Economics of
Energy and Natural resources

Lesson 2. Global Carbon Budget

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All the data is shown in billion tonnes CO_2 ($GtCO_2$)

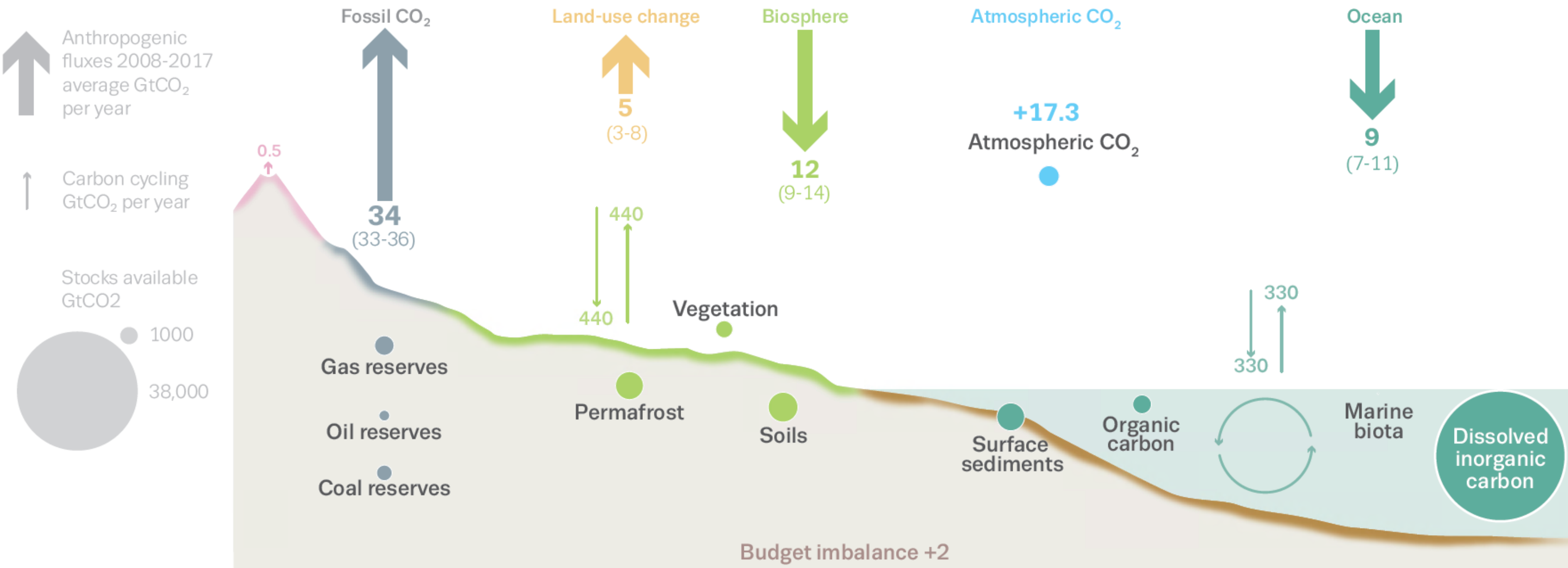
1 Gigatonne (Gt) = 1 billion tonnes = 1×10^{15}g = 1 Petagram (Pg)

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

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

Anthropogenic perturbation of the global carbon cycle

Perturbation of the global carbon cycle caused by anthropogenic activities, averaged globally for the decade 2008–2017 ($GtCO_2$/yr)

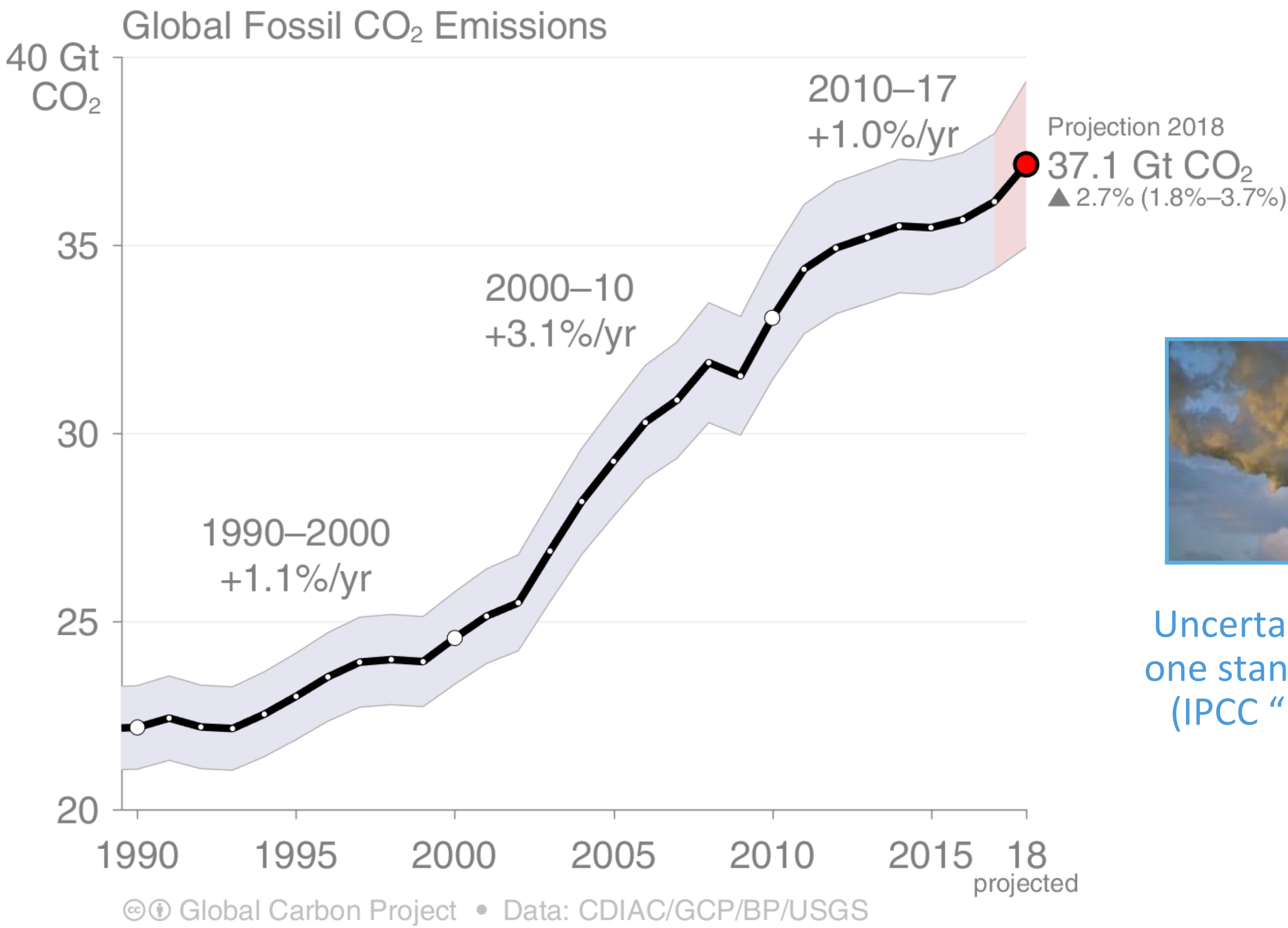


The budget imbalance is the difference between the estimated emissions and sinks.
Source: CDIAC; NOAA-ESRL; Le Quéré et al 2018; Ciais et al. 2013; Global Carbon Budget 2018

Global Fossil CO_2 Emissions

Global fossil CO_2 emissions: 36.2 ± 2 $GtCO_2$ in 2017, 63% over 1990

Projection for 2018: 37.1 ± 2 $GtCO_2$, 2.7% higher than 2017 (range 1.8% to 3.7%)

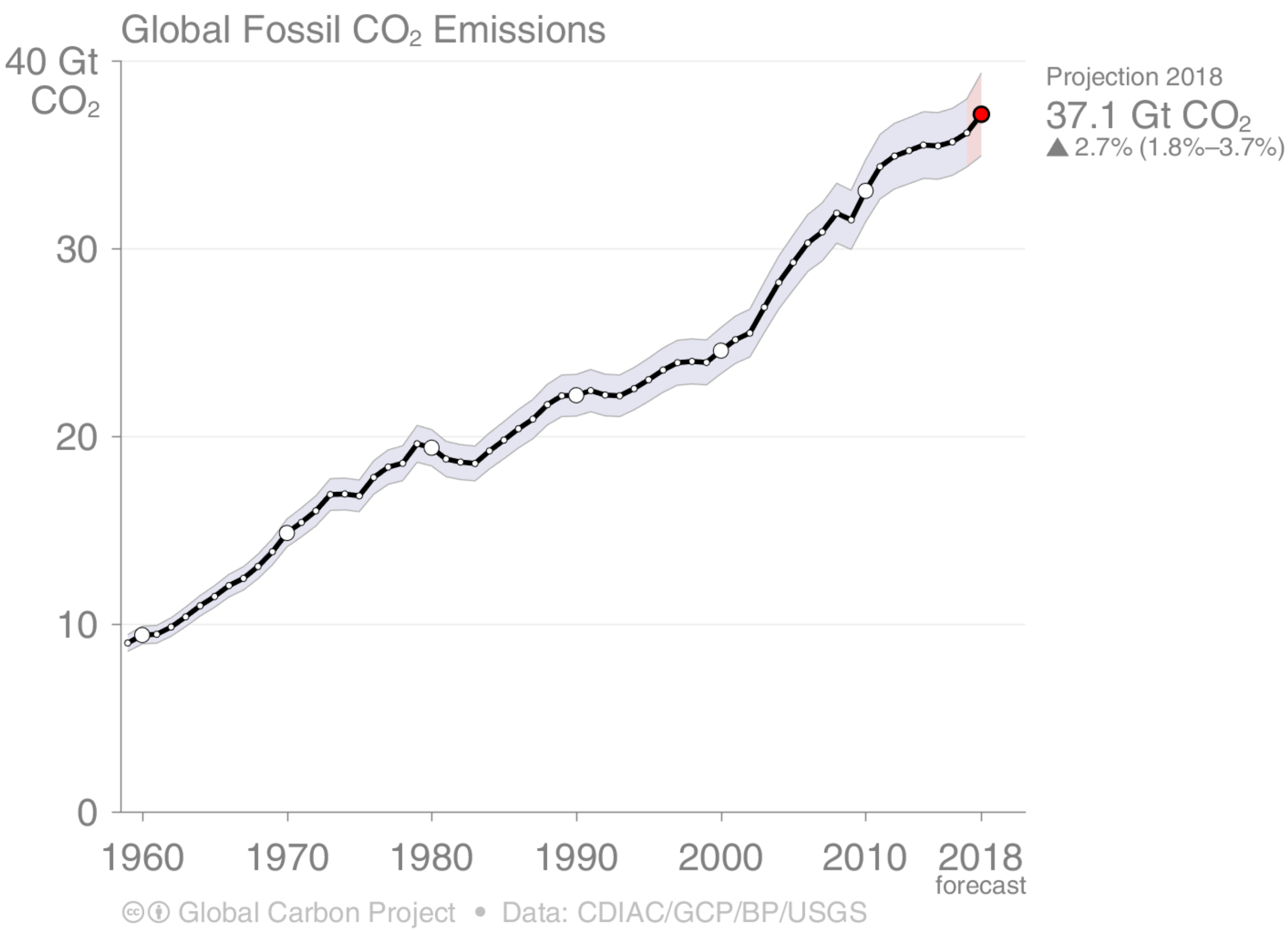


Uncertainty is ±5% for one standard deviation (IPCC "likely" range)

Estimates for 2015, 2016 and 2017 are preliminary; 2018 is a projection based on partial data.
Source: CDIAC; Le Quéré et al 2018; Global Carbon Budget 2018

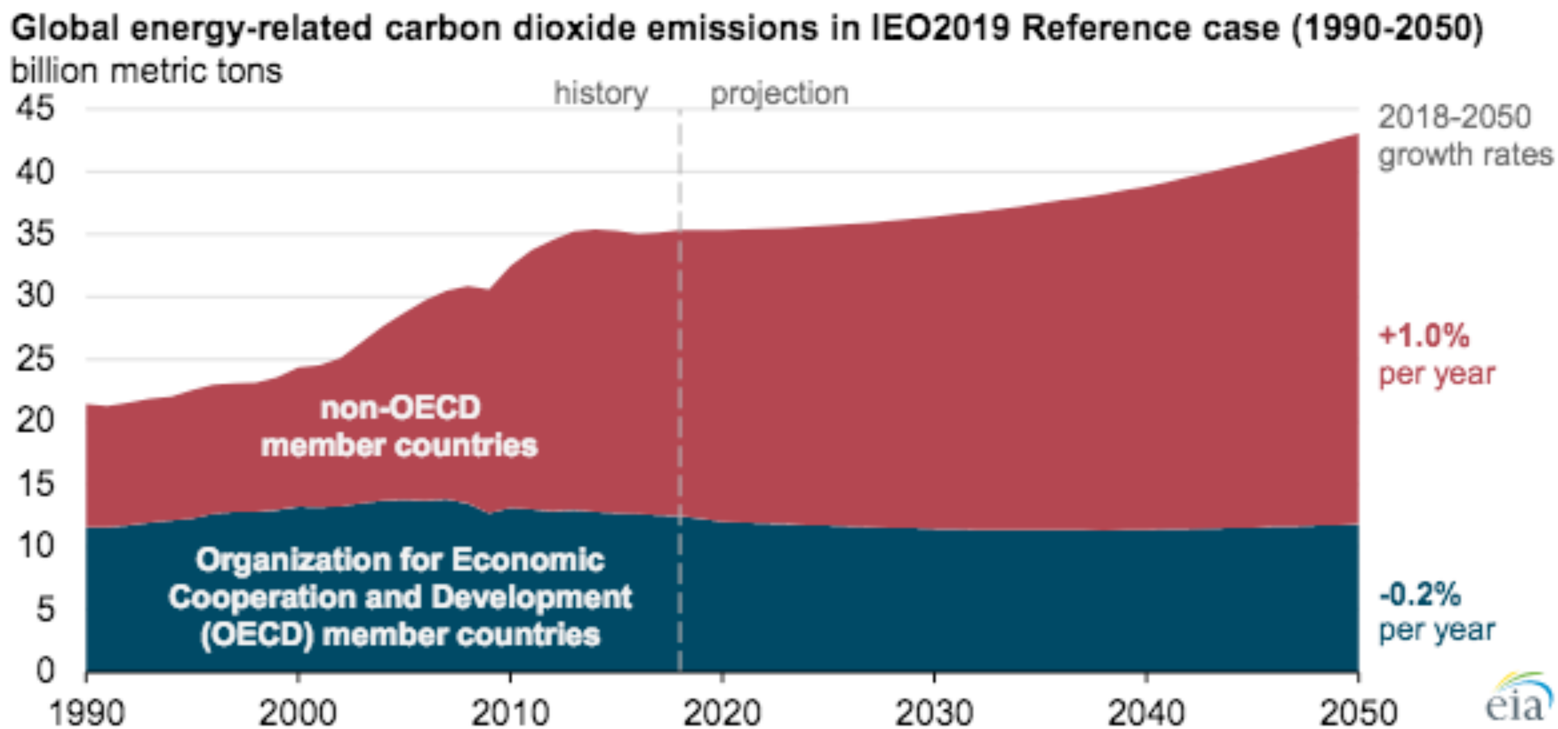
Global Fossil CO_2 Emissions

Global fossil CO_2 emissions have risen steadily over the last decades.
The peak in global emissions is not yet in sight.

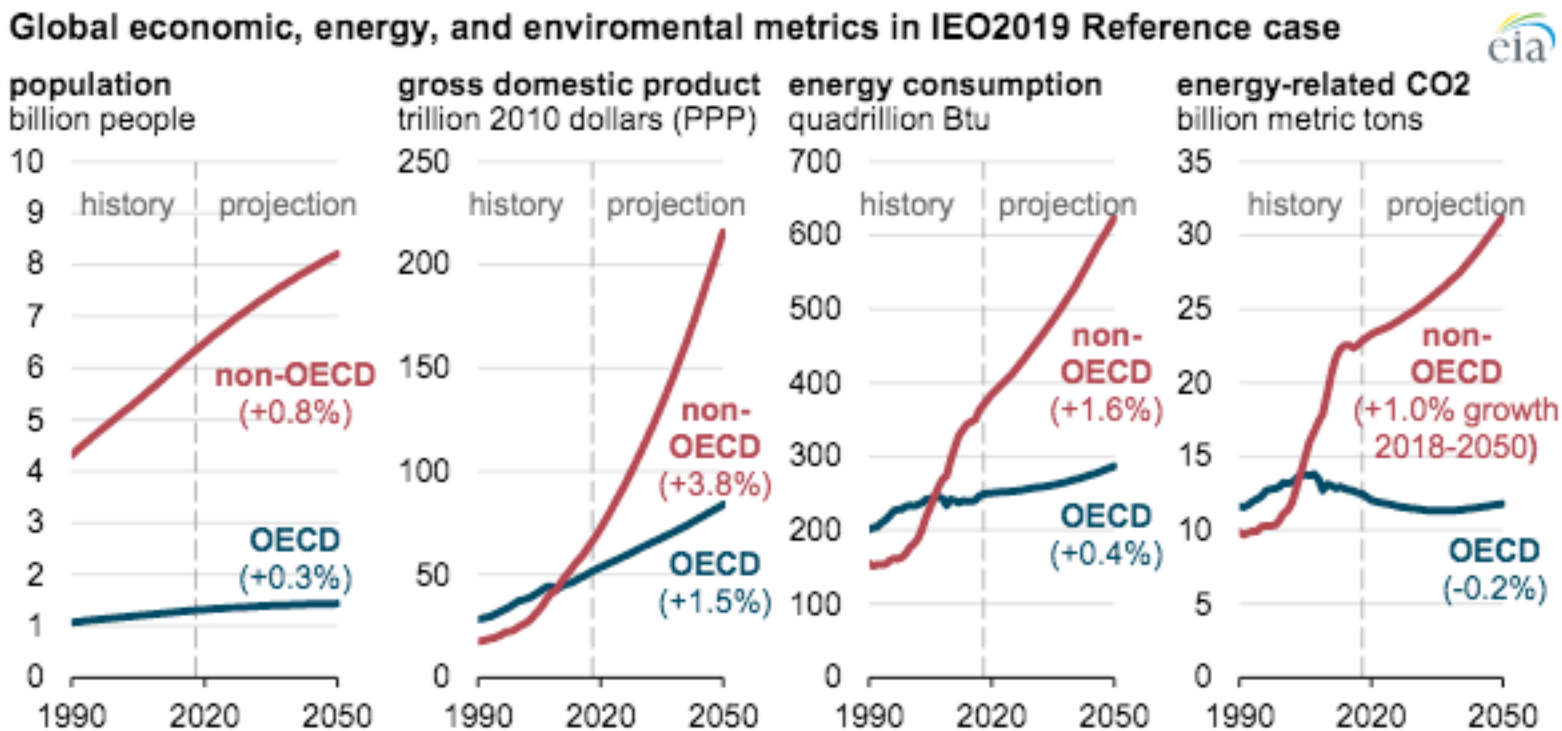


Estimates for 2015, 2016 and 2017 are preliminary ; 2018 is a projection based on partial data.
Source: [CDIAC]; [Le Quéré et al 2018]; [Global Carbon Budget 2018]

The U.S. Energy Information Administration (EIA) projects that global carbon dioxide (CO2) emissions from energy-related sources will continue to grow in the coming decades. EIA's International Energy Outlook 2019 (IEO2019) projects that global energy-related CO2 emissions will grow 0.6% per year from 2018 to 2050 in its Reference case. However, future growth in energy-related CO2 emissions is not evenly distributed across the world: relatively developed economies collectively have no emissions growth, so all of the future growth in energy-related CO2 emissions is among the group of countries outside the Organization for Economic Cooperation and Development (OECD).



Countries outside of the OECD collectively have more population, a larger gross domestic product, more energy consumption, and higher energy-related CO2 emissions compared with aggregated values from OECD countries. In IEO2019, growth rates for these data series are also higher for non-OECD countries than for OECD countries.

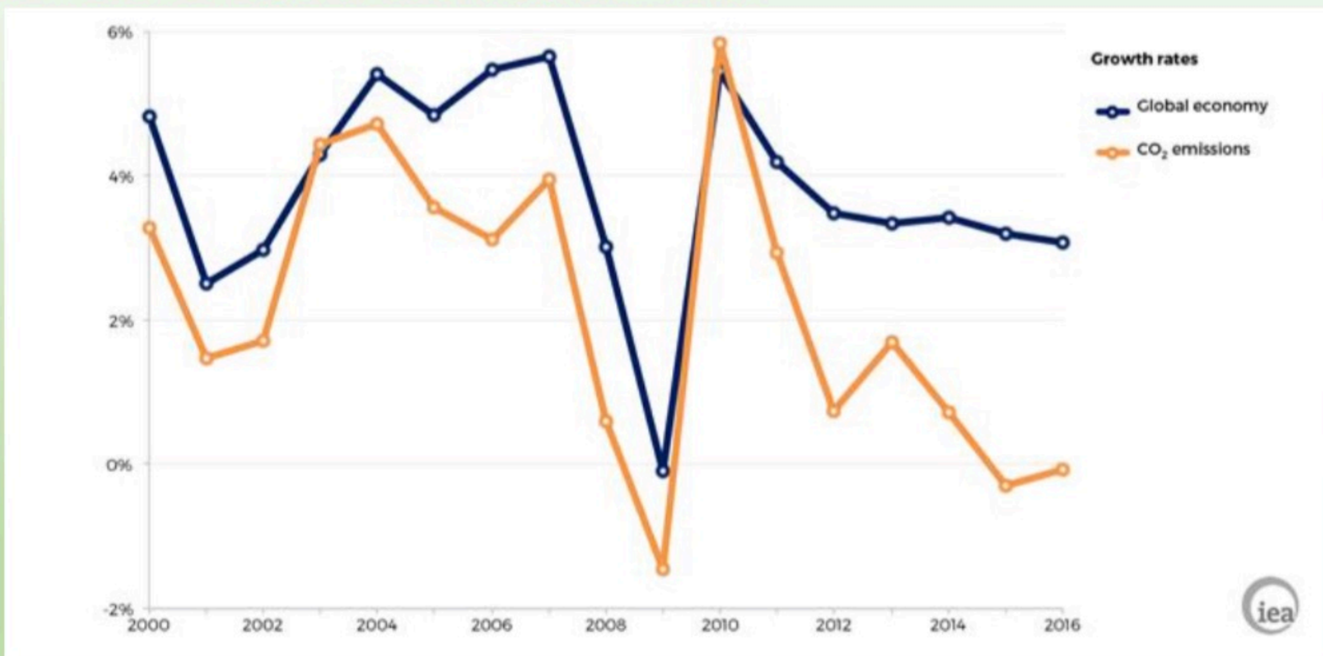


As non-OECD countries continue to grow, so does their demand for air conditioning, electronics, personal vehicles, and other energy services. These countries also have relatively energy-intensive industries, primarily because energy-intensive industrial processes often shift to non-OECD countries. Energy consumption in non-OECD countries increases by 1.6% per year from 2018 to 2050, and energy-related CO2 emissions increase by 1.0% per year.

trends for global emissions and the role of energy efficiency

For emissions per unit of GDP, all the five largest emitters have shown reductions between 1990 and 2014, in line with the decoupling observed globally (29%). Levels of emissions per GDP also vary significantly across regions, but much less in 2014 than in 1990. Although climate, economic structure and other variables can affect energy use, relatively high values of emissions per GDP indicate a potential for decoupling CO2emissions from economic growth, including through fuel switching away from carbon-intensive sources or from energy efficiency at all stages of the energy value chain (from raw material extraction to energy end-use).Globally, economic growth partially decoupled from energy use, as energy intensity decreased by 30% over the period. However, with a practically unchanged carbon intensity of the energy mix, the combined growth in population (37%) and in per capita GDP (62%) led to a significant increase in global CO2emissions between 1990 and 2014. However, due to differences in levels of economic, demographic and technological development and growth, emissions evolved at different rates in different countries and regions. Market forces, technology cost reductions, and concerns about climate change and air pollution were the main forces behind this decoupling of emissions and economic growth

Figure 2 – CO_2 emissions and global economy growth rates



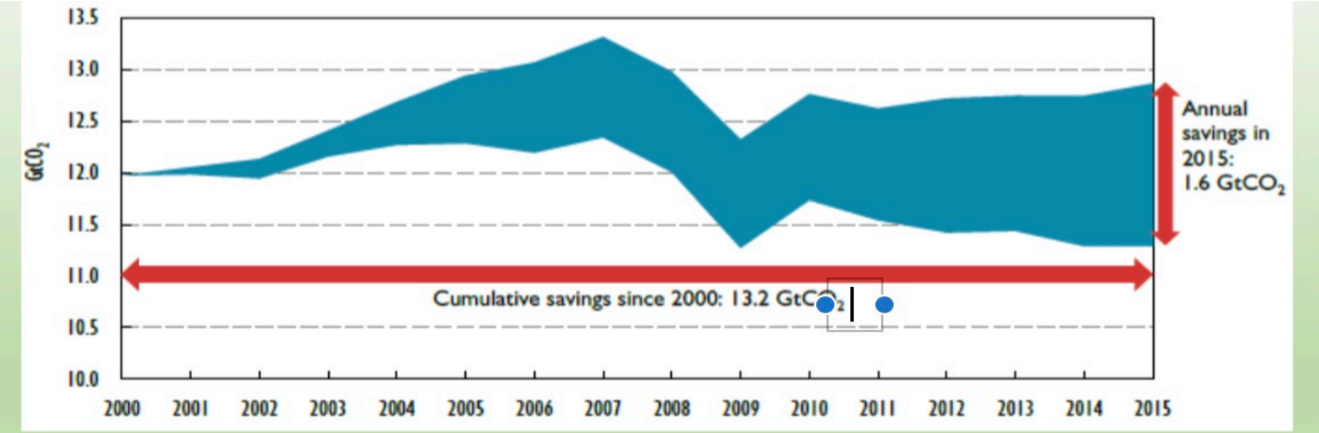
Source: IEA

Avoid GHG emissions from Energy Efficiency Improvements

After having looked at the historical trends, the pattern of CO2 emissions can be examined from another perspective, namely in terms of implications of energy efficiency interventions. As shown in the Energy Efficiency Market Report 2016, IEA countries saved an average of 490 United States dollars (USD) per capita and a total of USD 540 billion in energy expenditure in 2015 as a result of energy efficiency improvements since 2000.

Avoided primary and end-use fuel consumption from energy efficiency improvements also avoids GHG emissions. In 2015, efficiency allowed IEA countries to avoid 1.5 GtCO2, an amount exceeding Japan's total emissions for the same year. Cumulative savings since 2000 were 13 GtCO2 – greater than the 2015 emissions of all IEA countries (Figure 3).

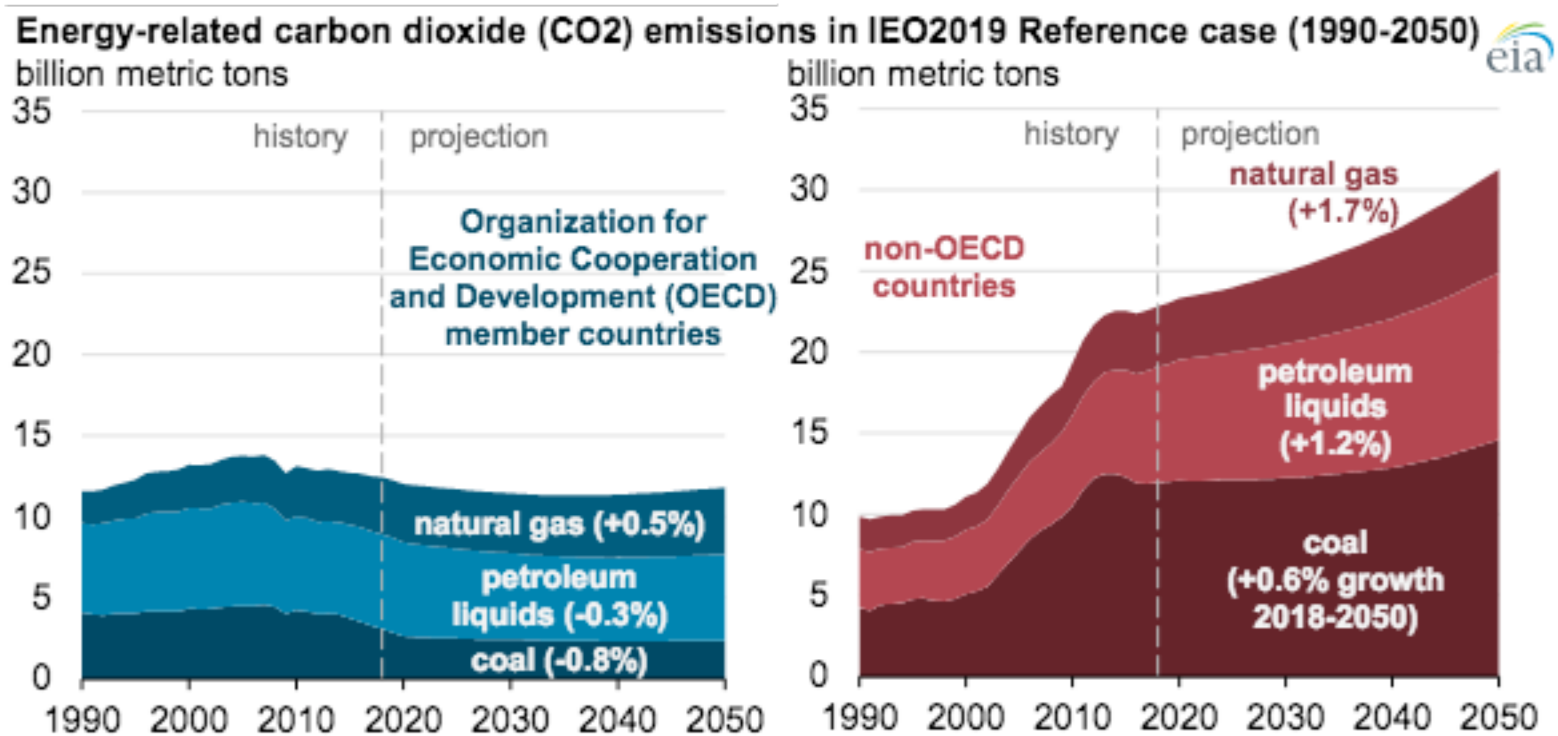
Over half of these GHG savings came from the industry and services sector. The residential sector accounted for approximately 400 million tonnes CO2 of avoided emissions. This effect emphasises the importance of seemingly small efficiency improvements such as in appliances and building envelopes; stacked together, they can significantly reduce GHGs over the medium term.



Energy efficiency also reduces local air pollution. The IEA World Energy Outlook has reported that existing and planned policies to increase energy efficiency and decarbonise energy supply contribute 40% to a global decline of SO_2 emissions, 35% to a decline in NOx emissions and 60% to a reduction of PM2.5 emissions by 2040.

As awareness of both these multiple benefits of energy efficiency grows – and of their economic and social value – they will become more important as drivers of further efficiency improvements. A detailed analysis of the pledges made for the Paris Agreement on climate change underscores the challenge of reaching more ambitious climate goals. As highlighted in World Energy Outlook 2016, government policies, as well as cost reductions across the energy sector, enable a doubling of improvements in energy efficiency over the next 25 years.

EIA projects that coal-related CO_2 emissions in non-OECD countries, especially China, will grow at the slowest rate among fossil fuels as natural gas replaces coal in power generation and in industrial applications. China emits the most energy-related CO_2 emissions in the world, and EIA projects that it will remain in that position through 2050. Although India's coal-related CO_2 emissions increase 2.8% annually from 2018 to 2050—the highest among the eight countries in EIA's international outlook—China remains the single largest emitter of coal-related CO_2 emissions in the world.



