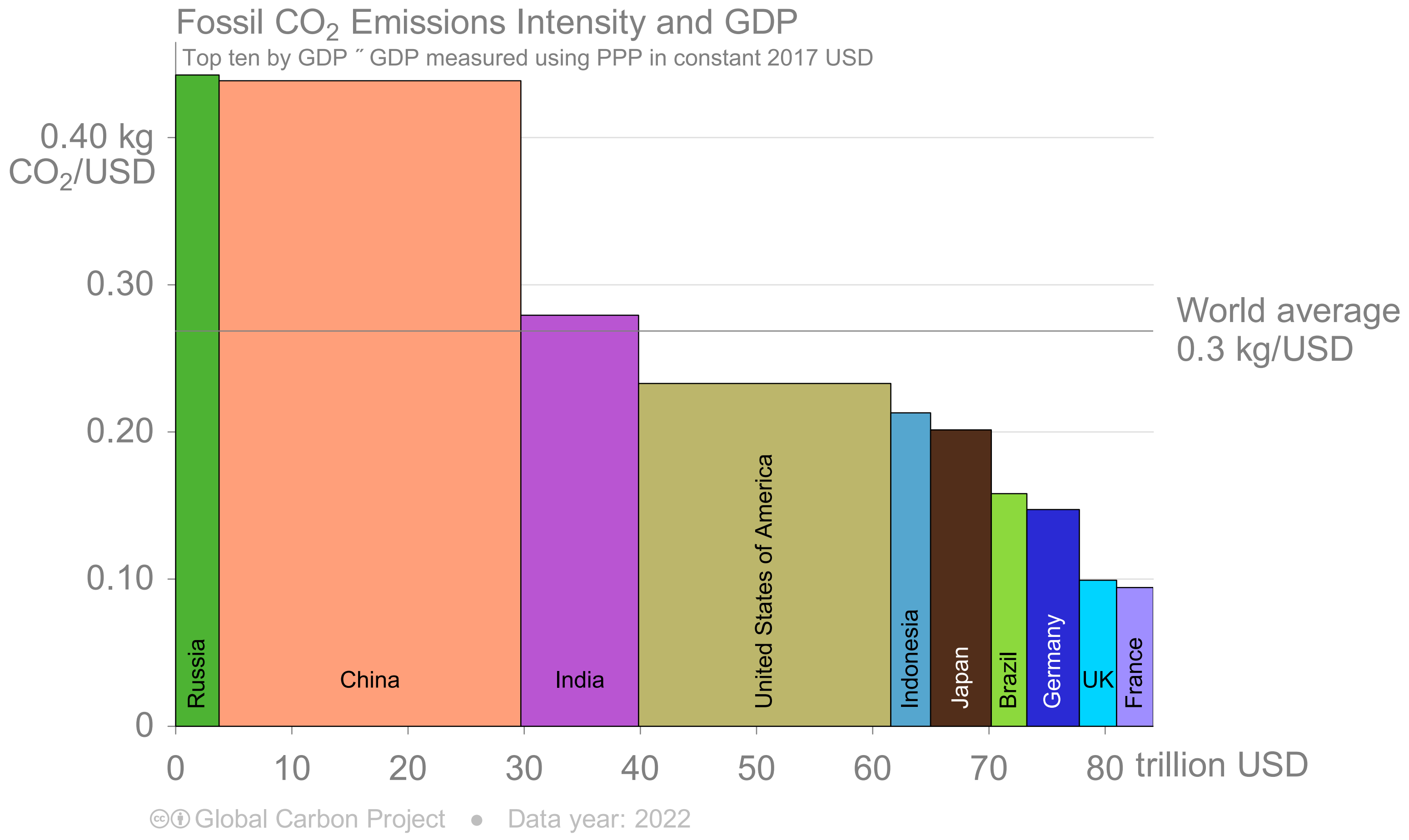


GDP: Gross Domestic Product (economic activity)

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

Fossil CO_2 emission intensity

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

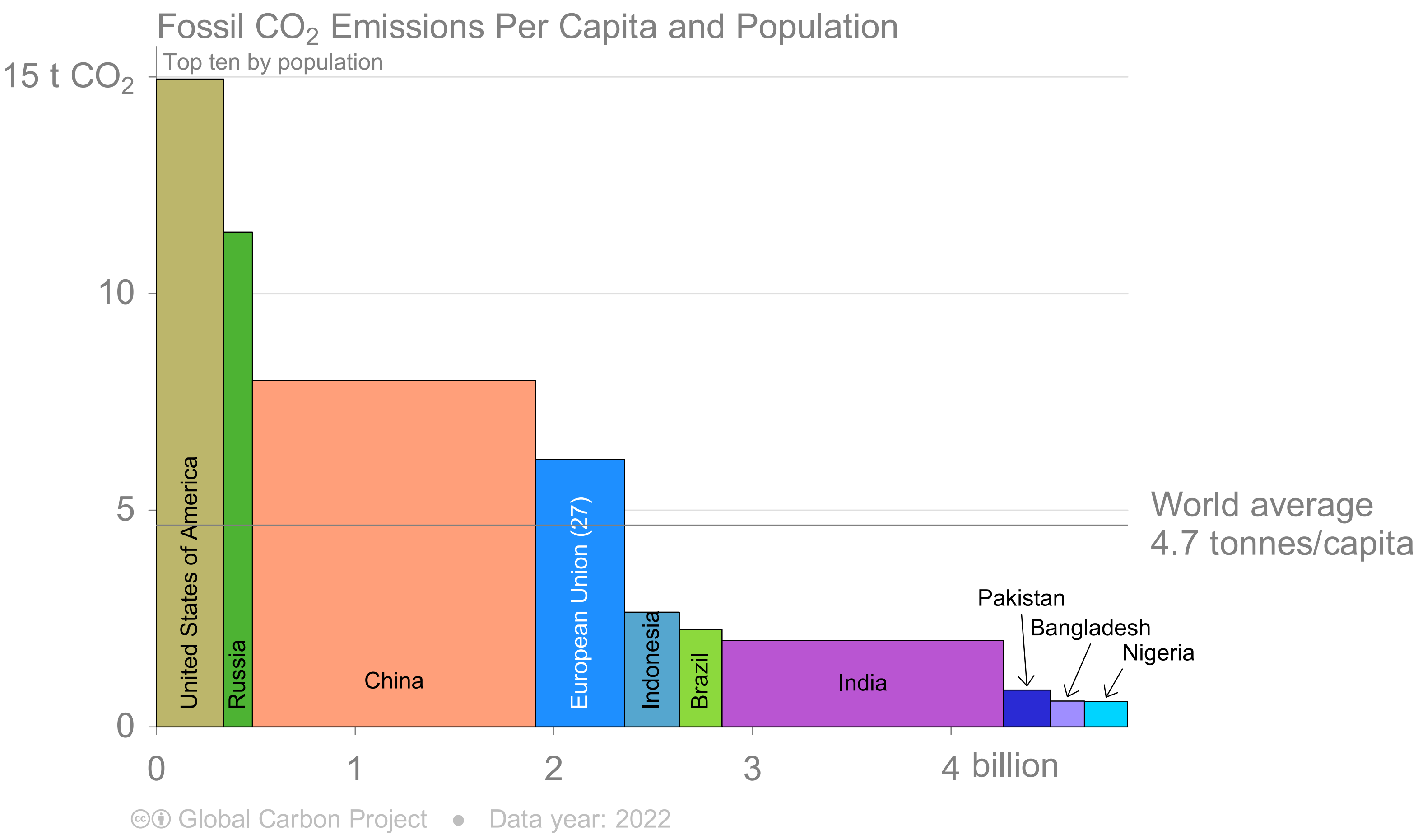


Emission intensity: Fossil CO_2 emissions divided by Gross Domestic Product (GDP)

