Doutoramento em Alterações Climáticas e Políticas de Desenvolvimento Sustentável

SEMINAR ENERGY & CLIMATE CHANGE

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NOVA SCHOOL OF SCIENCE & TECHNOLOGY

CENSE center for environmental and sustainability research

Agenda

UNIVERSIDADE NOVA DE LISBOA

1. Global Carbon Budget (GCP, 2020)
2. Global Methane Budget (GCP, 2020)
3. Global N2O Budget (GCP, 2020)

Global Carbon Budget

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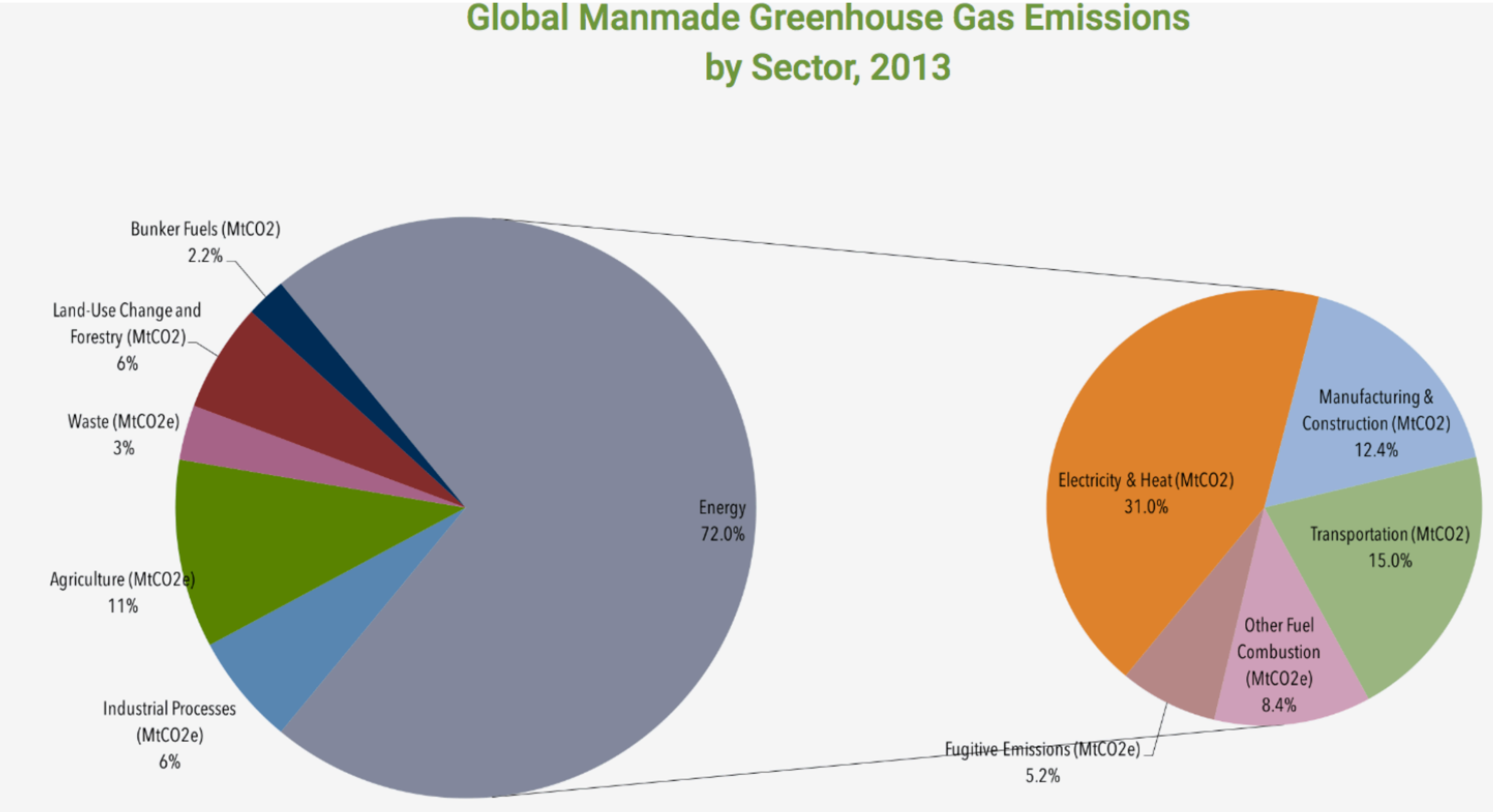


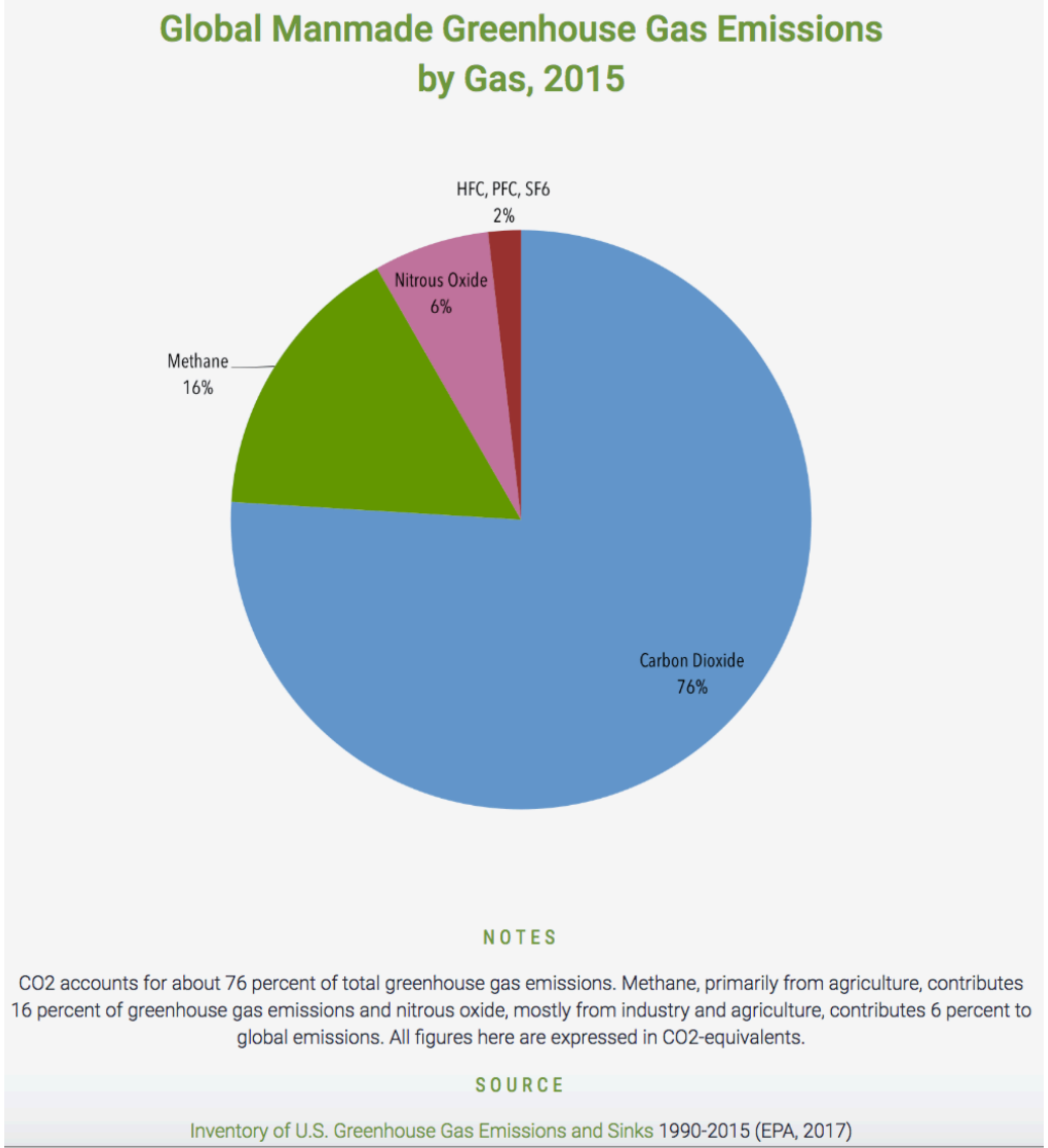
NOTES

Globally, the primary sources of greenhouse gas emissions are electricity and heat (31%), agriculture (11%), transportation (15%), forestry (6%) and manufacturing (12%). Energy production of all types accounts for 72 percent of all emissions.

SOURCE

Climate Analysis Indicators Tool (World Resources Institute, 2017).

Global Carbon Budget



Global warming potential

Table 2.14. *Lifetimes, radiative efficiencies and direct (except for CH_4) GWPs relative to CO_2. For ozone-depleting substances and their replacements, data are taken from IPCC/TEAP (2005) unless otherwise indicated.*

Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency ($W\ m^{-2}\ ppb^{-1}$)	Global Warming Potential for Given Time Horizon			
				SAR‡ (100-yr)	20-yr	100-yr	500-yr
Carbon dioxide	CO_2	See below[a]	[b]$1.4x10^{-5}$	1	1	1	1
Methane[c]	CH_4	12[c]	$3.7x10^{-4}$	21	72	25	7.6
Nitrous oxide	N_2O	114	$3.03x10^{-3}$	310	289	298	153
Substances controlled by the Montreal Protocol							
CFC-11	CCl_3F	45	0.25	3,800	6,730	4,750	1,620
CFC-12	CCl_2F_2	100	0.32	8,100	11,000	10,900	5,200
CFC-13	$CClF_3$	640	0.25		10,800	14,400	16,400
CFC-113	CCl_2FCClF_2	85	0.3	4,800	6,540	6,130	2,700
CFC-114	$CClF_2CClF_2$	300	0.31		8,040	10,000	8,730
CFC-115	$CClF_2CF_3$	1,700	0.18		5,310	7,370	9,990
Halon-1301	$CBrF_3$	65	0.32	5,400	8,480	7,140	2,760
Halon-1211	$CBrClF_2$	16	0.3		4,750	1,890	575
Halon-2402	$CBrF_2CBrF_2$	20	0.33		3,680	1,640	503
Carbon tetrachloride	CCl_4	26	0.13	1,400	2,700	1,400	435
Methyl bromide	CH_3Br	0.7	0.01		17	5	1
Methyl chloroform	CH_3CCl_3	5	0.06		506	146	45
HCFC-22	$CHClF_2$	12	0.2	1,500	5,160	1,810	549
HCFC-123	$CHCl_2CF_3$	1.3	0.14	90	273	77	24
HCFC-124	$CHClFCF_3$	5.8	0.22	470	2,070	609	185
HCFC-141b	CH_3CCl_2F	9.3	0.14		2,250	725	220
HCFC-142b	CH_3CClF_2	17.9	0.2	1,800	5,490	2,310	705

Source: IPCC 2018
(read more here ; section 2.10)

…continue

Global Carbon Budget

2020

The GCP is a Global Research Project of Future Earth
and a Research Partner of WCRP

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Read more here Friedlingstein et al 2020

GLOBAL CARBON PROJECT

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 in units of GtC and $GtCO_2$ are available from http://globalcarbonbudget.org/carbonbudget)

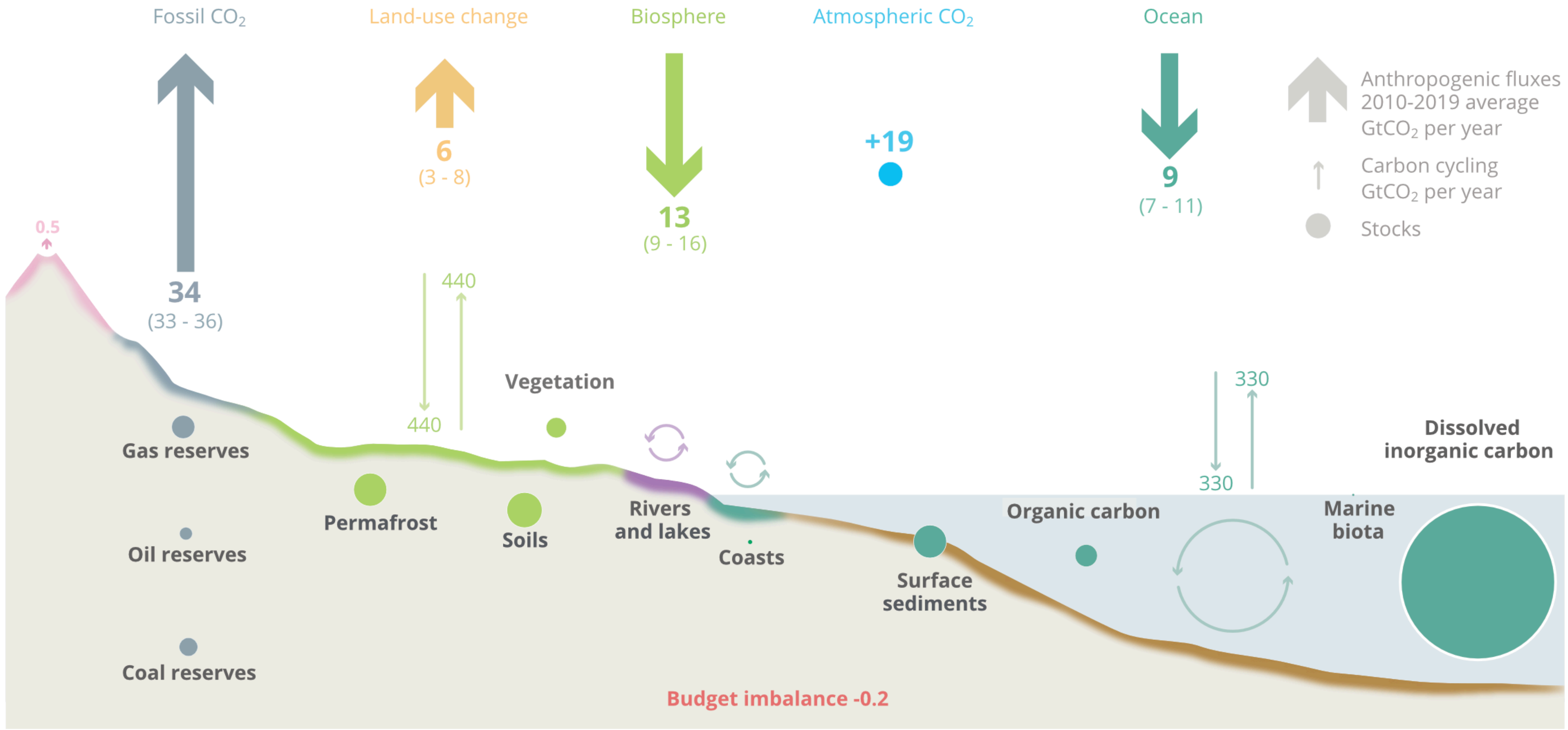
Most figures in this presentation are available for download as PNG, PDF and SVG files
from tinyurl.com/GCB20figs along with the data required to produce them.