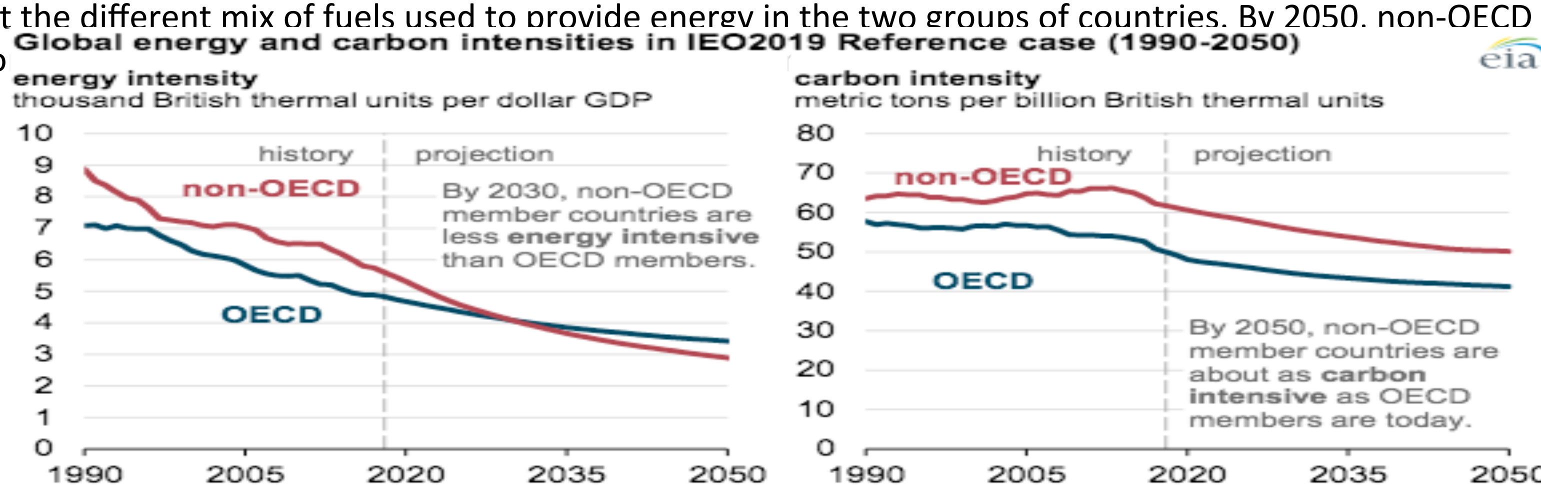
By comparison, OECD economies are relatively mature, so many energy services such as air conditioning, electronics, and personal transportation are fairly saturated. Population and economic growth is relatively low compared with non-OECD countries, and technology improvements largely offset increases in energy demand in buildings and vehicles.

OECD economic activity continues to become less energy intensive as these economies shift from energy-intensive manufacturing to less energy-intensive manufacturing and commercial services. EIA projects that energy-related CO2 emissions from OECD countries will decrease slightly (-0.2%) from 2018 to 2050 in the IEO2019 Reference case. OECD CO2 emissions from petroleum liquids and coal consumption decline, but emissions from natural gas consumption increase.

EIA expects the United States to remain the largest emitter of energy-related CO2 emissions among OECD members and the largest emitter of natural gas-related emissions among all countries, regardless of OECD membership, through 2050. Petroleum liquids-related CO2 emissions from the United States and China—the top two petroleum liquids-related CO2 emitters—are relatively similar throughout the projection period. EIA's IEO2019 Reference case projections for the United States are consistent with those in the Reference case of the Annual Energy Outlook 2019.

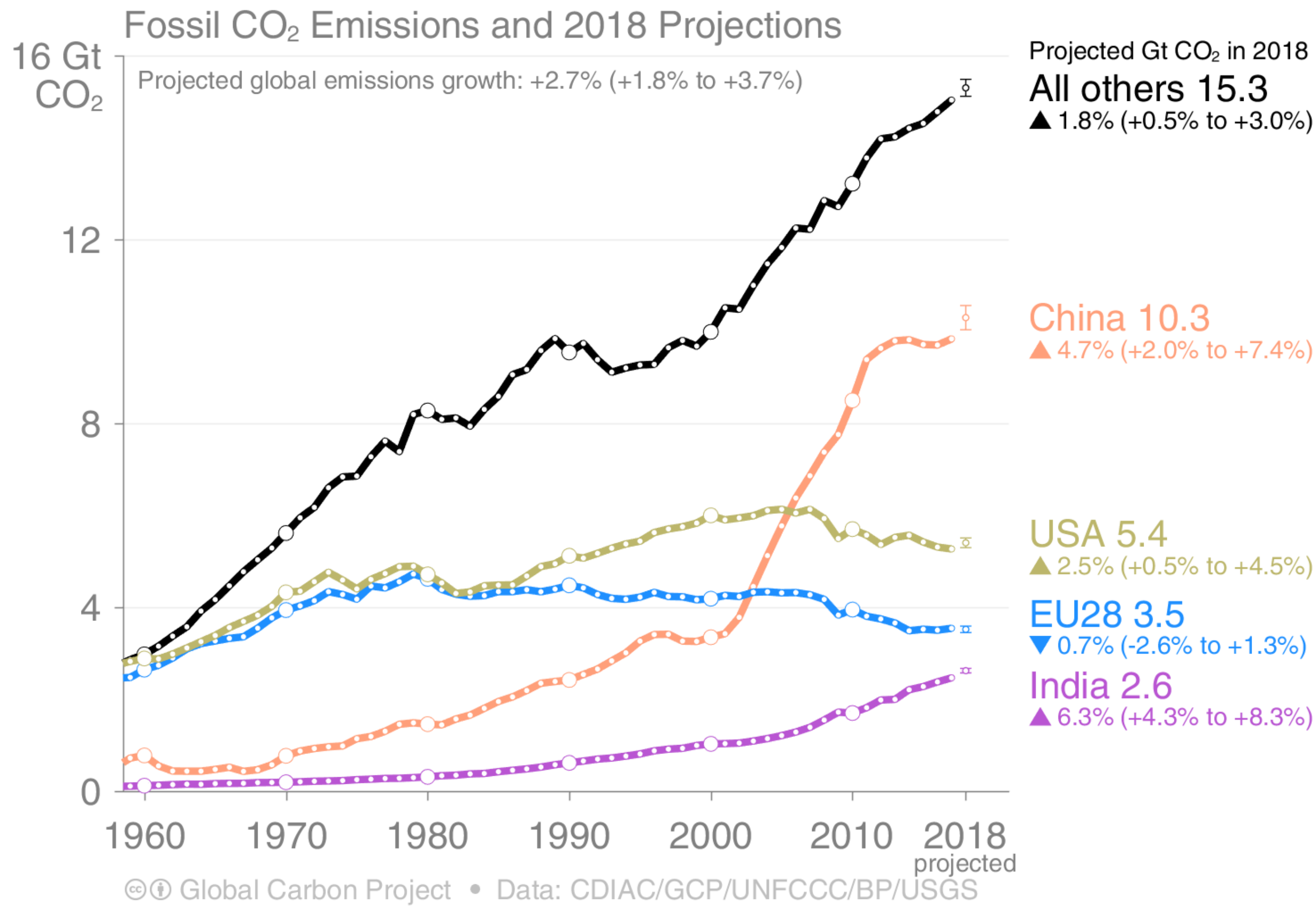
On a per capita basis, OECD countries emit far more energy-related CO2 than non-OECD countries: about 9.5 metric tons per person in OECD countries in 2018 compared with 3.6 metric tons per person in non-OECD countries. The gap between those groups is decreasing; by 2050, OECD countries will emit 8.2 metric tons per person compared with 3.8 metric tons per person in non-OECD countries.

Global energy intensities and carbon intensities also continue to decline. By 2032, non-OECD countries are expected to become less energy intensive than OECD countries, meaning they use less energy to generate economic activity. However, non-OECD countries are expected to remain more carbon intensive than OECD countries through 2050, meaning they generate more CO2 emissions per unit of energy consumed. Differences in energy and carbon intensities reflect the different mix of fuels used to provide energy in the two groups of countries. By 2050, non-OECD member econo



Emissions Projections for 2018

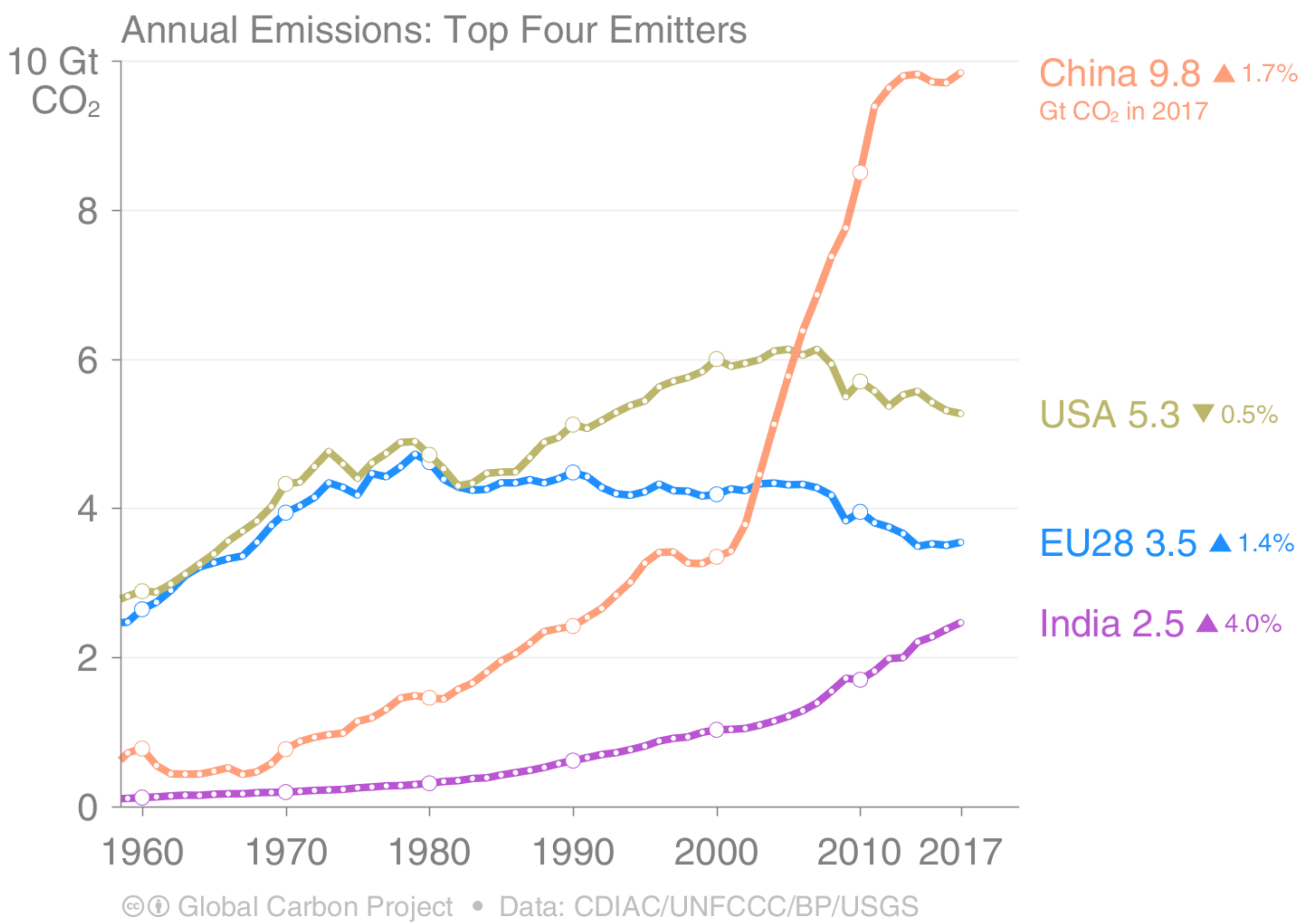
Global fossil CO_2 emissions are projected to rise by 2.7% in 2018 [range: +1.8% to +3.7%]
The global growth is driven by the underlying changes at the country level.



Source: [CDIAC](); [Jackson et al 2018](); [Le Quéré et al 2018](); [Global Carbon Budget 2018]()

Top emitters: Fossil CO_2 emissions

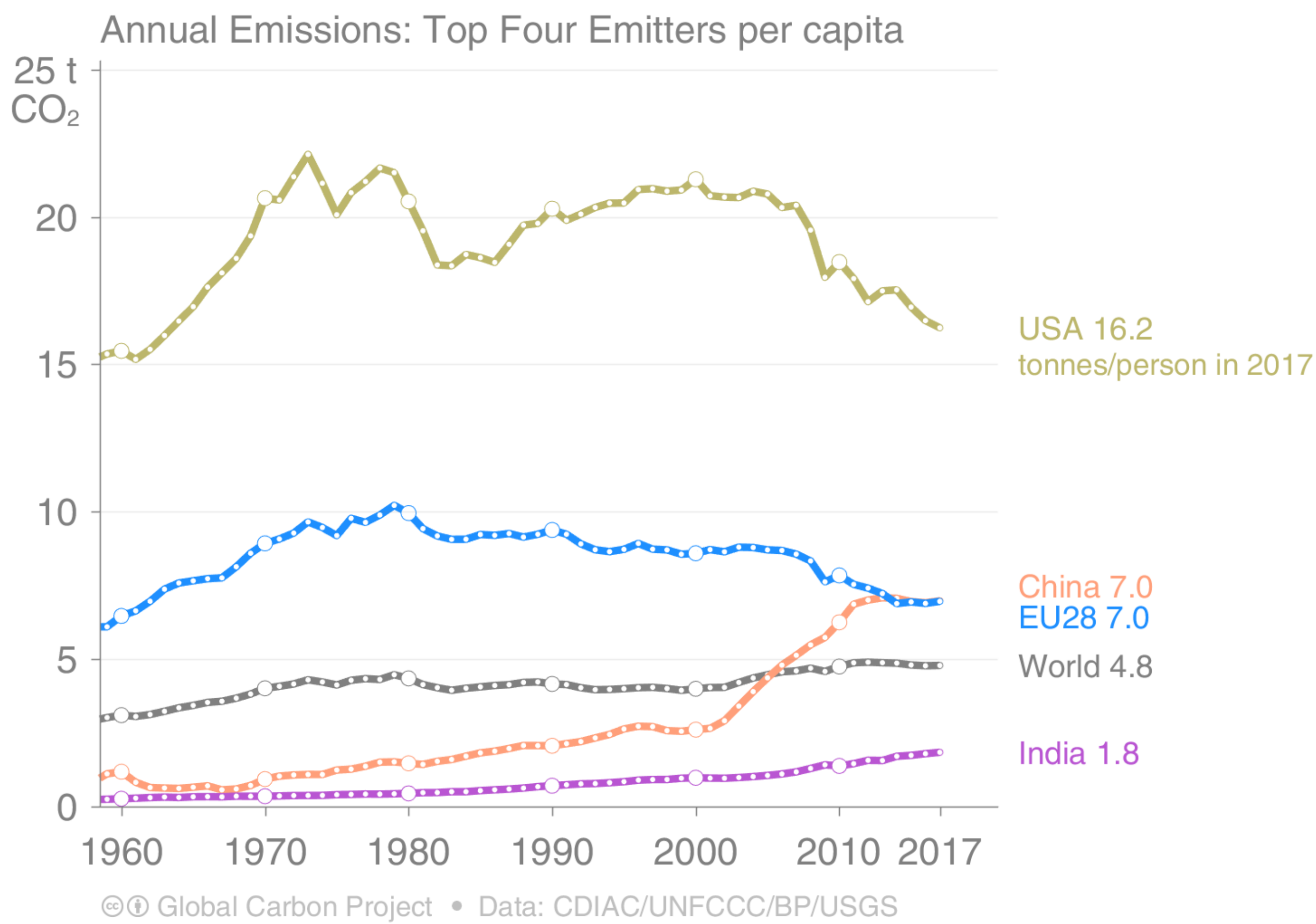
The top four emitters in 2017 covered 58% of global emissions
China (27%), United States (15%), EU28 (10%), India (7%)



Bunker fuels, used for international transport, are 3.2% of global emissions.
Statistical differences between the global estimates and sum of national totals are 0.7% of global emissions.
Source: [CDIAC]; [Le Quéré et al 2018]; [Global Carbon Budget 2018]

Top emitters: Fossil CO_2 Emissions per capita

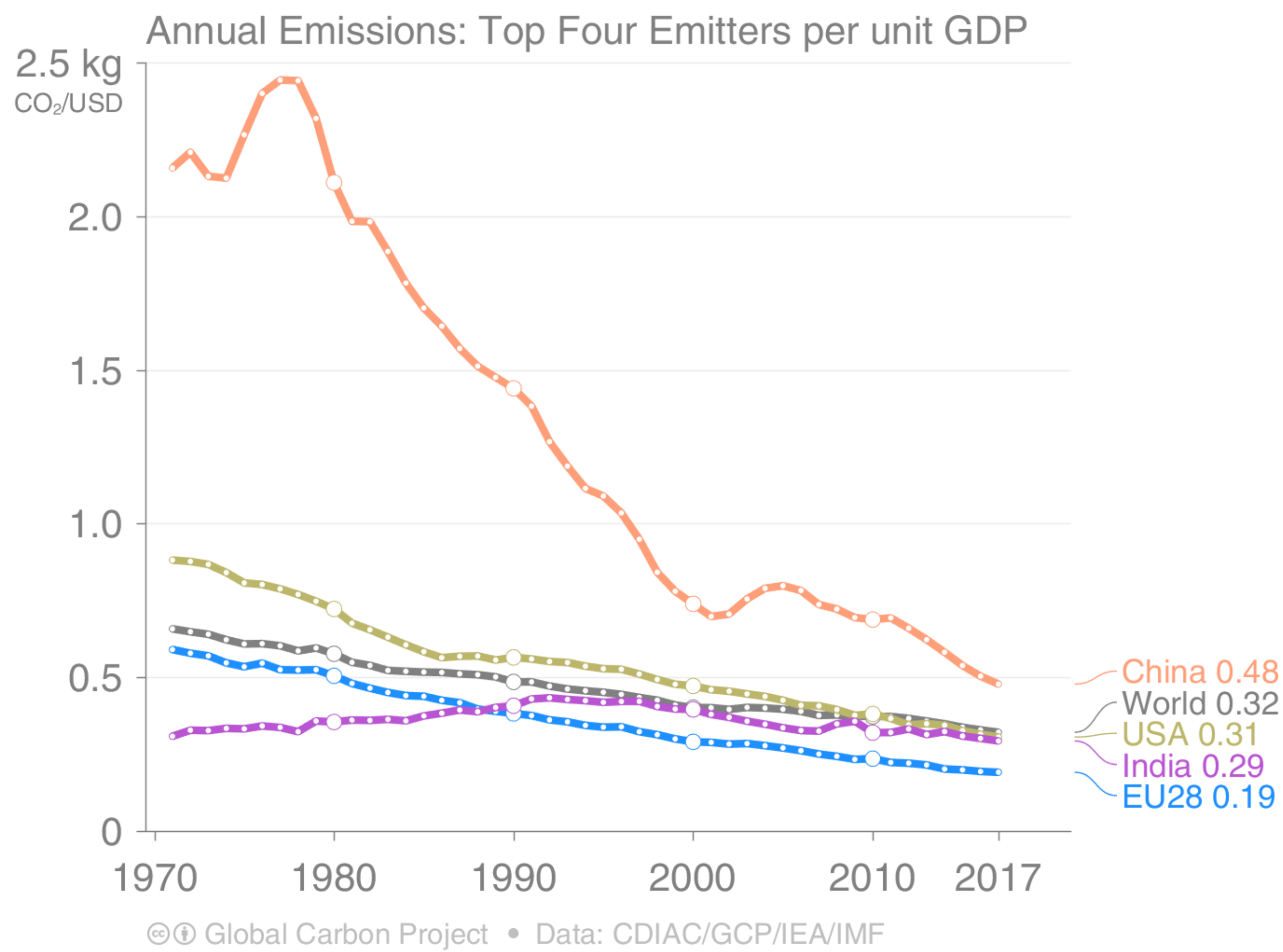
Countries have a broad range of per capita emissions reflecting their national circumstances



Source: [CDIAC]; [Le Quéré et al 2018]; [Global Carbon Budget 2018]

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.

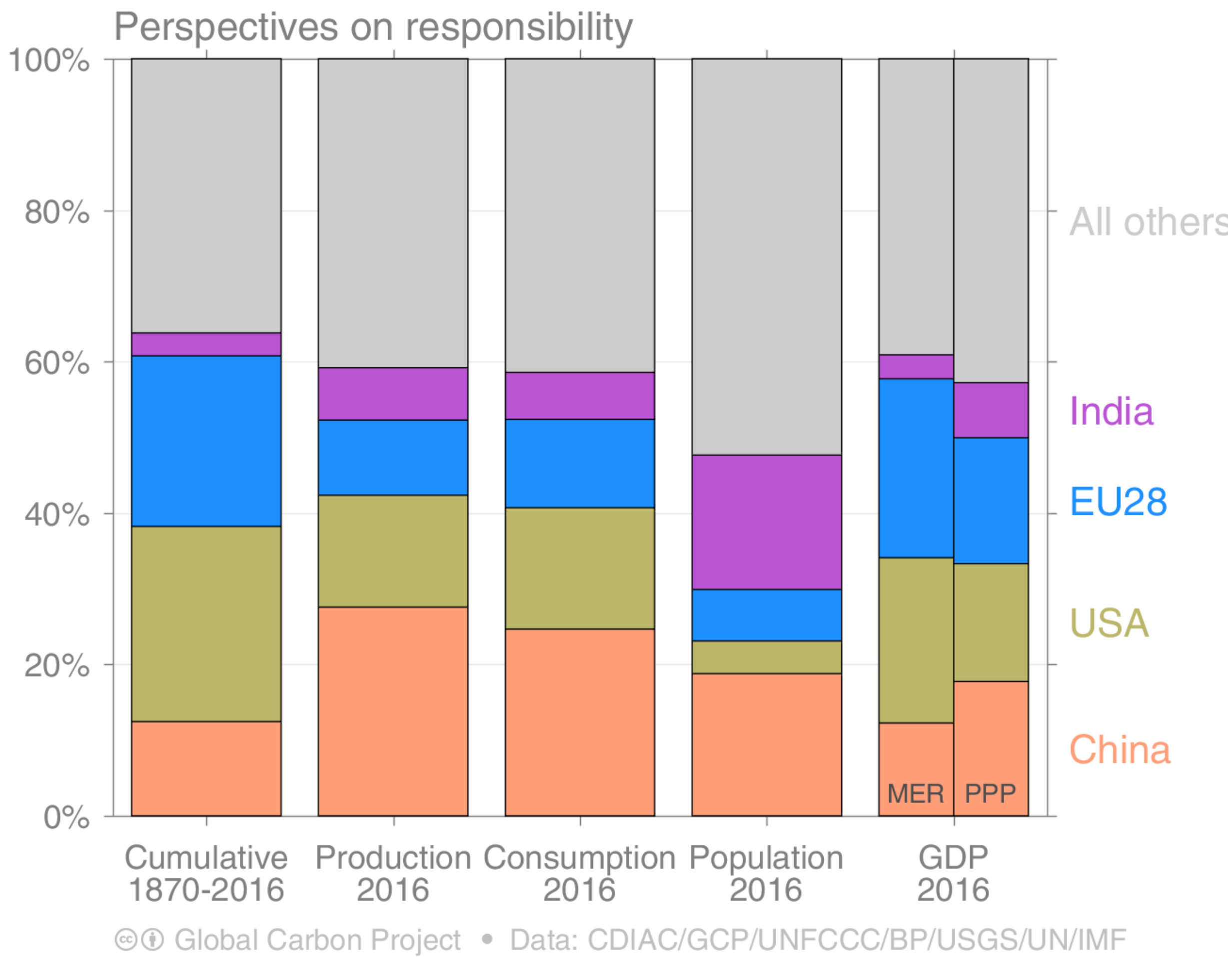


GDP is measured in purchasing power parity (PPP) terms in 2010 US dollars.

Source: [CDIAC](); [IEA 2017]() GDP to 2015, [IMF 2018]() growth rates to 2017; [Le Quéré et al 2018](); [Global Carbon Budget 2018]()

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: [CDIAC](); [United Nations](); [Le Quéré et al 2018](); [Global Carbon Budget 2018]()

Fossil CO_2 emissions growth: 2016–2017

Emissions in the China, India, and Turkey increased most in 2017
Emissions in USA declined, while all other countries combined increased

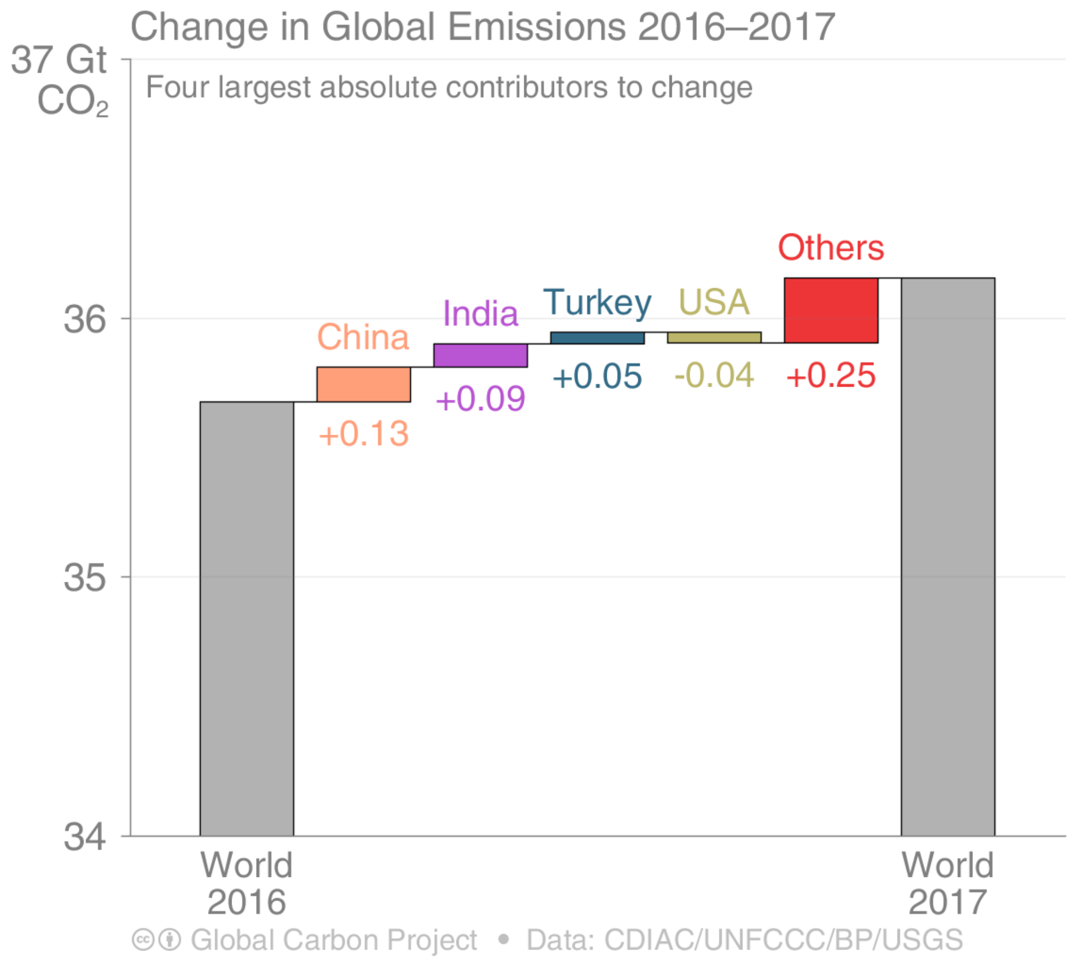
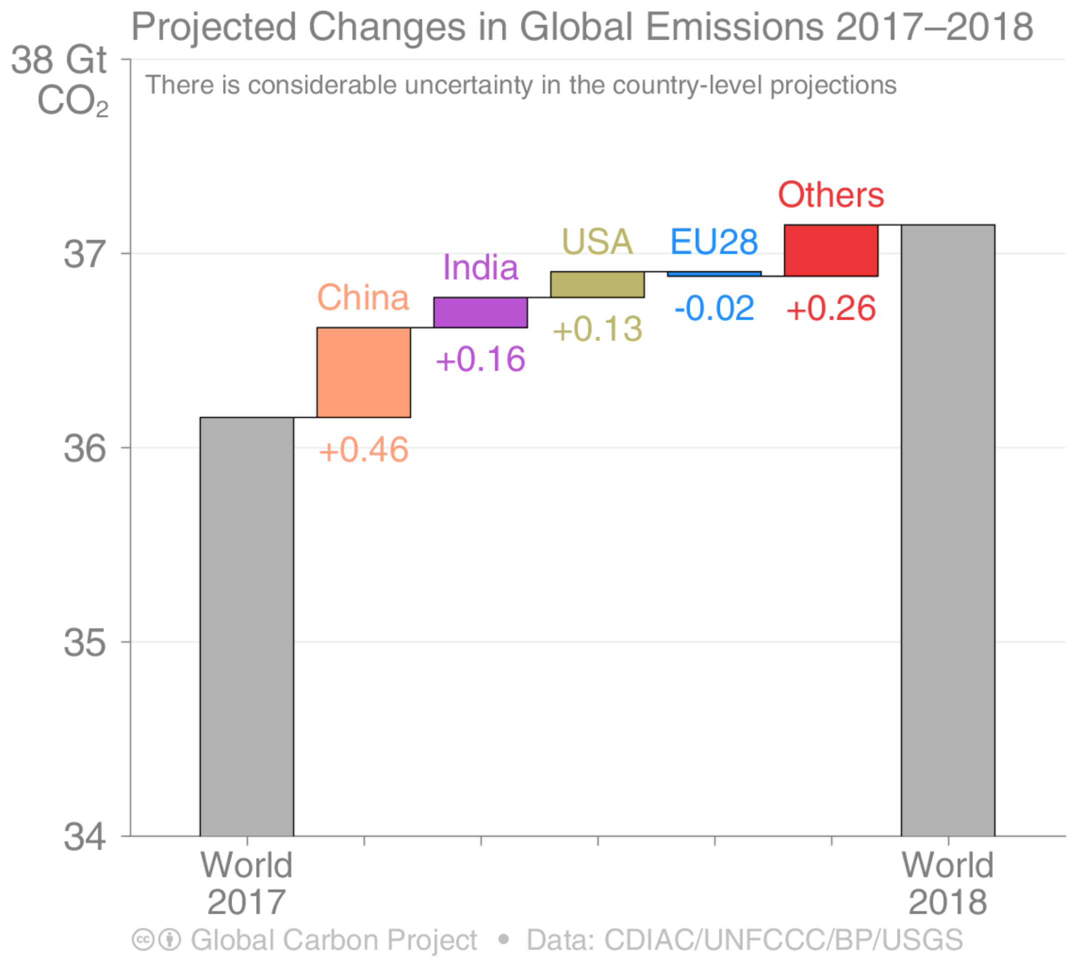


Figure shows the top four countries contributing to emissions changes in 2017
Source: [CDIAC](); [Le Quéré et al 2018](); [Global Carbon Budget 2018]()

Fossil CO_2 emissions growth: 2018 projection

Emissions in China, India, and the US are expected to increase in 2018, while emissions in the EU28 are expected to decline, and all other countries combined will most likely increase

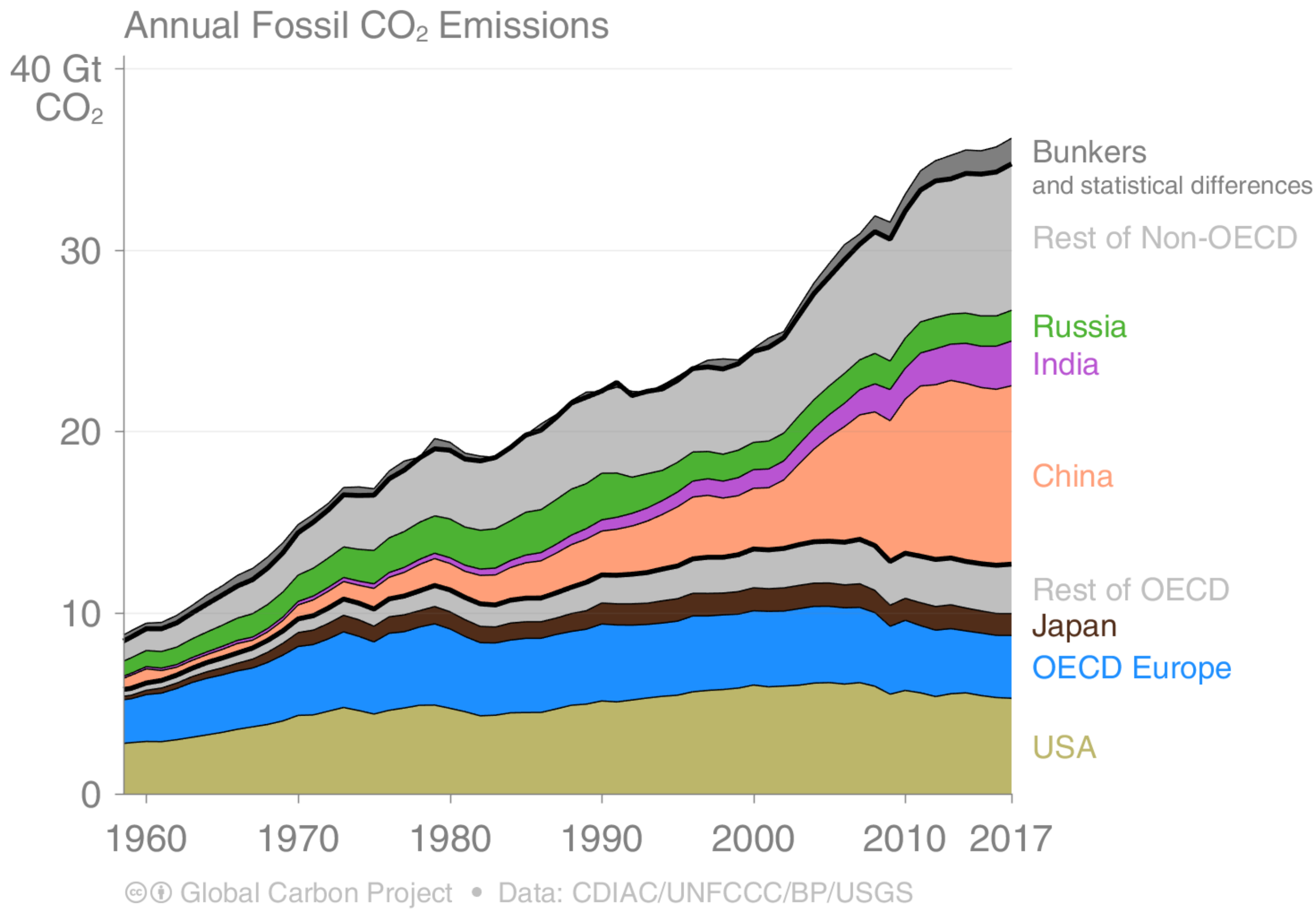


Our projection considers China, USA, EU28, and India independently, and the Others as an aggregated "Rest of World"