Source: Friedlingstein et al 2023; Global Carbon Project 2023

Fossil CO_2 Emissions per capita

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

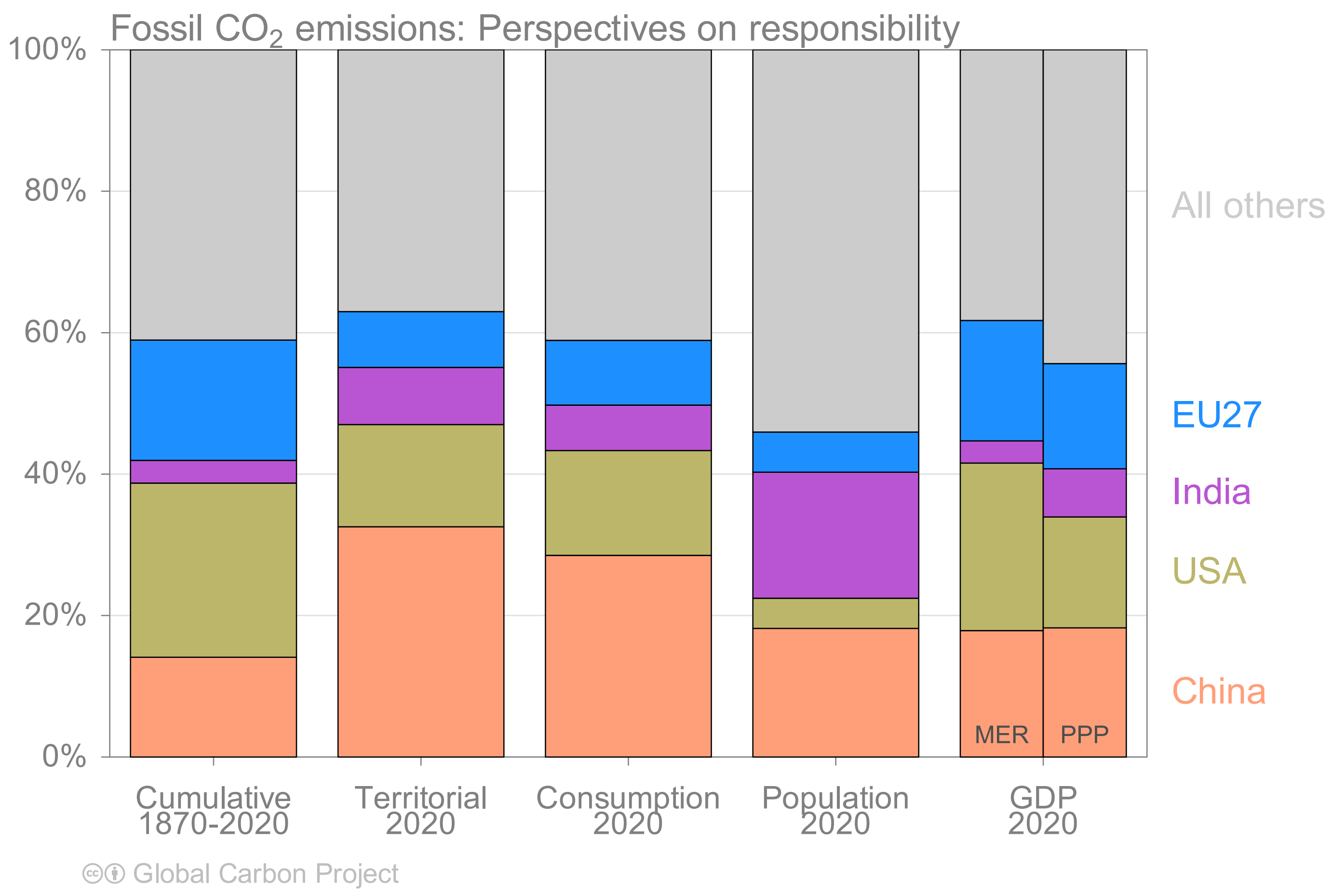


Emission per capita: Fossil CO_2 emissions divided by population

Source: Friedlingstein et al 2023; Global Carbon Project 2023

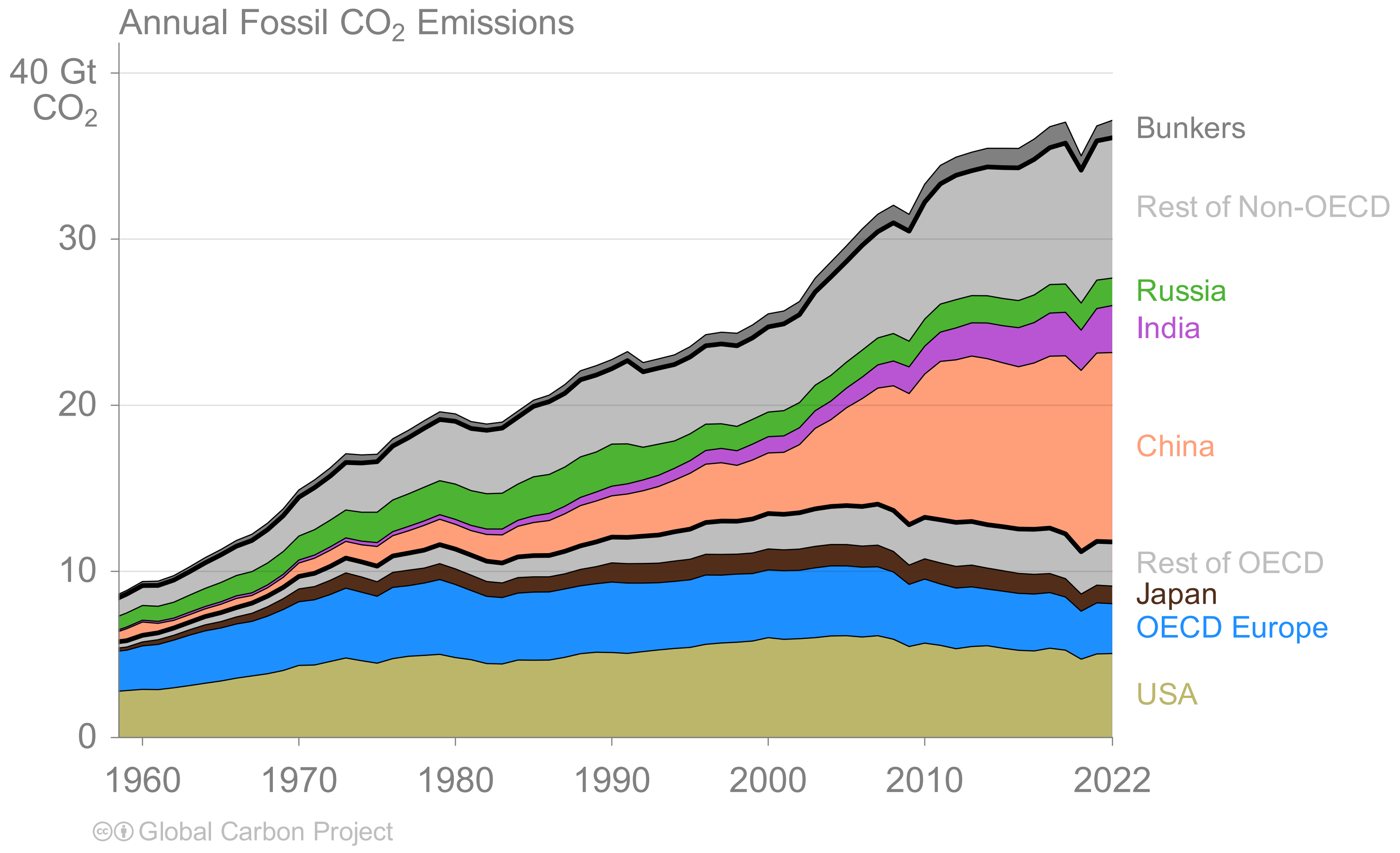
Alternative rankings of countries

The responsibility of individual countries depends on perspective.
Bars indicate fossil CO_2 emissions, population, and GDP.



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

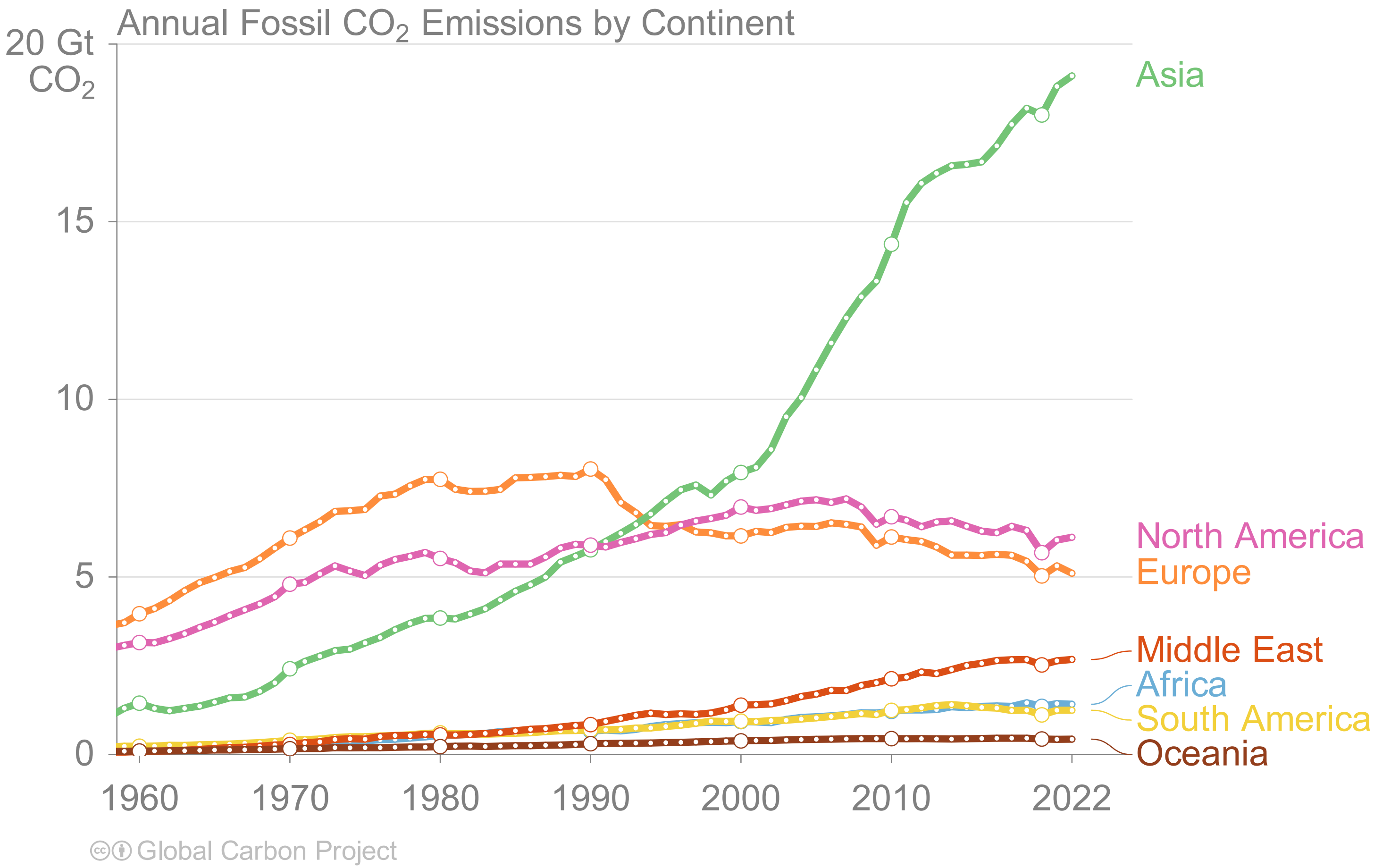
Breakdown of global fossil CO_2 emissions by country