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.

Anthropogenic perturbation of the global carbon cycle

Perturbation of the global carbon cycle caused by anthropogenic activities, averaged globally for the decade 2010–2019 ($GtCO_2$/yr)



The budget imbalance is the difference between the estimated emissions and sinks.
Source: CDIAC; NOAA-ESRL; Friedlingstein et al 2020; Ciais et al. 2013; Global Carbon Budget 2020

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2020 Results Summary

Region / Country	2019 emissions (billion tonnes/yr)	2019 growth (percent)	2020 projected growth** (percent)	2020 projected emissions** (billion tonnes/yr)
China	10.2	2.2%	-1.7%	10.0
USA	5.3	-2.6%	-12.2%	4.7
EU27	2.9	-4.5%	-11.3%	2.6
India	2.6	1.0%	-9.1%	2.4
World (incl. bunkers*)	36.4	0.1%	-6.7%	34.1

*bunkers: Emissions from use of international aviation and maritime navigation bunker fuels are not usually included in national totals

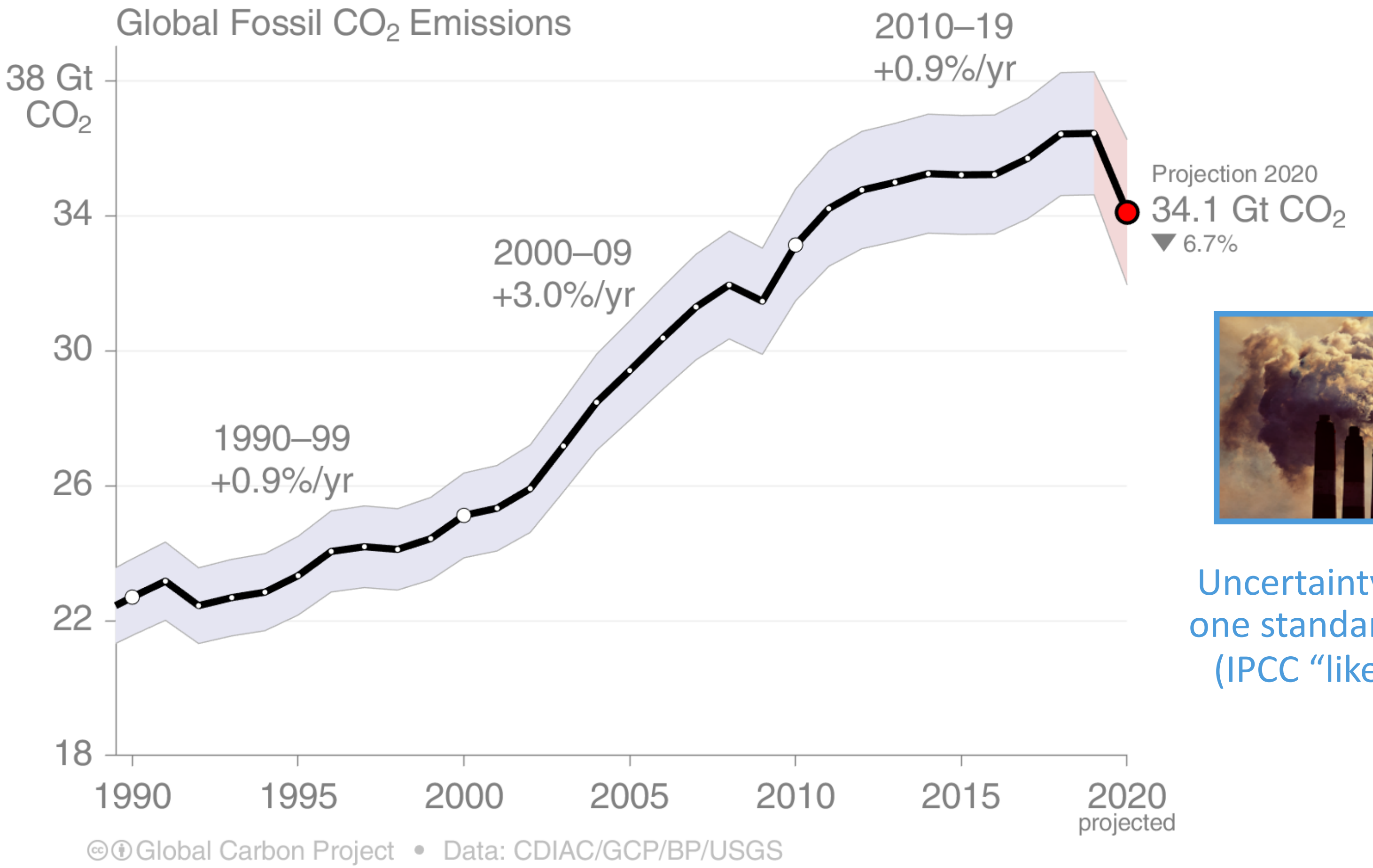
**Median of the four studies

Source: Friedlingstein et al 2020; Global Carbon Budget 2020

Global Fossil CO_2 Emissions

Global fossil CO_2 emissions: 36.4 ± 2 $GtCO_2$ in 2019, 61% over 1990

Projection for 2020: 34.1 ± 2 GtCO2, about 7% lower than 2019



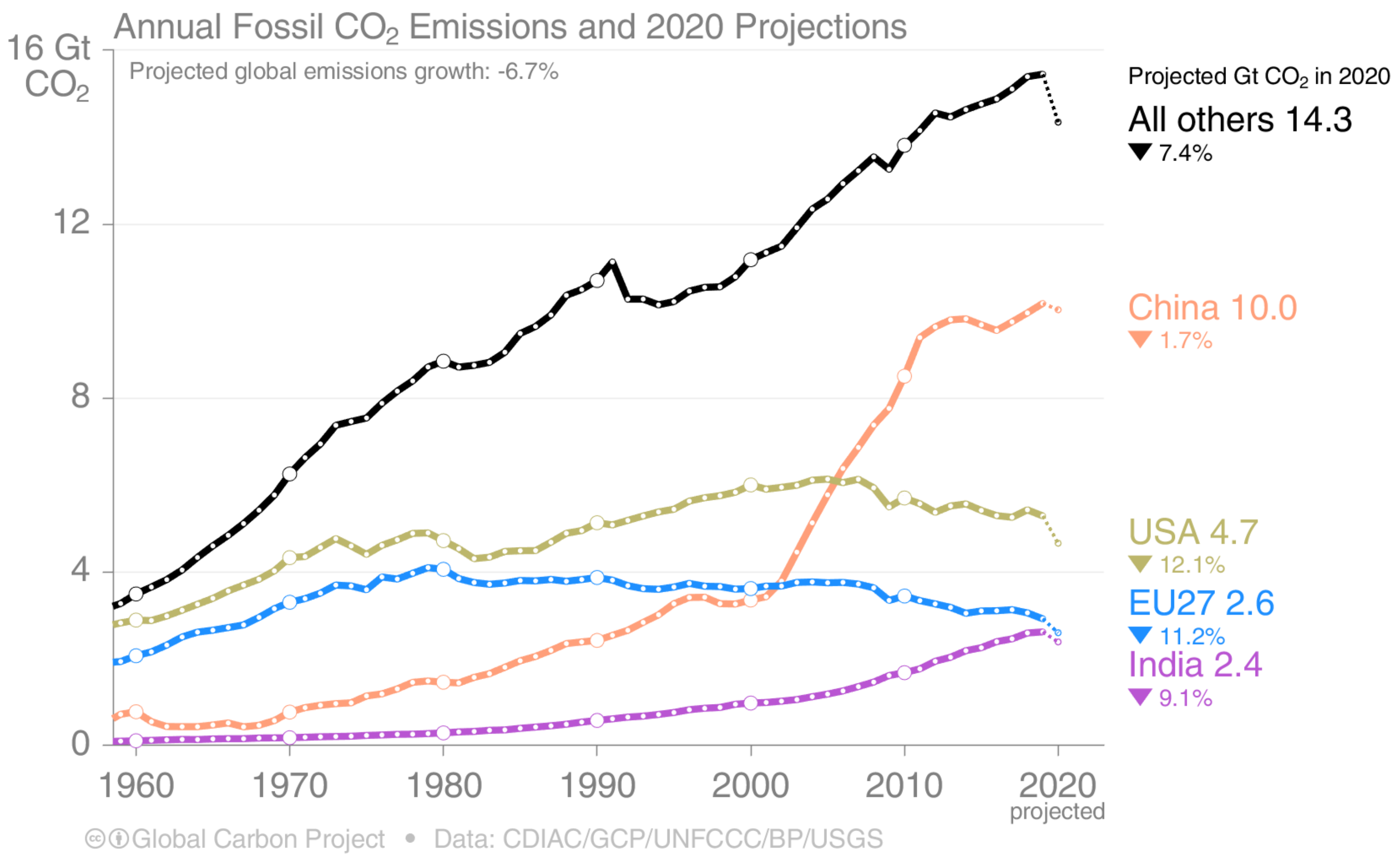
Uncertainty is ±5% for one standard deviation (IPCC “likely” range)

The 2020 projection is based on preliminary data and modelling, and is the median of the four studies.

Source: CDIAC; Friedlingstein et al 2020; Global Carbon Budget 2020

Emissions Projections for 2020

Global fossil CO_2 emissions are projected to decline by about 7% in 2020
Based on the median of four different estimates



The 2020 projections are based on preliminary data and modelling, and is the median of the four studies.
Source: CDIAC; Friedlingstein et al 2020; Global Carbon Budget 2020

Fossil CO_2 emissions growth: 2018–2020

Emissions are likely to decline in most countries in 2020, with the largest drops in USA, EU, and India
China's emissions have dropped less because of early recovery and significant economic stimulus

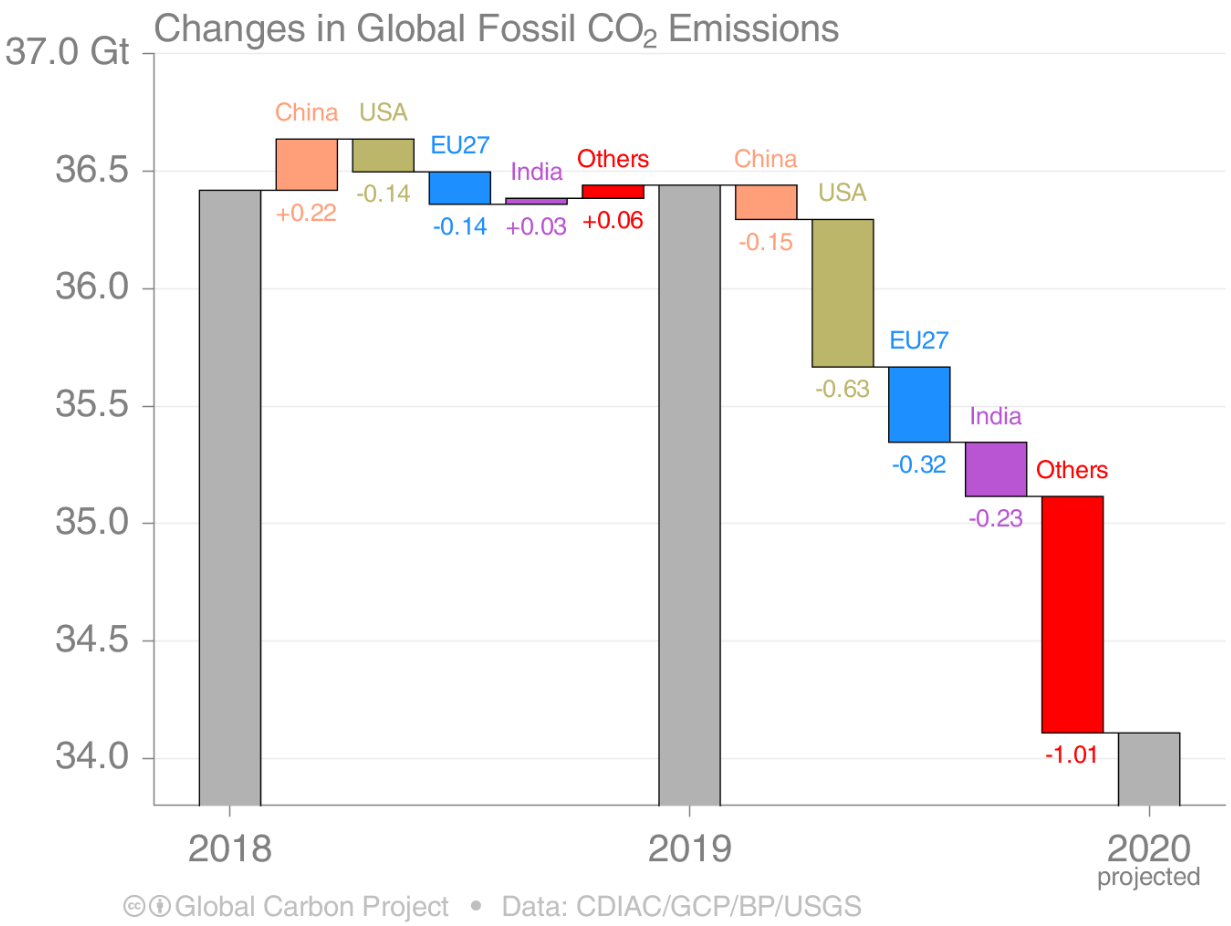


Figure shows the top four countries contributing to emissions changes
Source: CDIAC; Friedlingstein et al 2020; Global Carbon Budget 2020

UEA Projection: Overall impact of COVID-19 on regional emissions

While China’s emissions declined strongly during February,
emissions declines in the rest of the world reached their peaks in April.