Source: [CDIAC](); [Le Quéré et al 2018](); [Global Carbon Budget 2018]()

Breakdown of global fossil CO_2 emissions by country

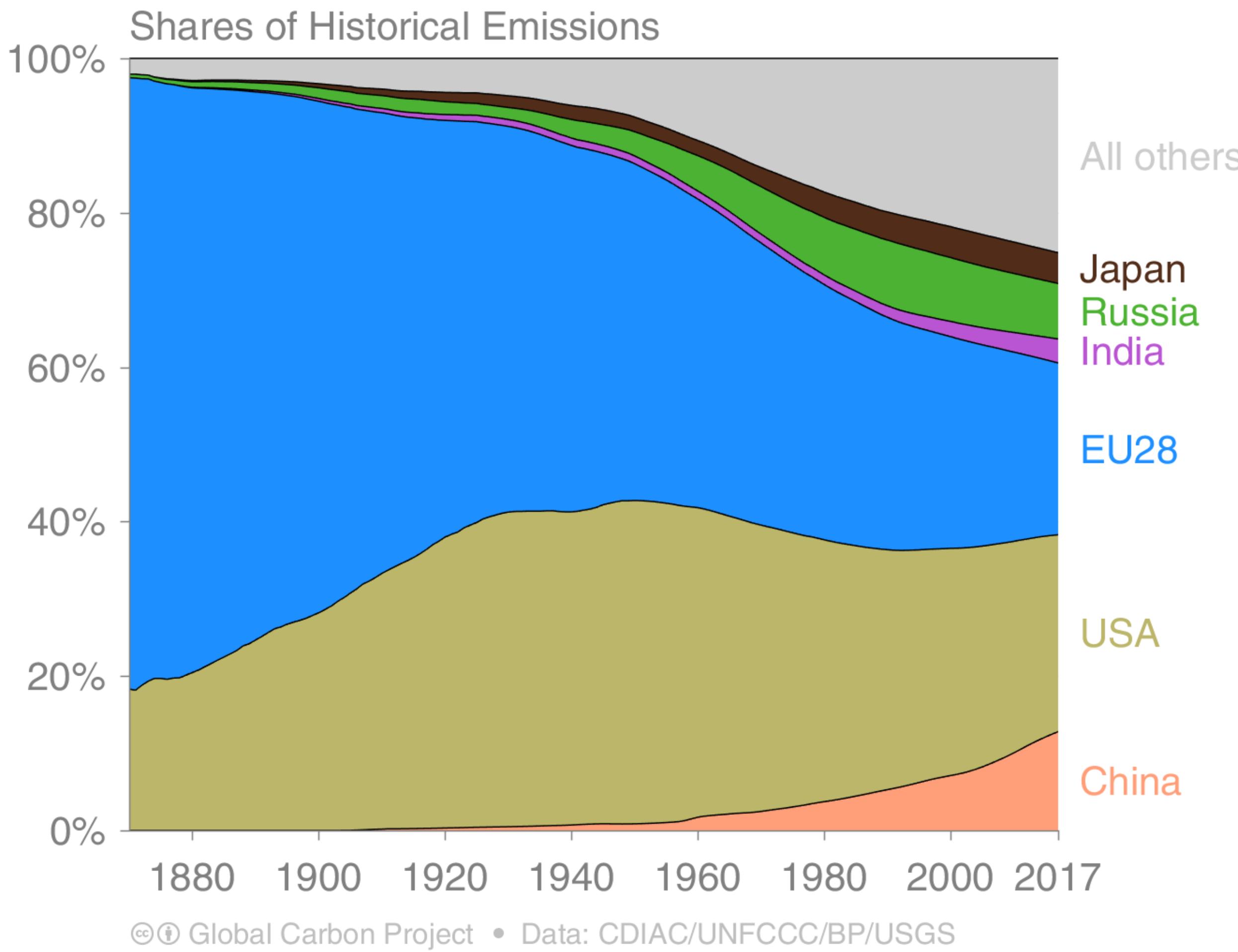
Emissions in OECD countries have increased by 5% since 1990, while those in non-OECD countries have more than doubled



Source: [CDIAC]; [Le Quéré et al 2018]; [Global Carbon Budget 2018]

Historical cumulative fossil CO_2 emissions by country

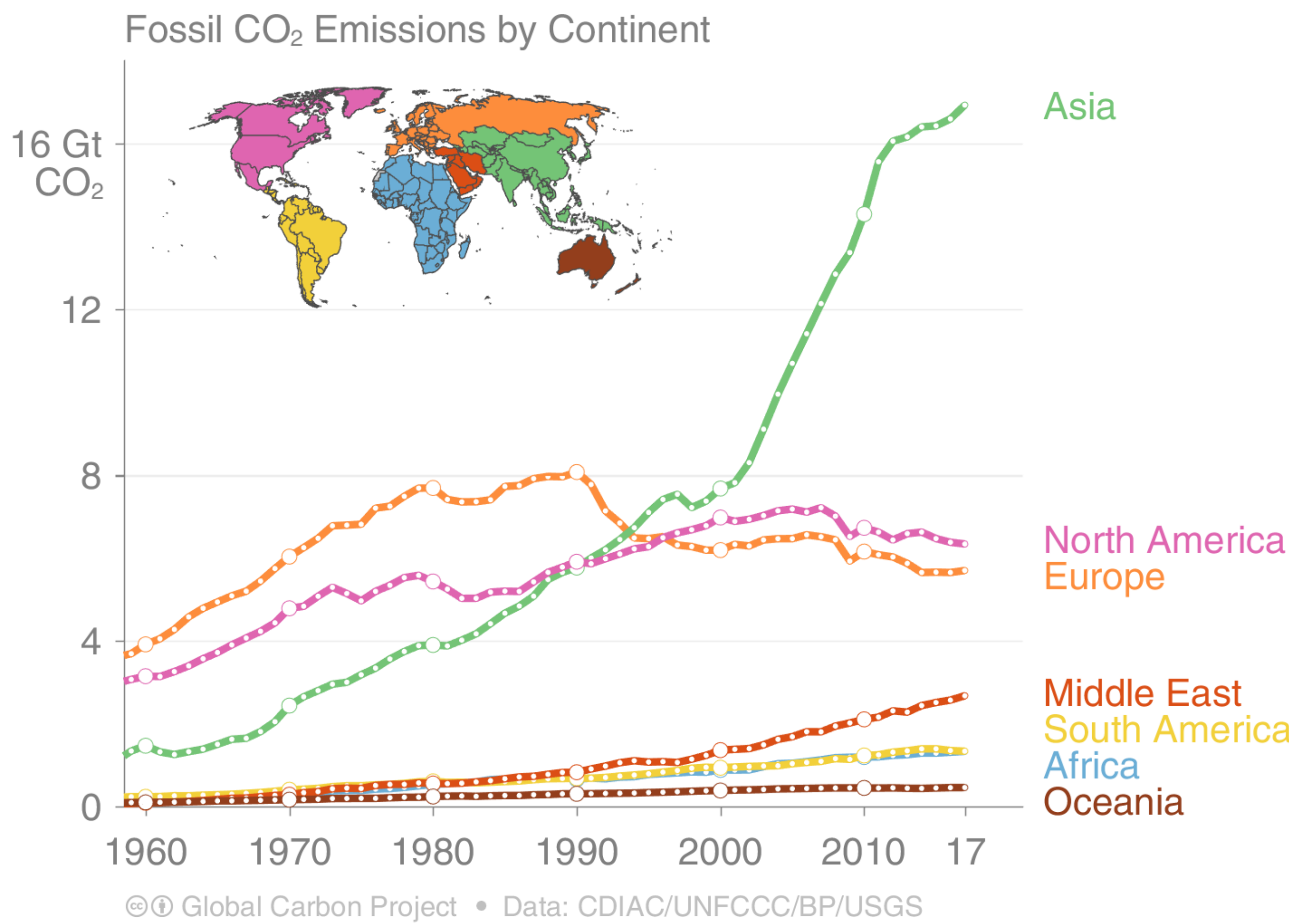
Cumulative fossil CO_2 emissions were distributed (1870–2017):
USA 25%, EU28 22%, China 13%, Russia 7%, Japan 4% and India 3%



Cumulative emissions (1990–2017) were distributed China 20%, USA 20%, EU28 14%, Russia 6%, India 5%, Japan 4%
'All others' includes all other countries along with bunker fuels and statistical differences
Source: [CDIAC](); [Le Quéré et al 2018](); [Global Carbon Budget 2018]()

Fossil CO_2 emissions by continent

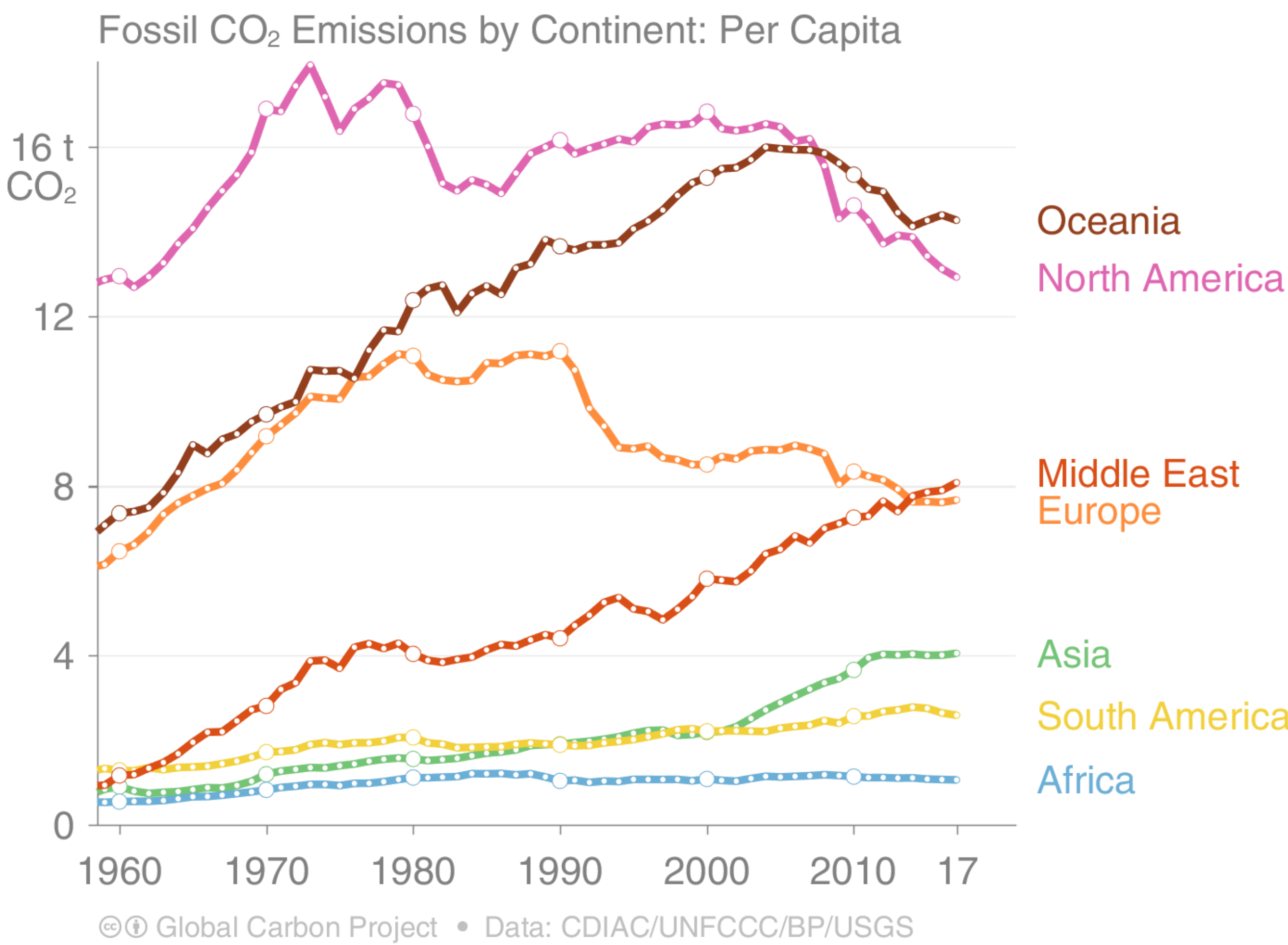
Asia dominates global fossil CO_2 emissions, while emissions in North America are of similar size to those in Europe, and the Middle East is growing rapidly.



Source: [CDIAC](); [Le Quéré et al 2018](); [Global Carbon Budget 2018]()

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.

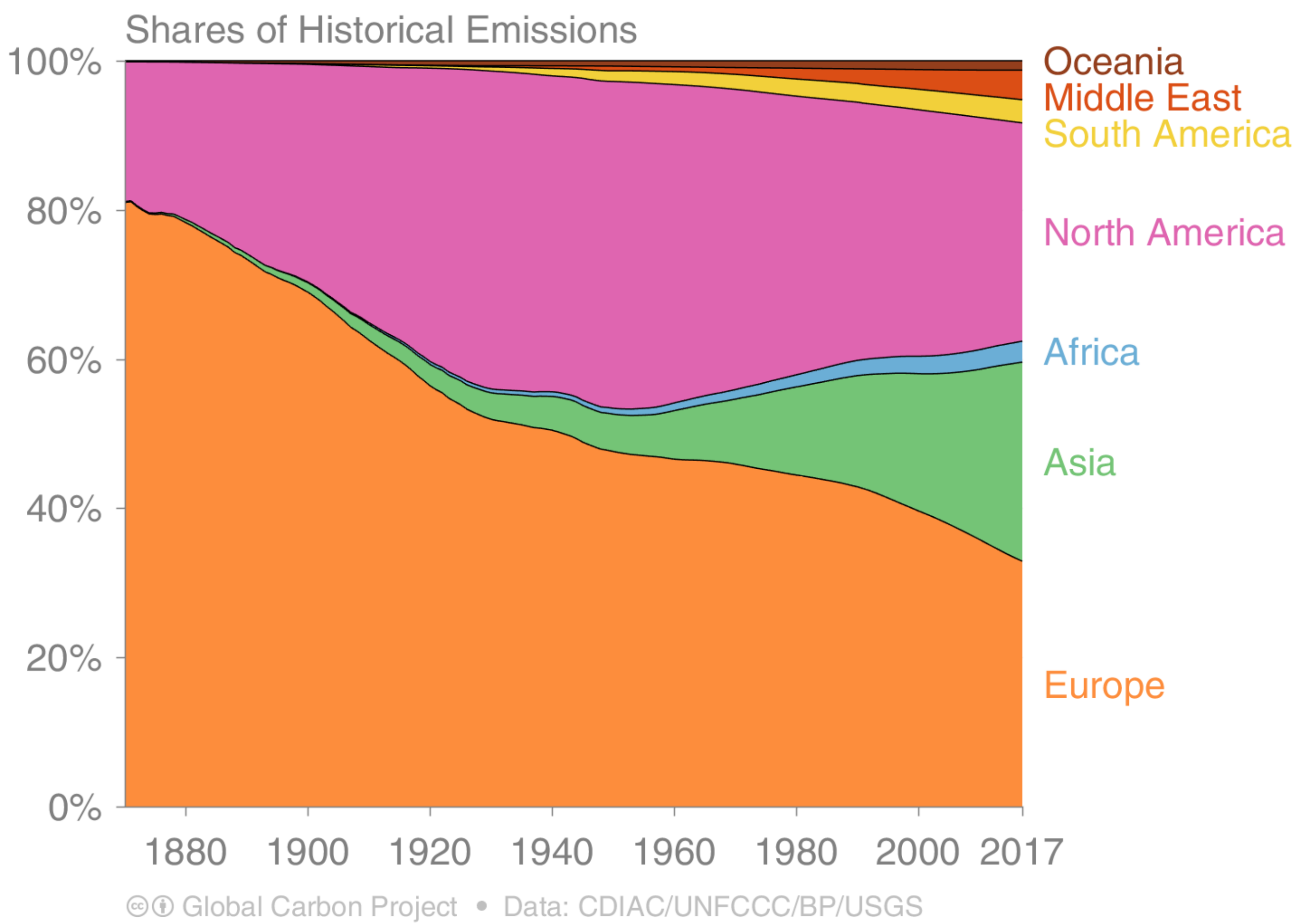


The global average was 4.8 tonnes per capita in 2017.

Source: [CDIAC]; [Le Quéré et al 2018]; [Global Carbon Budget 2018]

Historical cumulative emissions by continent

Cumulative fossil CO_2 emissions (1870–2017). North America and Europe have contributed the most cumulative emissions, but Asia is growing fast

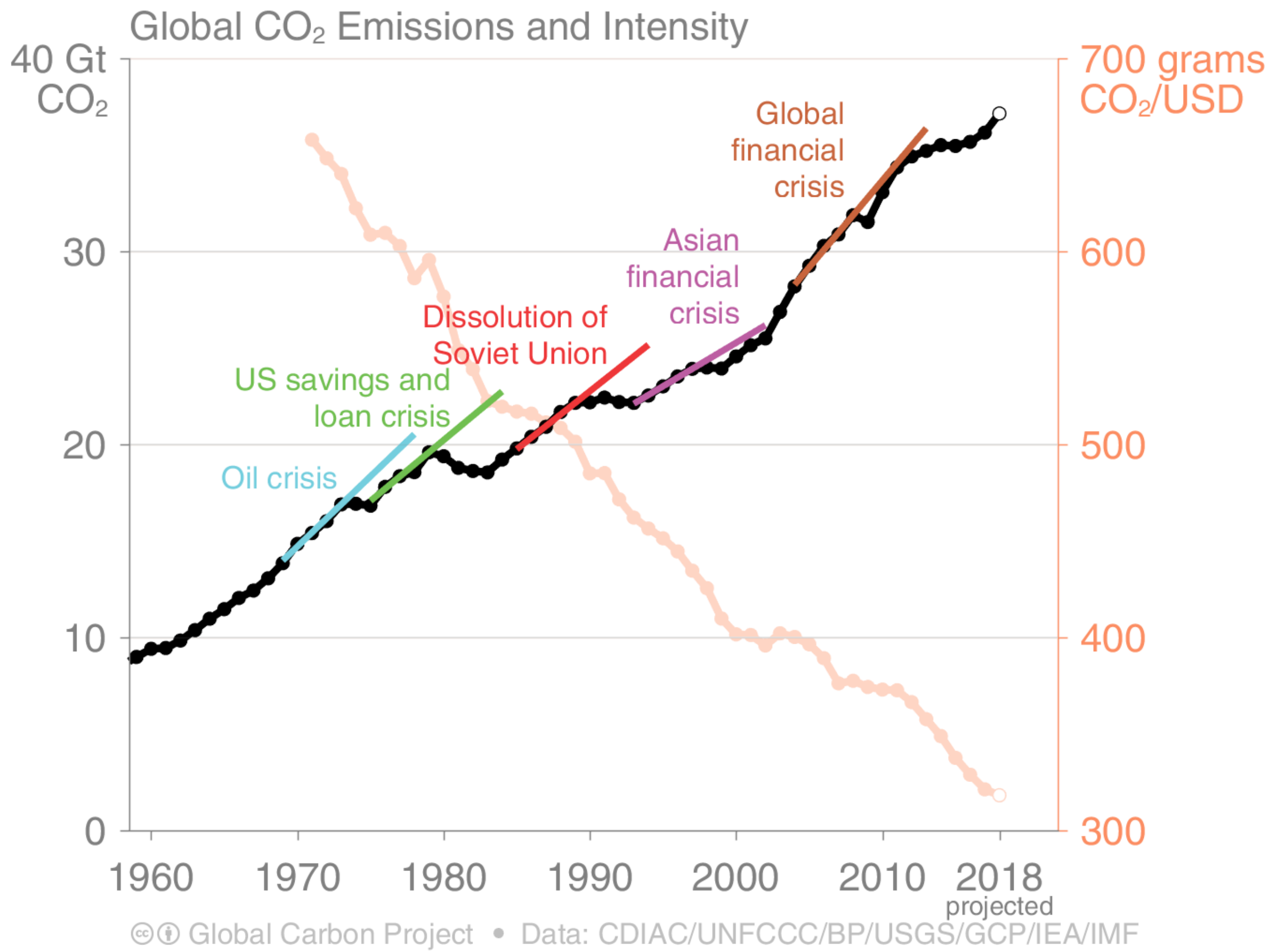


The figure excludes bunker fuels and statistical differences

Source: CDIAC; Le Quéré et al 2018; Global Carbon Budget 2018

Fossil CO_2 emission intensity

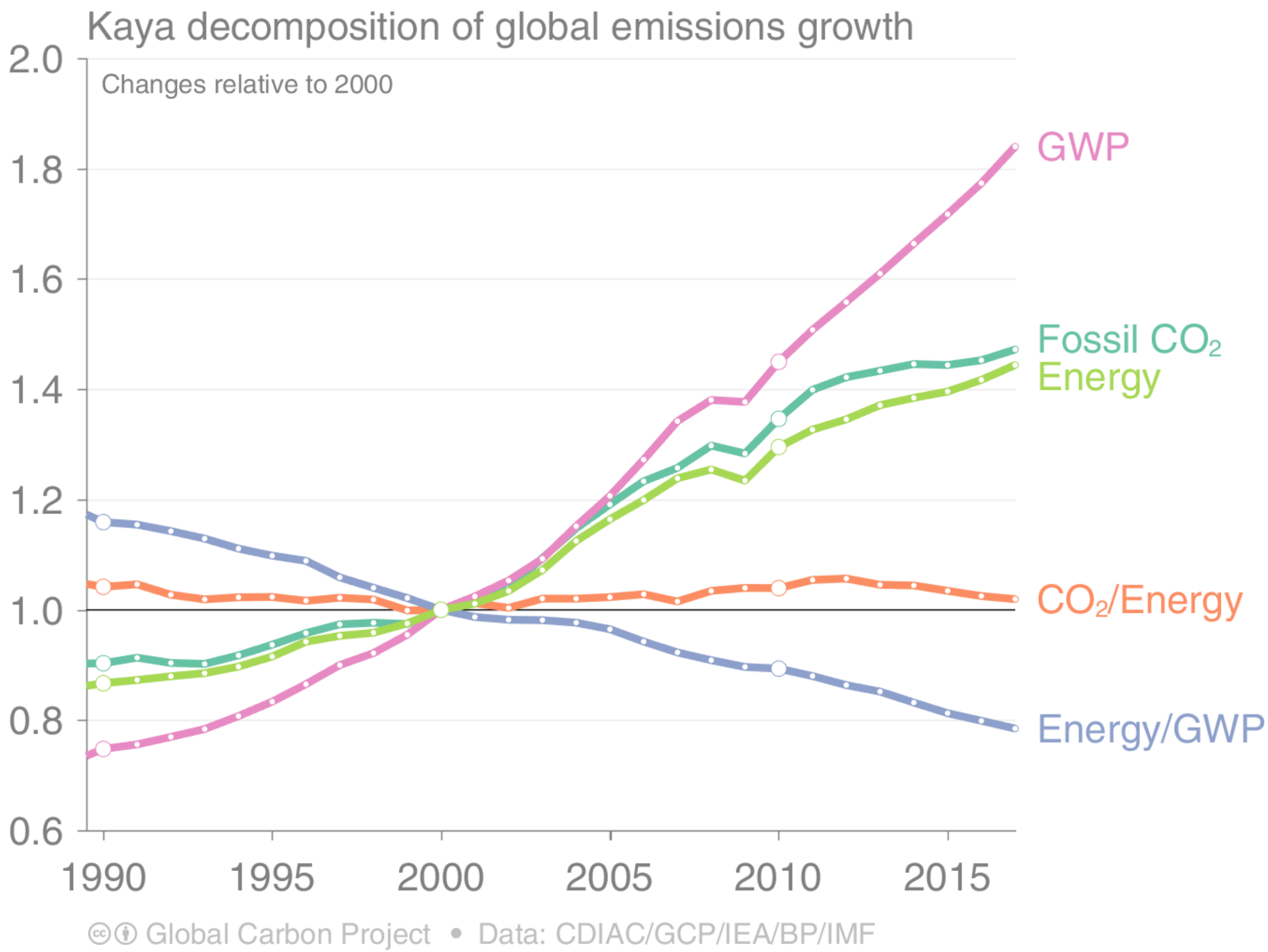
Global CO_2 emissions growth has generally resumed quickly from financial crises.
Emission intensity has steadily declined but not sufficiently to offset economic growth.



Economic activity is measured in purchasing power parity (PPP) terms in 2010 US dollars.
Source: [CDIAC]; [Peters et al 2012]; [Le Quéré et al 2018]; [Global Carbon Budget 2018]

Kaya decomposition

The Kaya decomposition illustrates that relative decoupling of economic growth from CO_2 emissions is driven by improved energy intensity (Energy/GWP)



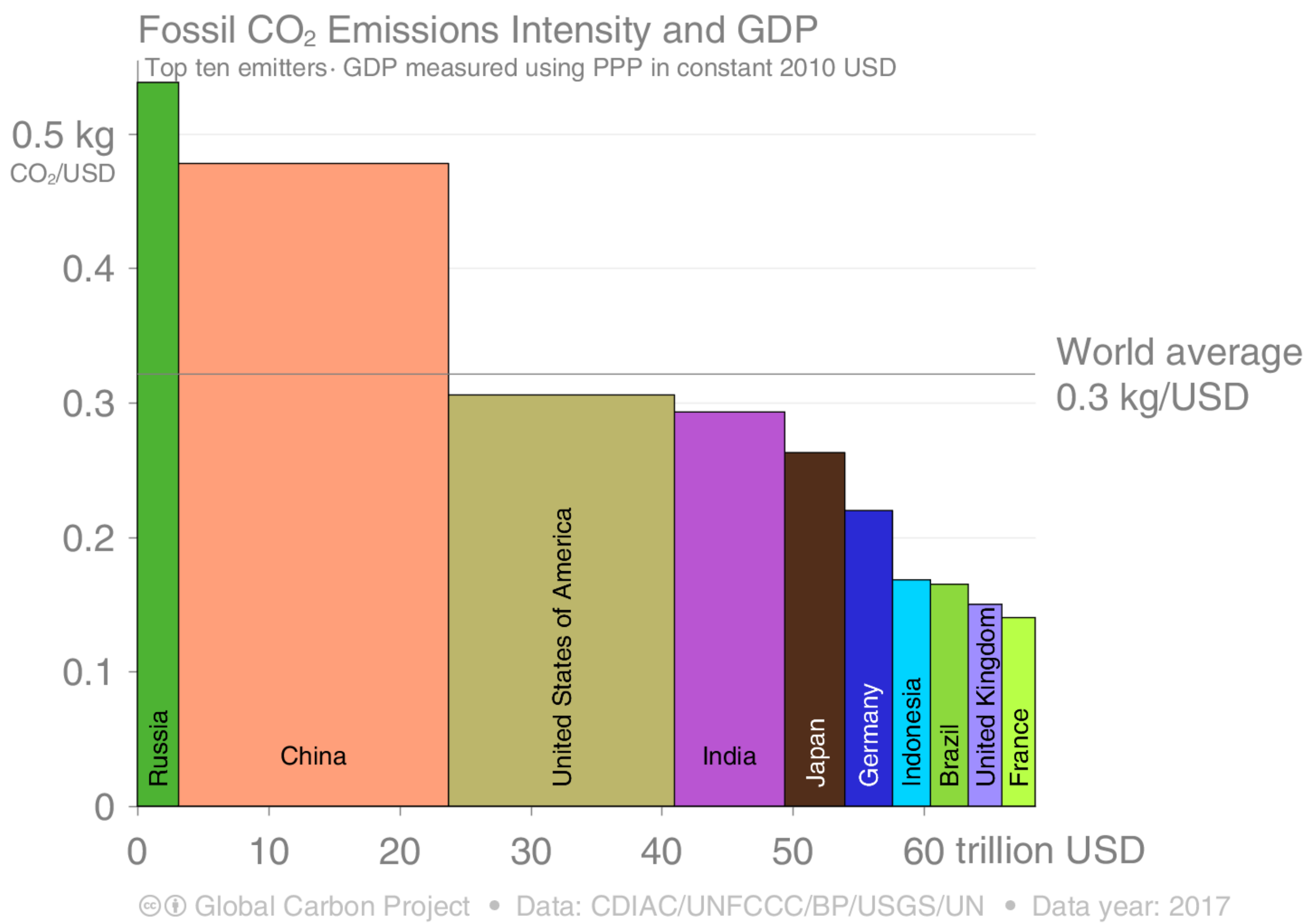
GWP: Gross World Product (economic activity)

Energy is Primary Energy from BP statistics using the substitution accounting method

Source: [Jackson et al 2018](); [Global Carbon Budget 2018]()

Fossil CO_2 emission intensity

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

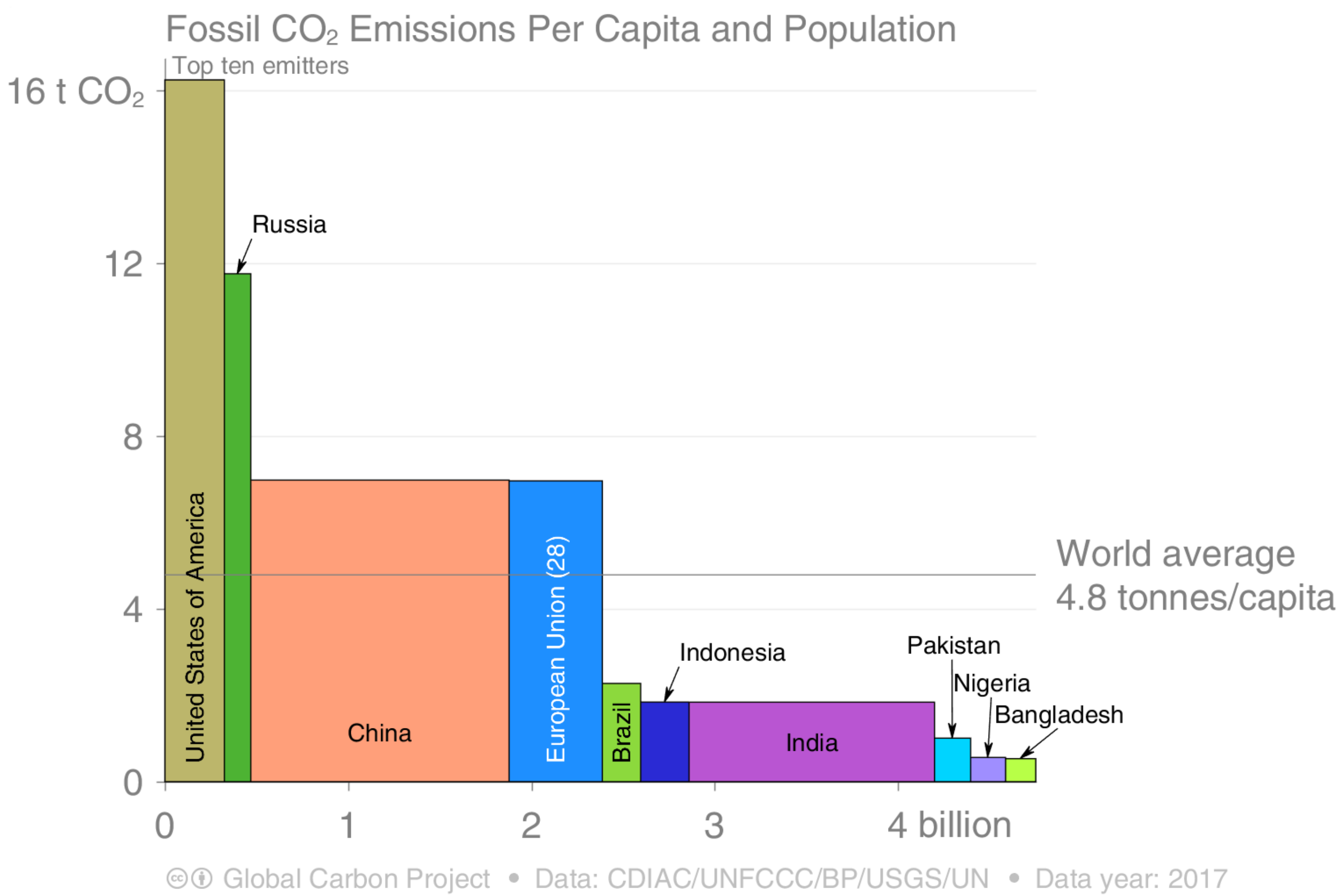


Emission intensity: Fossil CO_2 emissions divided by Gross Domestic Product (GDP)