Source: Friedlingstein et al 2023; Global Carbon Project 2023

Fossil CO_2 emissions by continent

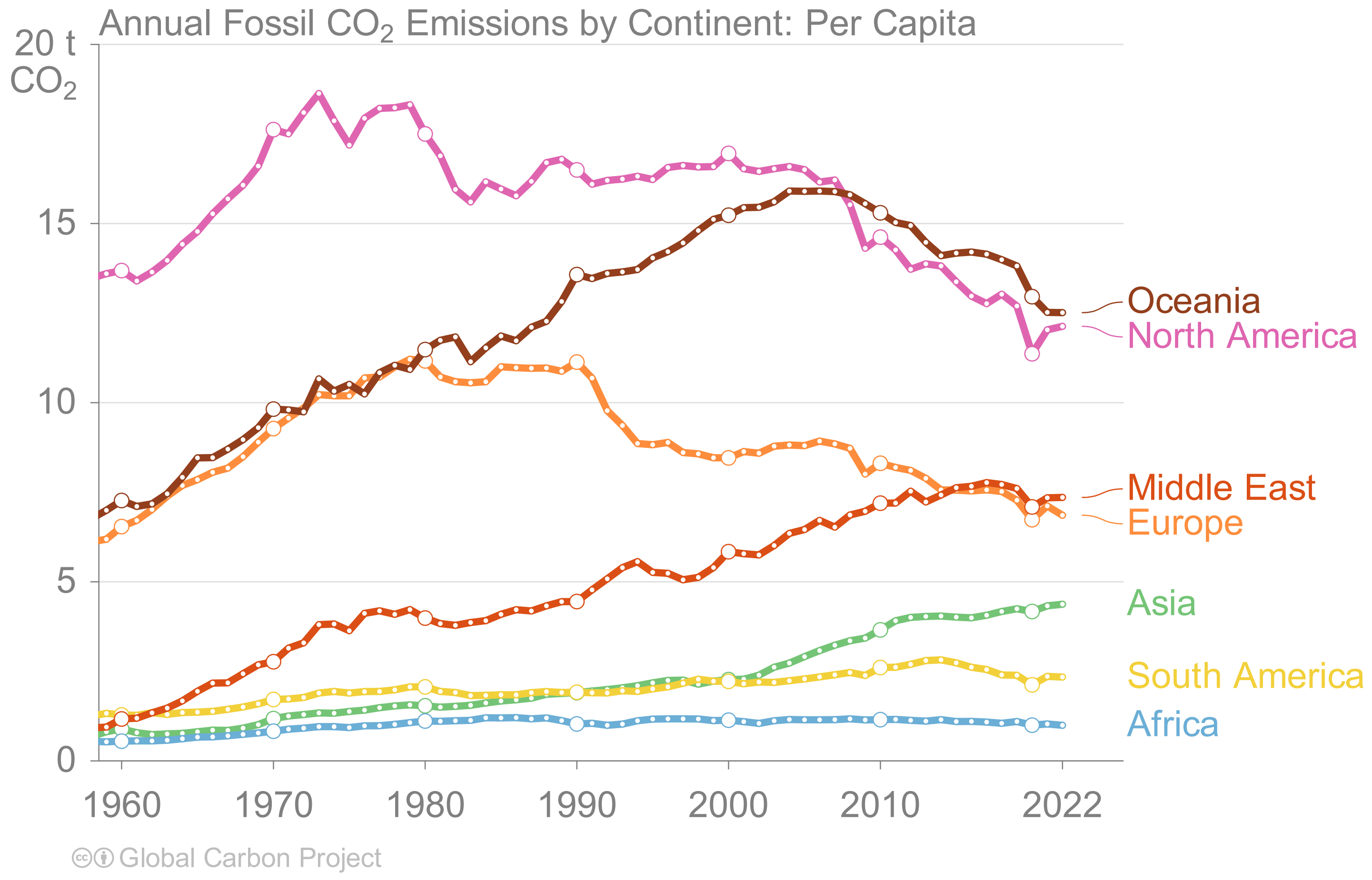
Asia dominates global fossil CO_2 emissions, while emissions in North America are of similar size to those in Europe, and the Middle East is growing rapidly.



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

Fossil CO_2 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.



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

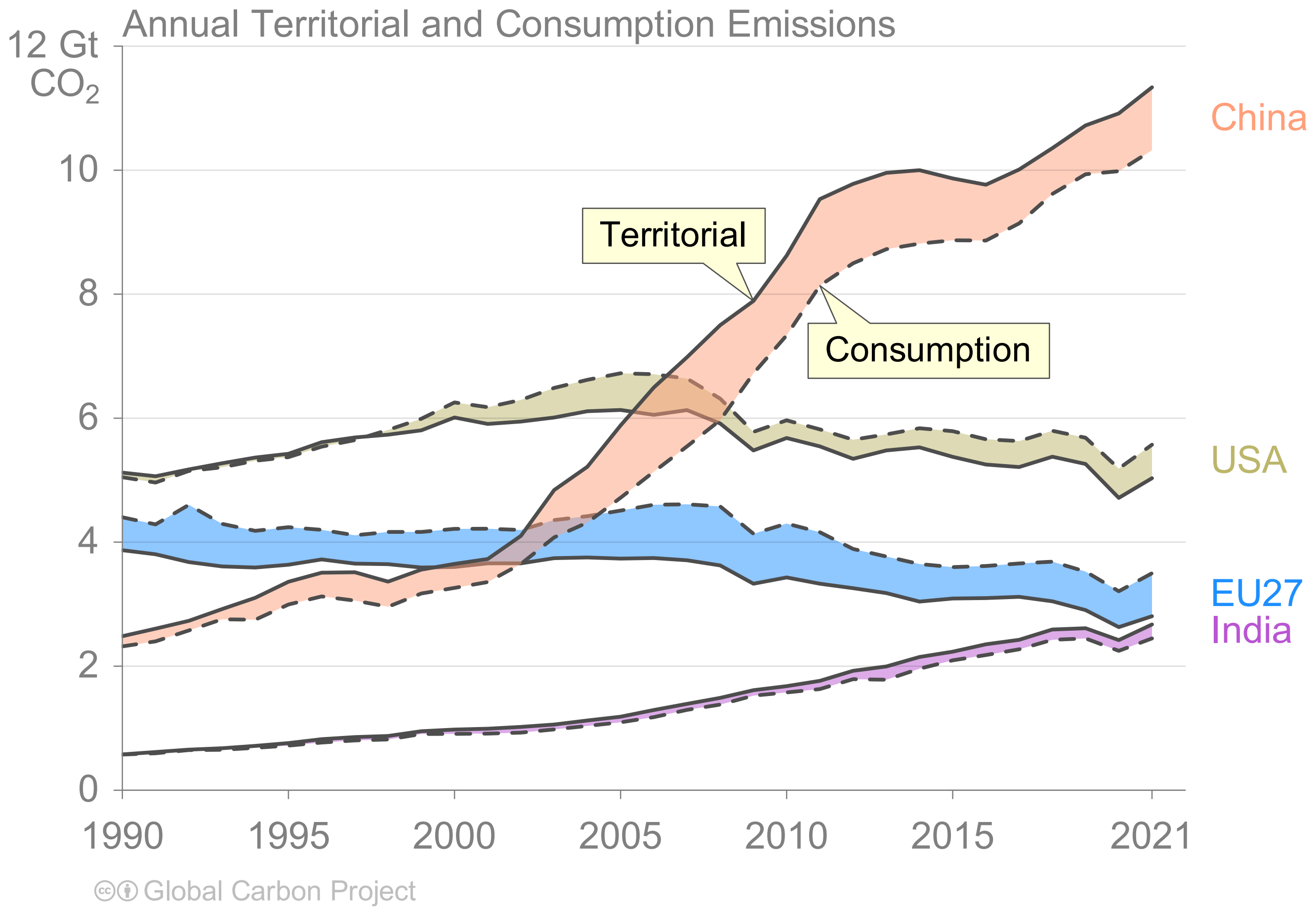
Additional Figures
Consumption-based Emissions

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 CO_2 emissions to consumption provides an alternative perspective.
USA and EU are net importers of embodied emissions, China and India are net exporters.