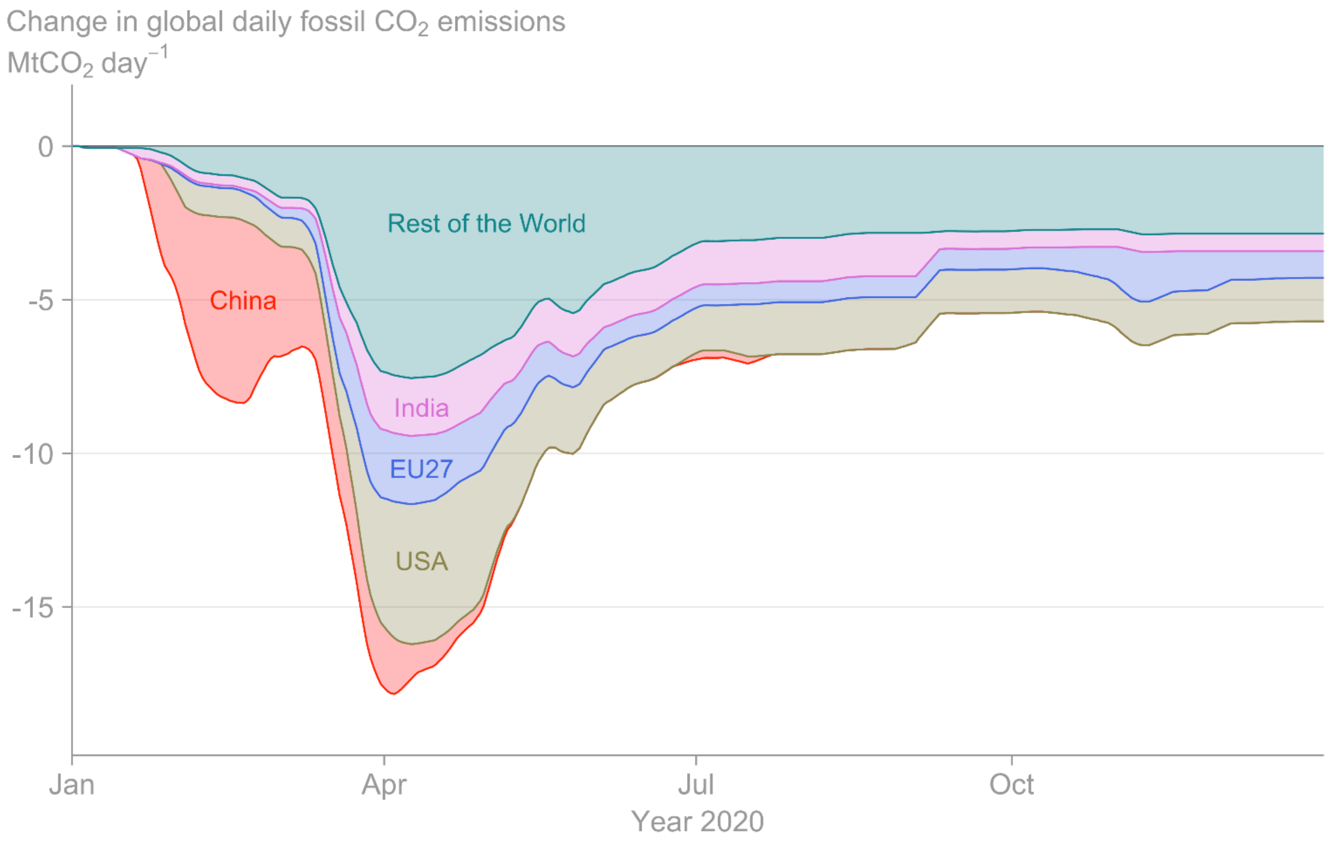
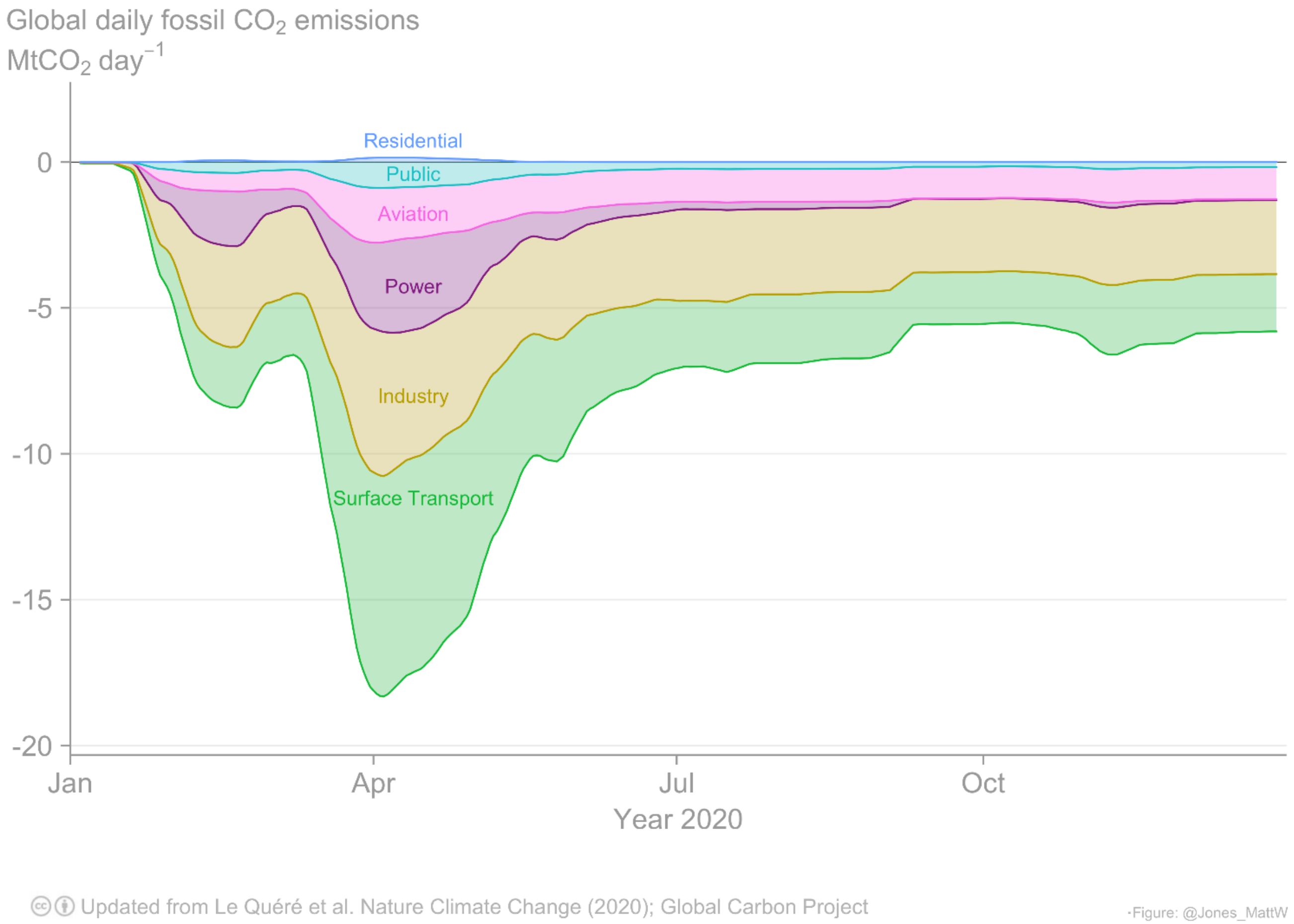


Figure: @Jones_MattW

Source: Le Quéré et al 2020; https://www.icos-cp.eu/gcp-covid19

UEA Projection: Overall impact of COVID-19 on emissions by sector

Global emissions from surface transport, especially road transport,
have been affected the most by the restrictions aimed at reducing infection rates.



Source: Le Quéré et al 2020; https://www.icos-cp.eu/gcp-covid19

Global Fossil CO_2 Emissions

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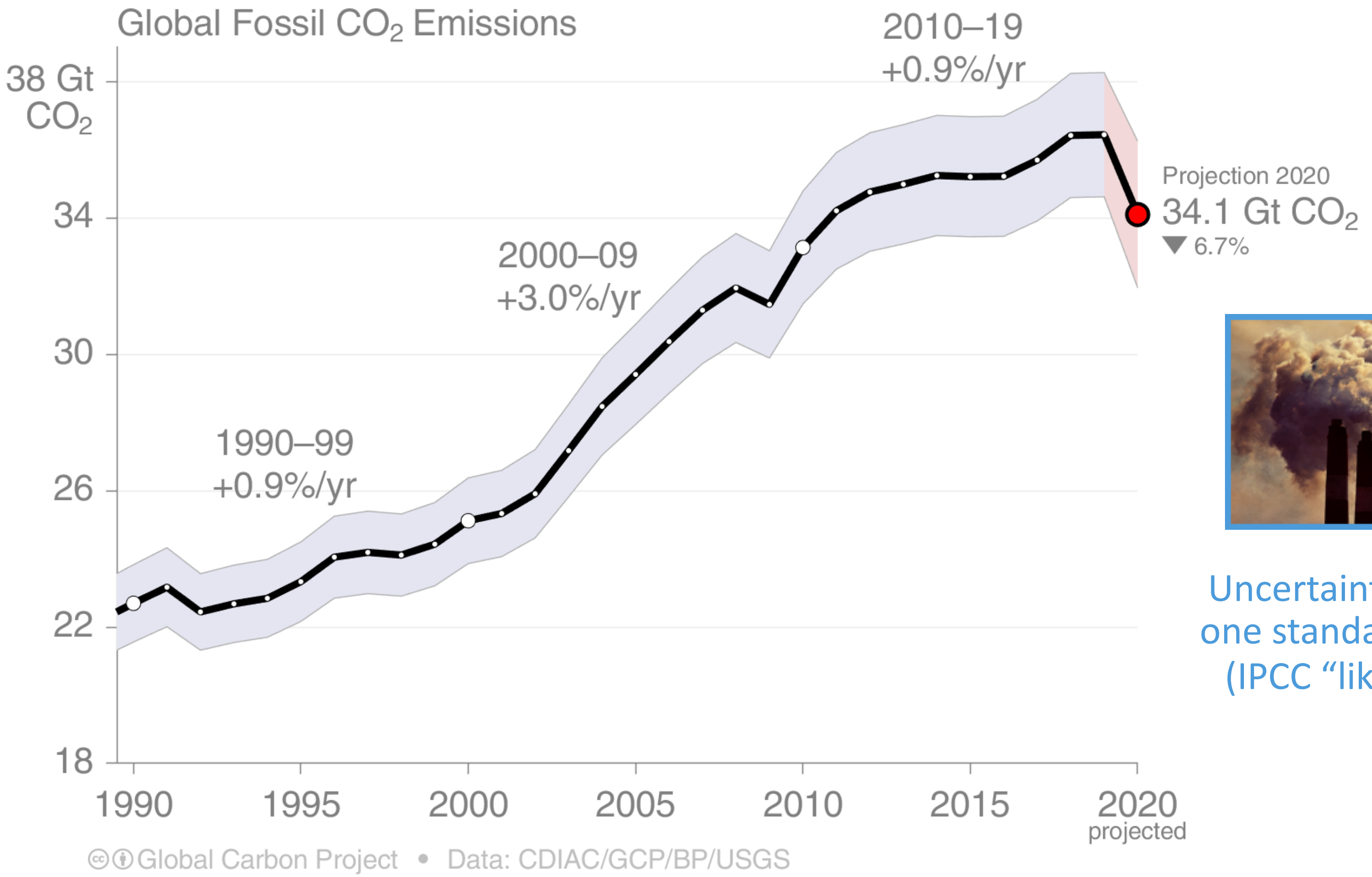
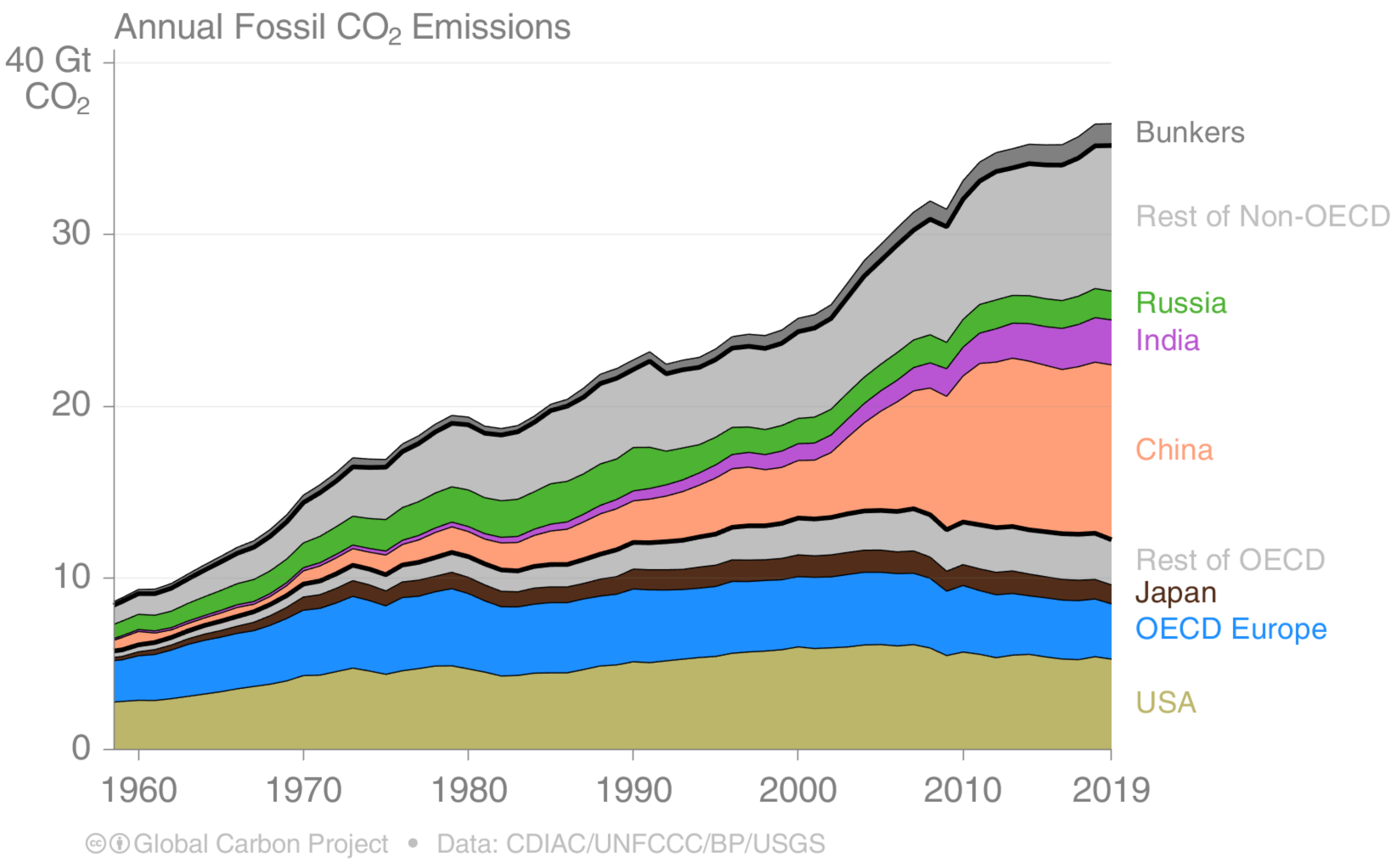