Source: [Global Carbon Budget 2018]

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: [Global Carbon Budget 2018]

Key statistics

Region/Country	Emissions 2017: Per capita	Total		Growth 2016–17	
	tCO_2 per person	$GtCO_2$	%	$GtCO_2$	%
Global (with bunkers)	4.8	36.15	100	0.478	0.0
OECD Countries					
OECD	9.8	12.67	35.0	0.061	0.8
USA	16.2	5.27	14.6	-0.041	-0.5
OECD Europe	7.1	3.46	9.6	0.034	1.3
Japan	9.5	1.21	3.3	0.001	0.3
South Korea	12.1	0.62	1.7	0.021	3.8
Canada	15.6	0.57	1.6	0.015	2.9
Non-OECD Countries					
Non-OECD	3.5	22.08	61.1	0.388	2.1
China	7.0	9.84	27.2	0.134	1.7
India	1.8	2.47	6.8	0.089	4.0
Russia	11.8	1.69	4.7	0.025	1.8
Iran	8.3	0.67	1.9	0.035	5.7
Saudi Arabia	19.3	0.64	1.8	0.003	0.8
International Bunkers					
Bunkers and statistical differences	-	1.41	3.9	0.029	2.1

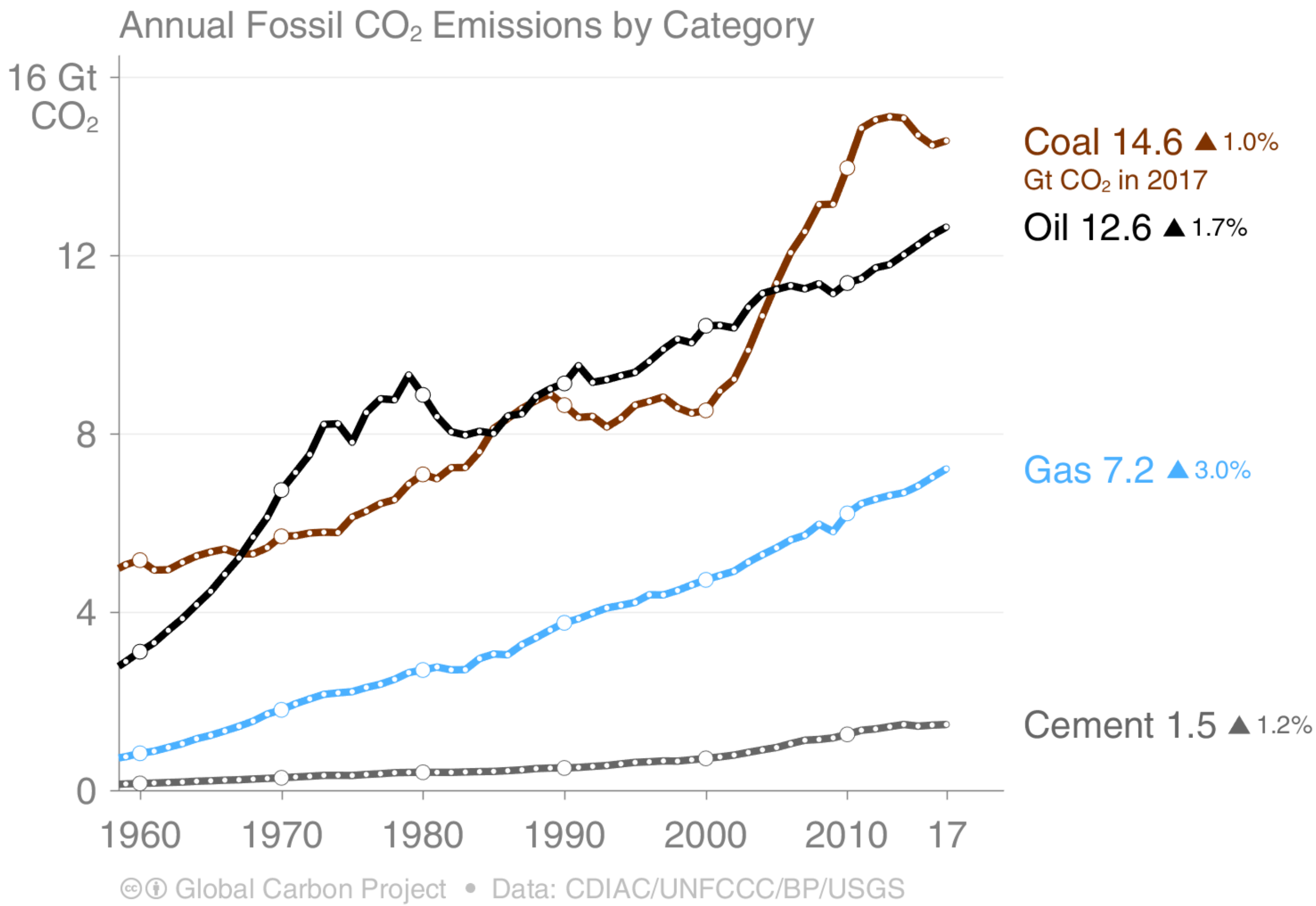
Source: CDIAC; Le Quéré et al 2018; Global Carbon Budget 2018

Fossil CO_2 Emissions by source

from fossil fuel use and industry

Fossil CO_2 Emissions by source

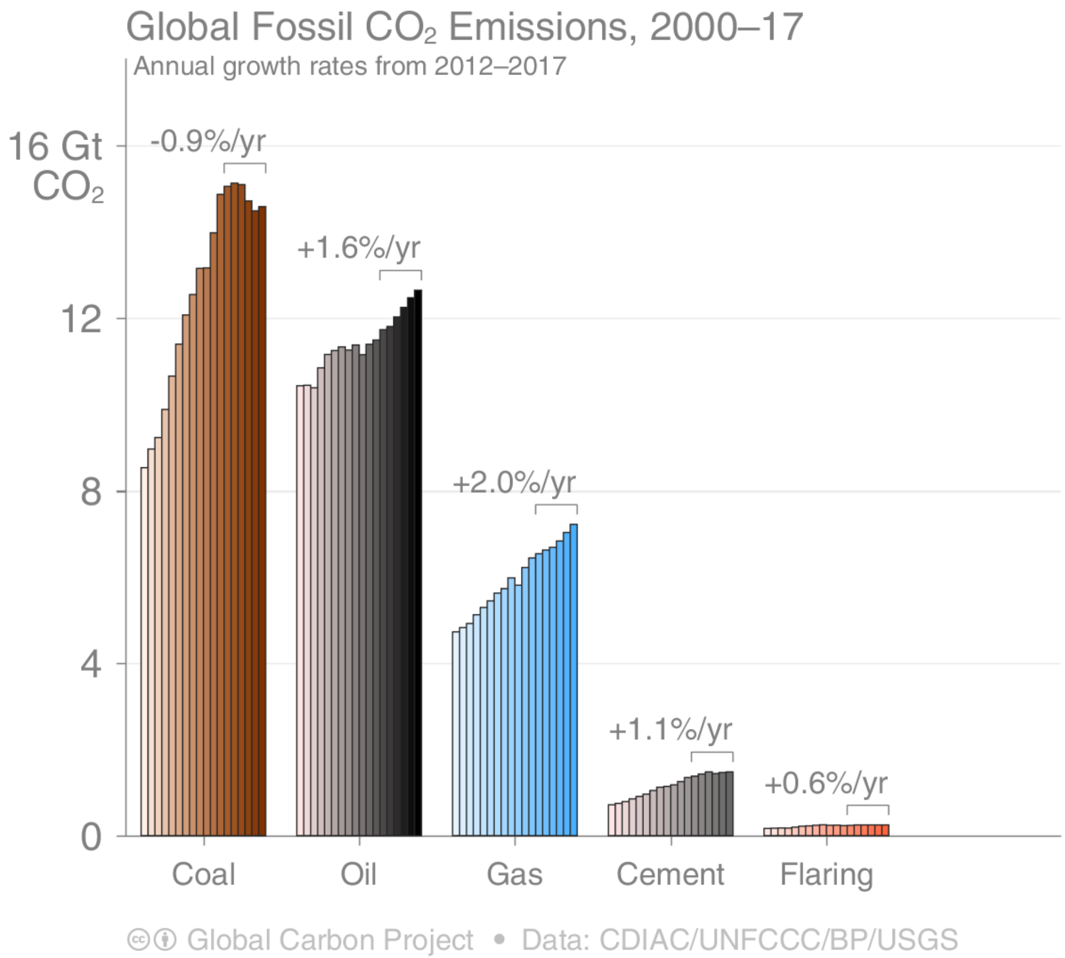
Share of global fossil CO_2 emissions in 2017:
coal (40%), oil (35%), gas (20%), cement (4%), flaring (1%, not shown)



Source: [CDIAC](); [Le Quéré et al 2018](); [Global Carbon Budget 2018]()

Fossil CO_2 Emissions by source

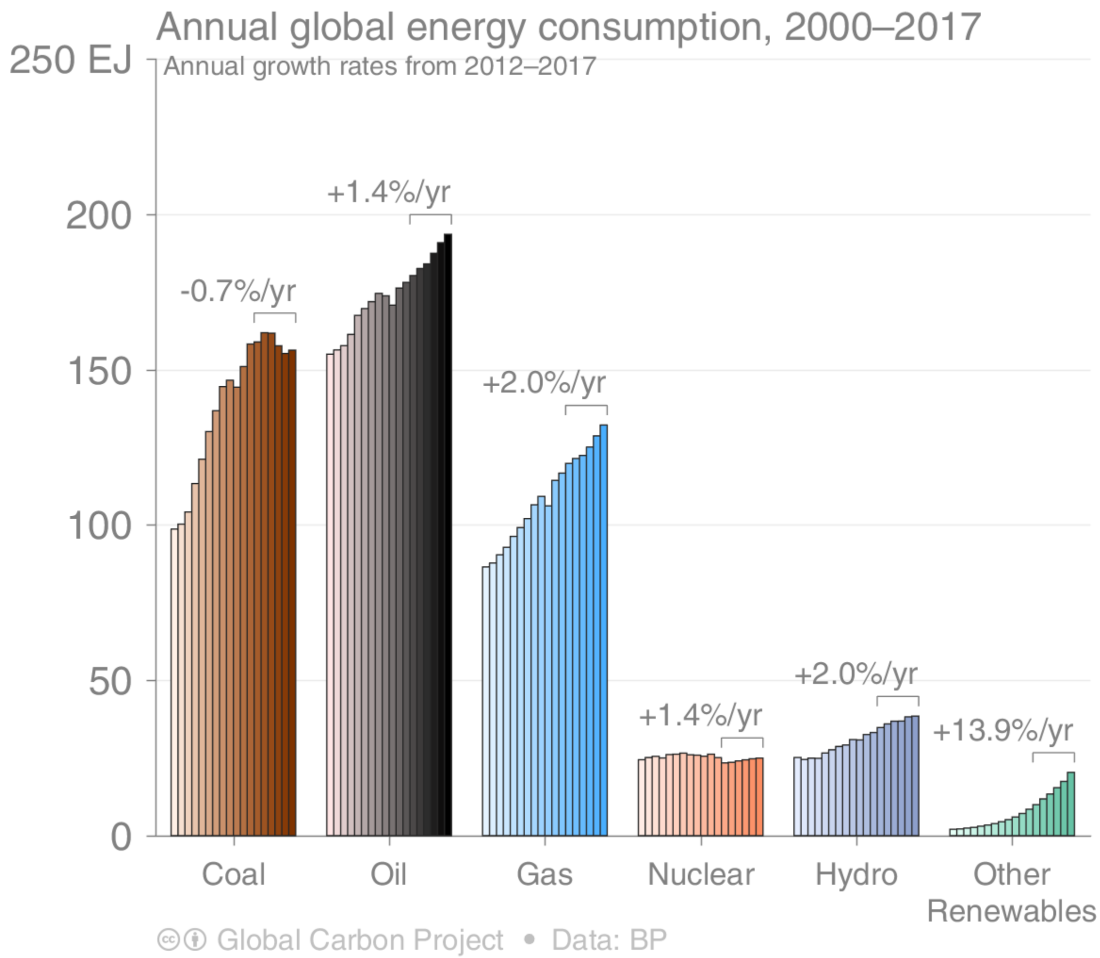
Emissions by category from 2000 to 2017, with growth rates indicated for the more recent period of 2012 to 2017



Source: CDIAC; Jackson et al 2018; Global Carbon Budget 2017

Energy use by source

Energy consumption by fuel source from 2000 to 2017, with growth rates indicated for the more recent period of 2012 to 2017

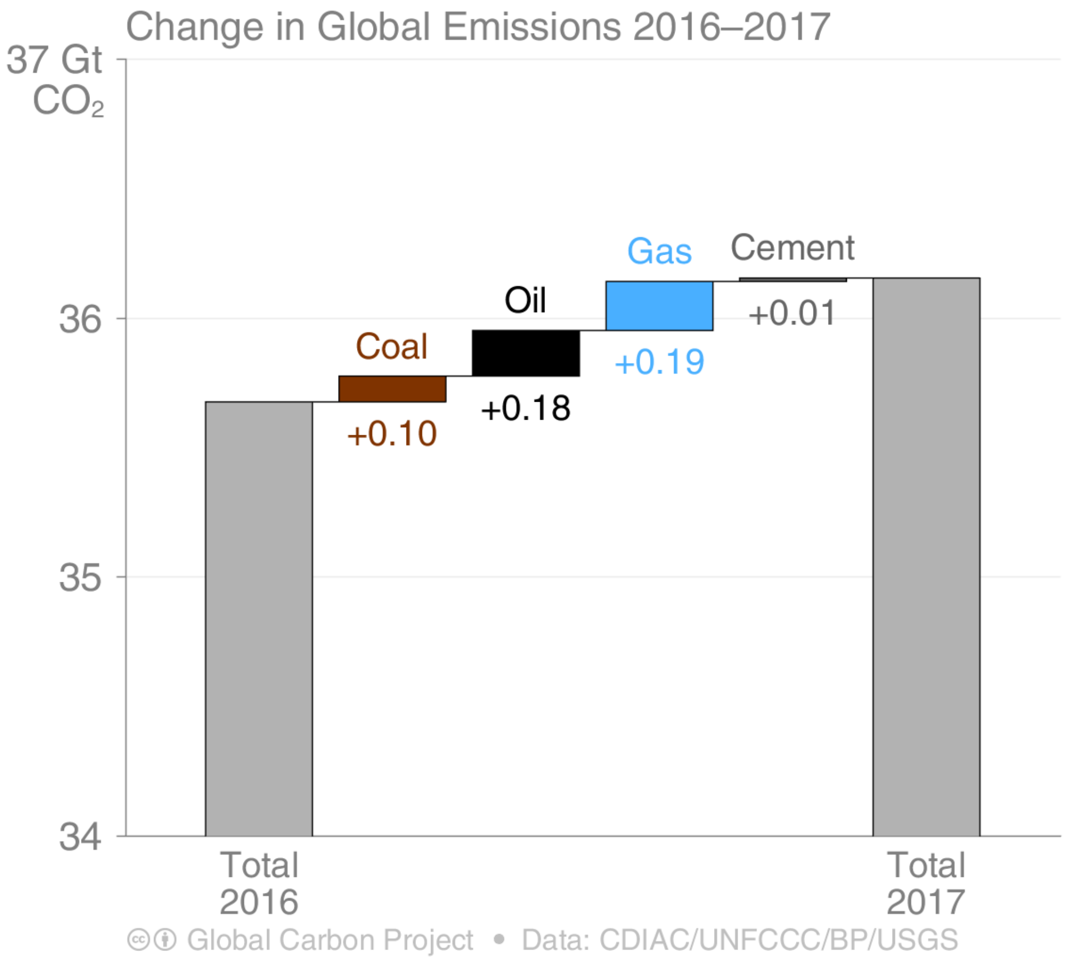


This figure shows "primary energy" using the BP substitution method (non-fossil sources are scaled up by an assumed fossil efficiency of 0.38)

Source: BP 2018; Jackson et al 2018; Global Carbon Budget 2018

Fossil CO_2 Emissions growth by source

All fossil fuels contributed to the growth in fossil CO_2 emissions in 2017



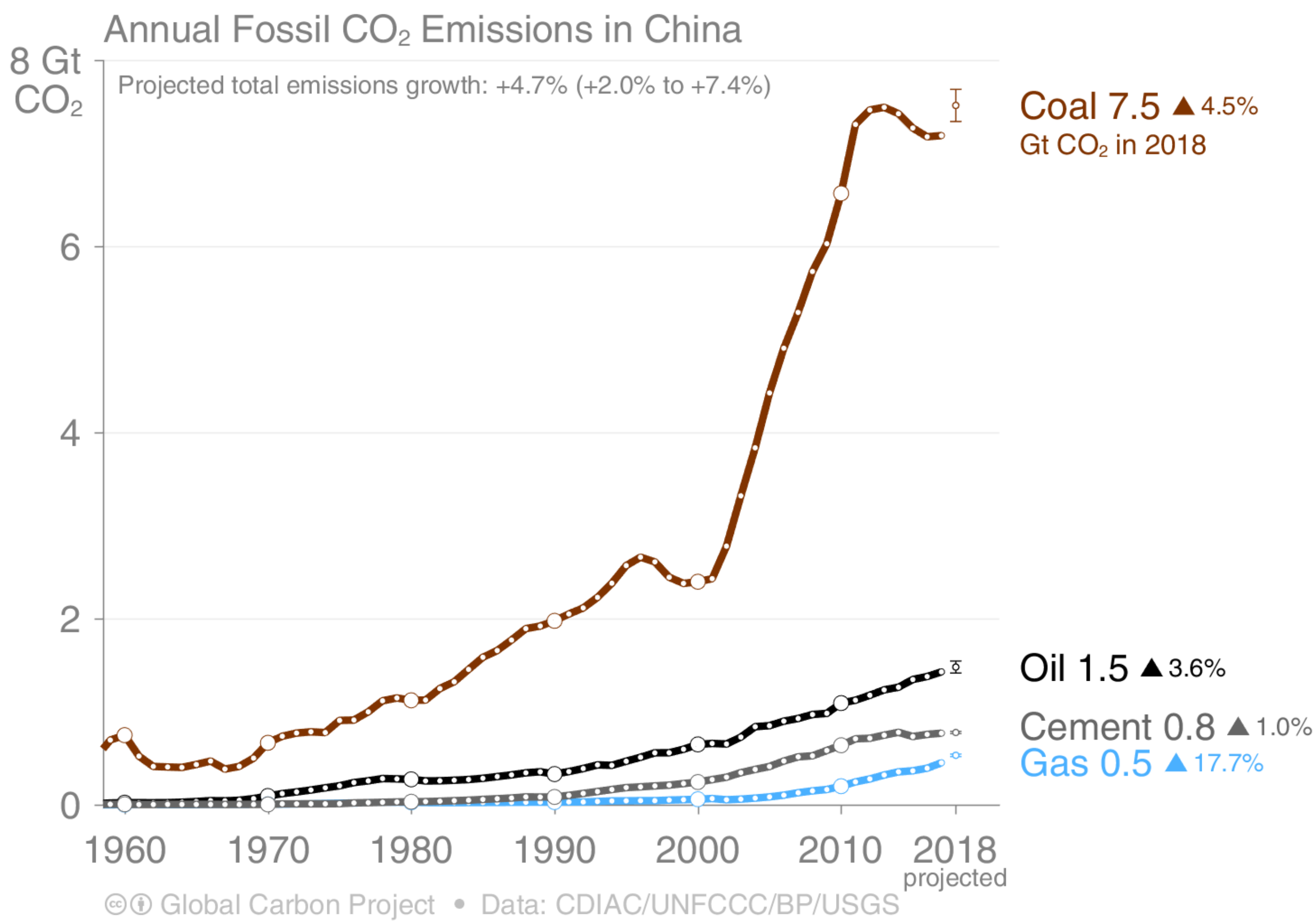
Source: CDIAC; Le Quéré et al 2018; Global Carbon Budget 2018

Fossil CO_2 Emission Projections 2018

from fossil fuel use and industry

Fossil CO_2 Emissions in China

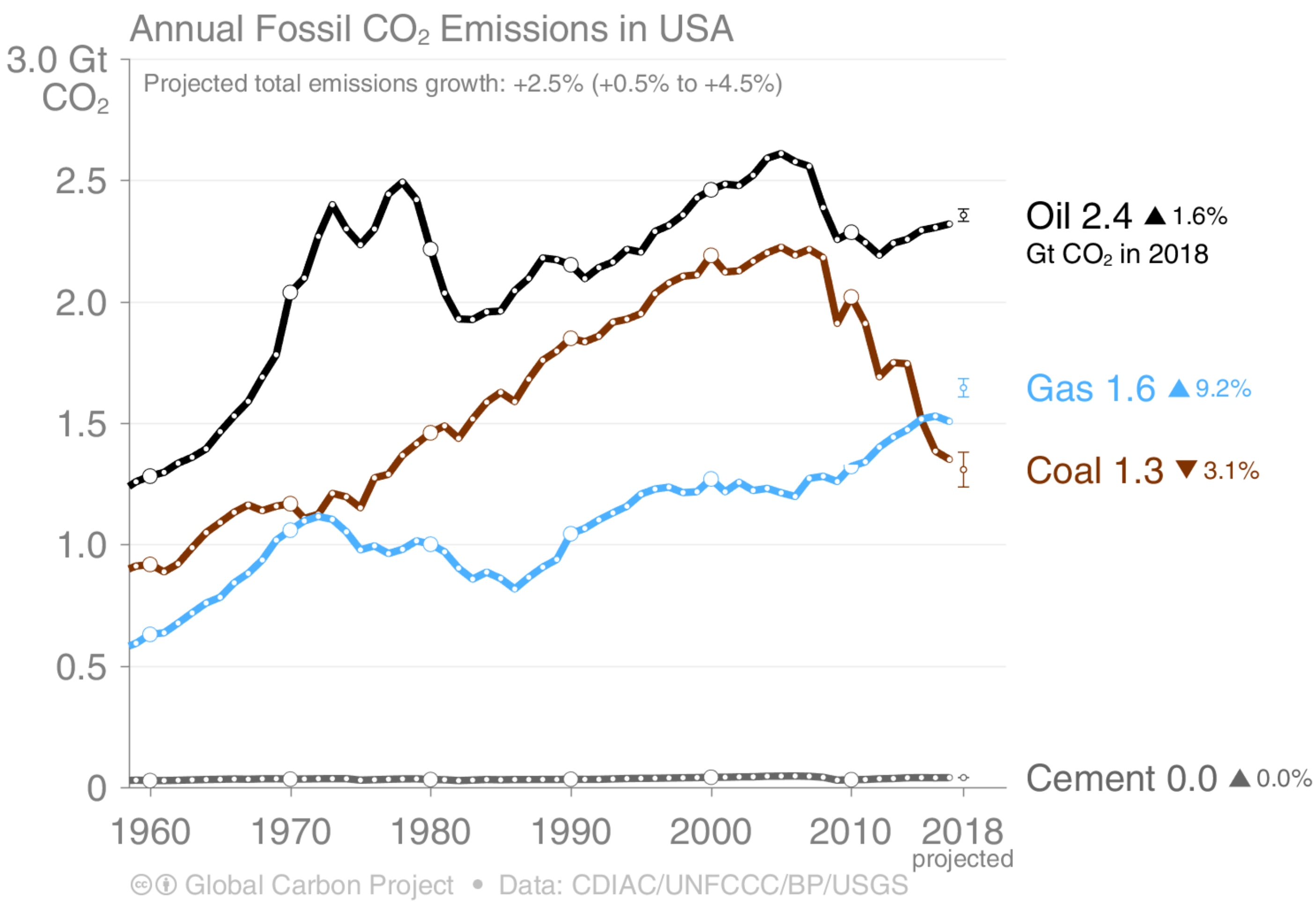
China's emissions are dominated by coal use, with strong and sustained growth in oil & gas
The recent declines in coal emissions may soon be undone if the return growth persists



Source: [CDIAC](); [Le Quéré et al 2018](); [Global Carbon Budget 2018]()

Fossil CO_2 Emissions in USA

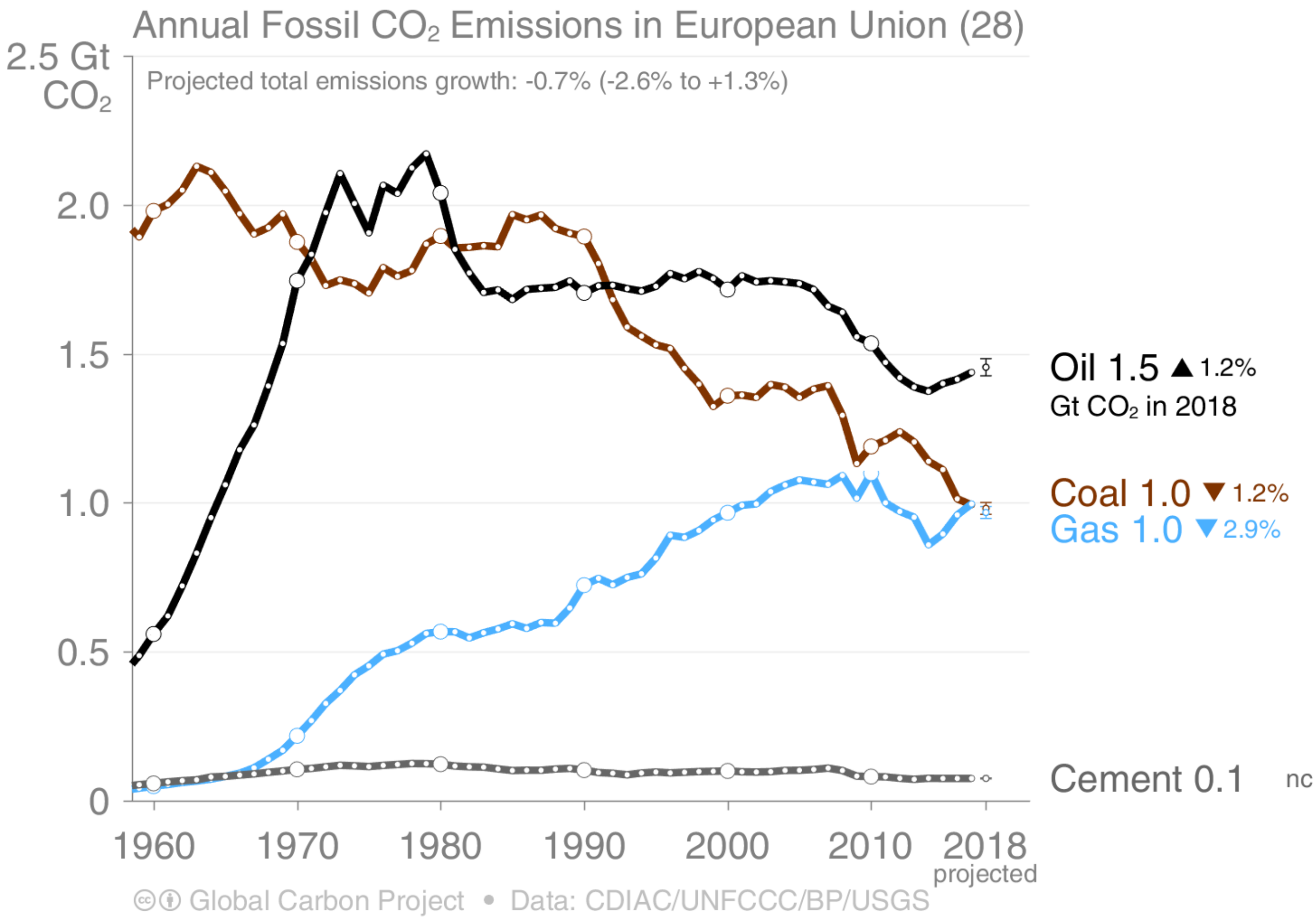
USA CO_2 emissions have declined since 2007, driven by coal being displaced by gas, solar, & wind. Oil use has returned to growth. Emissions growth in 2018 is driven partly by weather.



Source: [CDIAC](); [Le Quéré et al 2018](); [Global Carbon Budget 2018]()

Fossil CO_2 Emissions in the European Union (EU28)

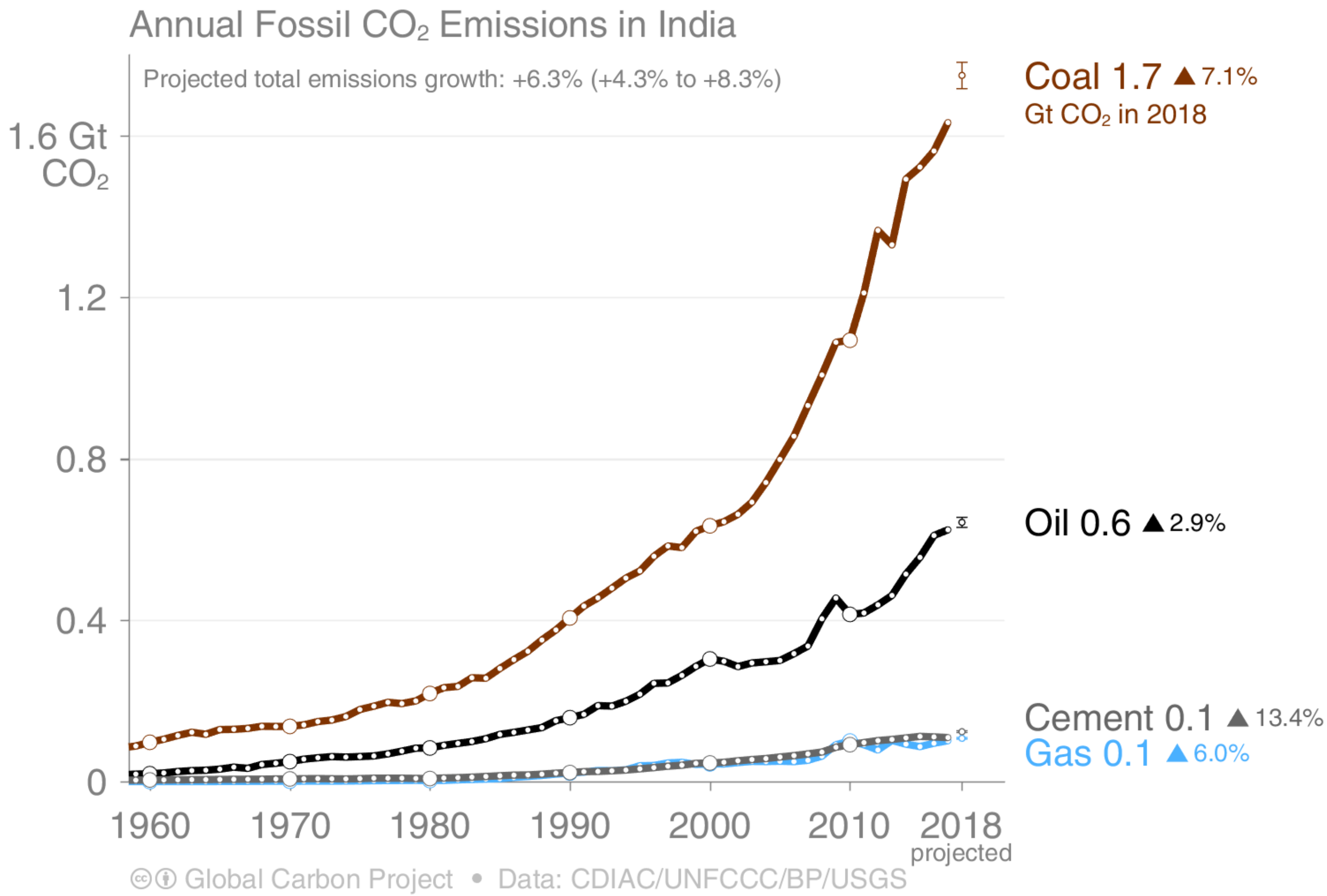
Emissions in the EU28 declined steadily from 2008 (the Global Financial Crisis) to 2014, but oil and gas emissions are growing again. A small decline is expected in 2018.