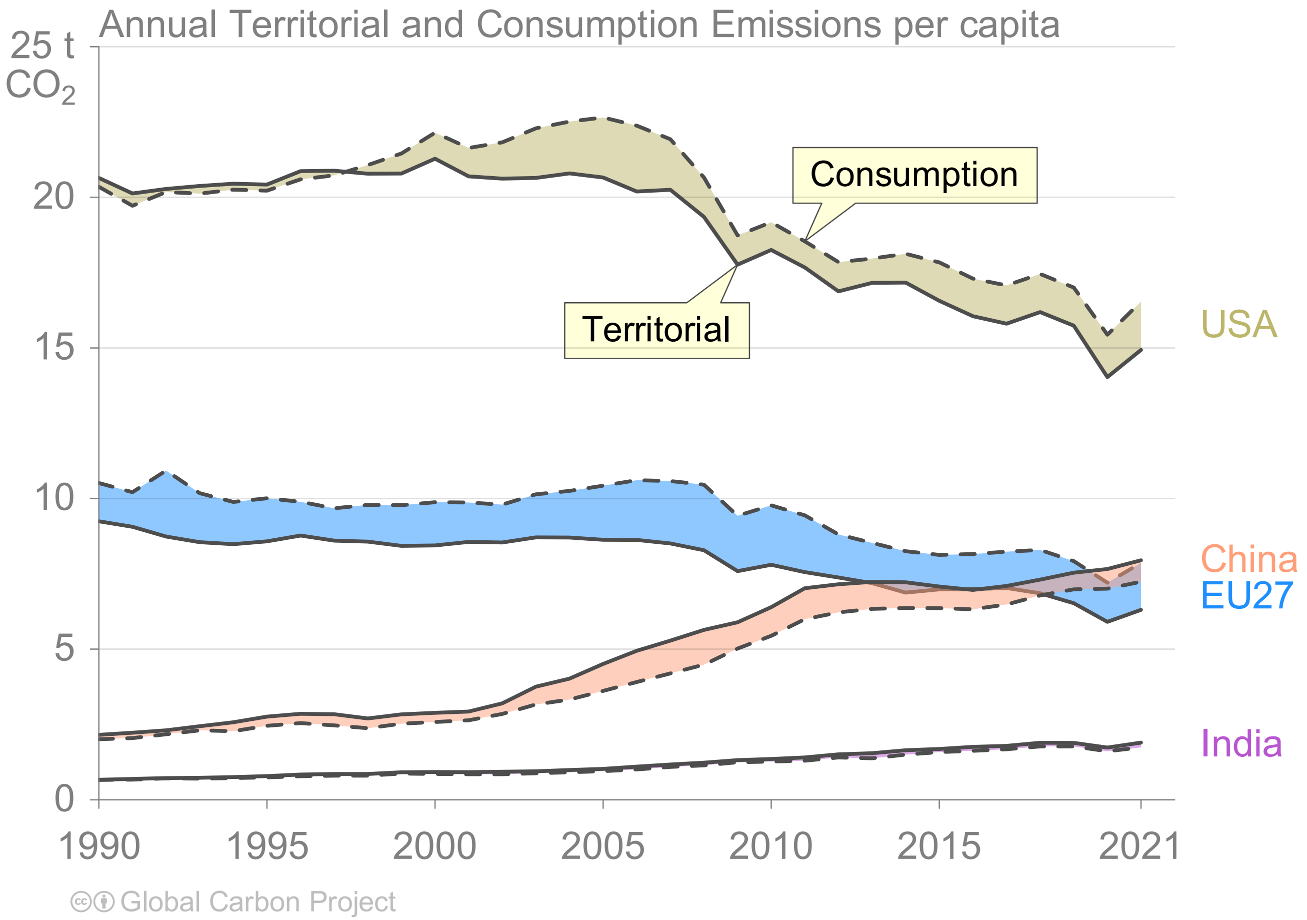


Consumption-based emissions are calculated by adjusting the standard emissions estimates to account for international trade

Source: Peters et al 2011; Friedlingstein et al 2023; Global Carbon Project 2023

Consumption-based emissions per person

The differences between fossil CO_2 emissions per capita is larger than the differences between consumption and territorial emissions.

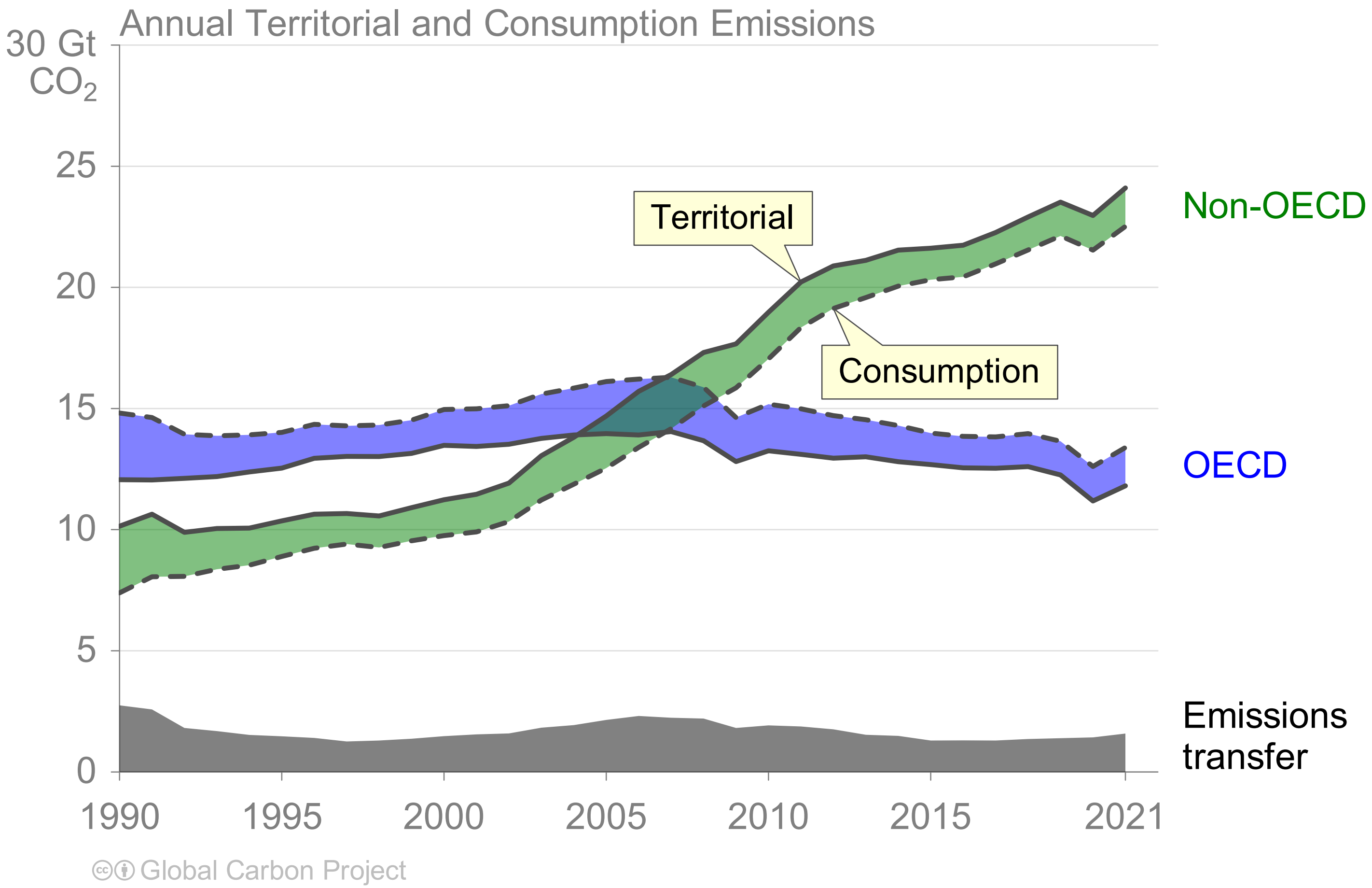


Consumption-based emissions are calculated by adjusting the standard emissions estimates to account for international trade

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

Consumption-based emissions (carbon footprint)