Uncertainty is ±5% for one standard deviation (IPCC "likely" range)

The 2020 projection is based on preliminary data and modelling, and is the median of the four studies.
Source: CDIAC; Friedlingstein et al 2020; Global Carbon Budget 2020

Breakdown of global fossil CO_2 emissions by country

Emissions in OECD countries have increased by 1% since 1990, despite declining 13% from their maximum in 2007
Emissions in non-OECD countries have more than doubled since 1990

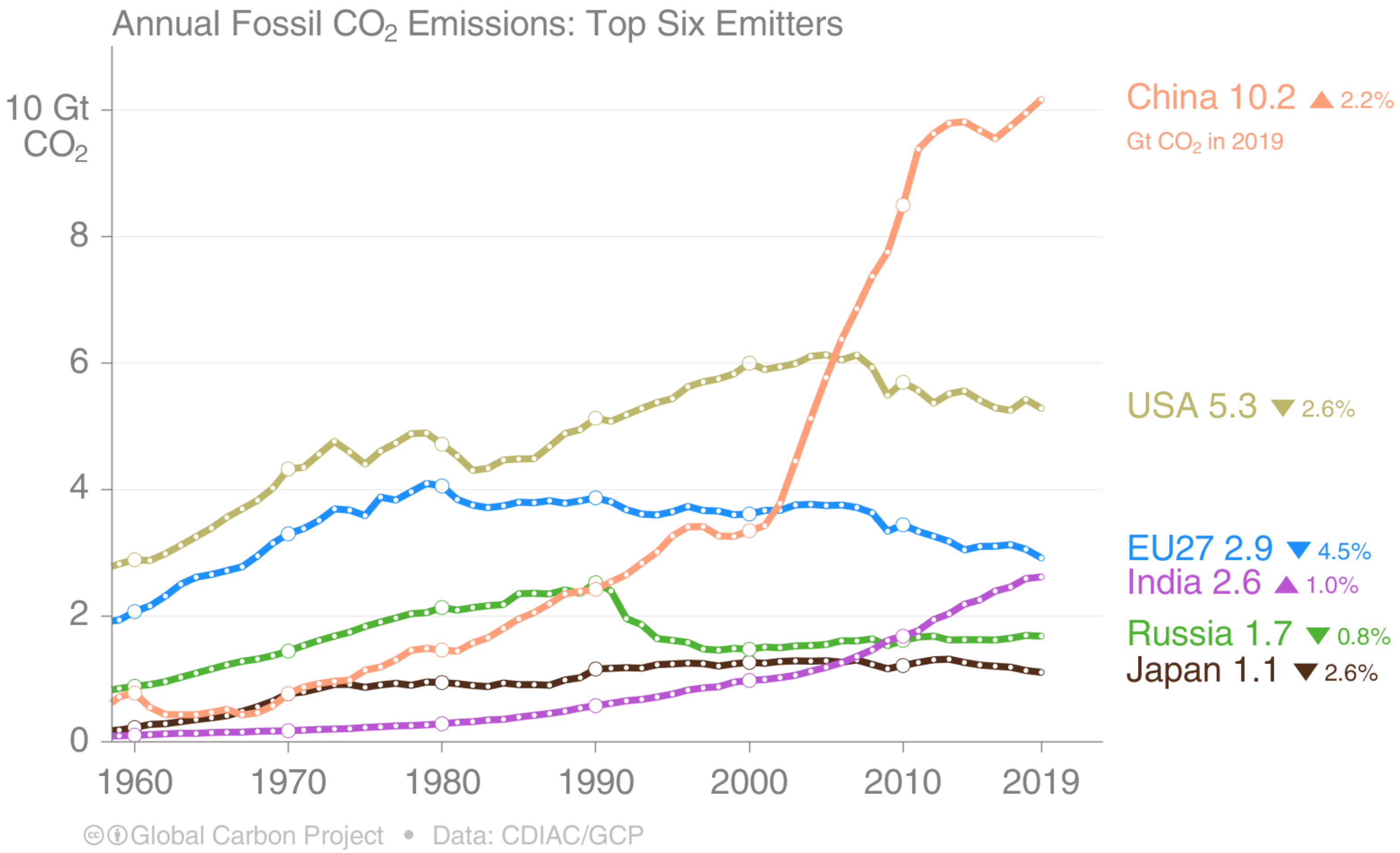


Source: CDIAC; Friedlingstein et al 2020; Global Carbon Budget 2020

Top emitters: Fossil CO_2 Emissions to 2019

The top six emitters in 2019 covered 65% of global emissions

China 28%, United States 15%, EU27 8%, India 7%, Russia 5%, and Japan 3%

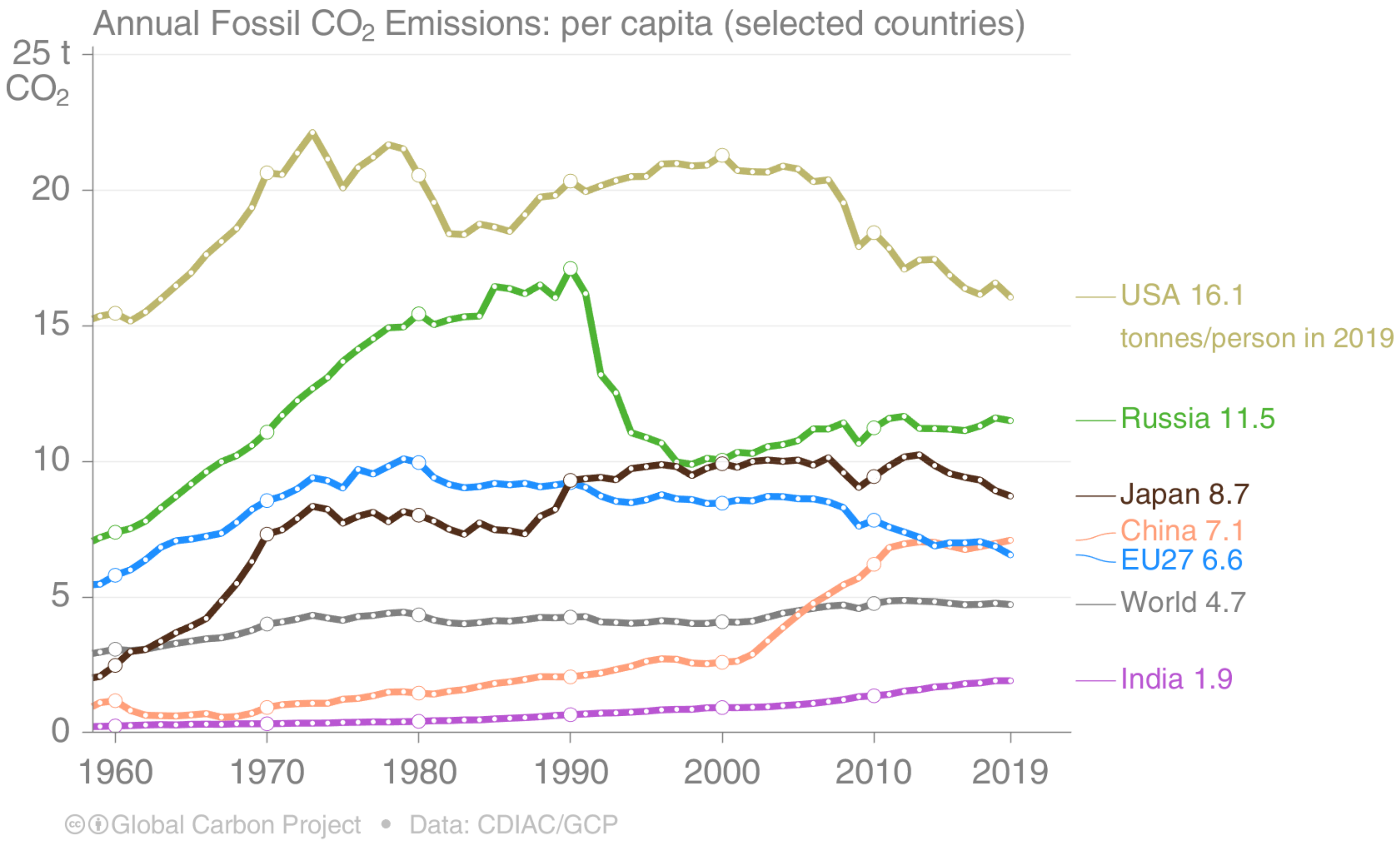


Bunker fuels, used for international transport, are 3.5% of global emissions.

Source: CDIAC; Peters et al 2019; Friedlingstein et al 2020; Global Carbon Budget 2020

Top emitters: Fossil CO_2 Emissions per capita to 2019

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



Portugal 5,0 tCO2/pax (2018)

Source: CDIAC; Friedlingstein et al 2020; Global Carbon Budget 2020

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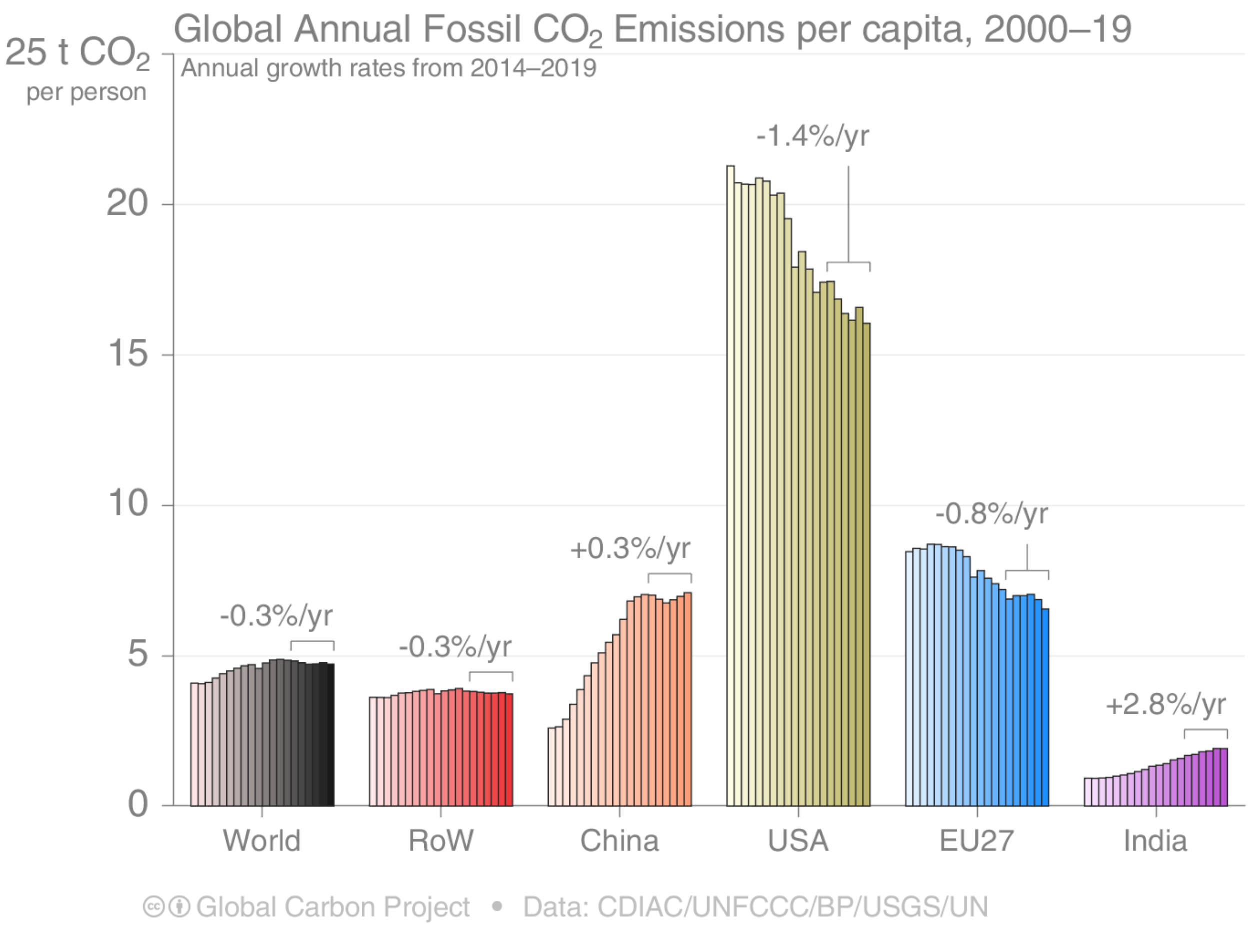
Per capita CO_2 emissions