Source: [CDIAC](); [Le Quéré et al 2018](); [Global Carbon Budget 2018]()

Fossil CO_2 Emissions in India

India's emissions are growing strongly along with rapid growth in economic activity.
Although India is rapidly deploying solar & wind power, coal continues to grow very strongly.

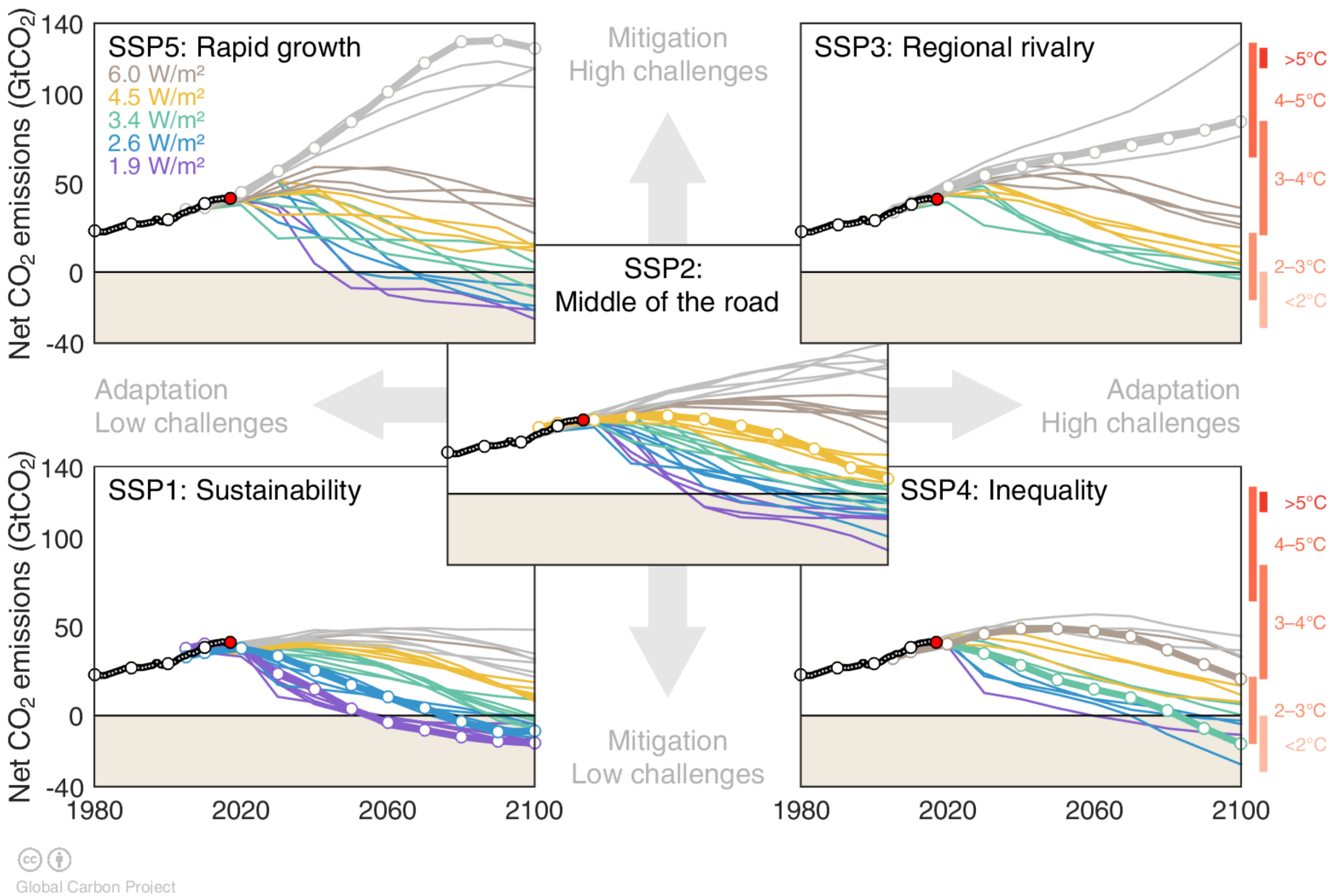


Source: [CDIAC](); [Le Quéré et al 2018](); [Global Carbon Budget 2018]()

Emission scenarios

Shared Socioeconomic Pathways (SSPs)

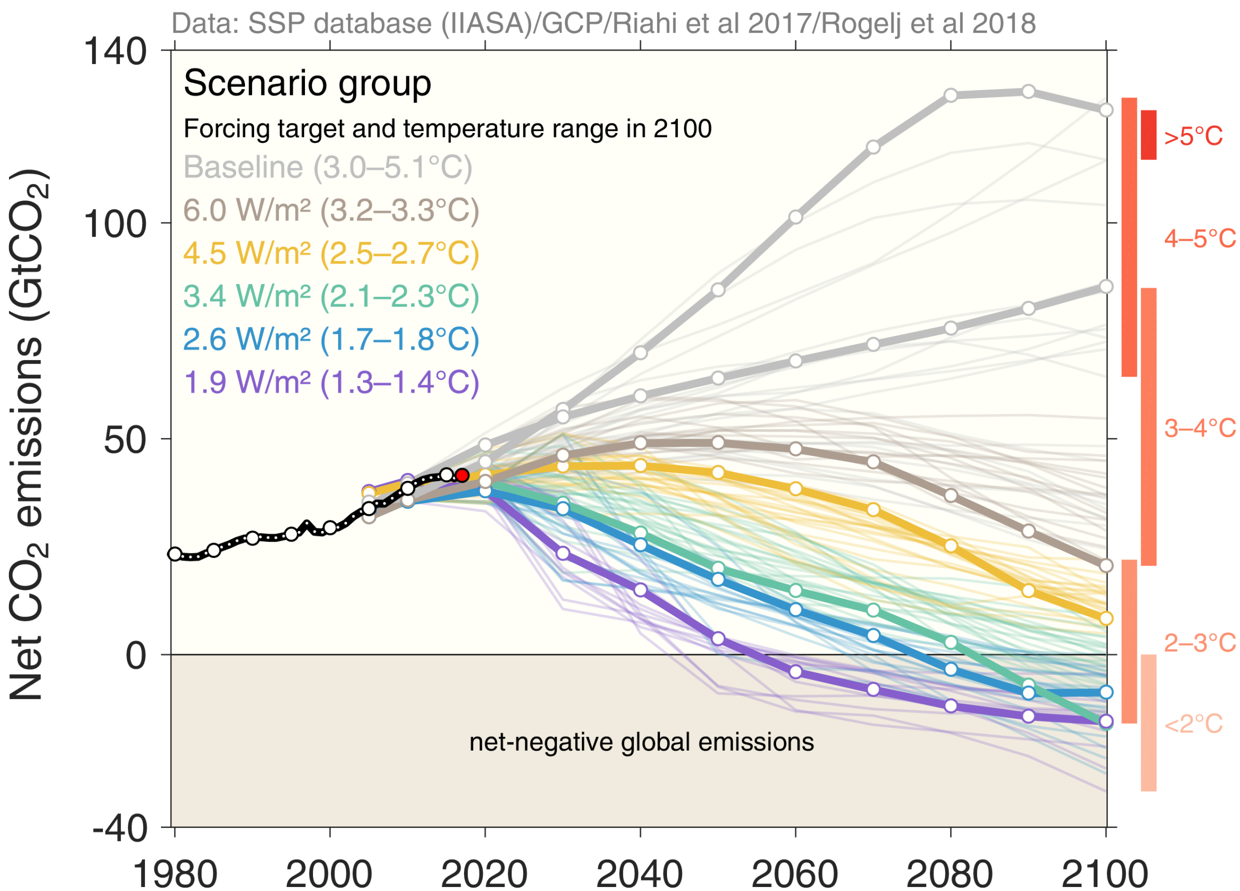
The Shared Socioeconomic Pathways (SSPs) are a set of five socioeconomic narratives that are used by Integrated Assessment Models to estimate potential future emission pathways



Marker Scenarios are in bold. Net emissions include those from land-use change and bioenergy with CCS.
Source: [Riahi et al. 2016](); [Rogelj et al. 2018](); [IIASA SSP Database](); [Global Carbon Budget 2018]()

Shared Socioeconomic Pathways (SSPs)

The Shared Socioeconomic Pathways (SSPs) lead to a broad range in baselines (grey), with more aggressive mitigation leading to lower temperature outcomes (grouped by colours)

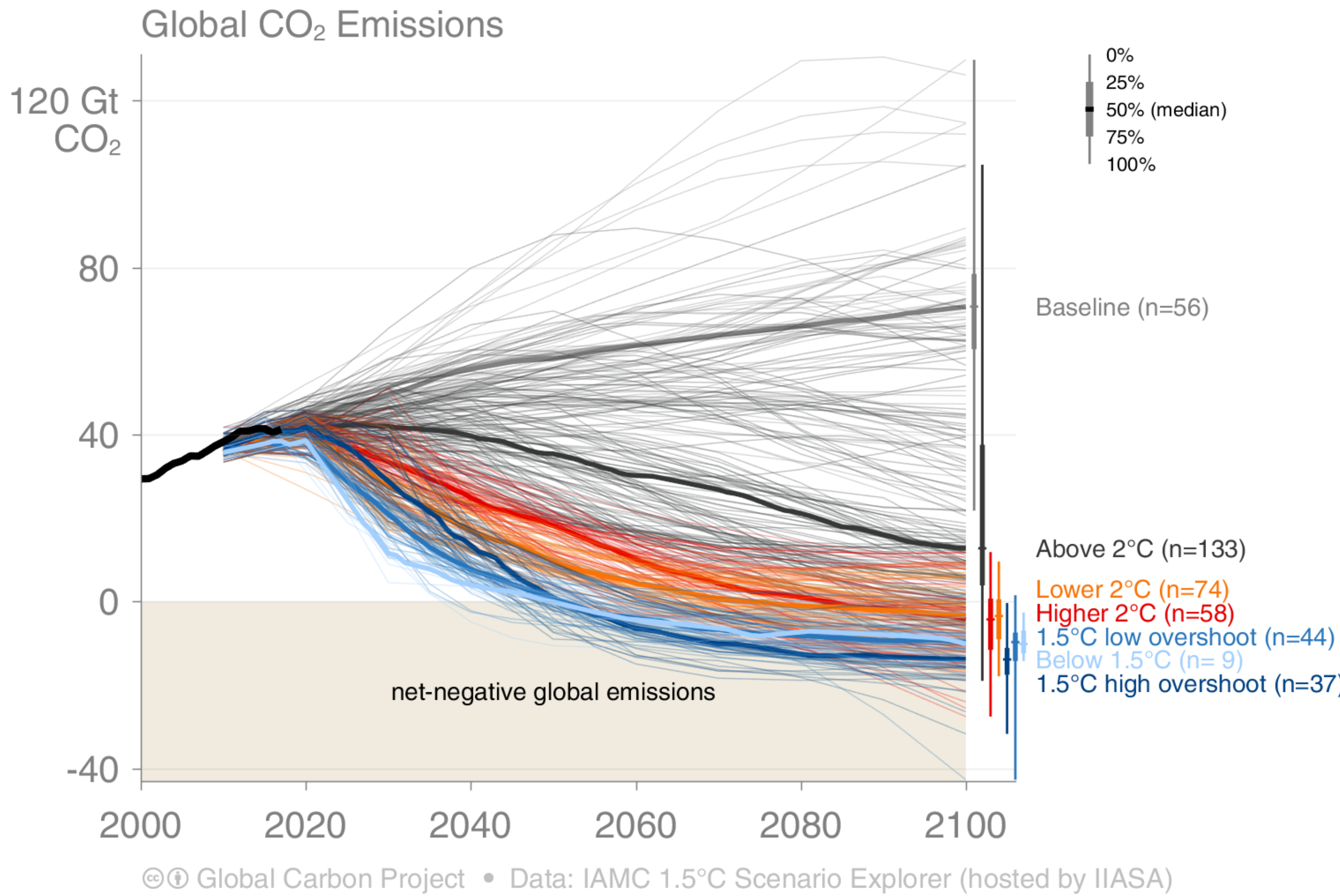


This set of quantified SSPs are based on the output of six Integrated Assessment Models (AIM/CGE, GCAM, IMAGE, MESSAGE, REMIND, WITCH). Net emissions include those from land-use change and bioenergy with CCS.

Source: Riahi et al. 2016; Rogelj et al. 2018; IIASA SSP Database; IAMC; Global Carbon Budget 2018

The IPCC Special Report on “Global Warming of 1.5°C”

The IPCC Special Report on “Global Warming of 1.5°C” presented new scenarios:
1.5°C scenarios require halving emissions by ~2030, net-zero by ~2050, and negative thereafter



Net emissions include those from land-use change and bioenergy with CCS.
Source: Huppmann et al 2018; IAMC 1.5C Scenario Database; IPCC SR15; Global Carbon Budget 2018

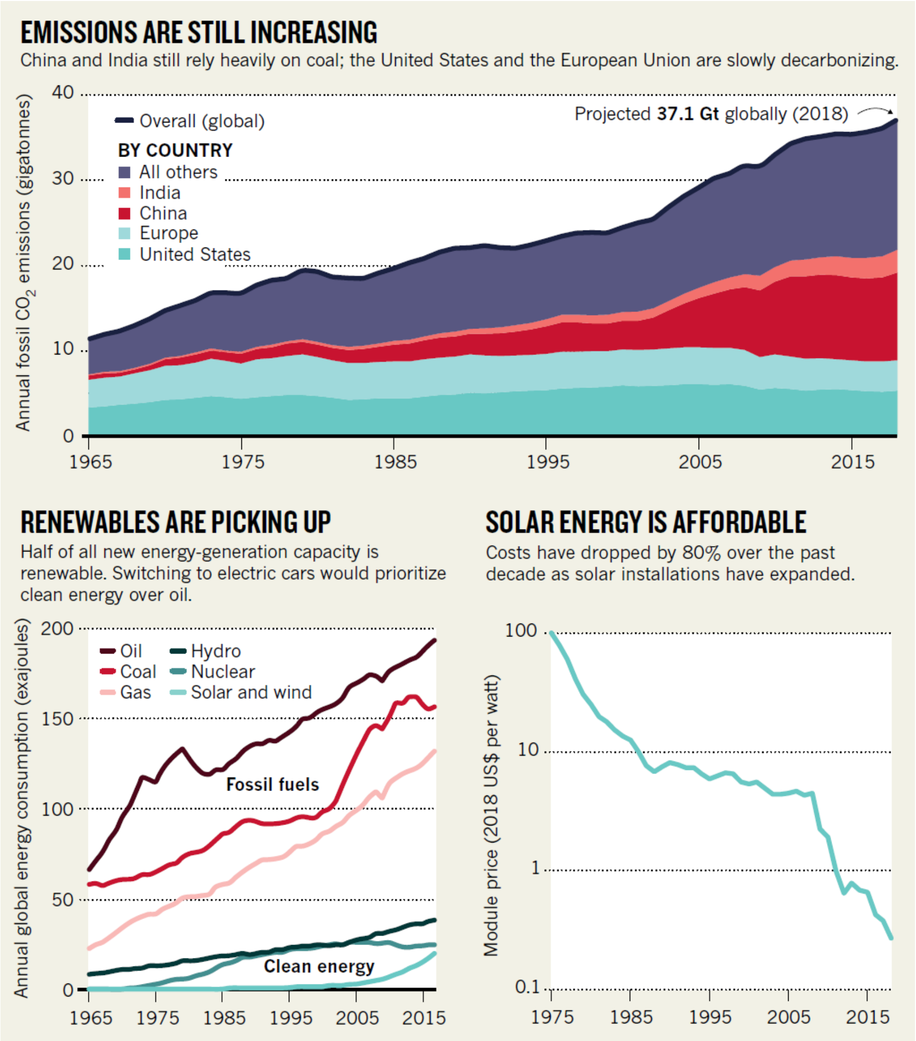
Nature commentary

Emissions are still rising: ramp up the cuts

With sources of renewable energy spreading fast, all sectors can do more to decarbonize the world, argue **Christiana Figueres** and colleagues.

Rising pressures

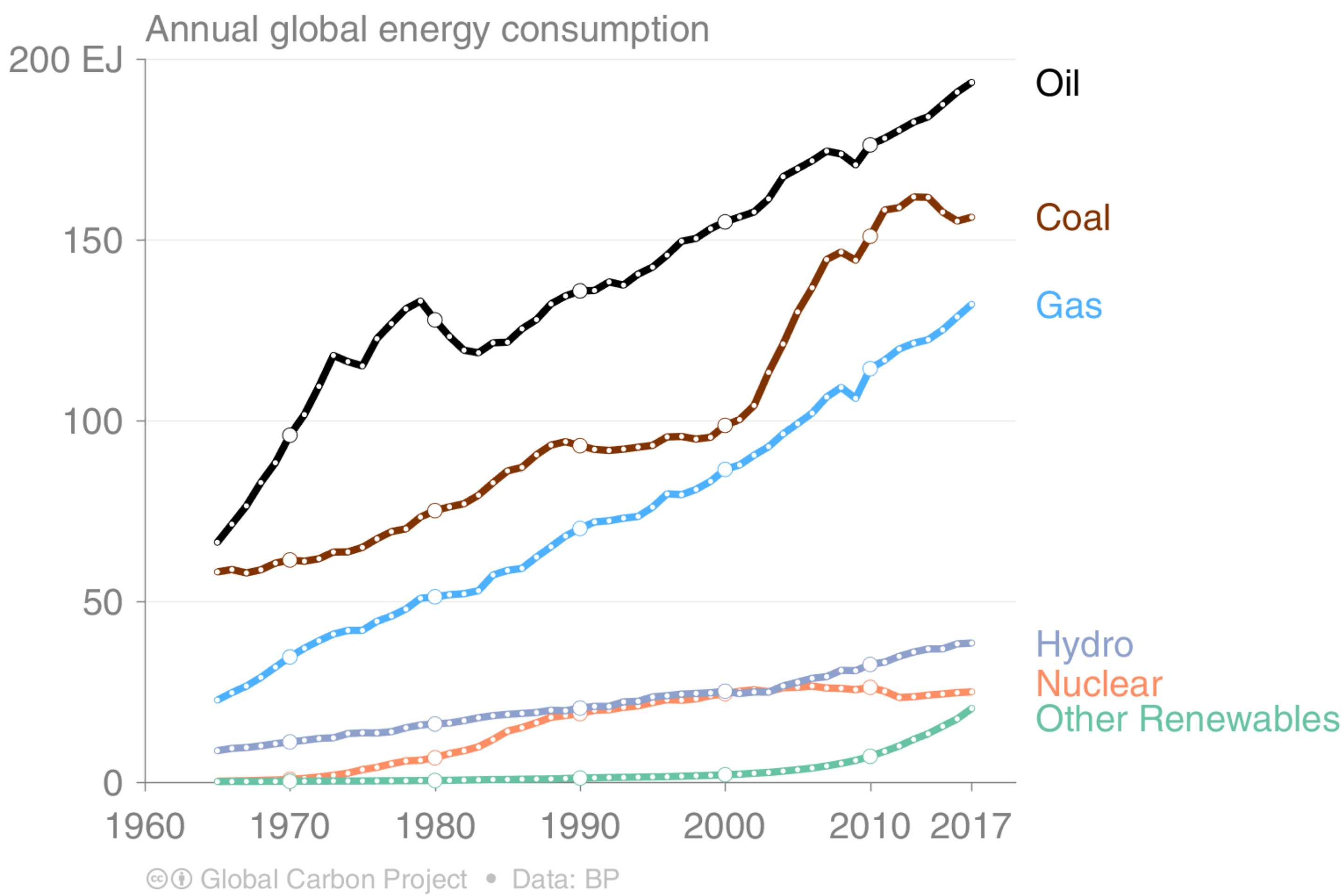
CO_2 emissions are growing after pausing for a few years. Clean energy sources are beginning to replace fossil fuels, as their costs become more competitive.



Source: [Figueres et al 2018](); [Global Carbon Budget 2018]()

Energy use by source

Renewable energy is growing exponentially, but this growth has so far been too low to offset the growth in fossil energy consumption.



This figure shows "primary energy" using the BP substitution method
(non-fossil sources are scaled up by an assumed fossil efficiency of 0.38)
Source: BP 2018; Figueres et al 2018; Global Carbon Budget 2018

Environmental Research Letters Commentary

Environmental Research Letters

EDITORIAL

Global energy growth is outpacing decarbonization

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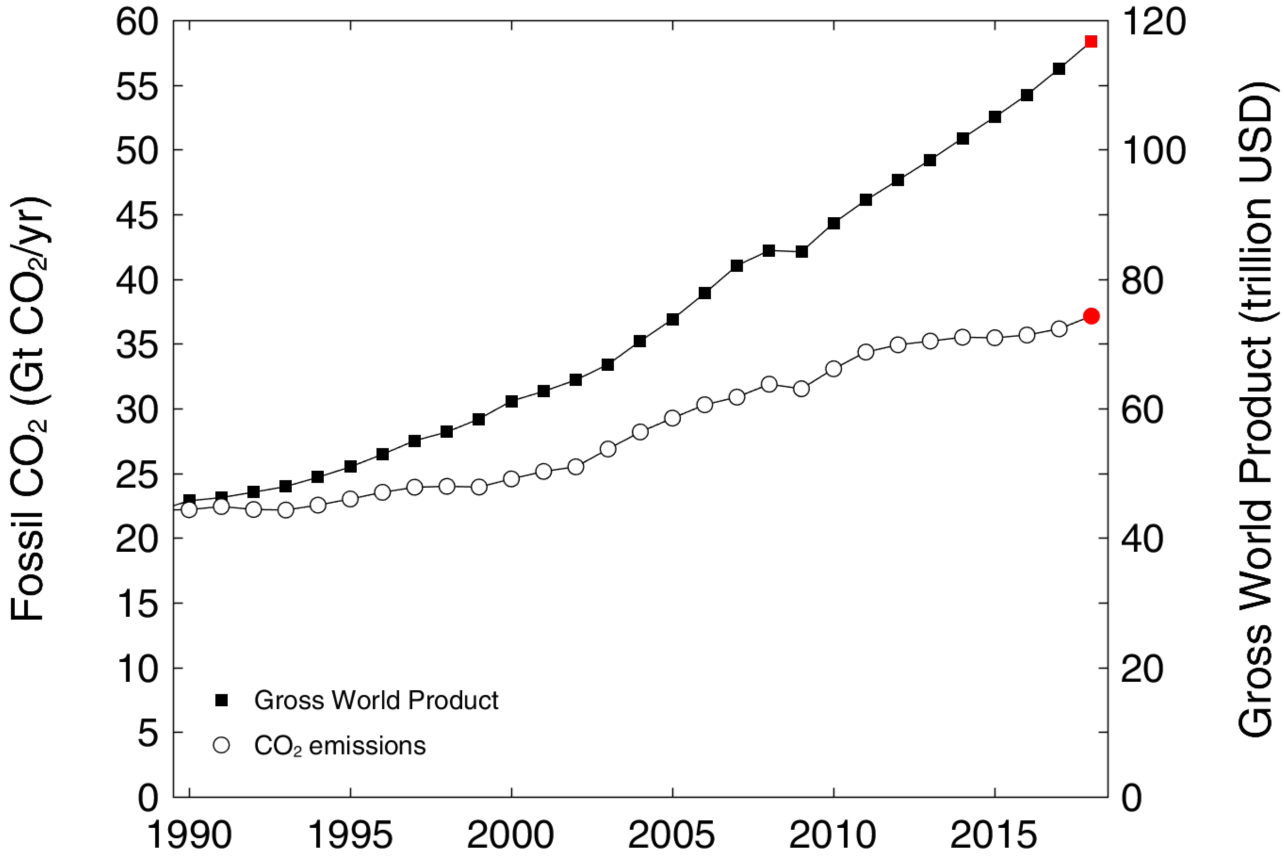
CO_2 emissions and economic activity

The global economy continues to grow faster than emissions. A step change is needed in emission intensity improvements to drive emissions down.

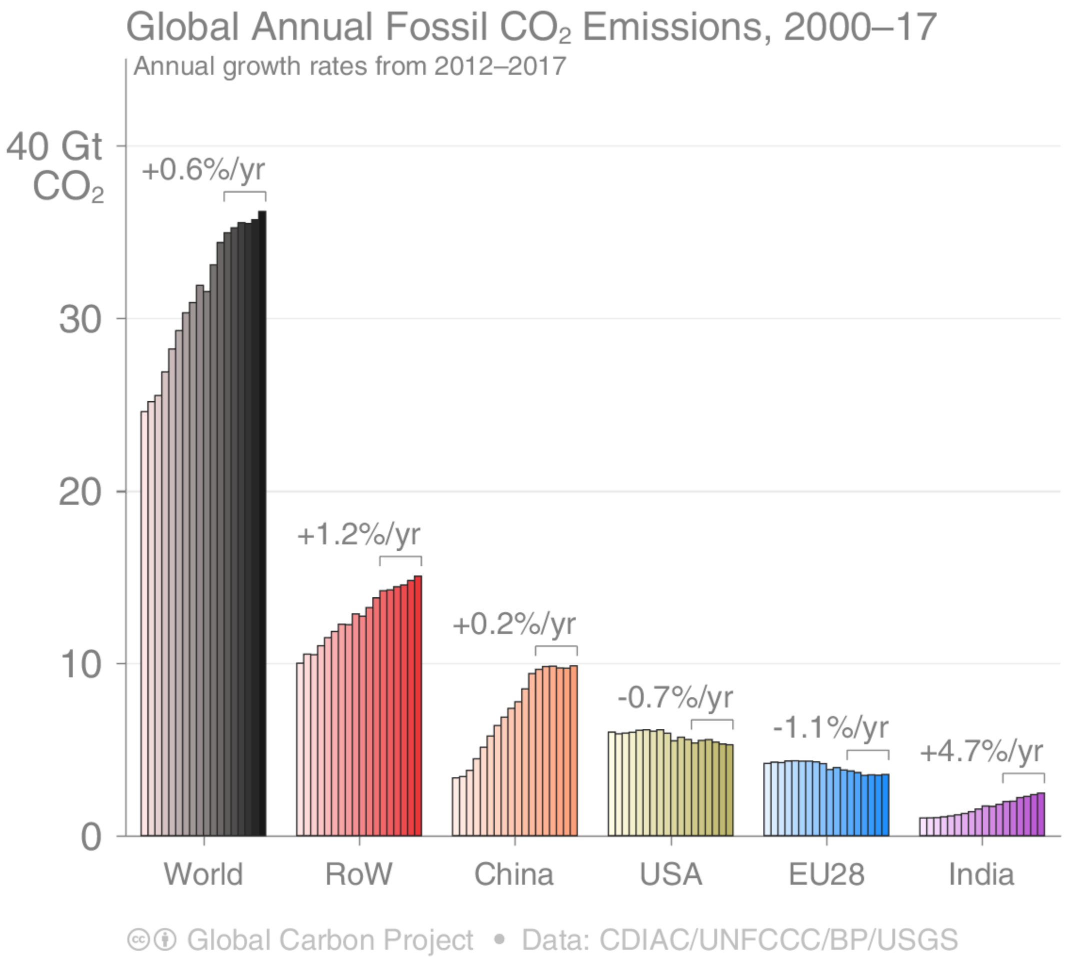


$CO_2 = CO_2$ intensity×GDP

Source: [Jackson et al 2018](); [Global Carbon Budget 2018]()

Top emitters: Fossil CO_2 Emissions

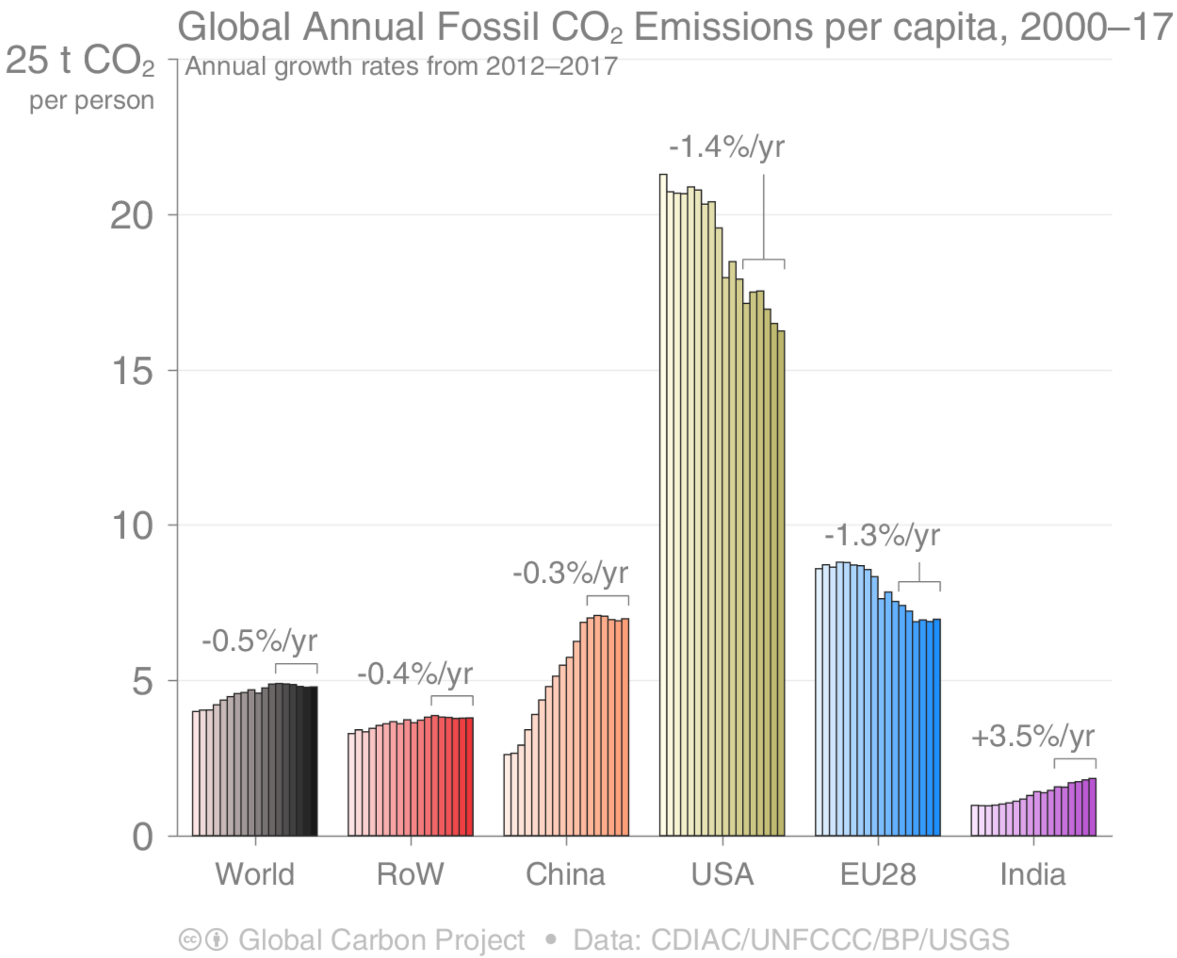
Emissions by country from 2000 to 2017, with the growth rates indicated for the more recent period of 2012 to 2017



Source: [CDIAC](); [Jackson et al 2018](); [Le Quéré et al 2018](); [Global Carbon Budget 2018]()

Per capita CO_2 emissions

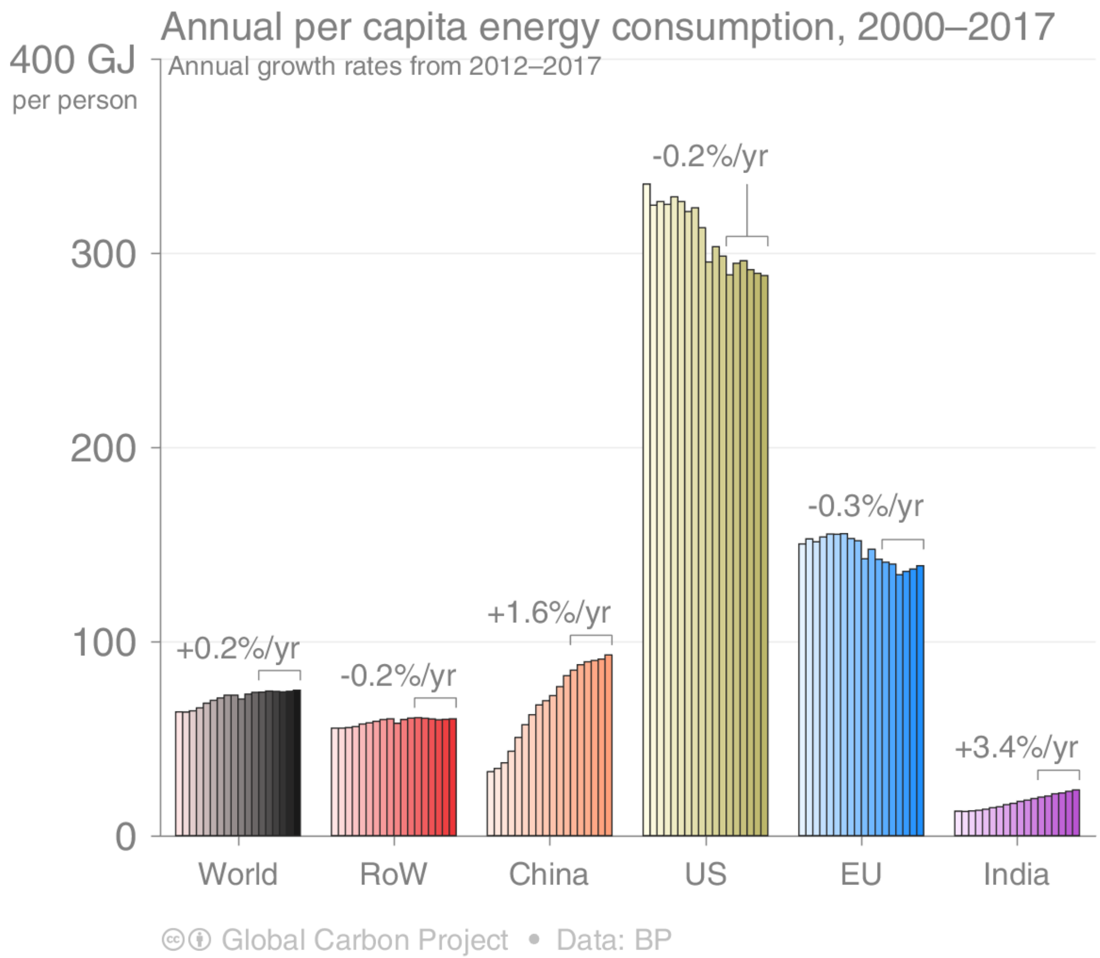
The US has high per capita emissions, but this has been declining steadily. China's per capita emissions have levelled out and is now the same as the EU. India's emissions are low per capita.