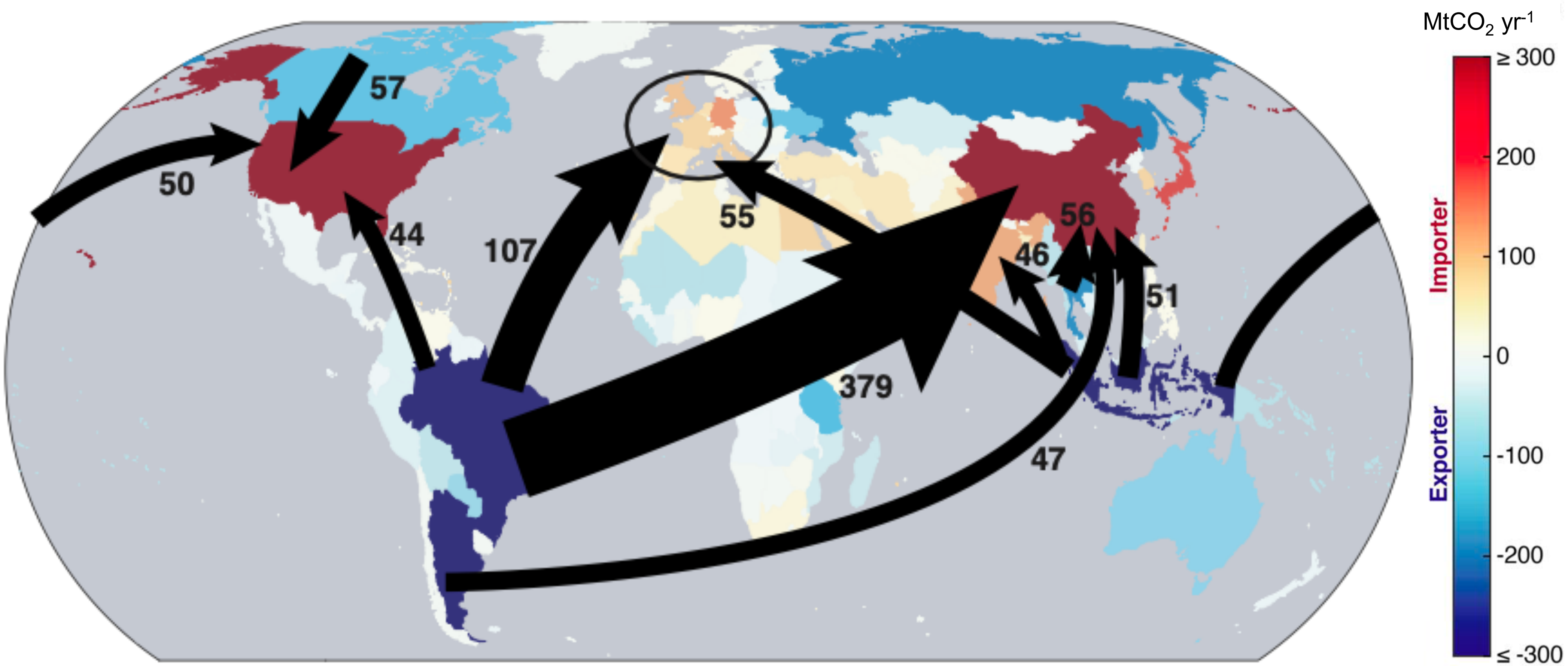
Transfers of emissions embodied in trade between OECD and non-OECD countries grew slowly during the 2000's, declined to 2015 and have been relatively flat since then.



Source: Peters et al 2011; Friedlingstein et al 2023; Global Carbon Project 2023

Major flows from production to consumption (2017) — Land Use Change CO_2

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.



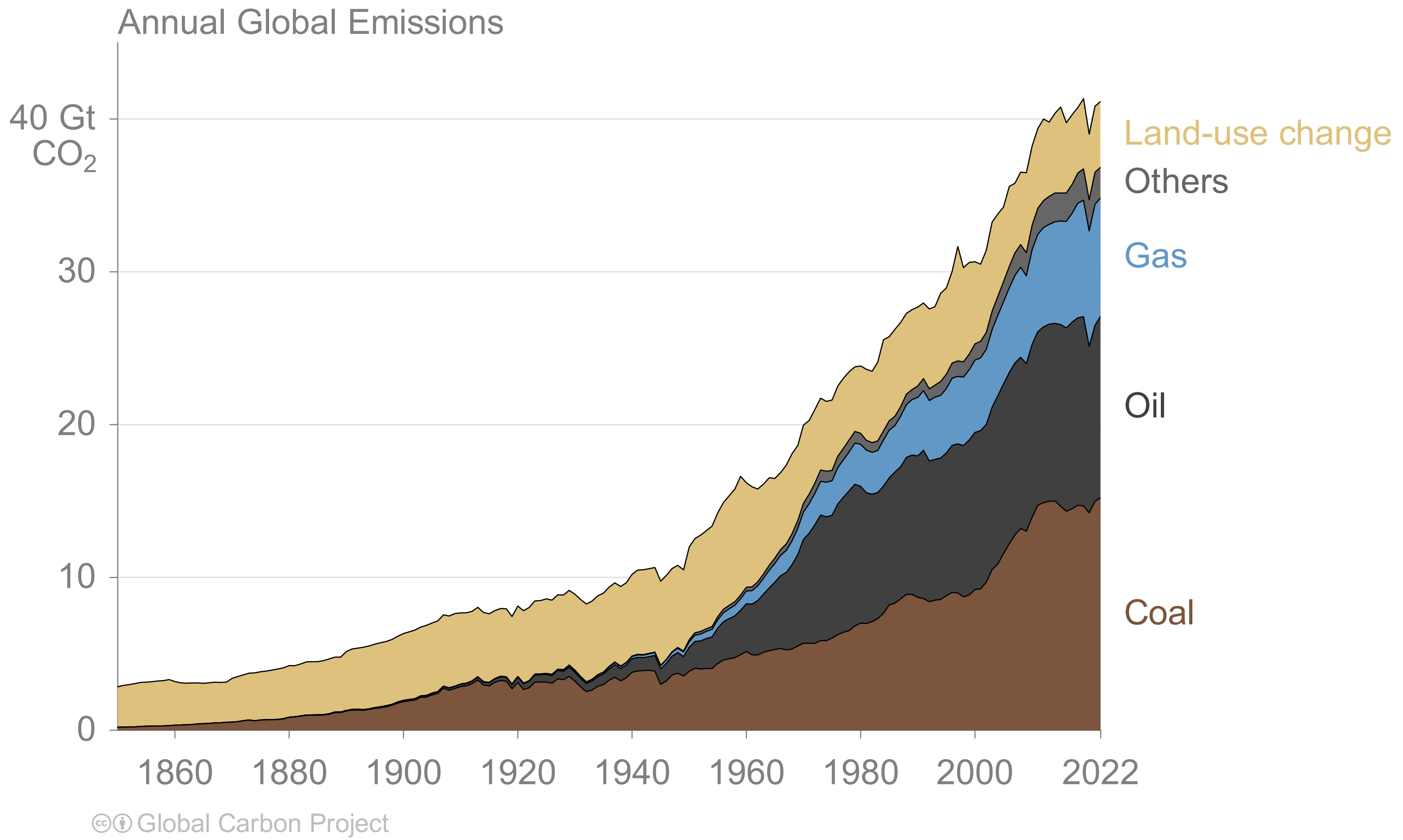
Values for 2017. EU27 is treated as one region. Units: $MtCO_2$

Source: [Hong et al 2022]

Additional Figures
Historical Emissions

Total global emissions by source

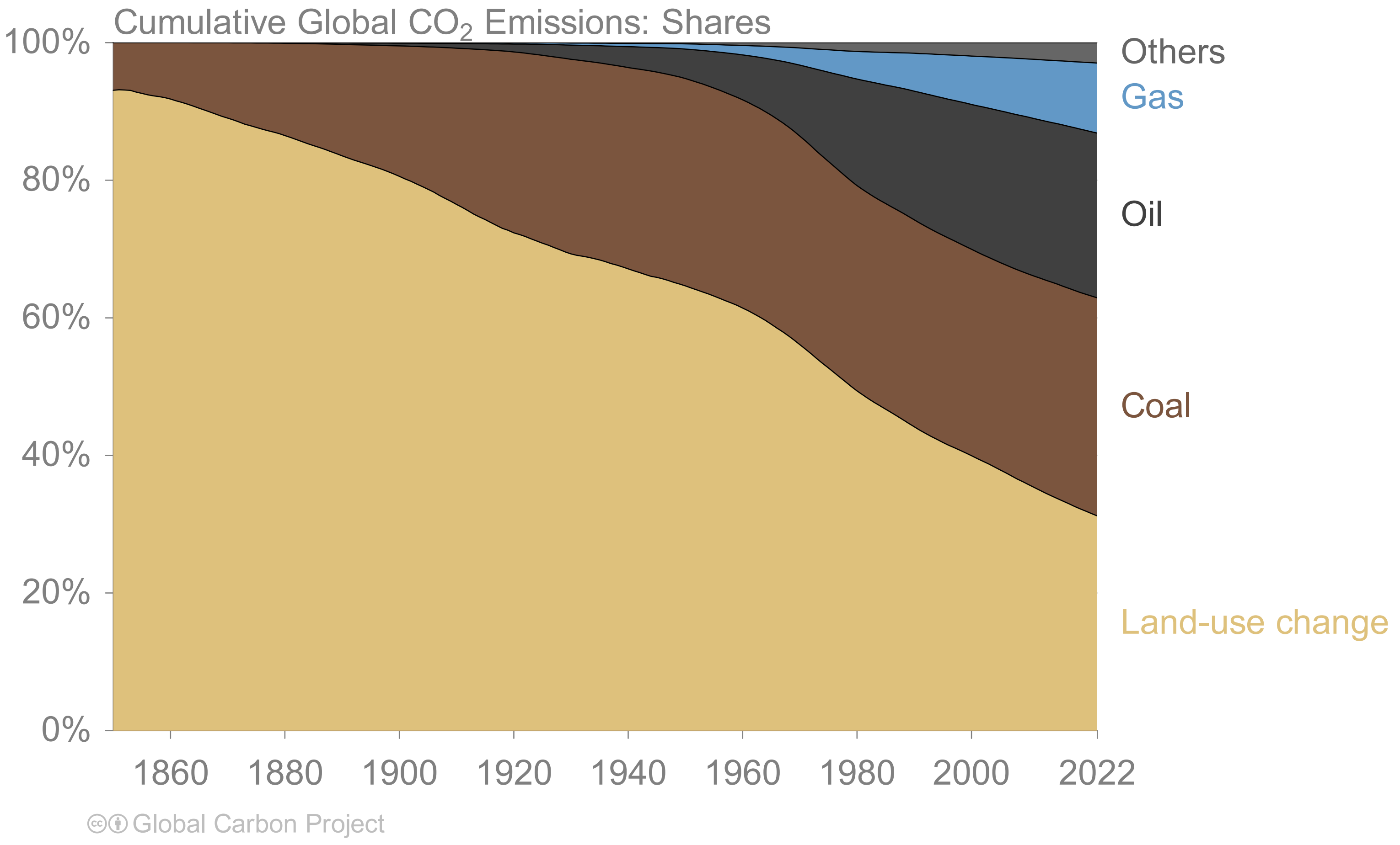
Land-use change was the dominant source of annual CO_2 emissions until around 1950.
Fossil CO_2 emissions now dominate global changes.