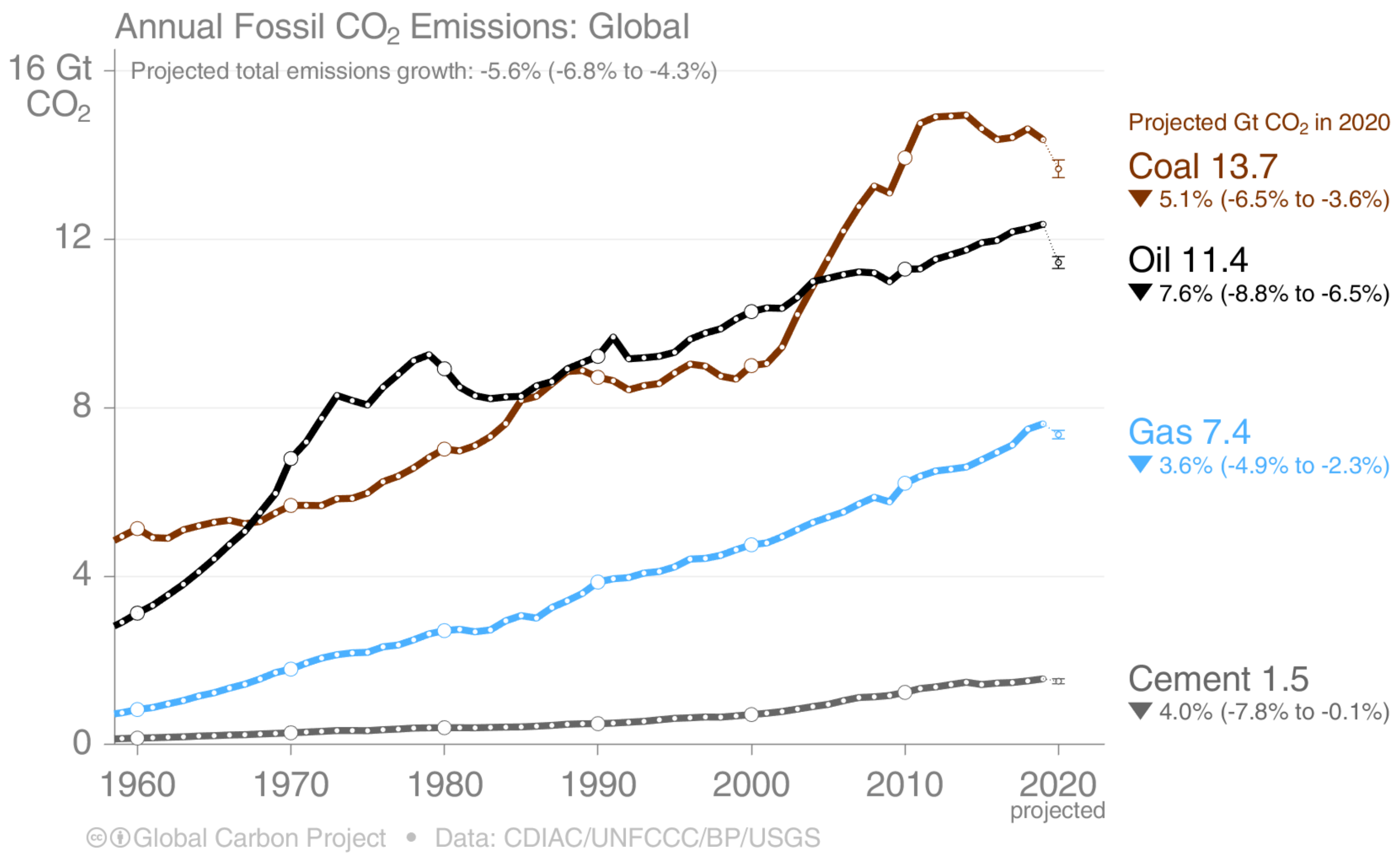
The US has high per capita emissions, but this has been declining steadily. China's per capita emissions have levelled out and are now the same as the EU. India's emissions are low per capita.



Source: Jackson et al 2019; Global Carbon Budget 2020

Fossil CO_2 Emissions by source

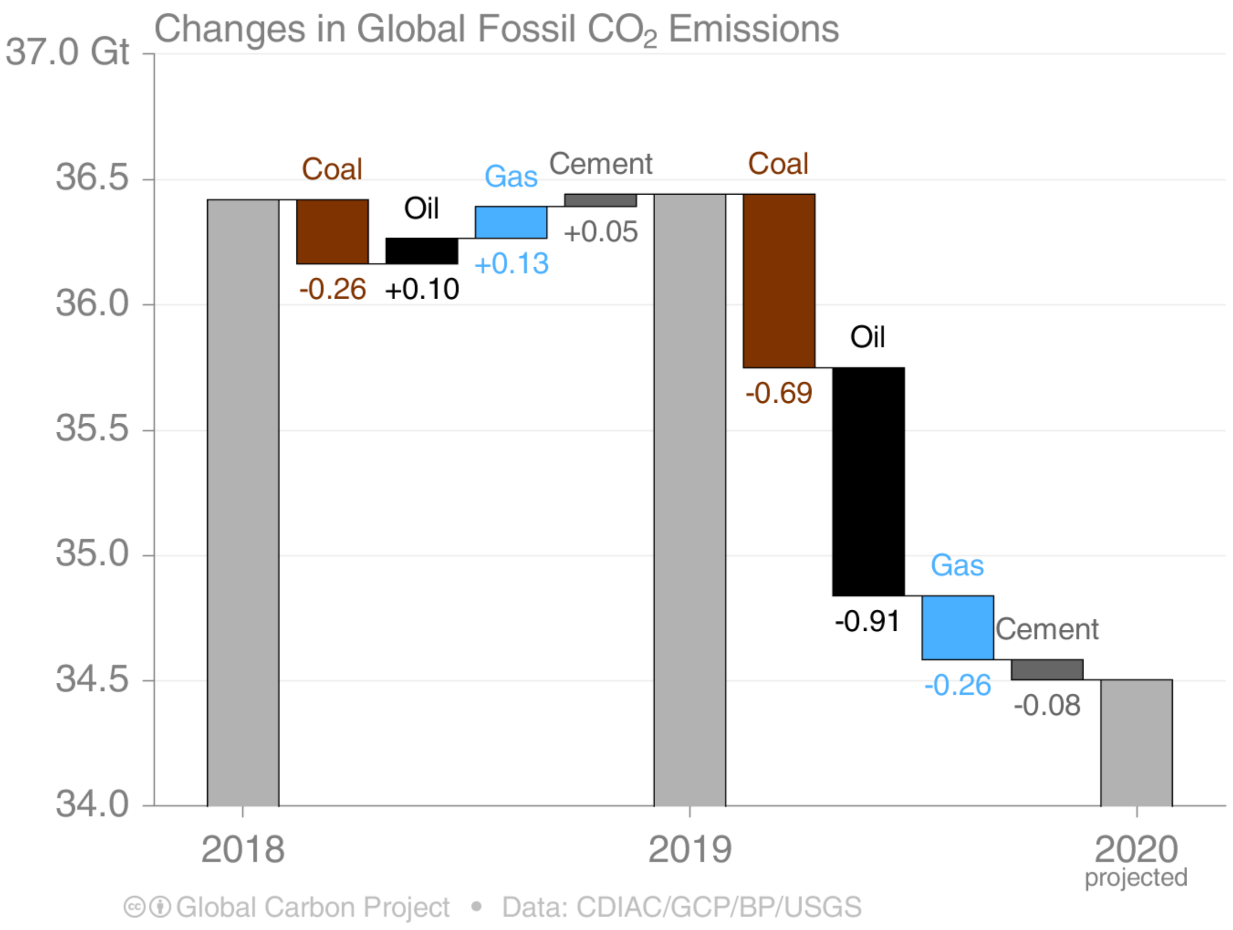
Share of global fossil CO_2 emissions in 2019: coal (39%), oil (33%), gas (21%), cement (4%), flaring (1%, not shown)
Projection by fuel type is based on monthly data (GCP analysis)



Source: CDIAC; Friedlingstein et al 2020; Global Carbon Budget 2020

Fossil CO_2 emissions growth: 2018–2020

Global emissions in 2020 have dropped across all categories, but particularly in coal from reduced electricity demand, and in oil from reduced transportation



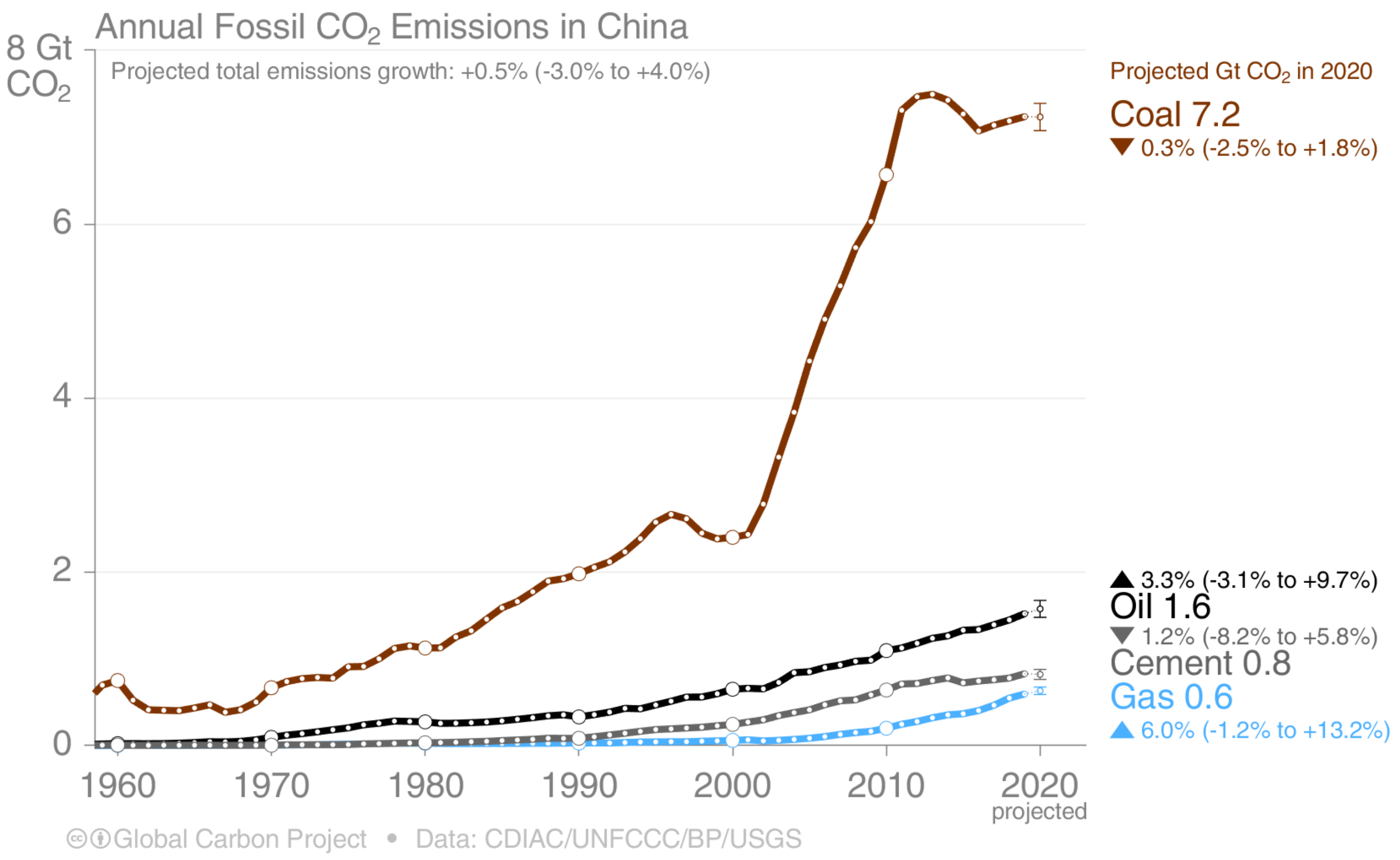
Source: CDIAC; Friedlingstein et al 2020; Global Carbon Budget 2020

Fossil CO_2 Emission by source for top emitters

from fossil fuel use and industry
results from GCP's analysis of monthly data

Fossil CO_2 Emissions in China

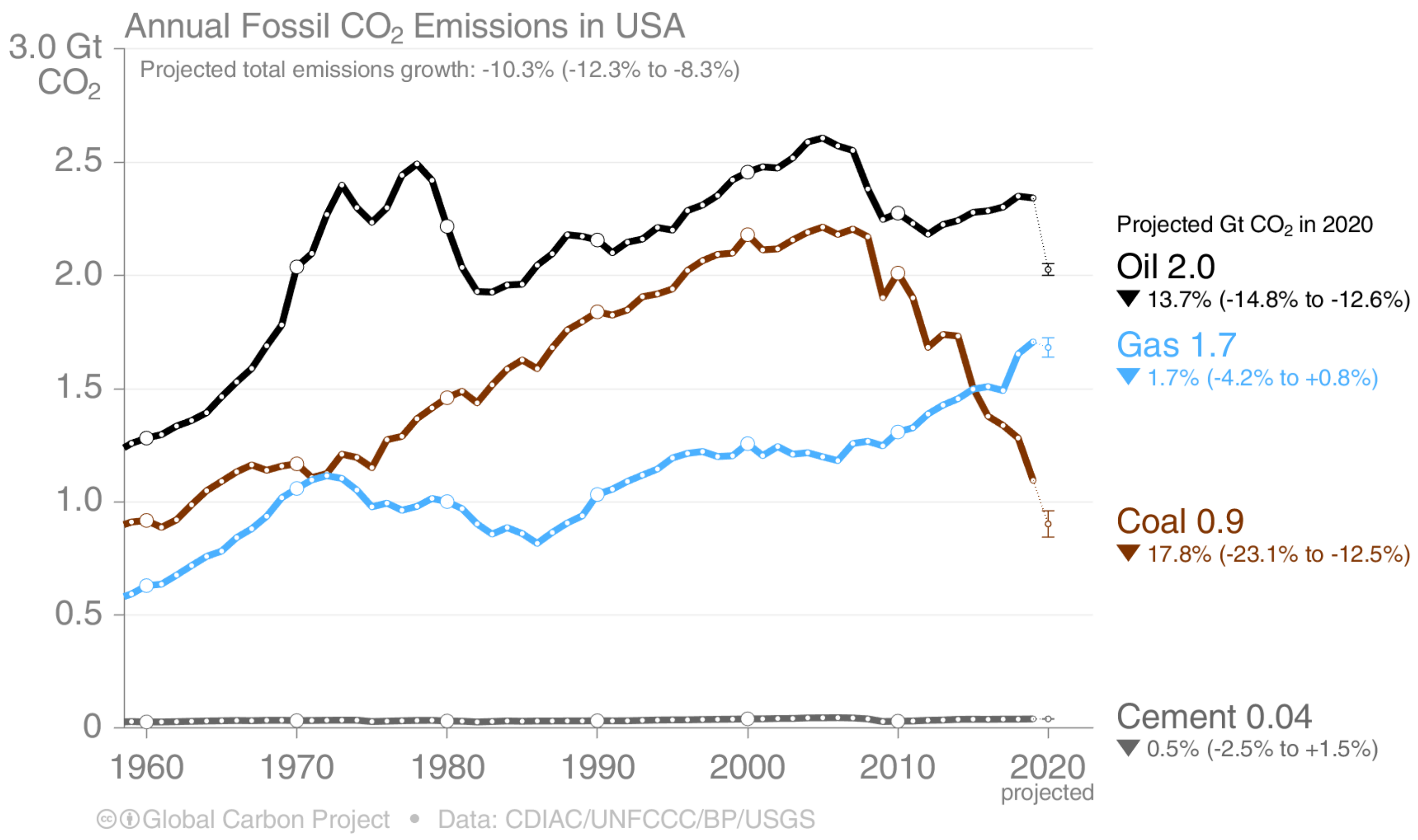
Annual emissions for China hide the story of 2020, suggesting no impact from the global pandemic
Emissions from oil and natural gas continue to grow strongly