Source: [Jackson et al 2018](); [Global Carbon Budget 2018]()

Per capita energy use

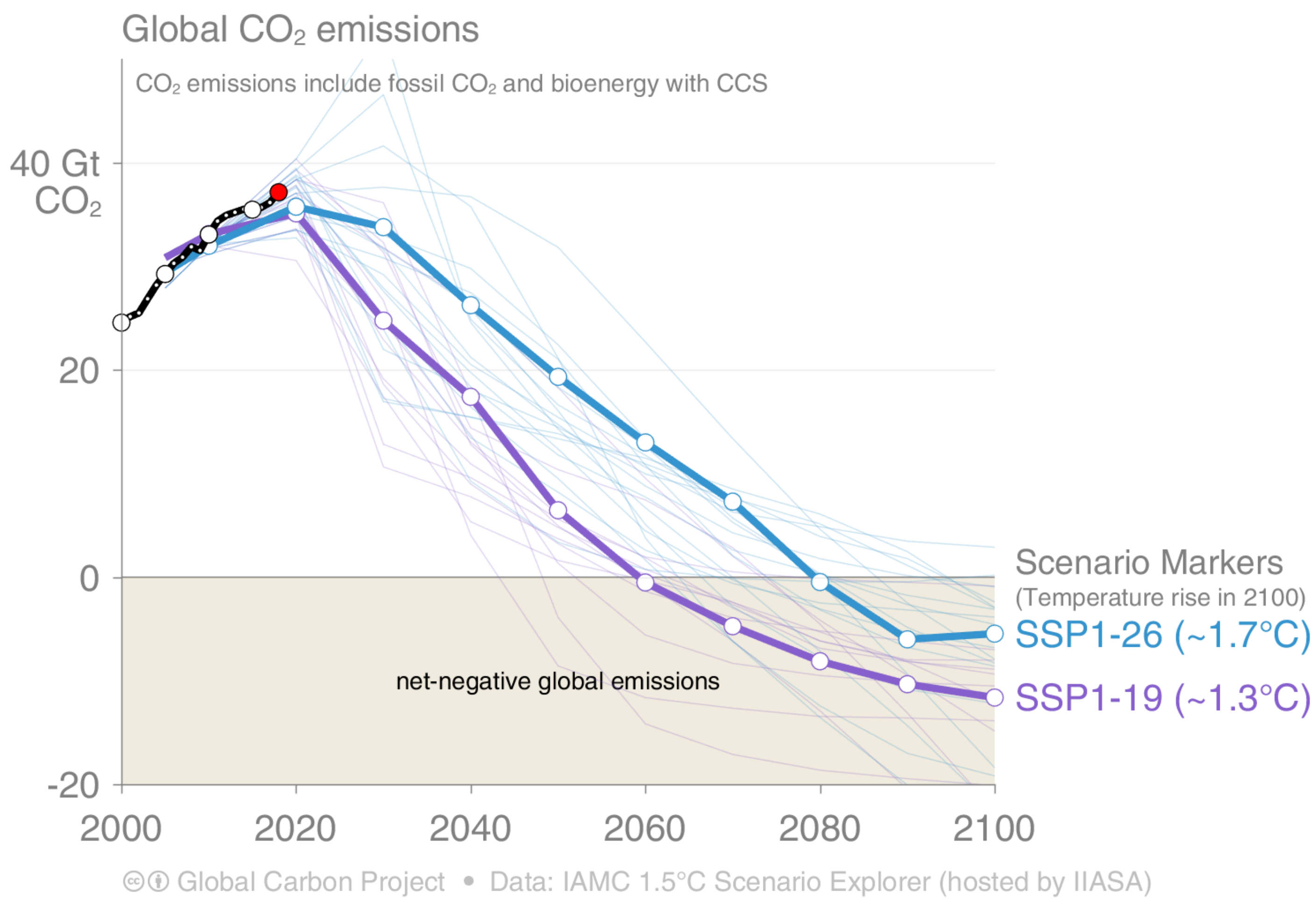
There are large differences in energy use per capita between countries, with some differences to emissions per capita due to differences in the country-level energy mix



Source: BP 2018; Jackson et al 2018; Global Carbon Budget 2018

Emissions must decline rapidly

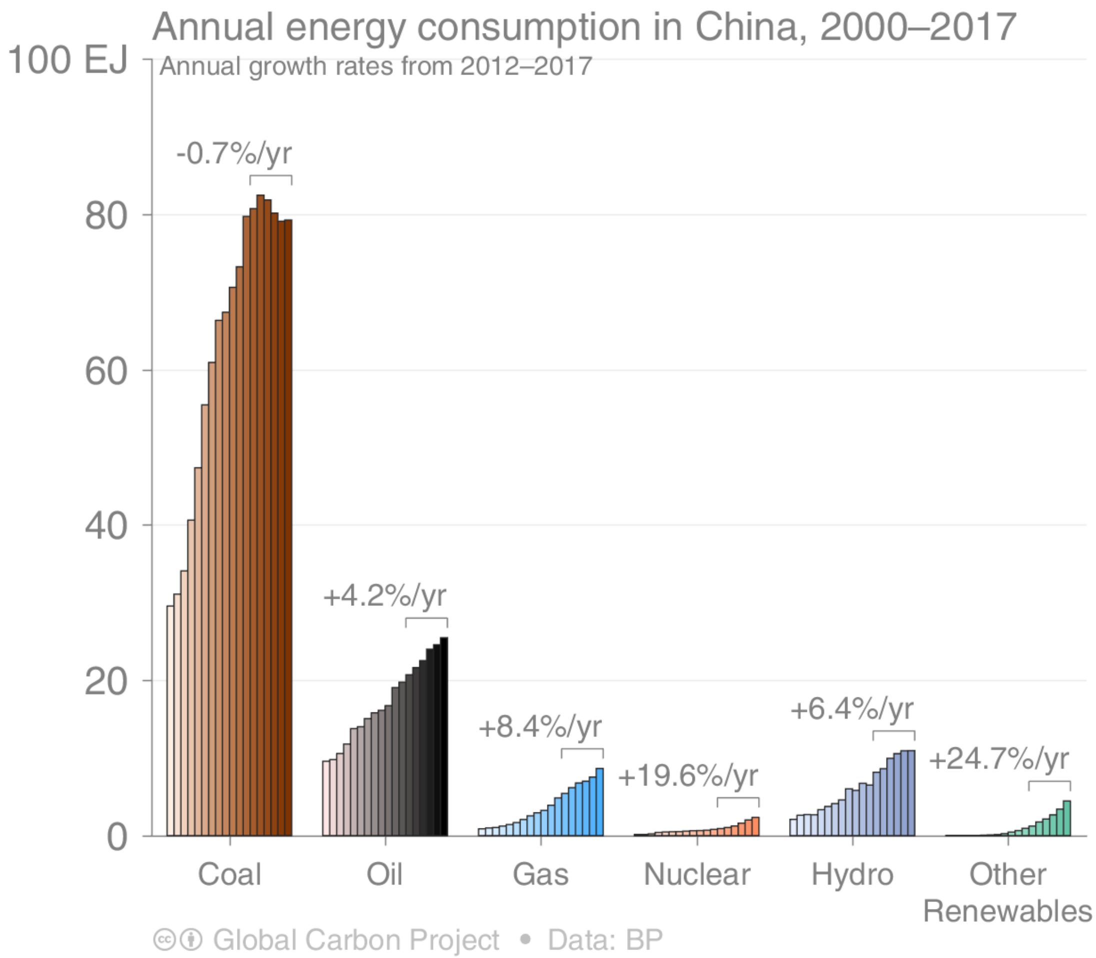
CO_2 emissions need to rapidly decline to follow pathways consistent with the Paris targets
(Projection for 2018 emissions in red)



Source: Huppmann et al 2018; IAMC 1.5C Scenario Database; IPCC SR15; Jackson et al 2018; Global Carbon Budget 2018

Energy use in China

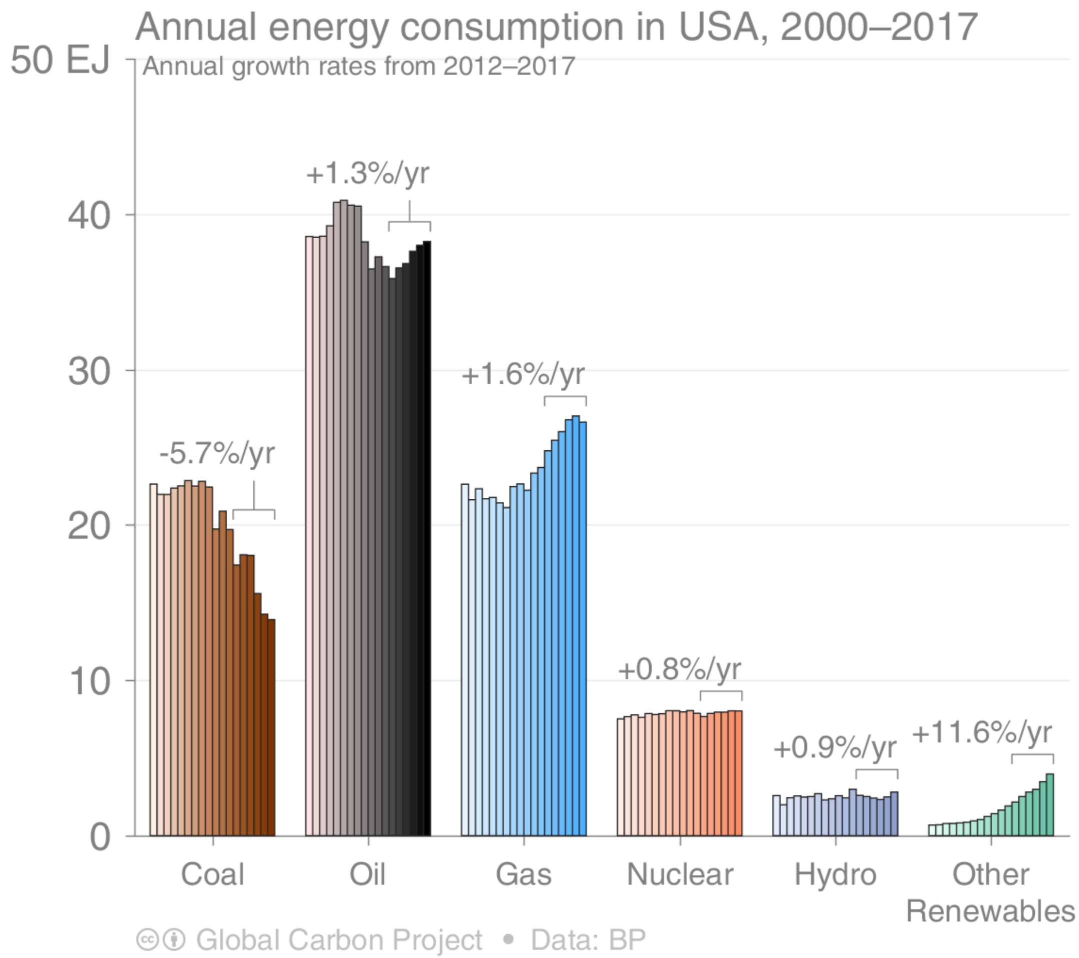
Coal consumption in energy units may have already peaked in China, while consumption of all other energy sources is growing strongly



Source: [BP 2018](); [Jackson et al 2018](); [Global Carbon Budget 2018]()

Energy use in USA

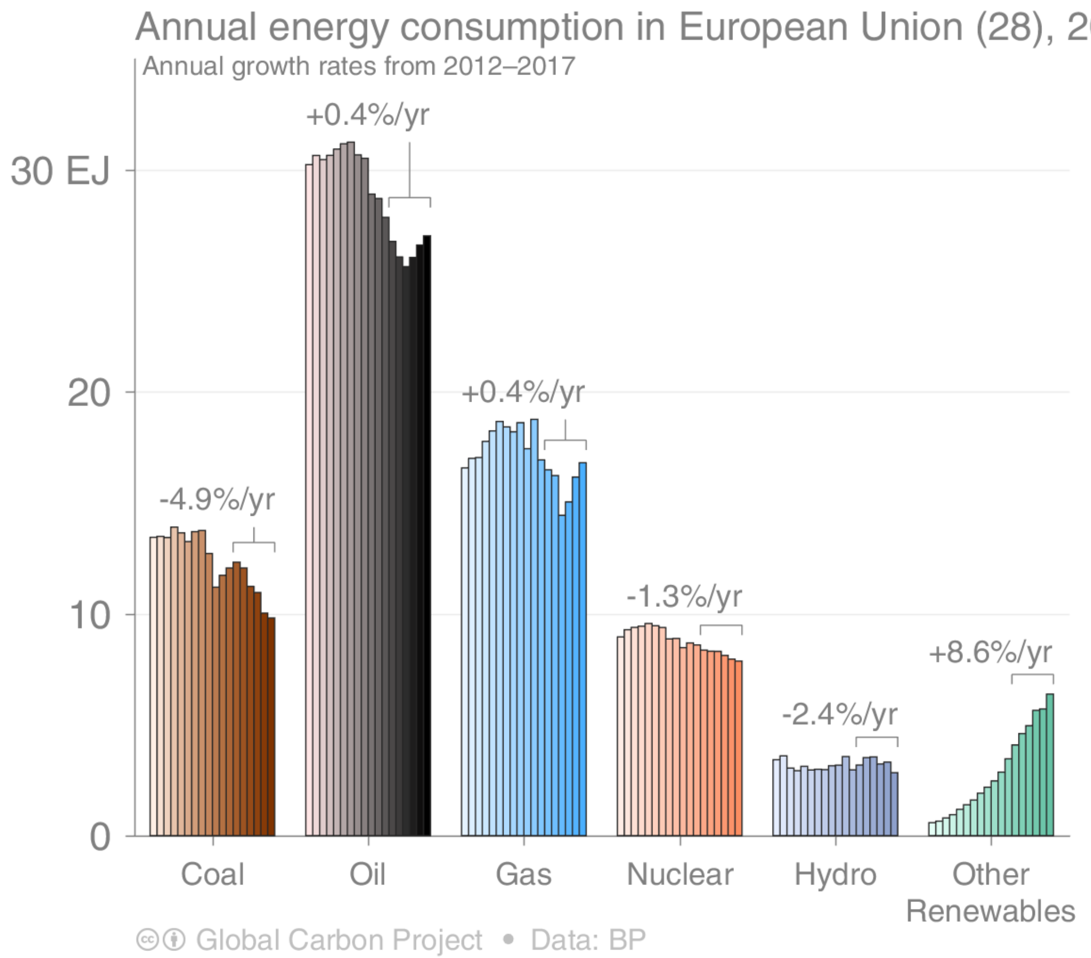
Coal consumption has declined sharply in recent years with the shale gas boom and strong renewables growth. Growth in oil consumption has resumed.



Source: [BP 2018](); [Jackson et al 2018](); [Global Carbon Budget 2018]()

Energy use in the European Union

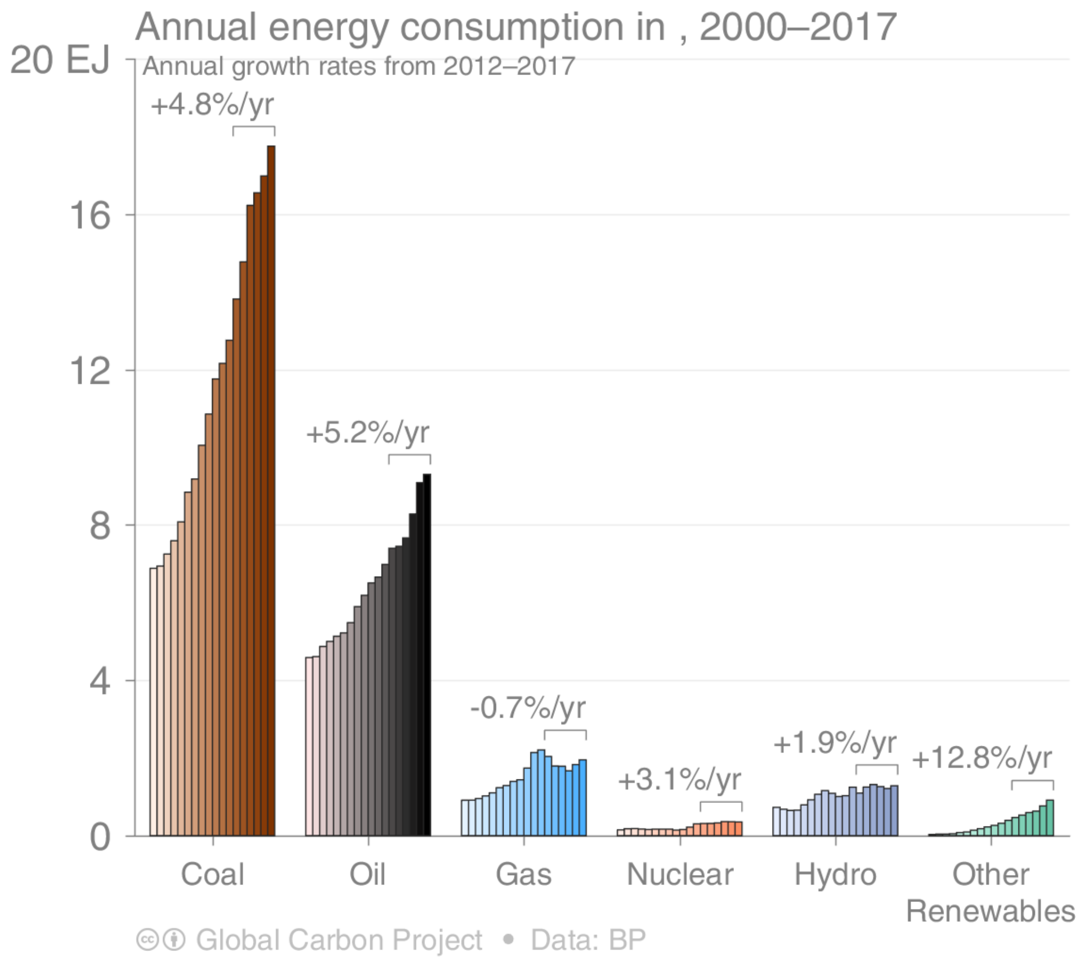
Consumption of both oil and gas has rebounded in recent years, while coal continues to decline. Renewables are growing strongly.



Source: [BP 2018](); [Jackson et al 2018](); [Global Carbon Budget 2018]()

Energy use in India

Consumption of coal and oil in India is growing very strongly, as are renewables, albeit from a lower base.



Source: [BP 2018]; [Jackson et al 2018]; [Global Carbon Budget 2018]

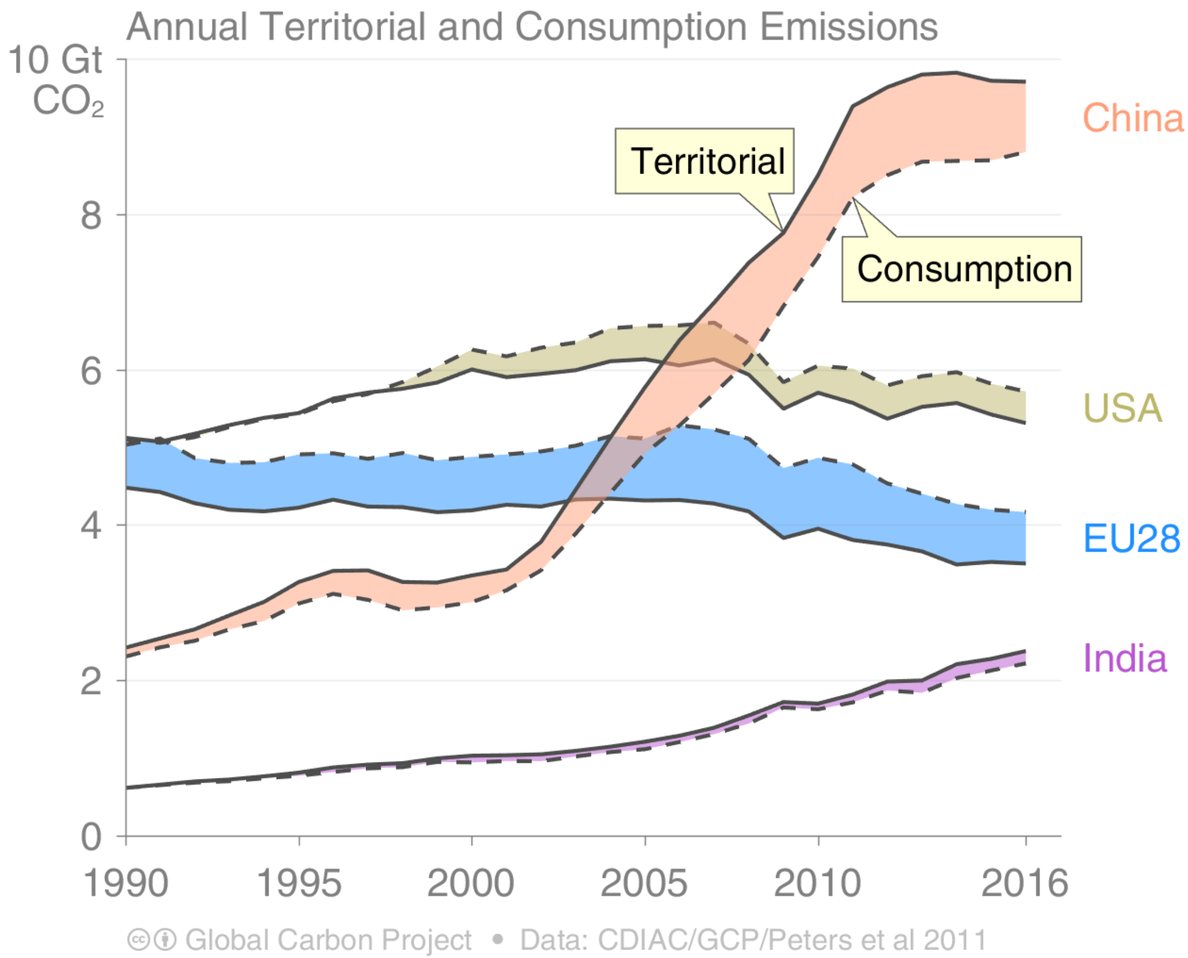
Consumption-based Emissions

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 EU28 are net importers of embodied emissions, China and India are net exporters.

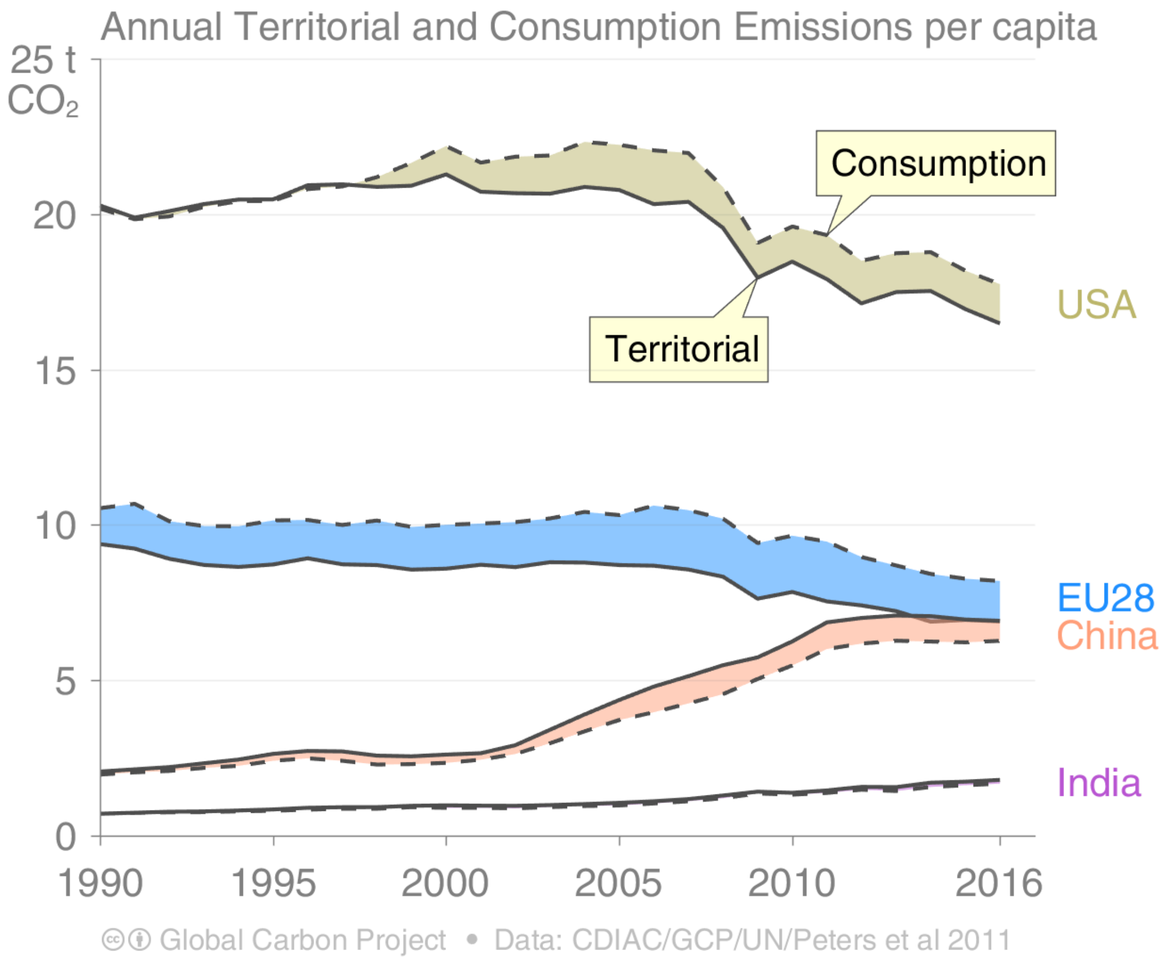


Consumption-based emissions are calculated by adjusting the standard production-based emissions to account for international trade

Source: [Peters et al 2011]; [Le Quéré et al 2018]; [Global Carbon Project 2018]

Consumption-based emissions per person

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

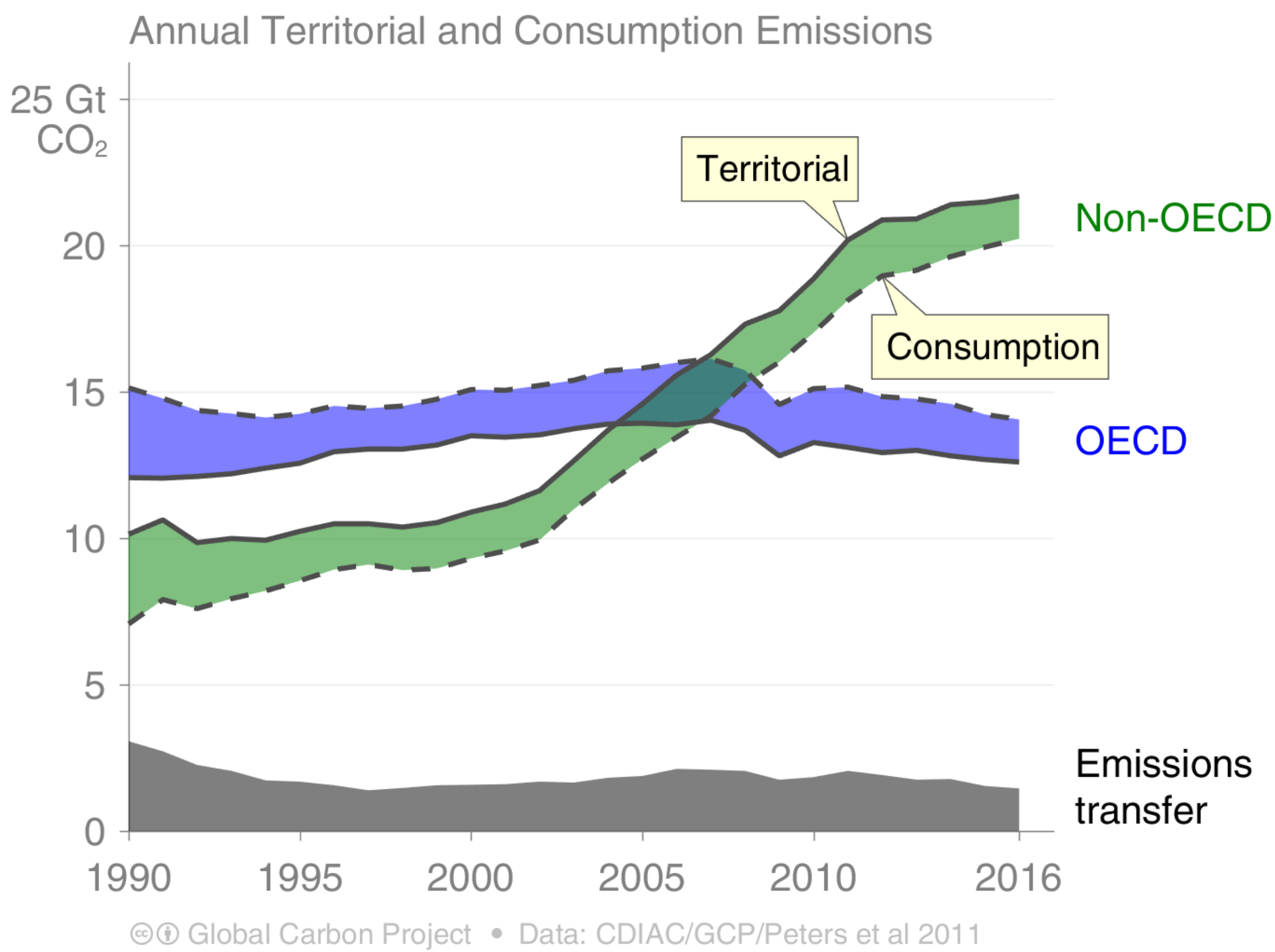


Consumption-based emissions are calculated by adjusting the standard production-based emissions to account for international trade

Source: [Peters et al 2011](); [Le Quéré et al 2018](); [Global Carbon Project 2018]()

Consumption-based emissions (carbon footprint)

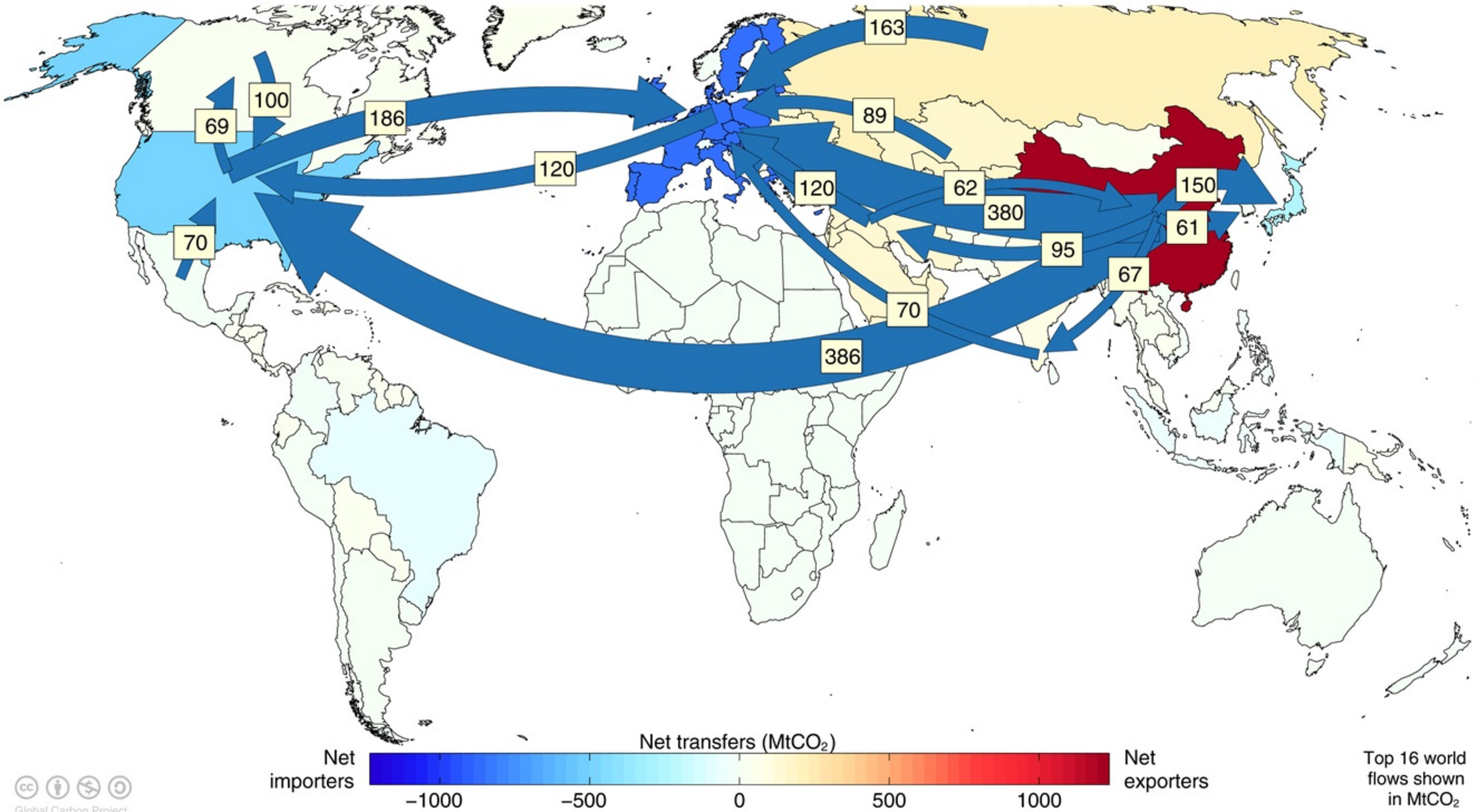
Transfers of emissions embodied in trade between OECD and non-OECD countries grew slowly during the 2000's, but has since slowly declined.