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

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

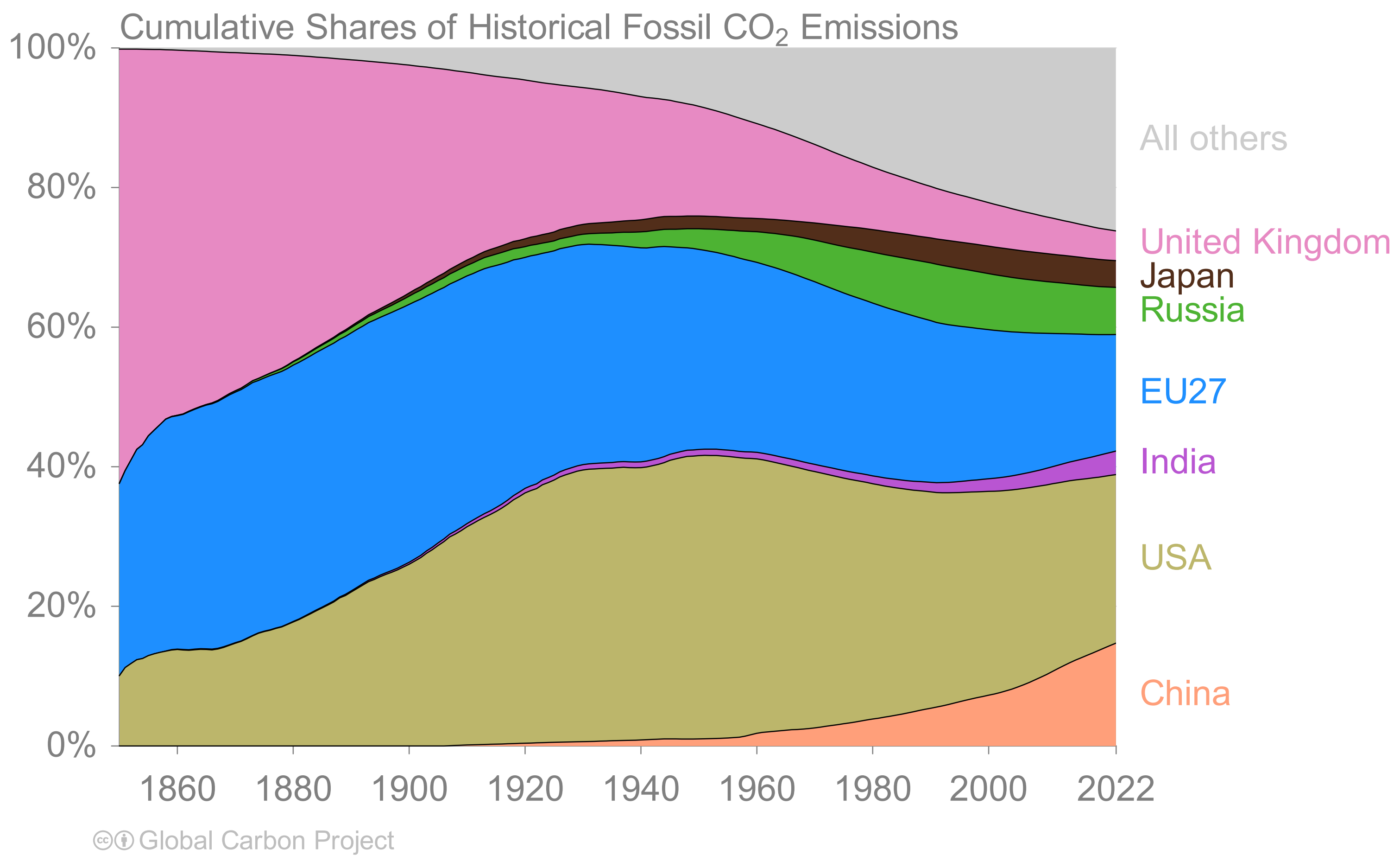
Historical cumulative emissions by source



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

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

Historical cumulative fossil CO_2 emissions by country

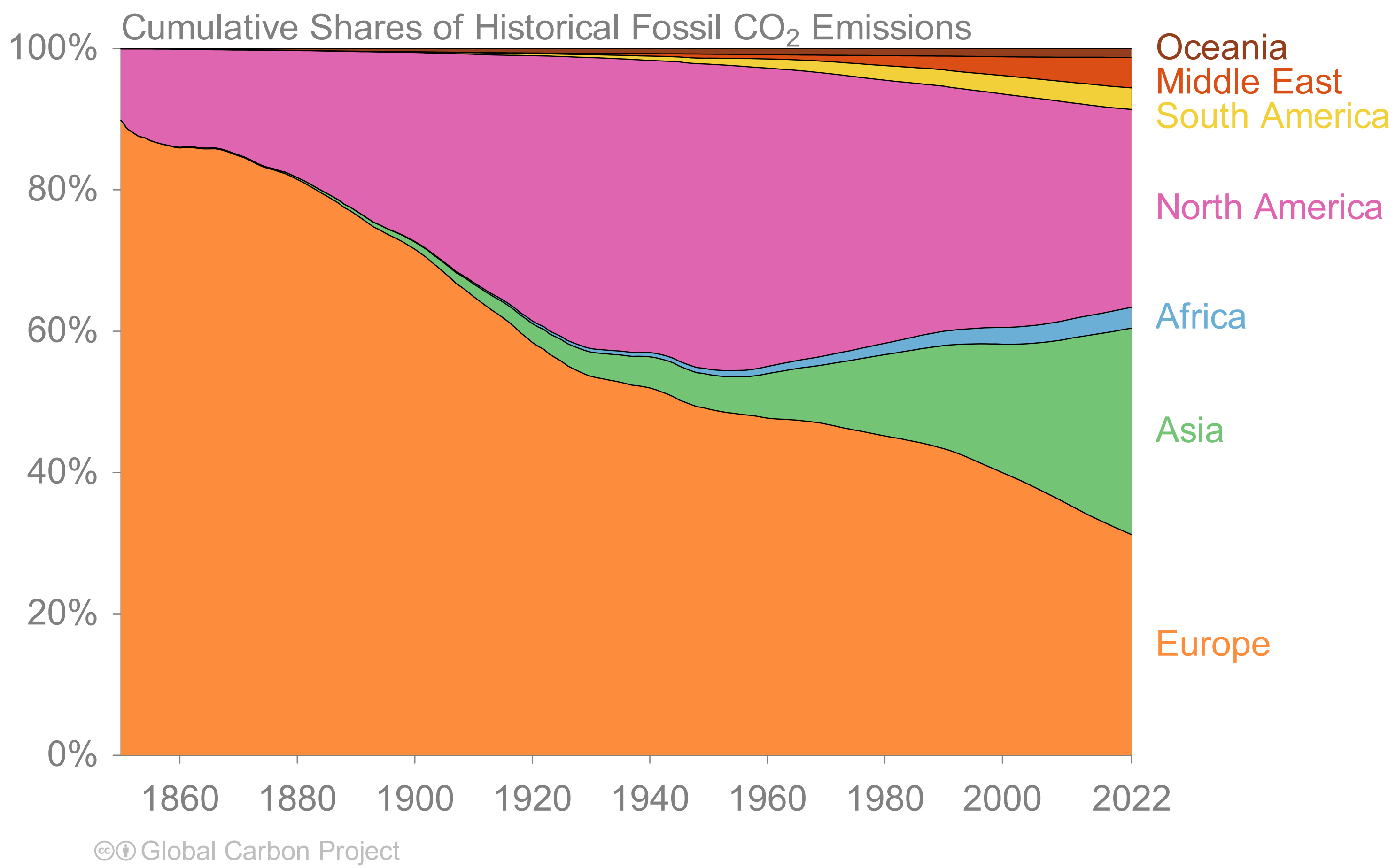


'All others' includes all other countries along with emissions from international aviation and maritime shipping

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

Historical cumulative emissions by continent

Cumulative fossil CO_2 emissions (1850–2022). North America and Europe have contributed the most cumulative emissions, but Asia is growing fast