Source: CDIAC; Friedlingstein et al 2020; Global Carbon Budget 2020

Fossil CO_2 Emissions in USA

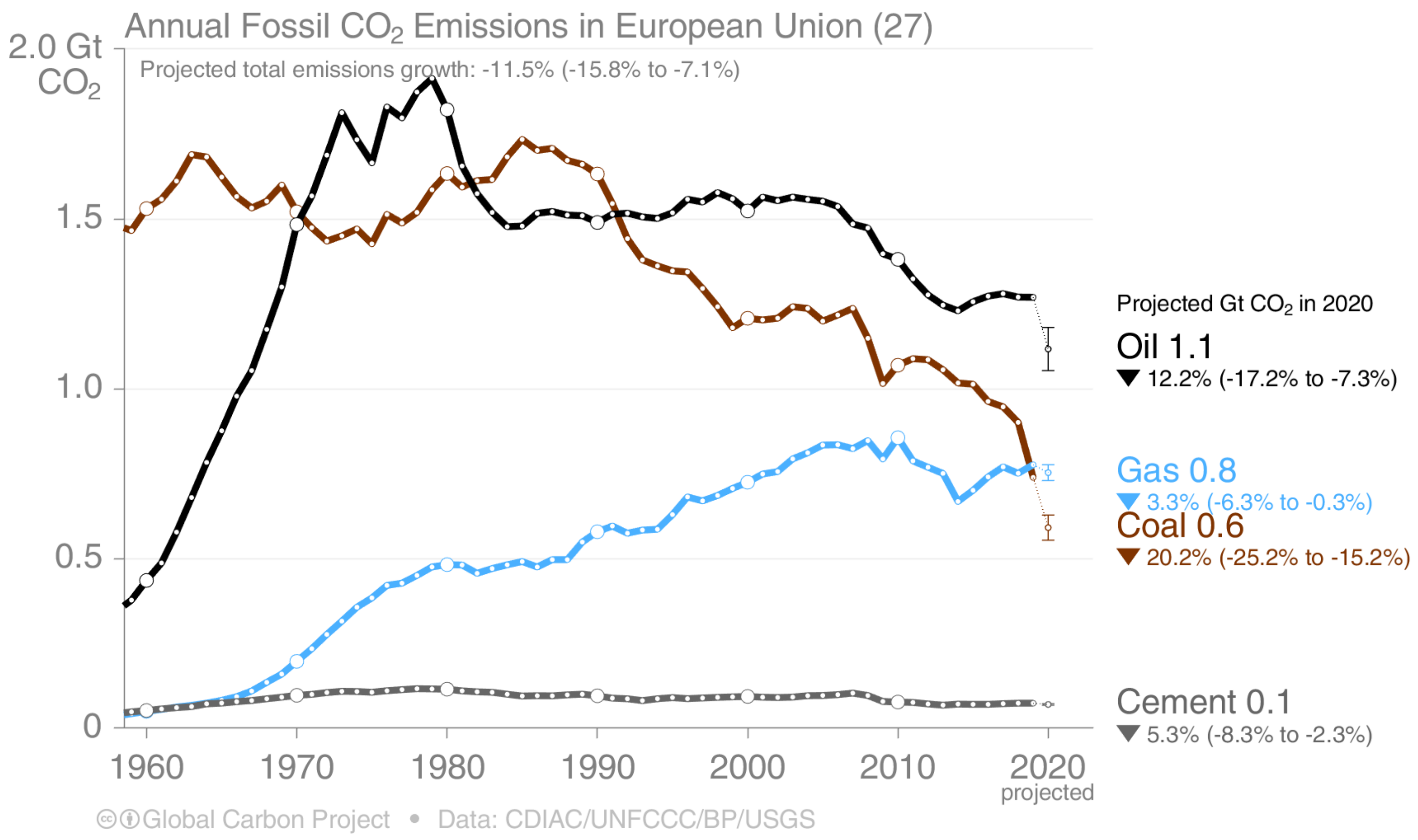
The USA's emissions from oil are expected to decline sharply in 2020 as a result of restrictions on transportation
Coal emissions also decline, while the recent strong growth in natural gas falters.



Source: CDIAC; EIA 2020; Friedlingstein et al 2020; Global Carbon Budget 2020

Fossil CO_2 Emissions in the European Union (EU27)

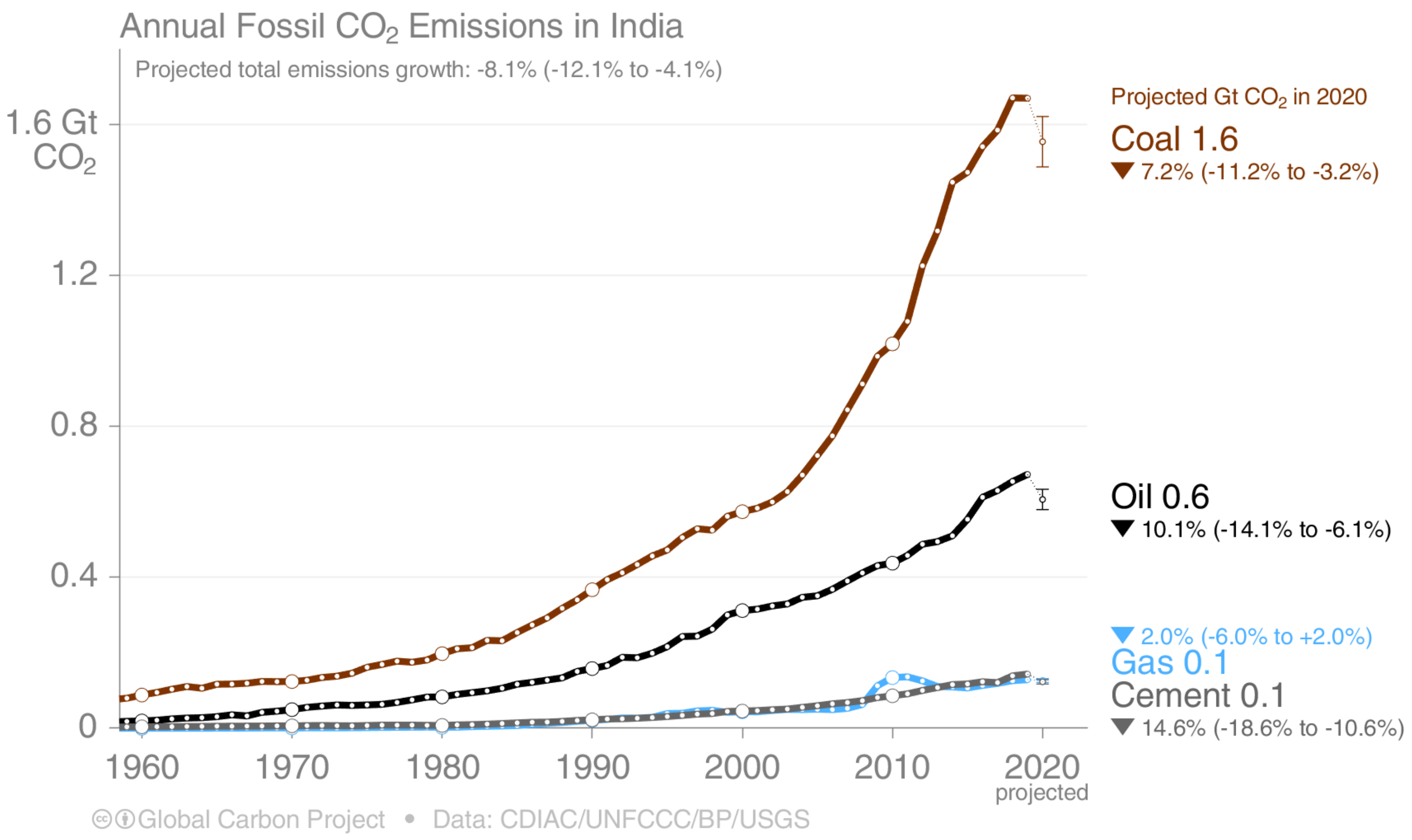
Emissions in the EU see sharp declines in both oil and coal due to the pandemic, with less effect seen for natural gas



Source: CDIAC; Friedlingstein et al 2020; Global Carbon Budget 2020

Fossil CO_2 Emissions in India

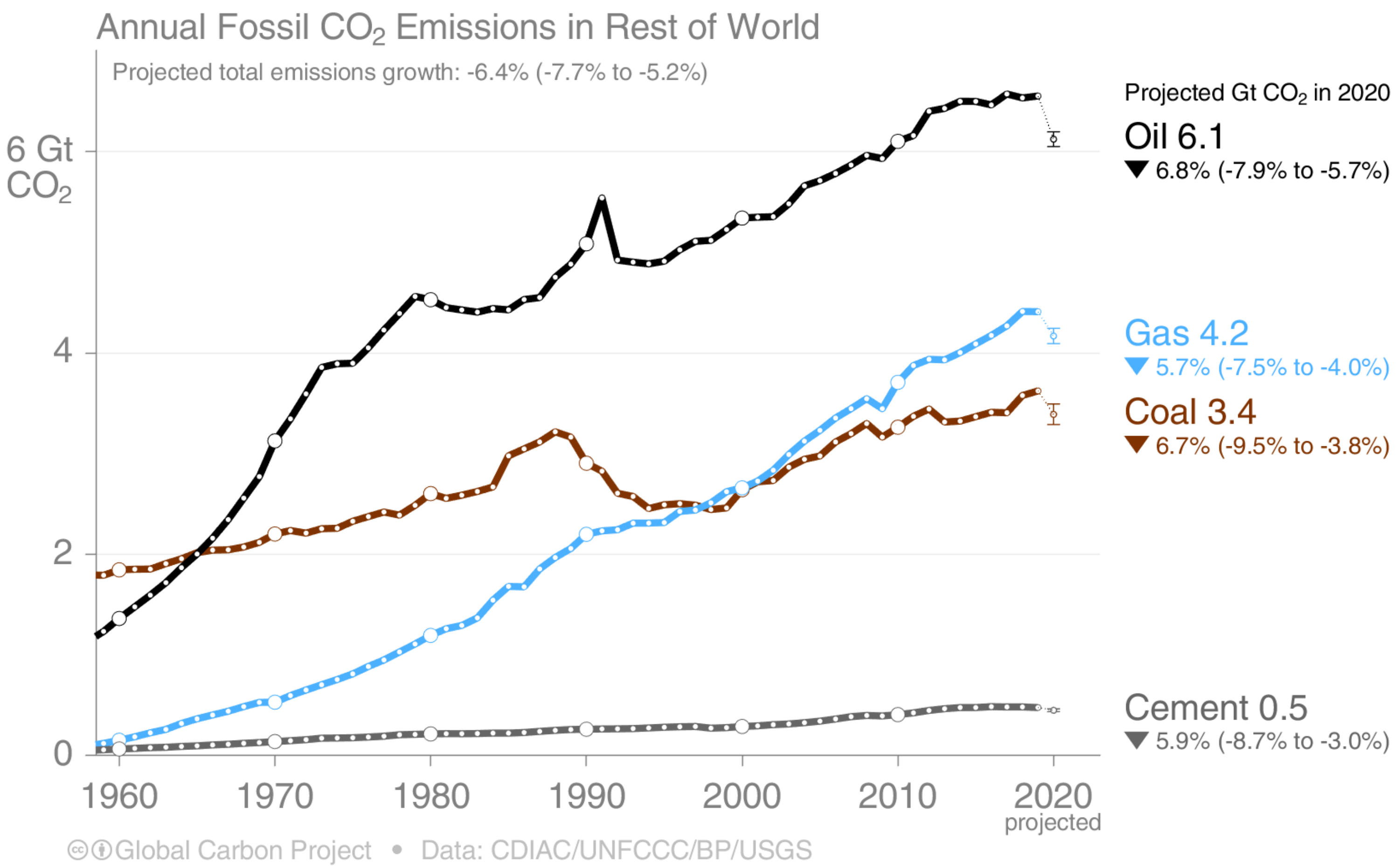
India's emissions are likely to drop about 8% in 2020, following substantial contractions in economic activity because of strict lockdowns in response to the pandemic