Source: [CDIAC](); [Peters et al 2011](); [Le Quéré et al 2018](); [Global Carbon Budget 2018]()

Major flows from production to consumption

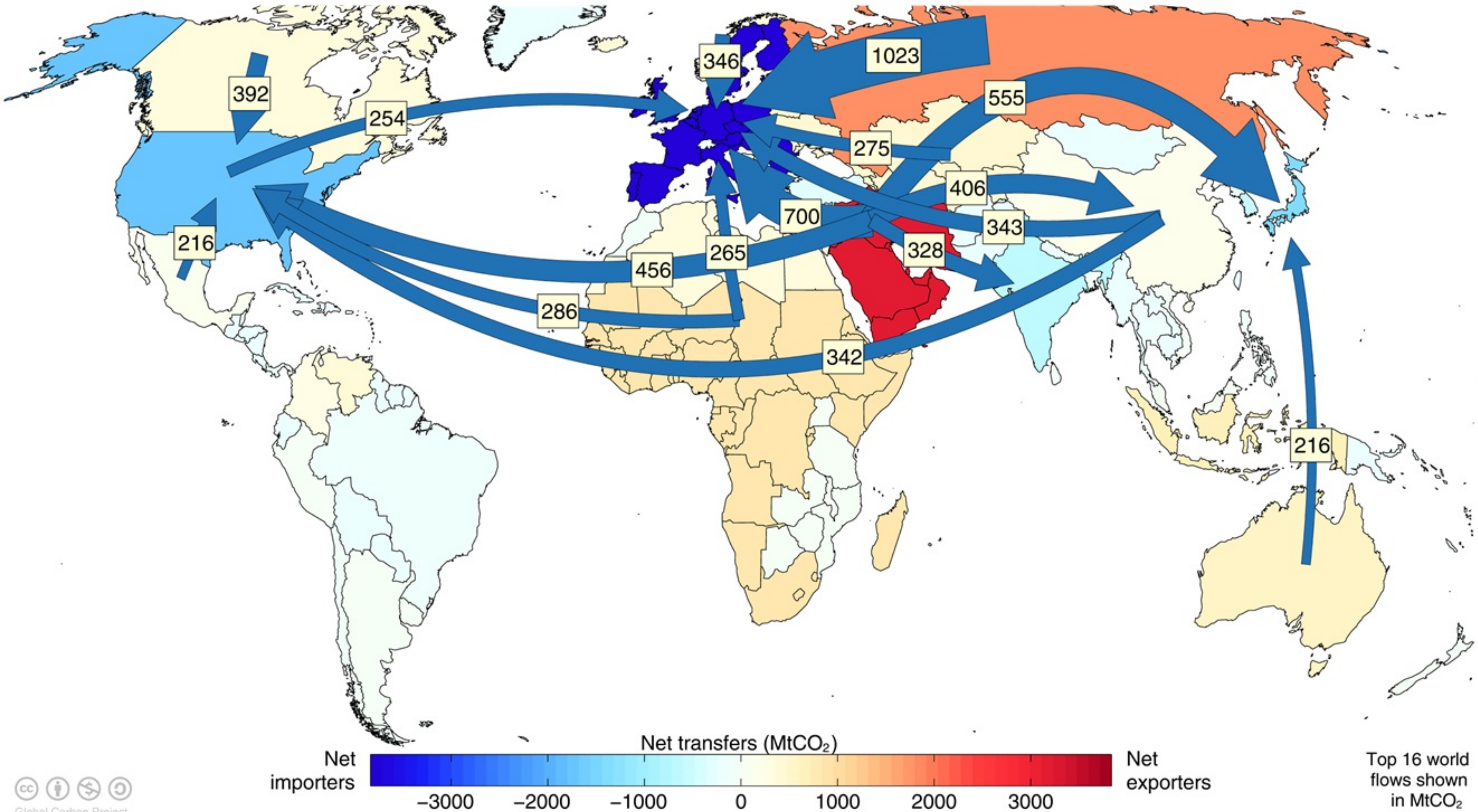
Flows from location of generation of emissions to location of consumption of goods and services



Values for 2011. EU is treated as one region. Units: $MtCO_2$
Source: Peters et al 2012

Major flows from extraction to consumption

Flows from location of fossil fuel extraction to location of consumption of goods and services



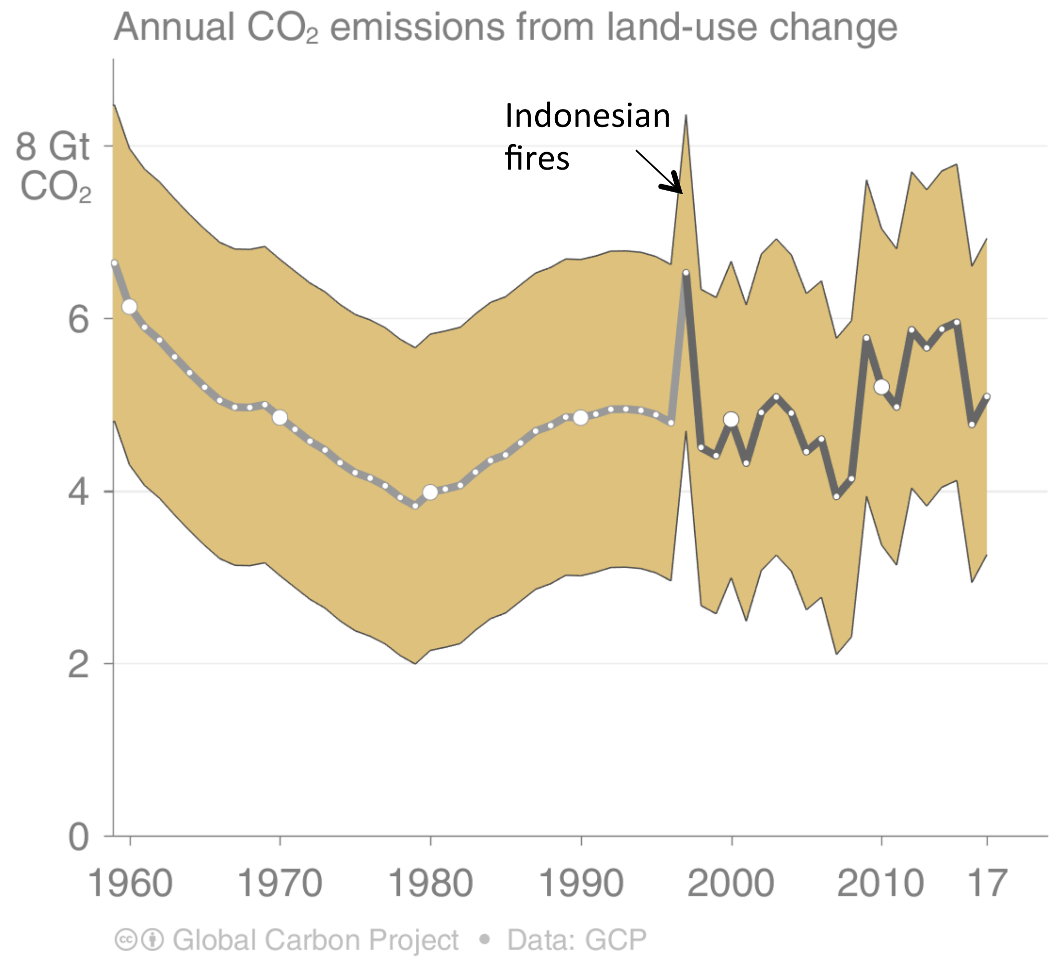
Values for 2011. EU is treated as one region. Units: $MtCO_2$

Source: [Andrew et al 2013]

Land-use Change Emissions

Land-use change emissions

Land-use change emissions are highly uncertain, with no clear trend in the last decade.

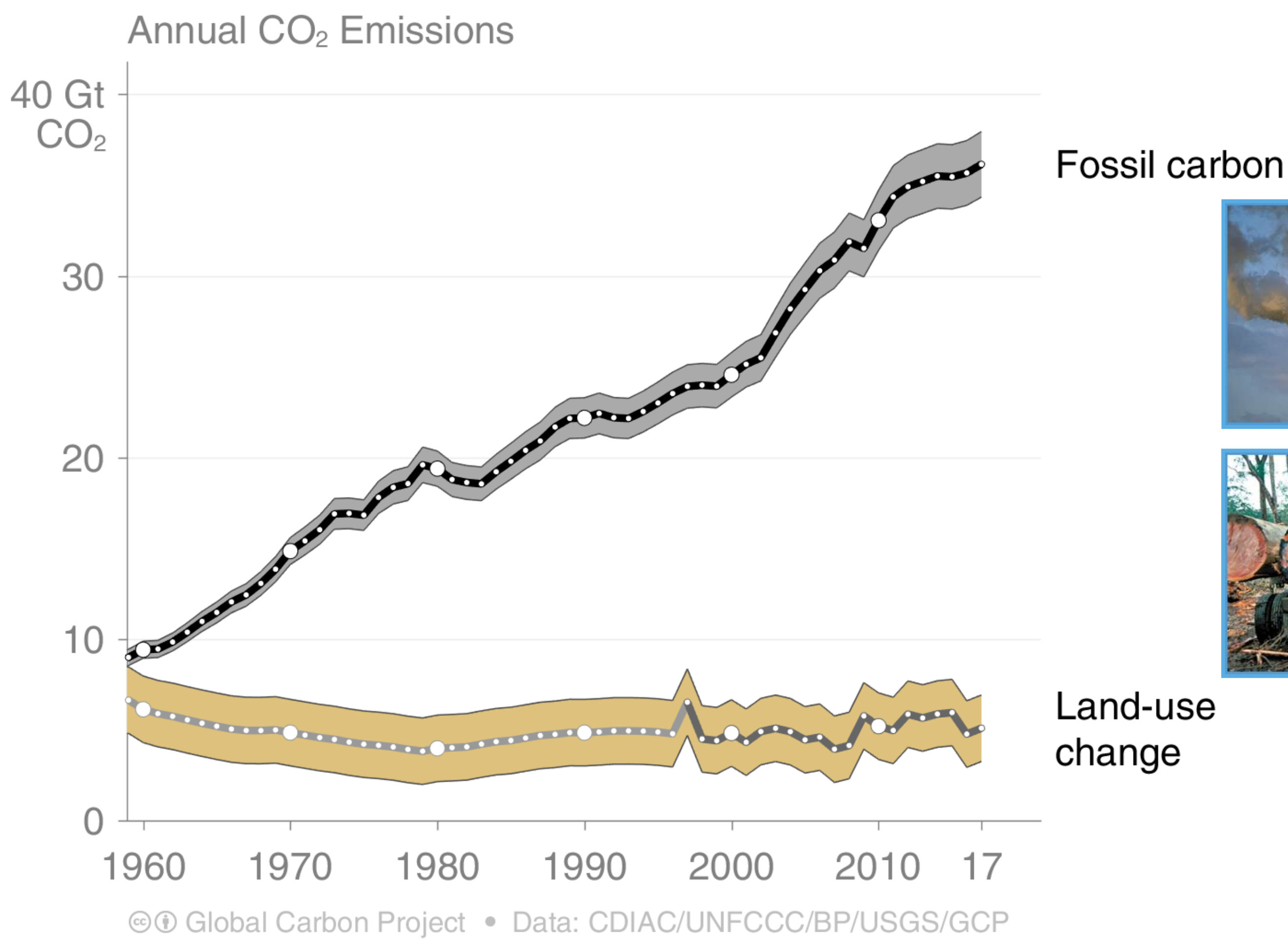


Estimates from two bookkeeping models, using fire-based variability from 1997

Source: Houghton and Nassikas 2017; Hansis et al 2015; van der Werf et al. 2017; Le Quéré et al 2018; Global Carbon Budget 2018

Total global emissions

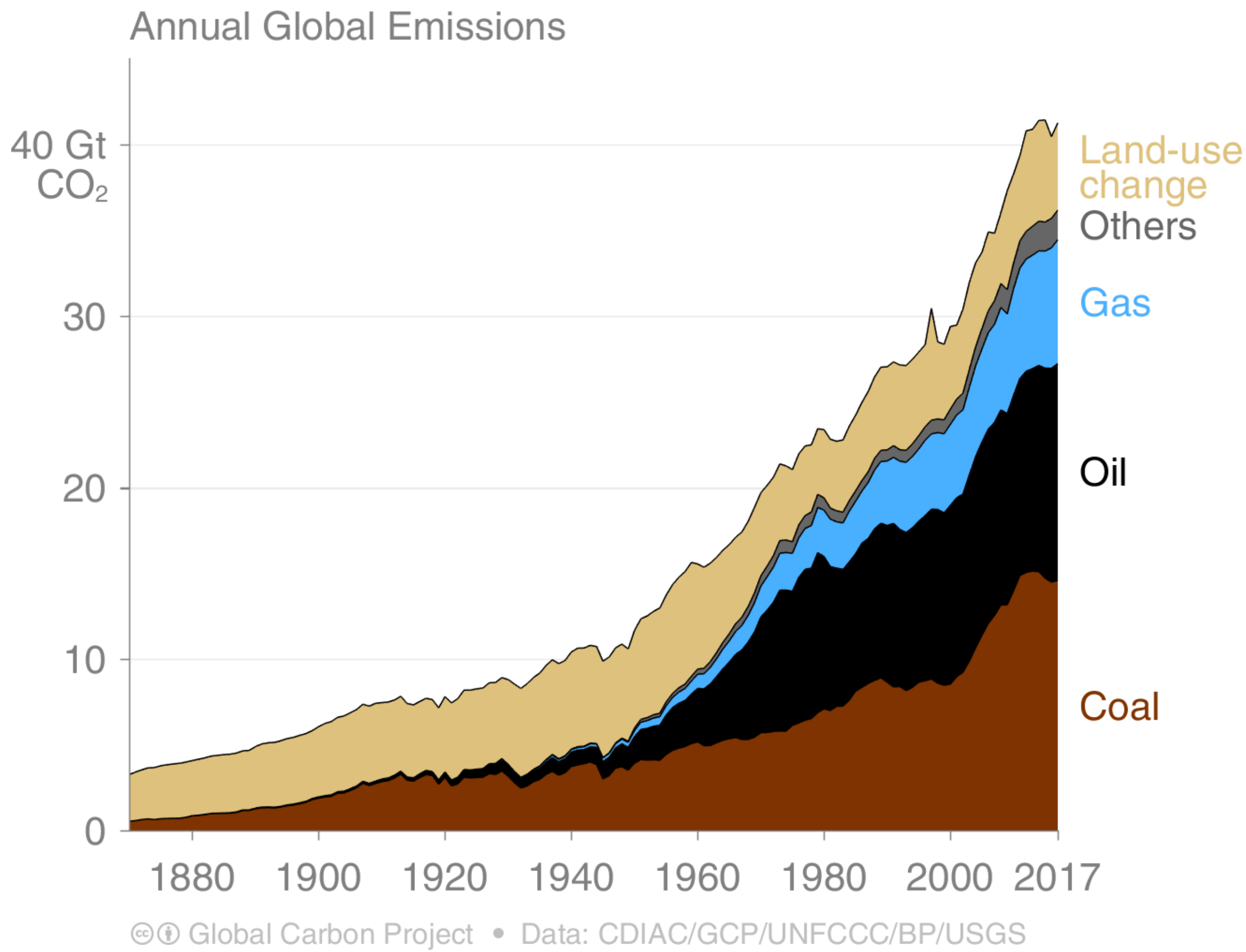
Total global emissions: 41.2 ± 2.8 $GtCO_2$ in 2017, 53% over 1990
Percentage land-use change: 43% in 1960, 13% averaged 2008–2017



Land-use change estimates from two bookkeeping models, using fire-based variability from 1997
Source: CDIAC; Houghton and Nassikas 2017; Hansis et al 2015; van der Werf et al. 2017; Le Quéré et al 2018; Global Carbon Budget 2018

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.

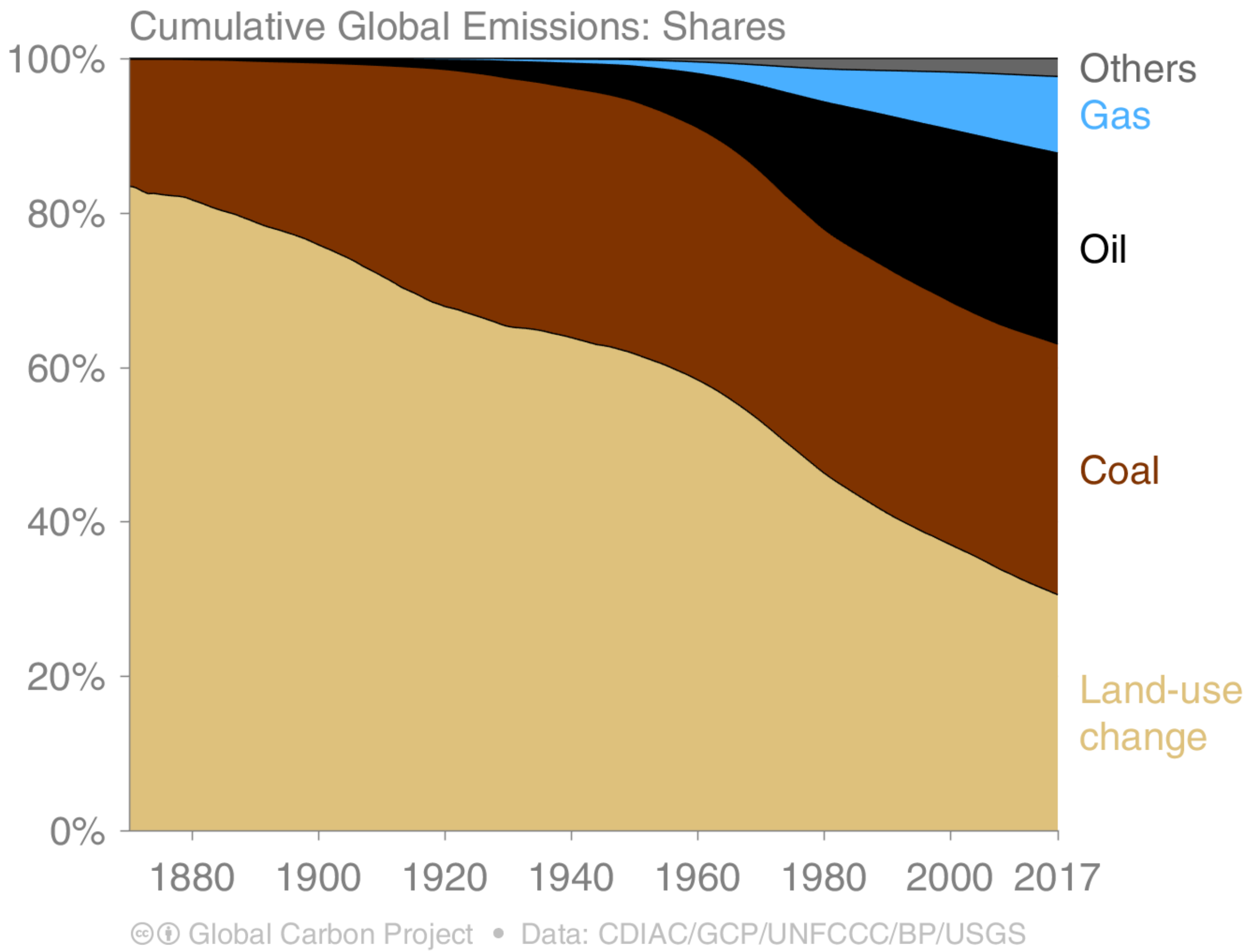


Others: Emissions from cement production and gas flaring

Source: CDIAC; Houghton and Nassikas 2017; Hansis et al 2015; Le Quéré et al 2018; Global Carbon Budget 2018

Historical cumulative emissions by source

Land-use change represents about 31% of cumulative emissions over 1870–2017, coal 32%, oil 25%, gas 10%, and others 2%



Others: Emissions from cement production and gas flaring

Source: [CDIAC]; [Houghton and Nassikas 2017]; [Hansis et al 2015]; [Le Quéré et al 2018]; [Global Carbon Budget 2018]

Closing the Global Carbon Budget

Fate of anthropogenic CO_2 emissions (2008–2017)

Sources = Sinks

34.4 $GtCO_2$/yr
87%

13%
5.3 $GtCO_2$/yr

17.3 $GtCO_2$/yr
44%

29%
11.6 $GtCO_2$/yr

22%
8.9 $GtCO_2$/yr

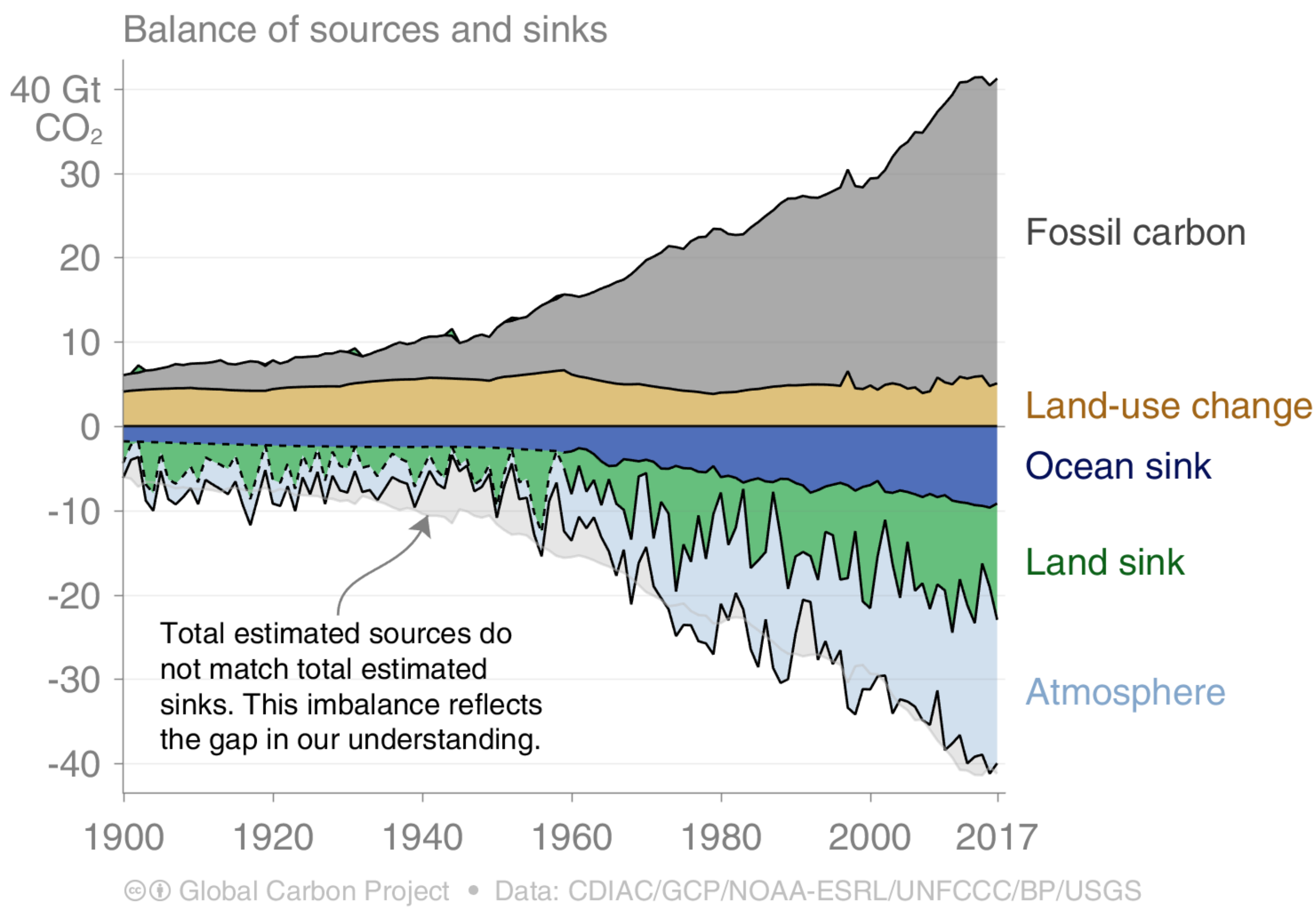
Budget Imbalance:
(the difference between estimated sources & sinks)

5%
1.9 $GtCO_2$/yr

Source: CDIAC; NOAA-ESRL; Houghton and Nassikas 2017; Hansis et al 2015; Le Quéré et al 2018; Global Carbon Budget 2018

Global carbon budget

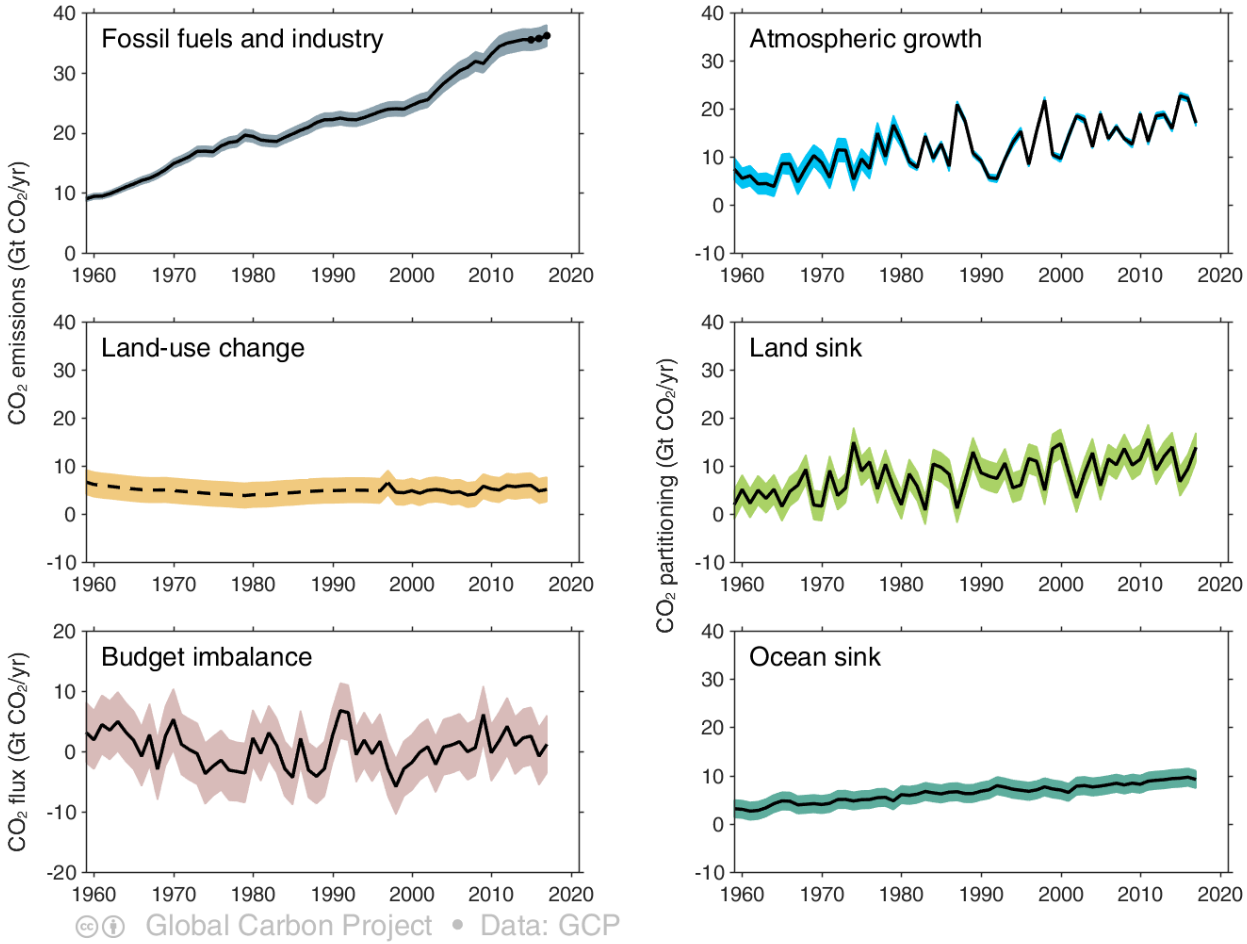
Carbon emissions are partitioned among the atmosphere and carbon sinks on land and in the ocean
The “imbalance” between total emissions and total sinks reflects the gap in our understanding



Source: CDIAC; NOAA-ESRL; Houghton and Nassikas 2017; Hansis et al 2015; Joos et al 2013; Khatiwala et al. 2013; DeVries 2014; Le Quéré et al 2018; Global Carbon Budget 2018