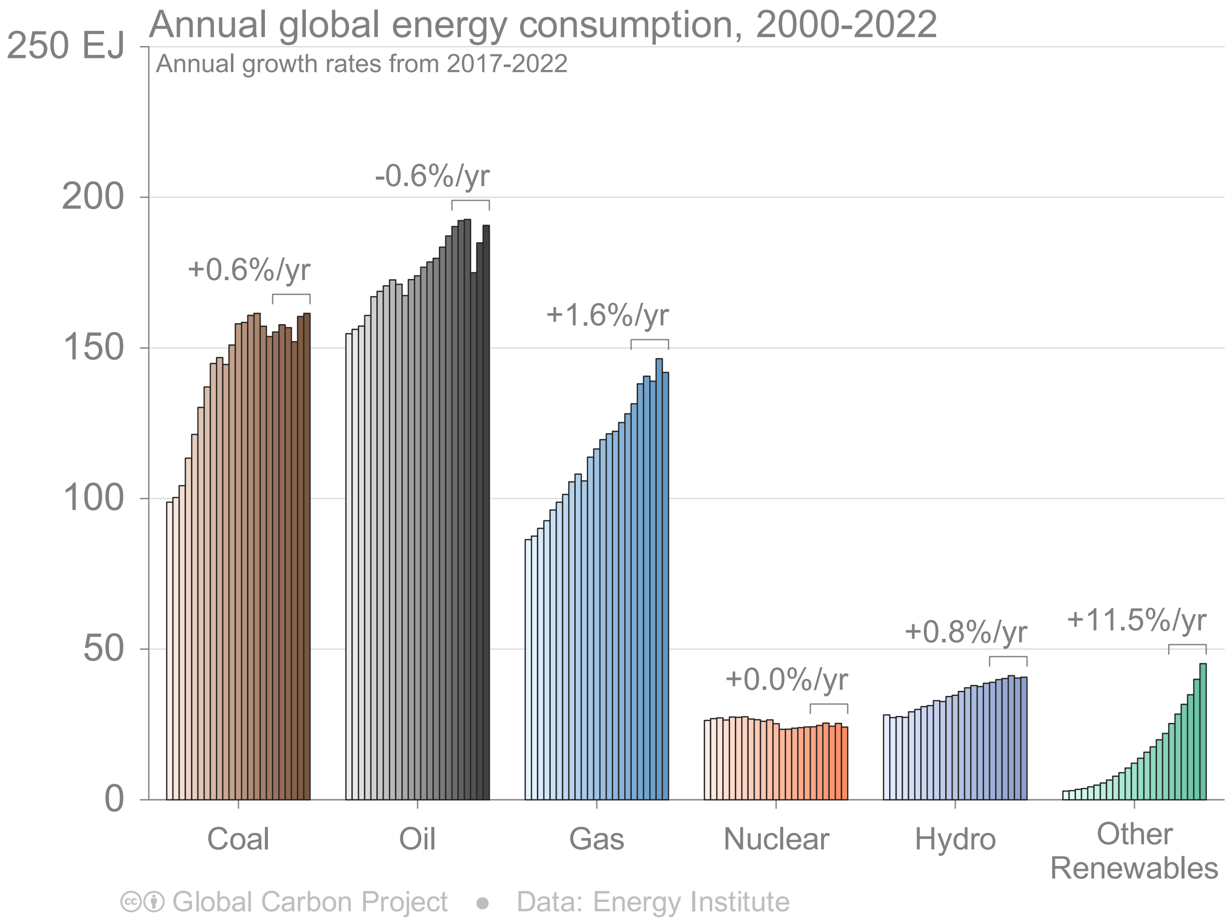
The figure excludes emissions from international aviation and maritime shipping

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]()

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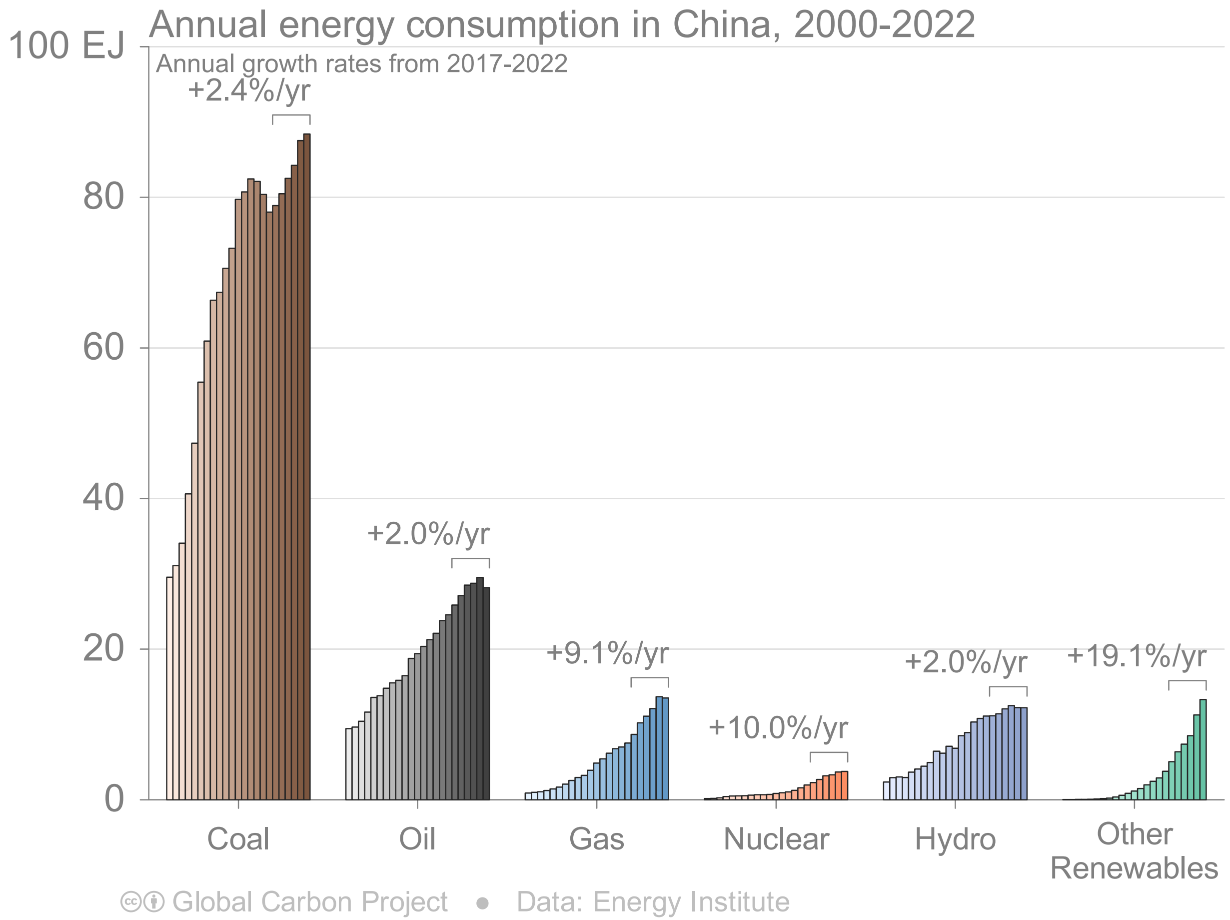
Energy use by source: China

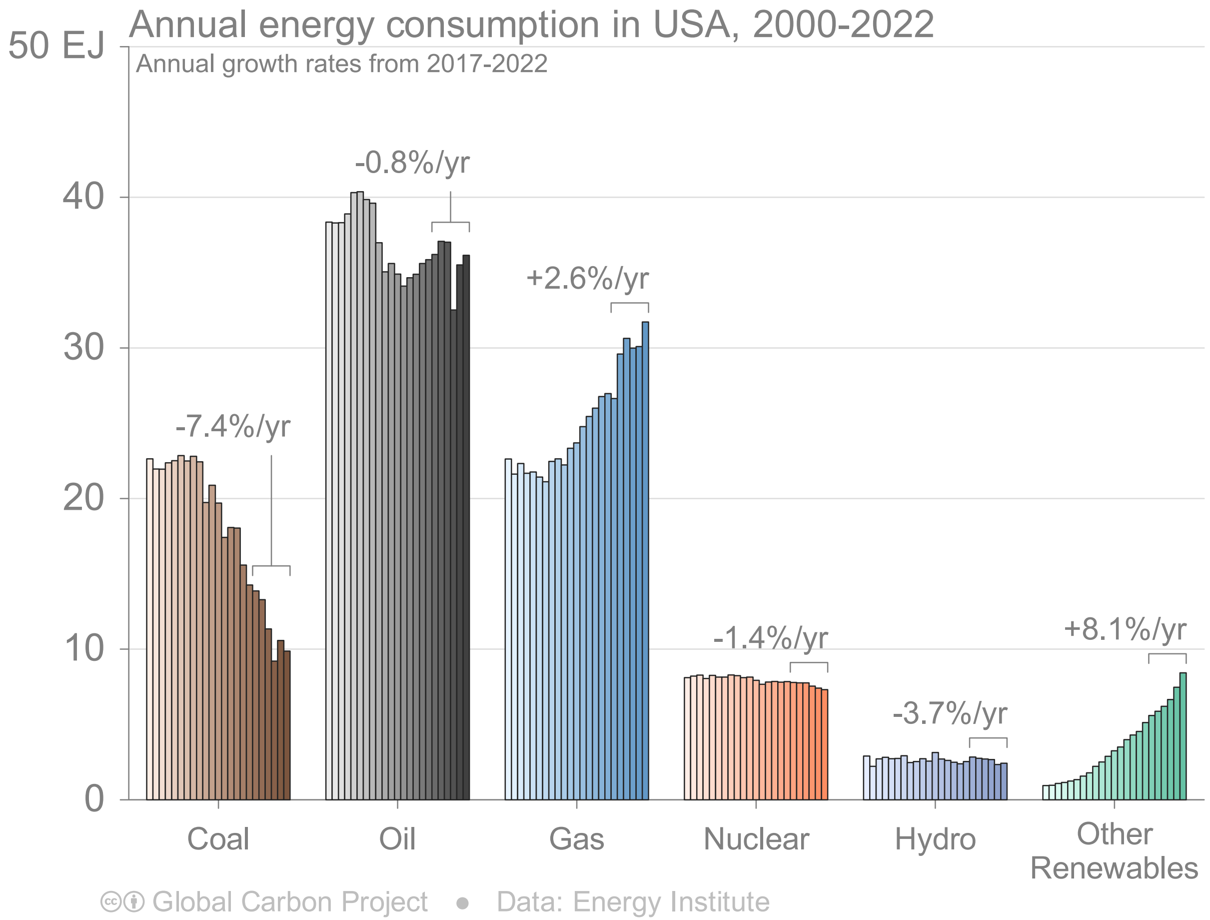
Coal consumption in energy units has returned to peak levels,
while consumption of all other energy sources is growing strongly