Source: CDIAC; Friedlingstein et al 2020; Global Carbon Budget 2020

Fossil CO_2 Emissions in Rest of World

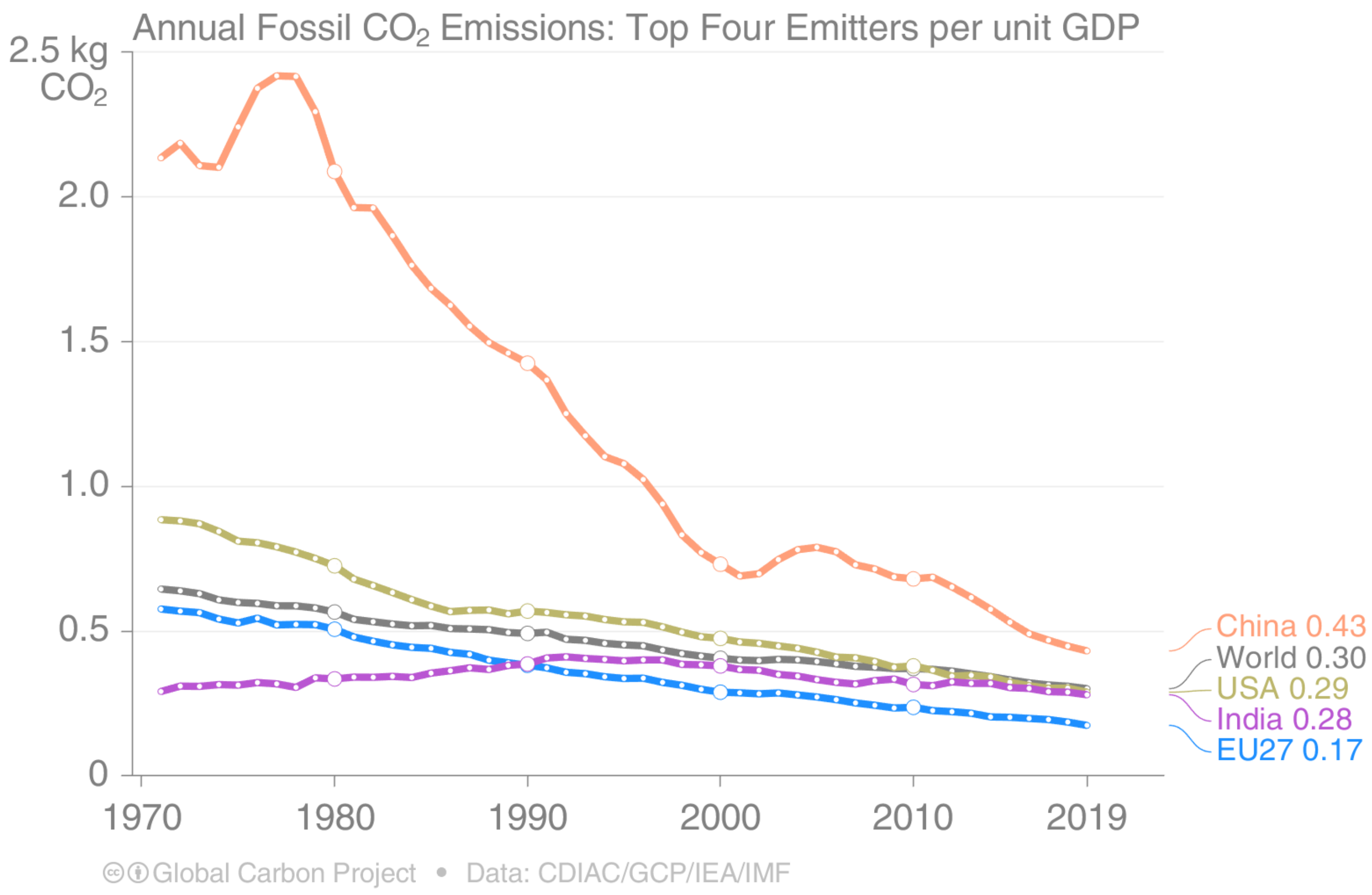
Emissions in the Rest of the World are expected to drop sharply in 2020, on the back of weaker economic activity.
Growth is estimated based on efficiency improvements of the last 10 years combined with projected economic growth.



The Rest of the World is the global total less China, US, EU, and India. It also includes international aviation and marine bunkers.
Source: CDIAC; Friedlingstein et al 2020; Global Carbon Budget 2020

Top emitters: Fossil CO_2 Emission Intensity

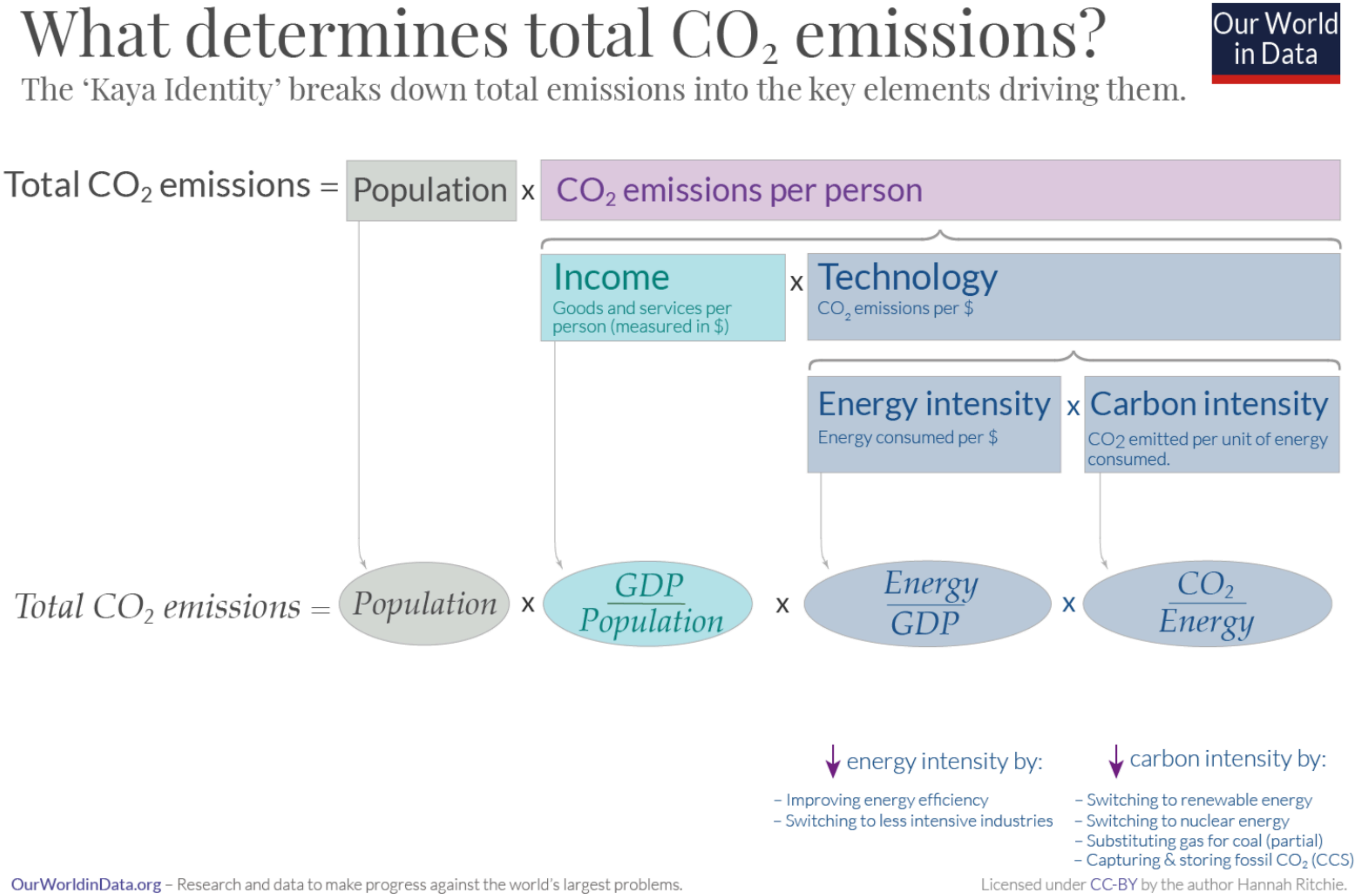
Emission intensity (emission per unit economic output) generally declines over time.
In many countries, these declines are insufficient to overcome economic growth.



Carbon intensity:
How much CO_2 is emitted for each wealth (GDP) unit produced?

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

Source: CDIAC; IEA 2019 GDP to 2016, IMF 2020 growth rates to 2019; Friedlingstein et al 2020; Global Carbon Budget 2020



What determines total CO2 emissions?
The 'Kaya Identity' breaks down total emissions into the key elements driving them.
Our World in Data
Total CO2 emissions =
Population
x
CO2 emissions per person
Income
Goods and services per person (measured in $)
x
Technology
CO2 emissions per $
Energy intensity
Energy consumed per $
x
Carbon intensity
CO2 emitted per unit of energy consumed.
Total CO2 emissions =
Population
x
GDP / Population
x
Energy / GDP
x
CO2 / Energy
energy intensity by:
– Improving energy efficiency
– Switching to less intensive industries
carbon intensity by:
– Switching to renewable energy
– Switching to nuclear energy
– Substituting gas for coal (partial)
– Capturing & storing fossil CO2 (CCS)
OurWorldinData.org – Research and data to make progress against the world's largest problems.
Licensed under CC-BY by the author Hannah Ritchie.

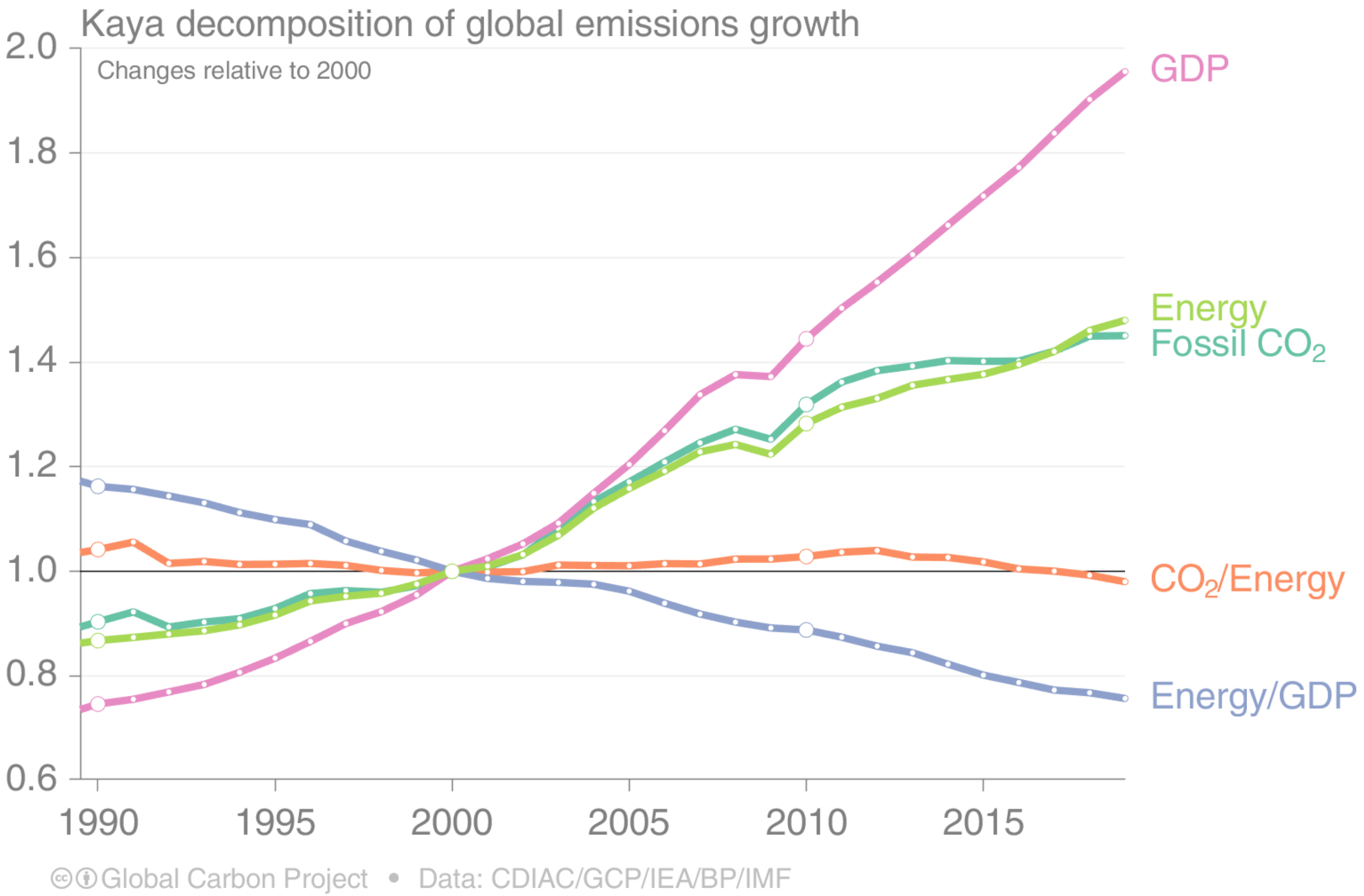
Kaya decomposition

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

$$F = P \times \frac{G}{P} \times \frac{E}{G} \times \frac{F}{E}$$

where:
F = Global CO2 emissions from human sources
P = Global population
G = Global Gross Domestic Product (GDP)
E = Energy consumption

Brief on Kaya entity



Carbon intensity of energy

Energy intensity

GDP: Gross Domestic Product (economic activity)
Energy is Primary Energy from BP statistics using the substitution accounting method
Source: Jackson et al 2019; Global Carbon Budget 2020