Changes in the budget over time

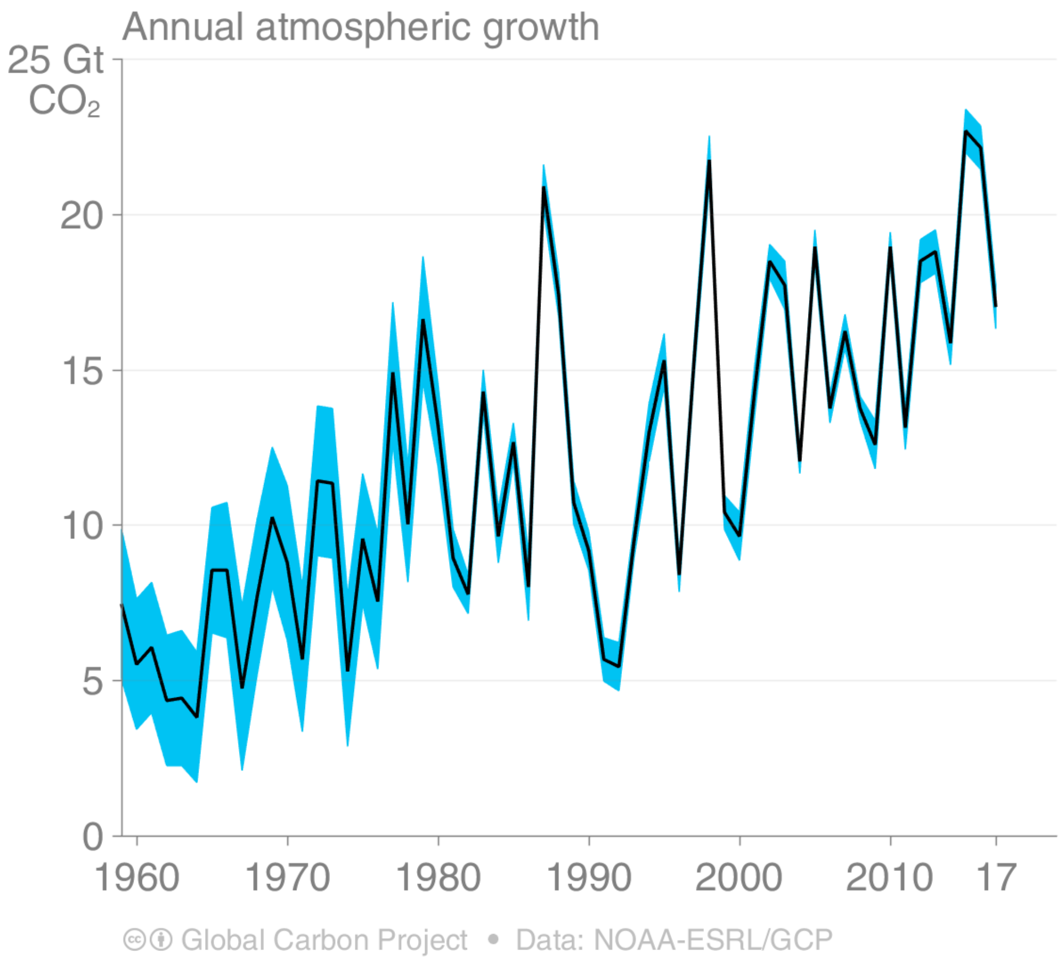
The sinks have continued to grow with increasing emissions, but climate change will affect carbon cycle processes in a way that will exacerbate the increase of CO_2 in the atmosphere



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: CDIAC; NOAA-ESRL; Houghton and Nassikas 2017; Hansis et al 2015; Le Quéré et al 2018; Global Carbon Budget 2018

Atmospheric concentration

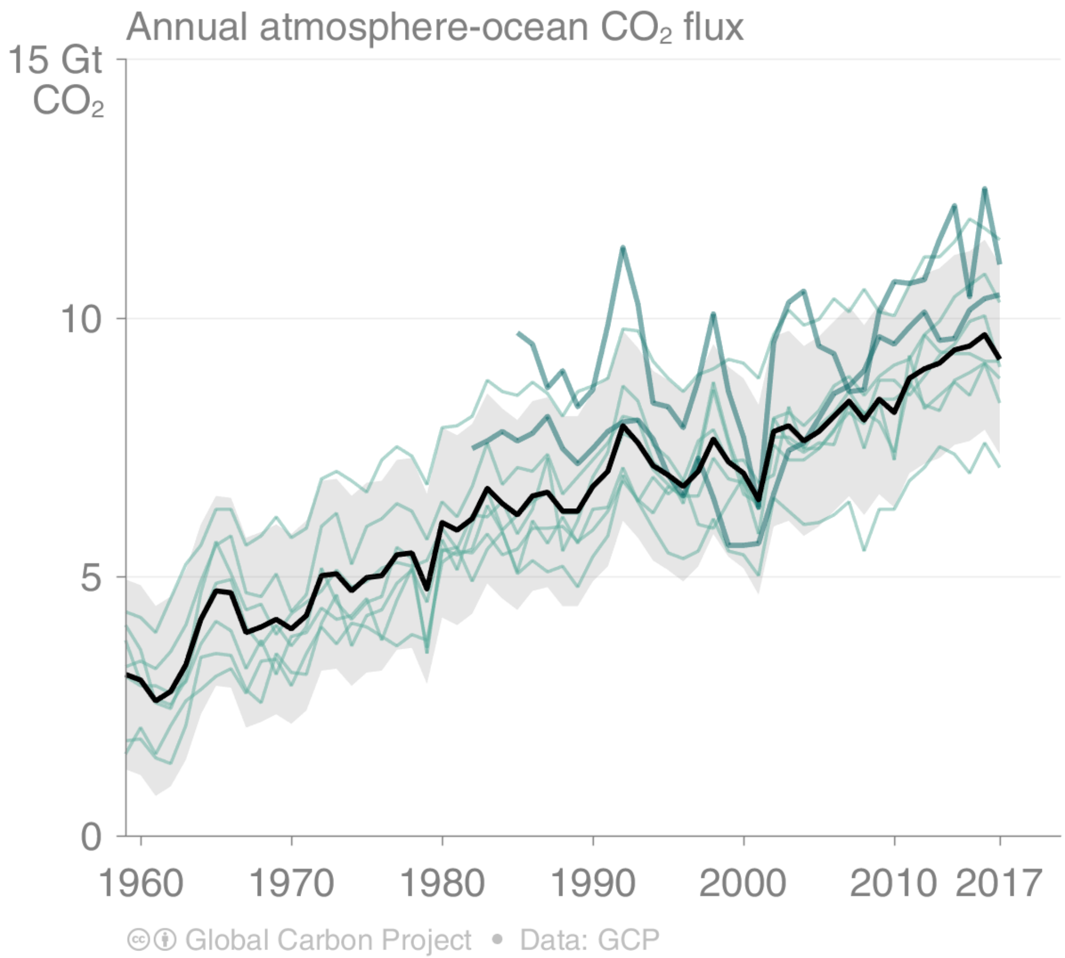
The atmospheric concentration growth rate has shown a steady increase
The high growth in 1987, 1998, & 2015–16 reflect a strong El Niño, which weakens the land sink



Source: [NOAA-ESRL](); [Global Carbon Budget 2018]()

Ocean sink

The ocean carbon sink continues to increase
8.9±2 $GtCO_2$/yr for 2008–2017 and 9.2±2 $GtCO_2$/yr in 2017

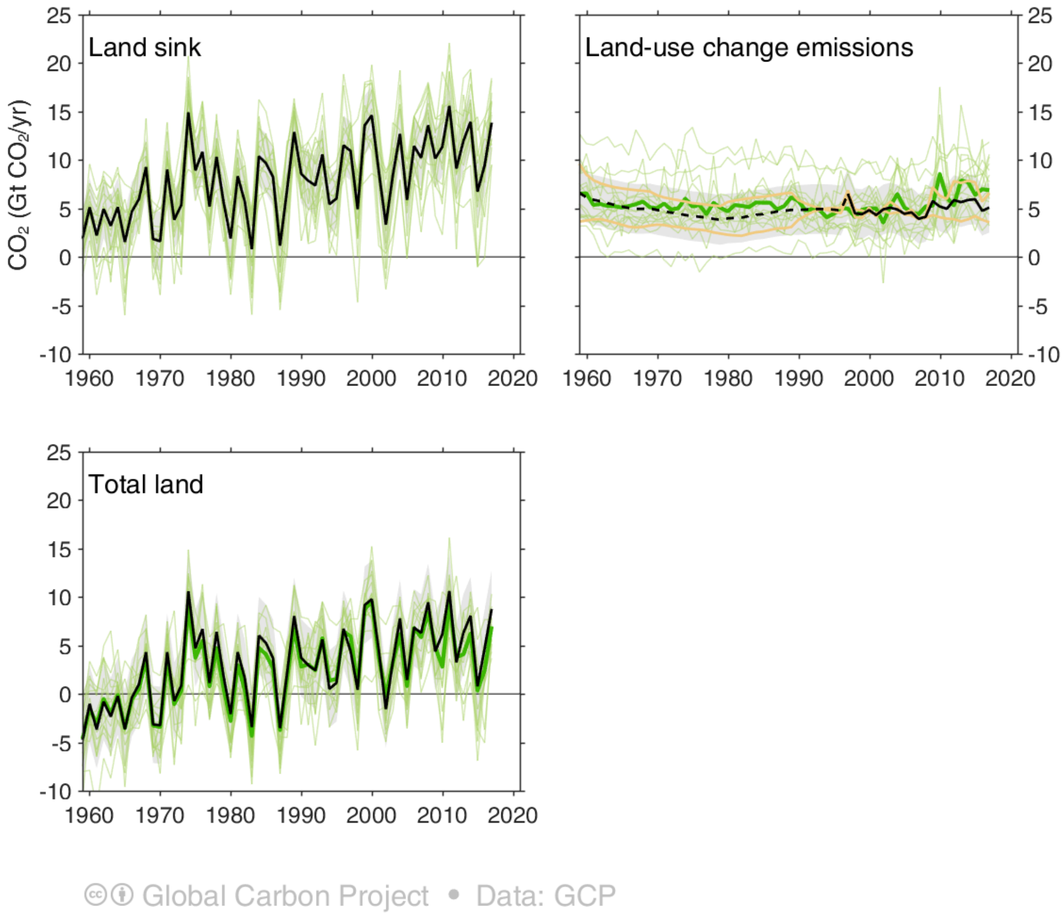


Source: SOCATv6; Bakker et al 2016; Le Quéré et al 2018; Global Carbon Budget 2018

Individual estimates from: Aumont and Bopp (2006); Berthet et al. (2018); Buitenhuis et al. (2010); Doney et al. (2009); Hauck et al. (2016); Landschützer et al. (2016); Mauritsen et al. (2018); Rödenbeck et al. (2014); Schwinger et al. (2016). Full references provided in Le Quéré et al. (2018).

Terrestrial sink

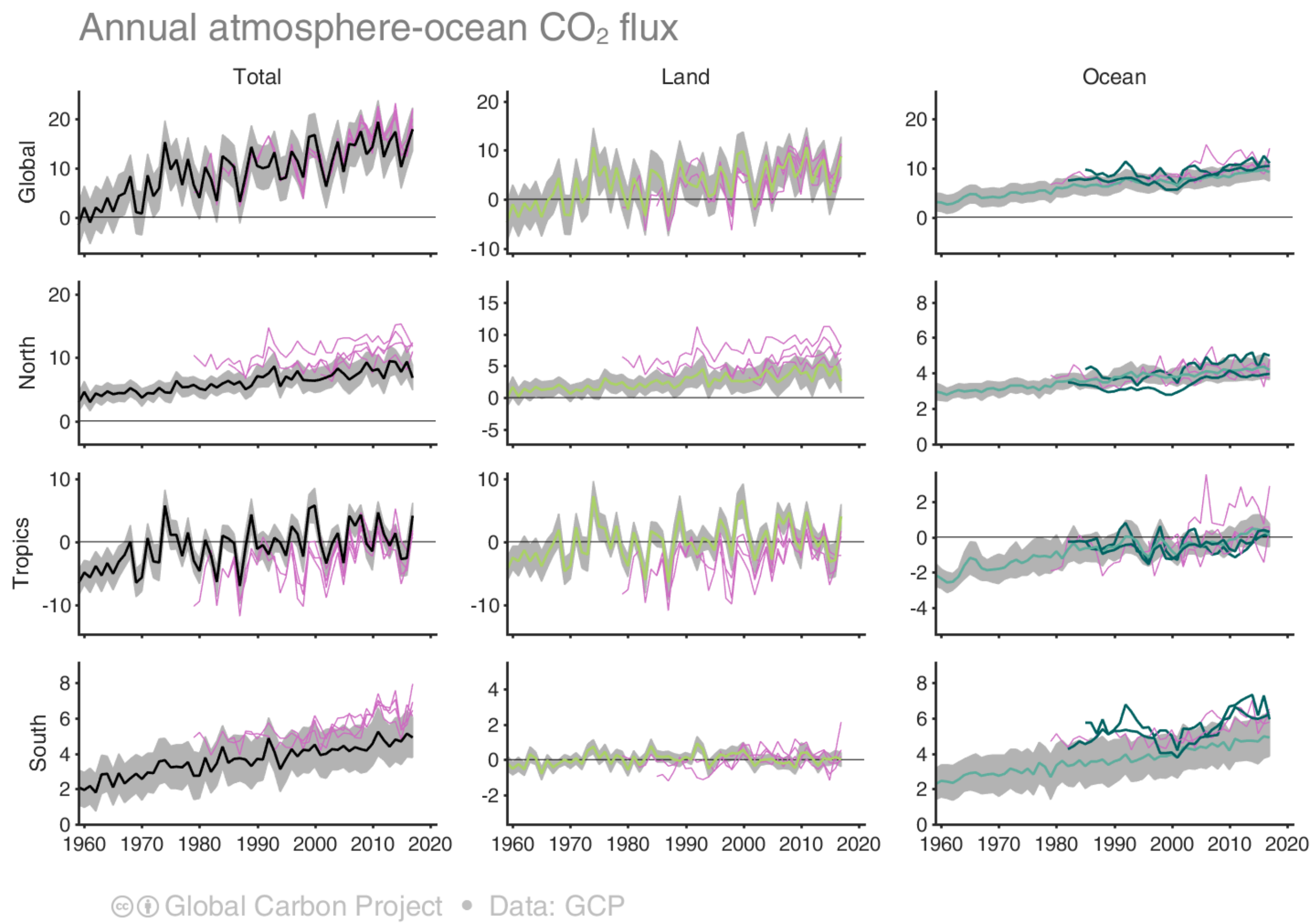
The land sink was 11.6±3 GtCO2/yr during 2008–2017 and 13.9±3 $GtCO_2$/yr in 2017
Total CO_2 fluxes on land (including land-use change) are constrained by atmospheric inversions



Source: [Le Quéré et al 2018](#) (see Table 4 for detailed references)

Total land and ocean fluxes

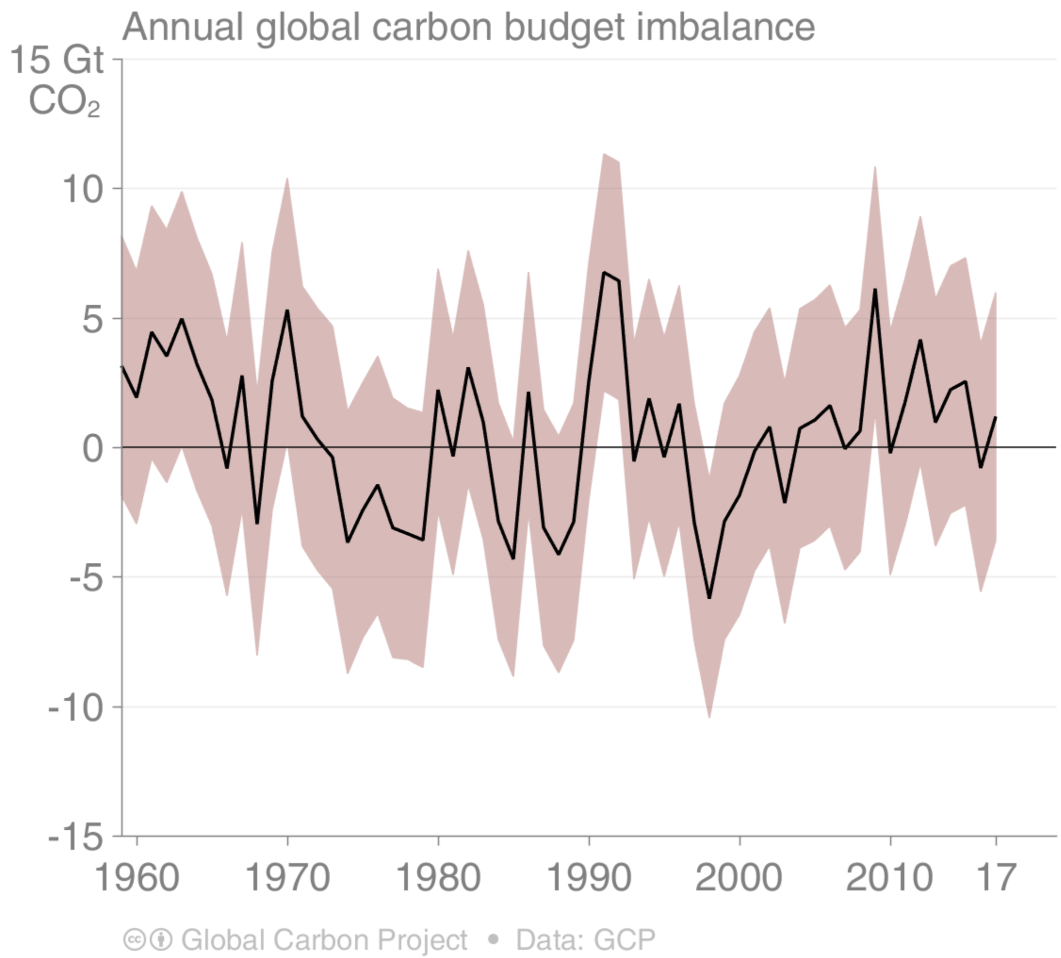
Total land and ocean fluxes show more interannual variability in the tropics



Source: [Le Quéré et al 2018](#) (see Table 4 for detailed references)

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: [Le Quéré et al 2018](); [Global Carbon Budget 2018]()

Global carbon budget

The cumulative contributions to the global carbon budget from 1870
The carbon imbalance represents the gap in our current understanding of sources & sinks

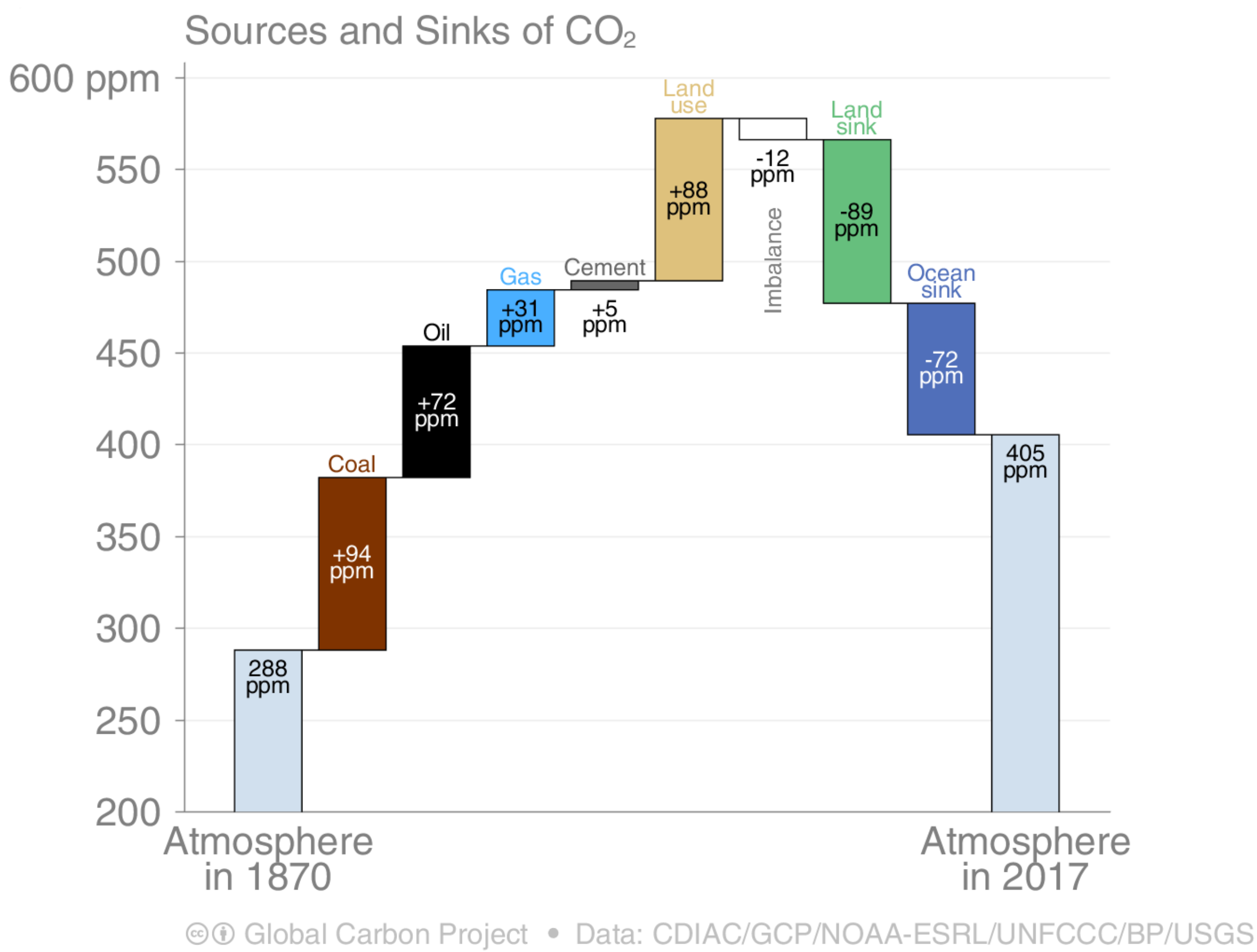
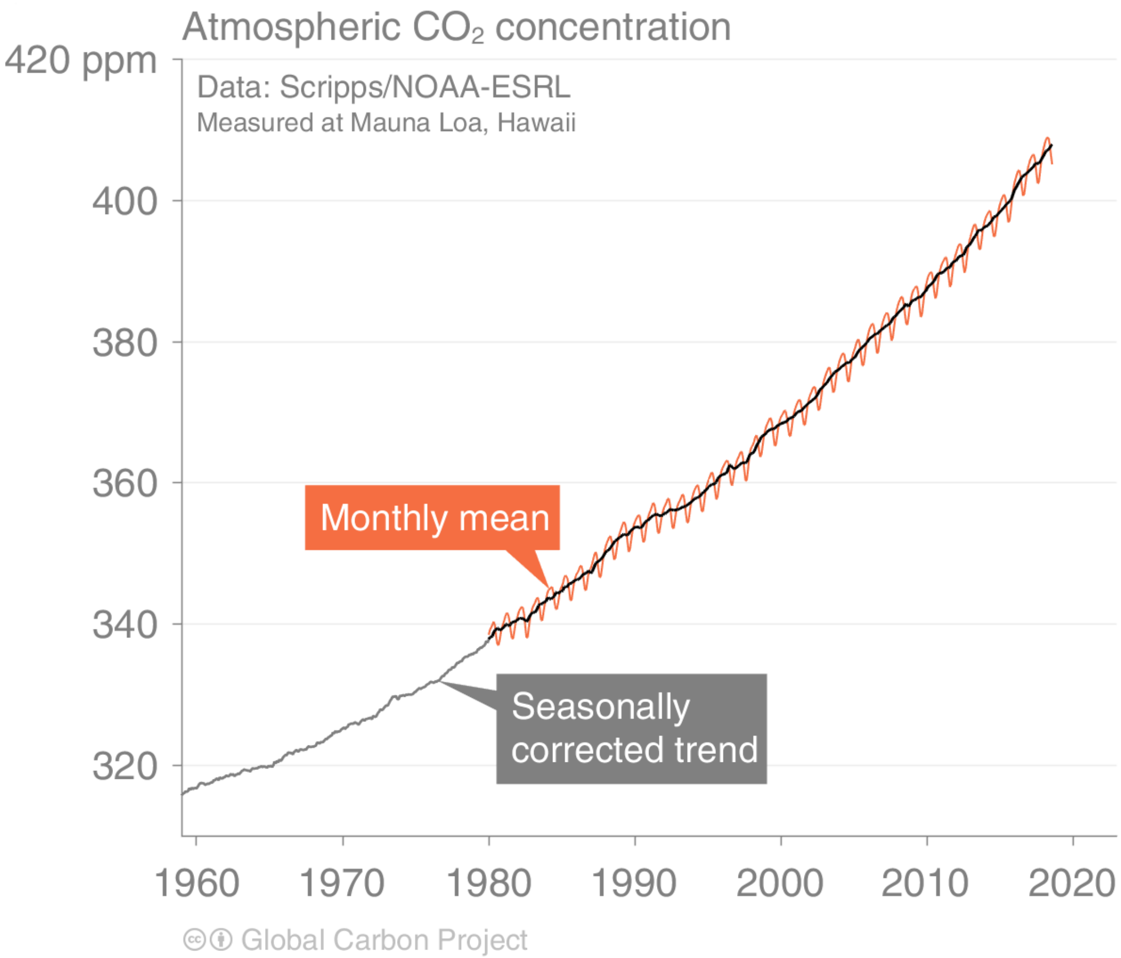


Figure concept from [Shrink That Footprint]

Source: [CDIAC]; [NOAA-ESRL]; [Houghton and Nassikas 2017]; [Hansis et al 2015]; [Joos et al 2013]; [Khatiwala et al. 2013]; [DeVries 2014]; [Le Quéré et al 2018]; [Global Carbon Budget 2018]

Atmospheric concentration

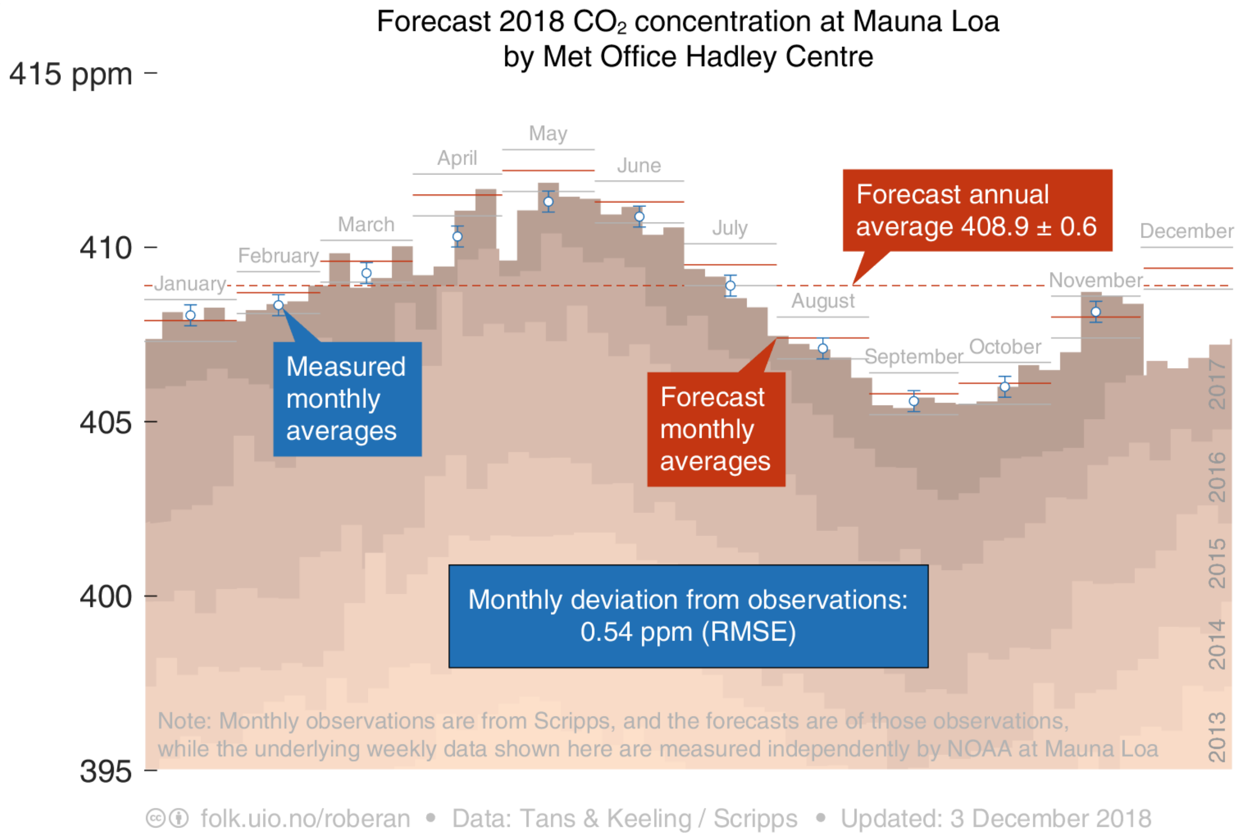
The global CO_2 concentration increased from ~277ppm in 1750 to 405ppm in 2017 (up 46%)
2016 was the first full year with concentration above 400ppm



Globally averaged surface atmospheric CO_2 concentration. Data from: NOAA-ESRL after 1980;
the Scripps Institution of Oceanography before 1980 (harmonised to recent data by adding 0.542ppm)
Source: NOAA-ESRL; Scripps Institution of Oceanography; Le Quéré et al 2018; Global Carbon Budget 2018

Seasonal variation of atmospheric CO_2 concentration

Weekly CO_2 concentration measured at Mauna Loa stayed above 400ppm throughout 2016 and is forecast to average 408.9 in 2018



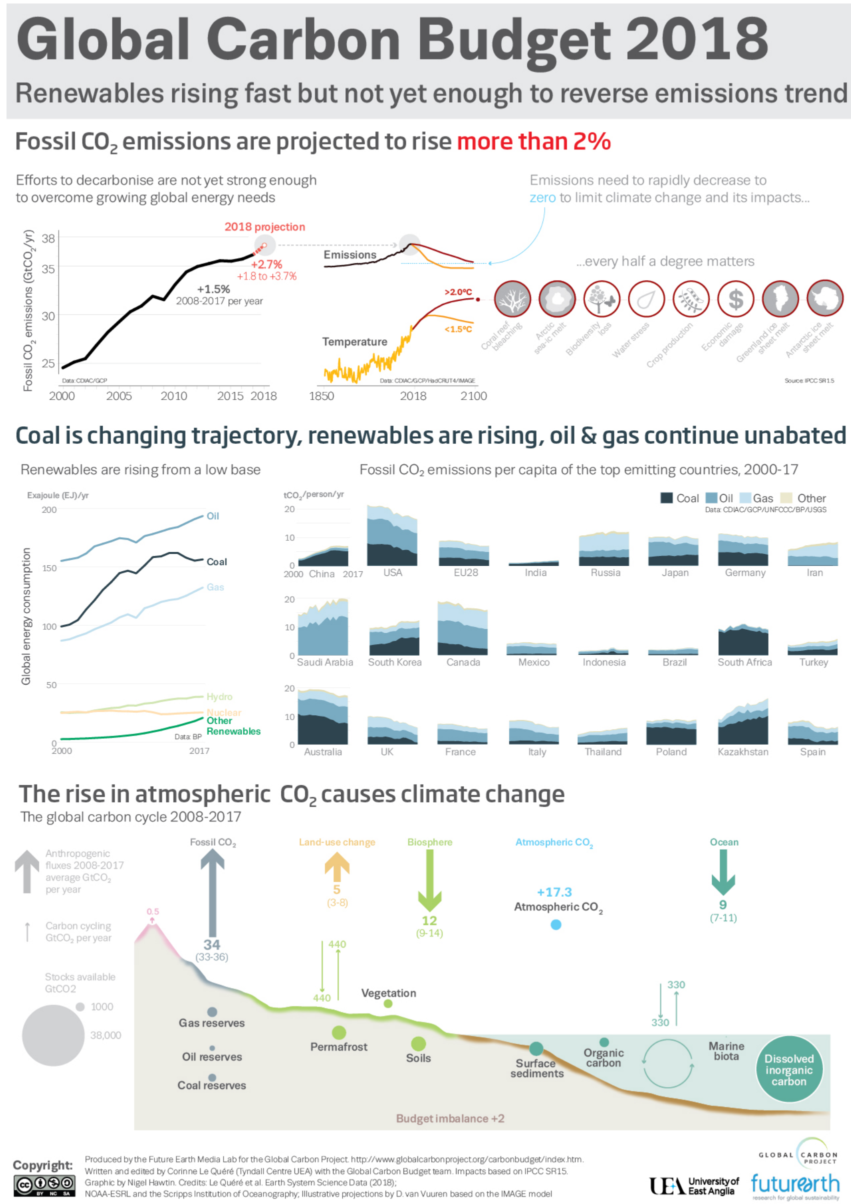
Forecasts are [an update](#) of [Betts et al 2016](#). The deviation from monthly observations is 0.24 ppm (RMSE).
Updates of [this figure](#) are available, and [another](#) on the drivers of the atmospheric growth

Data source: Tans and Keeling (2018), [NOAA-ESRL](#), [Scripps Institution of Oceanography](#)

End notes

Infographic

futurearth
Research. Innovation. Sustainability.



[Download in full resolution]

Acknowledgements

The work presented in the **Global Carbon Budget 2018** 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.

We also want thank each of the many funding agencies that supported the individual components of this release. A full list in provided in Table A5 of Le Quéré et al. 2018.
https://doi.org/10.5194/essd-10-2141-2018

We also thanks the Fondation BNP Paribas for supporting the Global Carbon Atlas.

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

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