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.

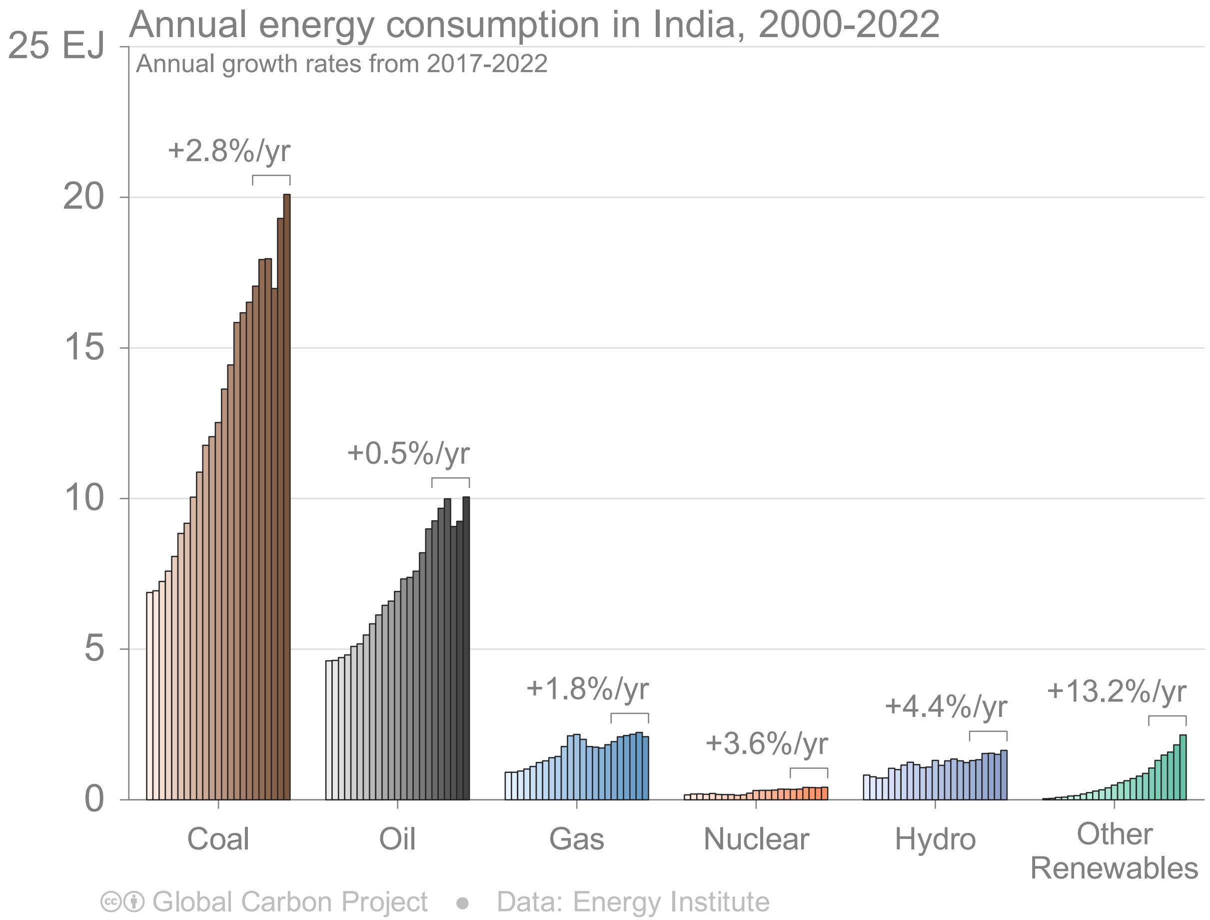


This figure shows "primary energy" using the BP substitution method
(non-fossil sources are scaled up by an assumed fossil efficiency of approximately 0.38)
Source: Energy Institute, 2023; Global Carbon Project 2023

GLOBAL CARBON project

Energy use by source: India

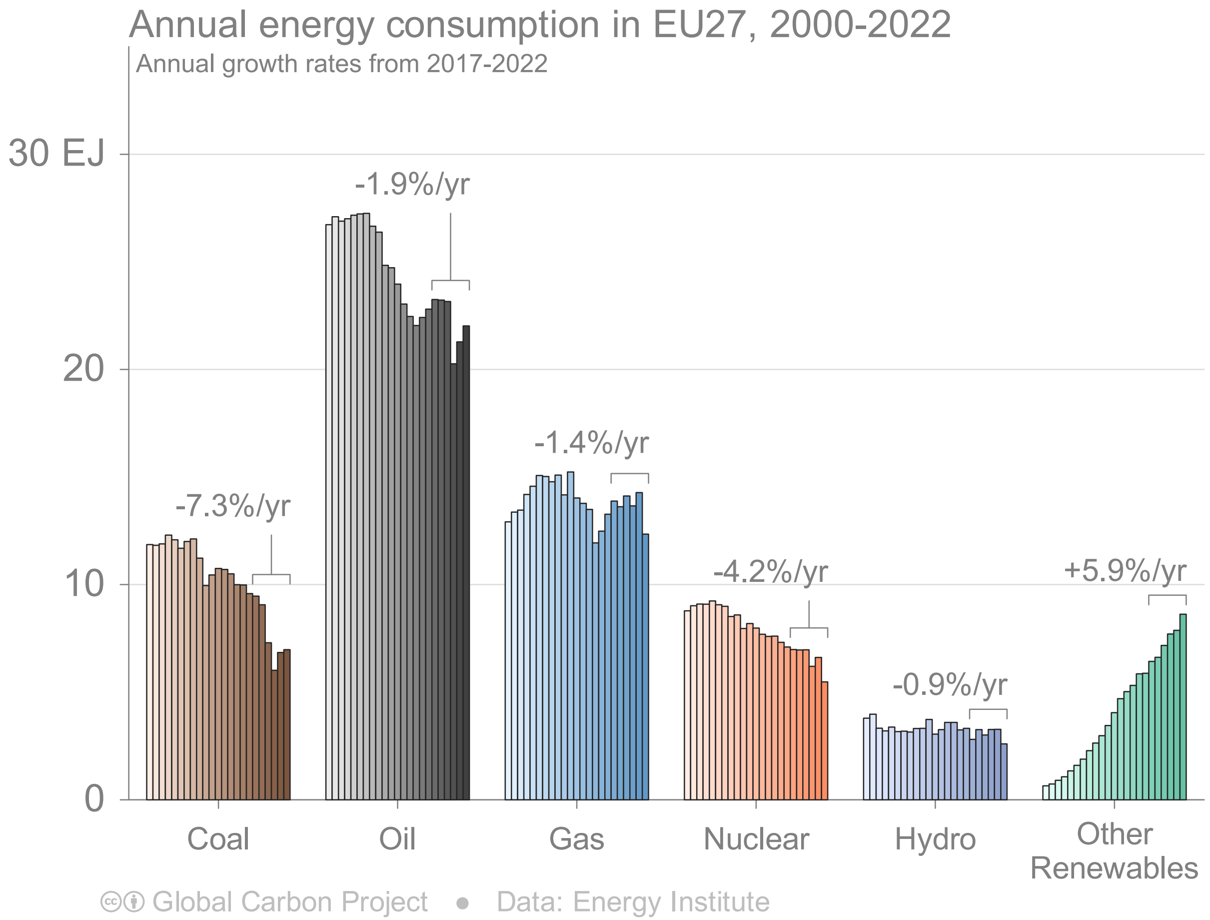
Pandemic year 2020 temporarily interrupted India's strong growth in energy consumption.
Consumption of coal and oil dominate.



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.



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