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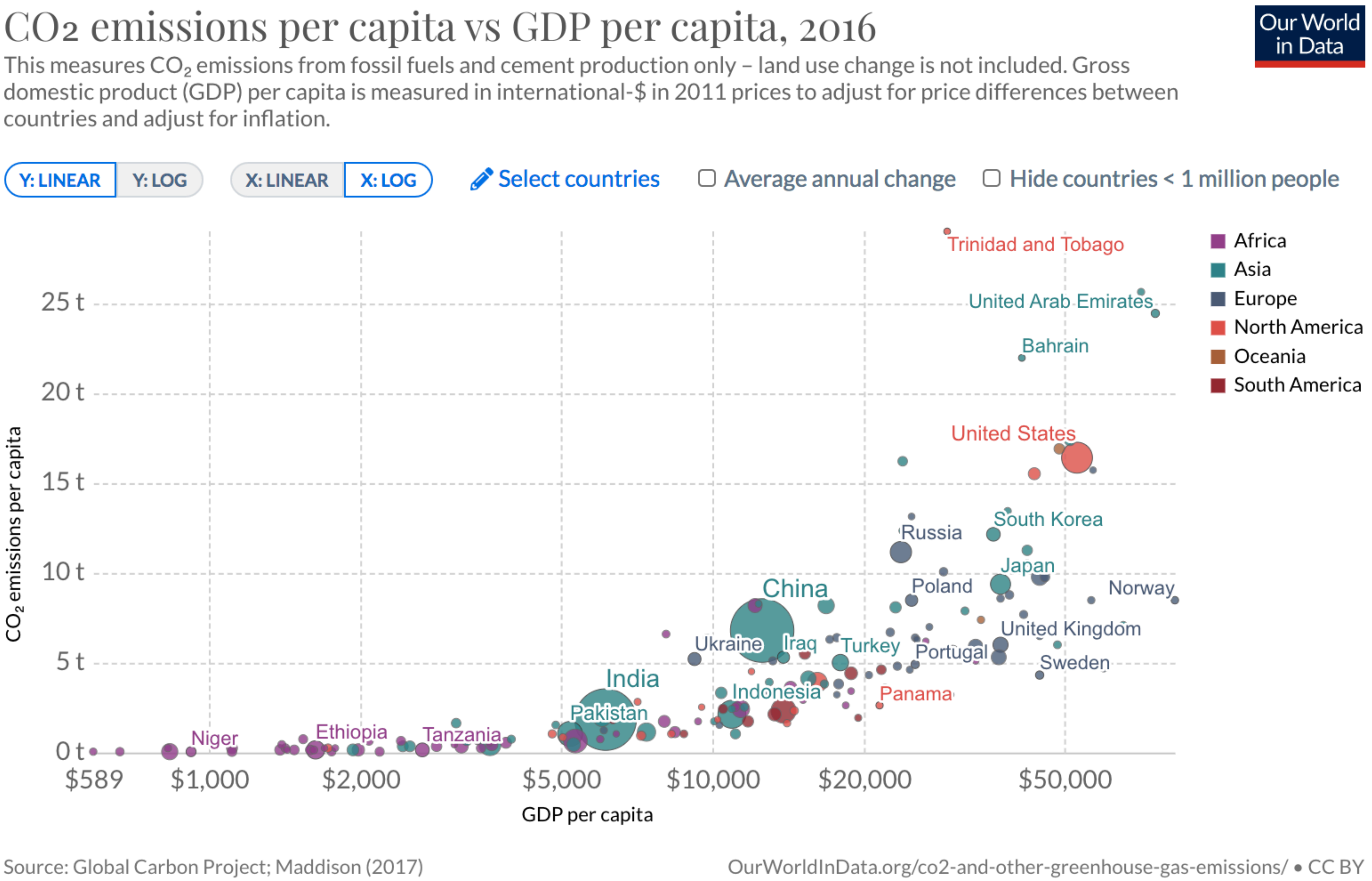
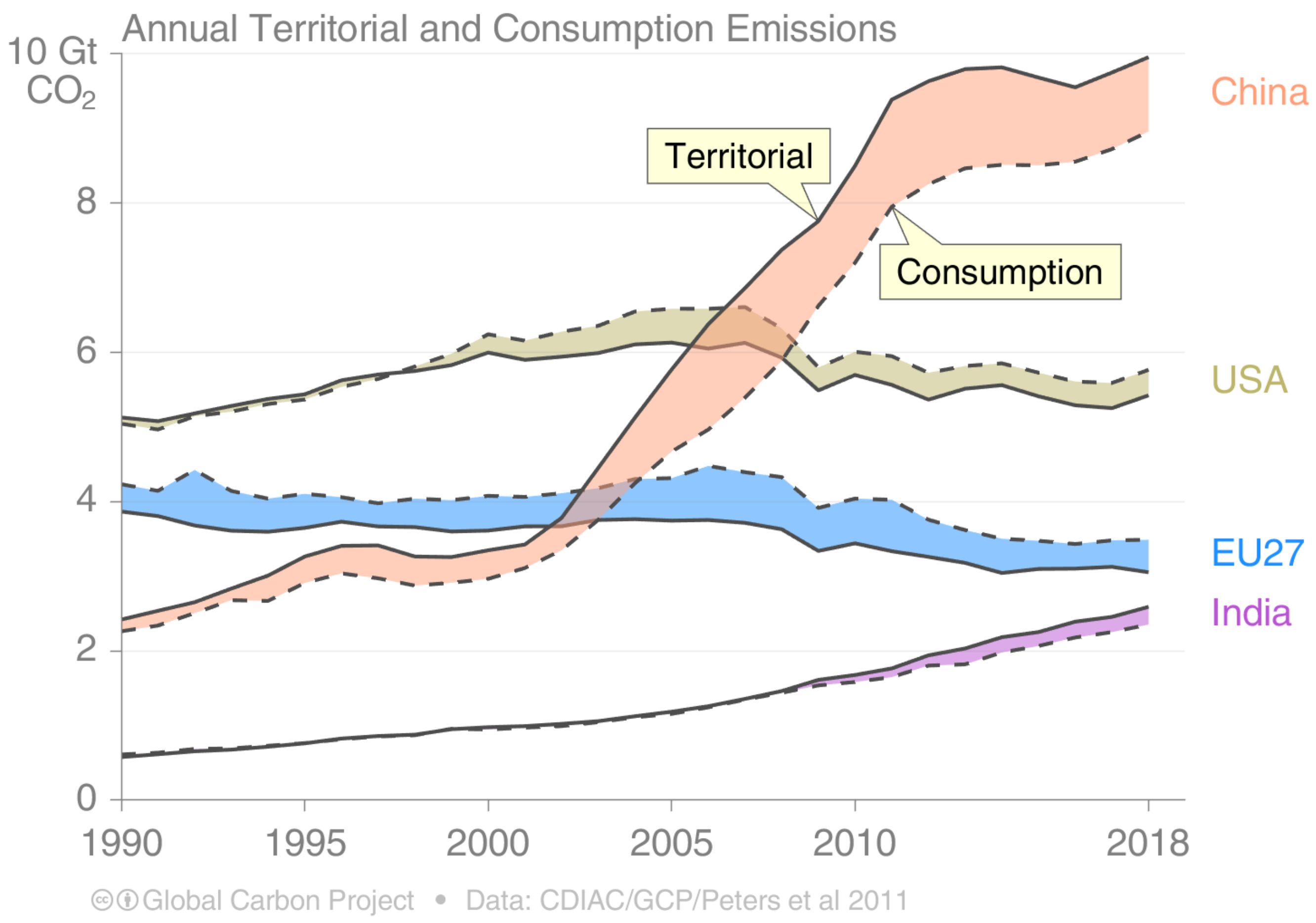


Explore more here:
https://ourworldindata.org/emissions-drivers

Consumption-based emissions (carbon footprint)

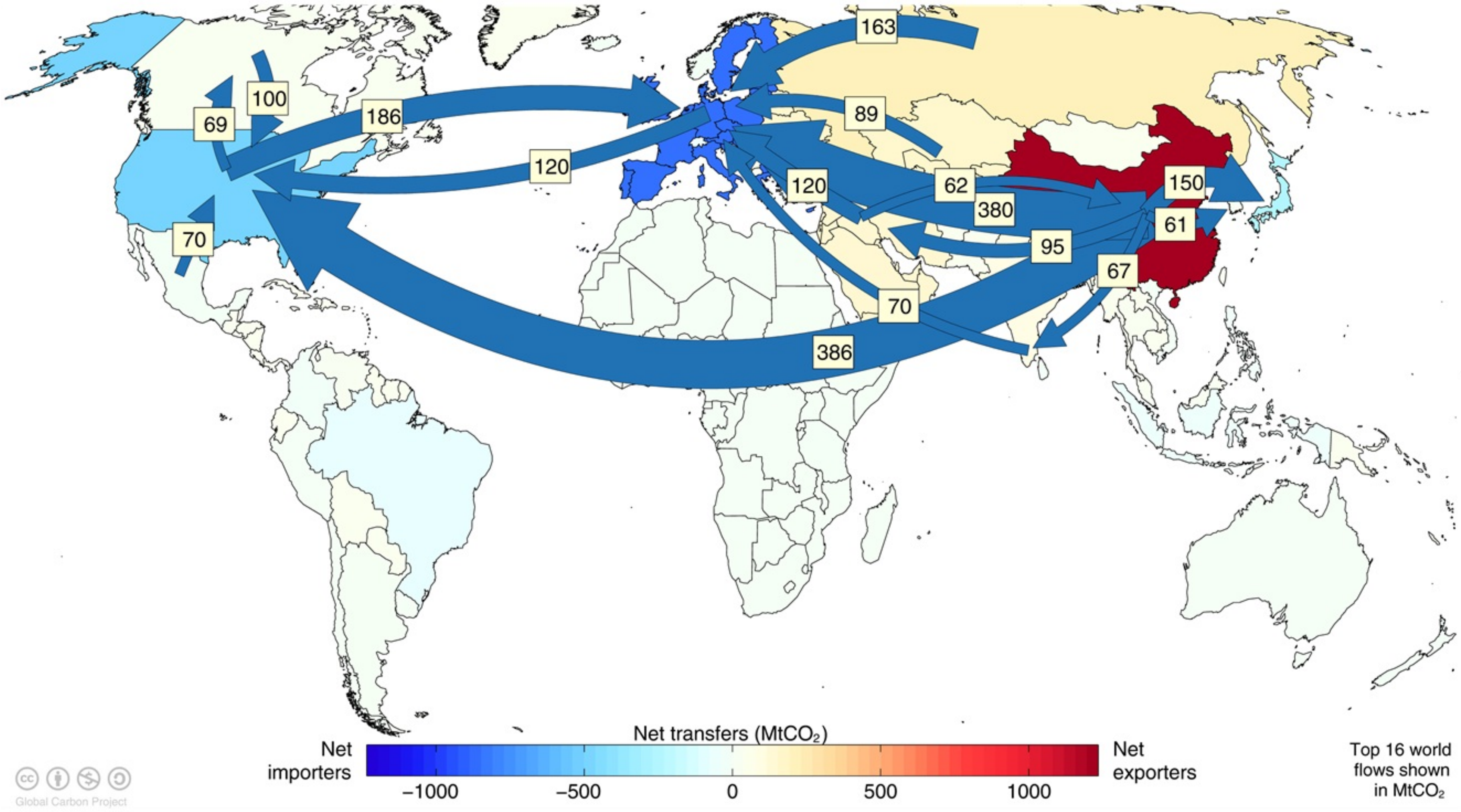
Allocating fossil CO_2 emissions to consumption provides an alternative perspective.
USA and EU28 are net importers of embodied emissions, China and India are net exporters.



Consumption-based emissions are calculated by adjusting the
standard production-based emissions to account for international trade
Source: Peters et al 2011; Friedlingstein et al 2020; Global Carbon Project 2019

Major flows from production to consumption

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



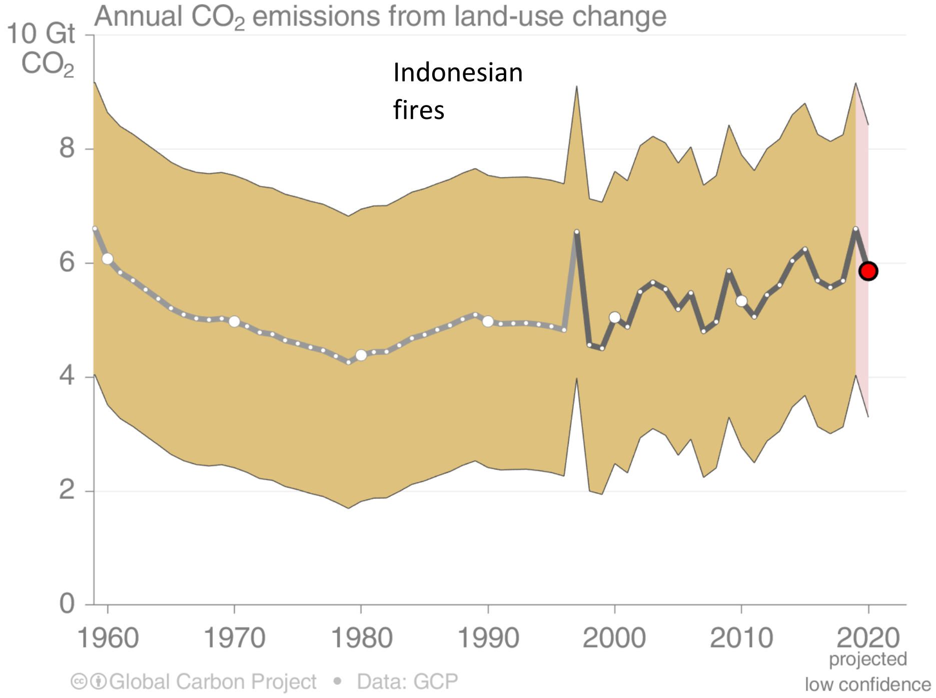
Values for 2011. EU is treated as one region. Units: $MtCO_2$
Source: Peters et al 2012

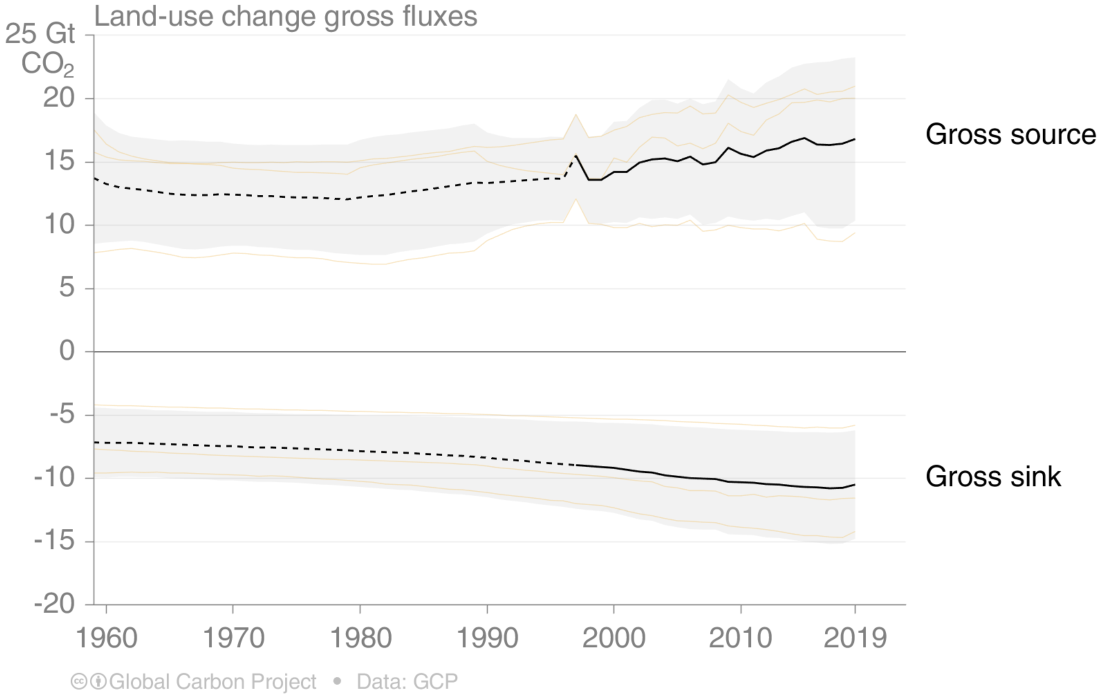
Land-use Change Emissions

Land-use change emissions

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

Net land-use emissions are the difference between CO_2 source, primarily from deforestation, and CO_2 sink, primarily from abandonment of agricultural land





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

Source: Houghton and Nassikas 2017; Hansis et al 2015; Gasser et al 2020; van der Werf et al. 2017; Friedlingstein et al 2020; Global Carbon Budget 2020

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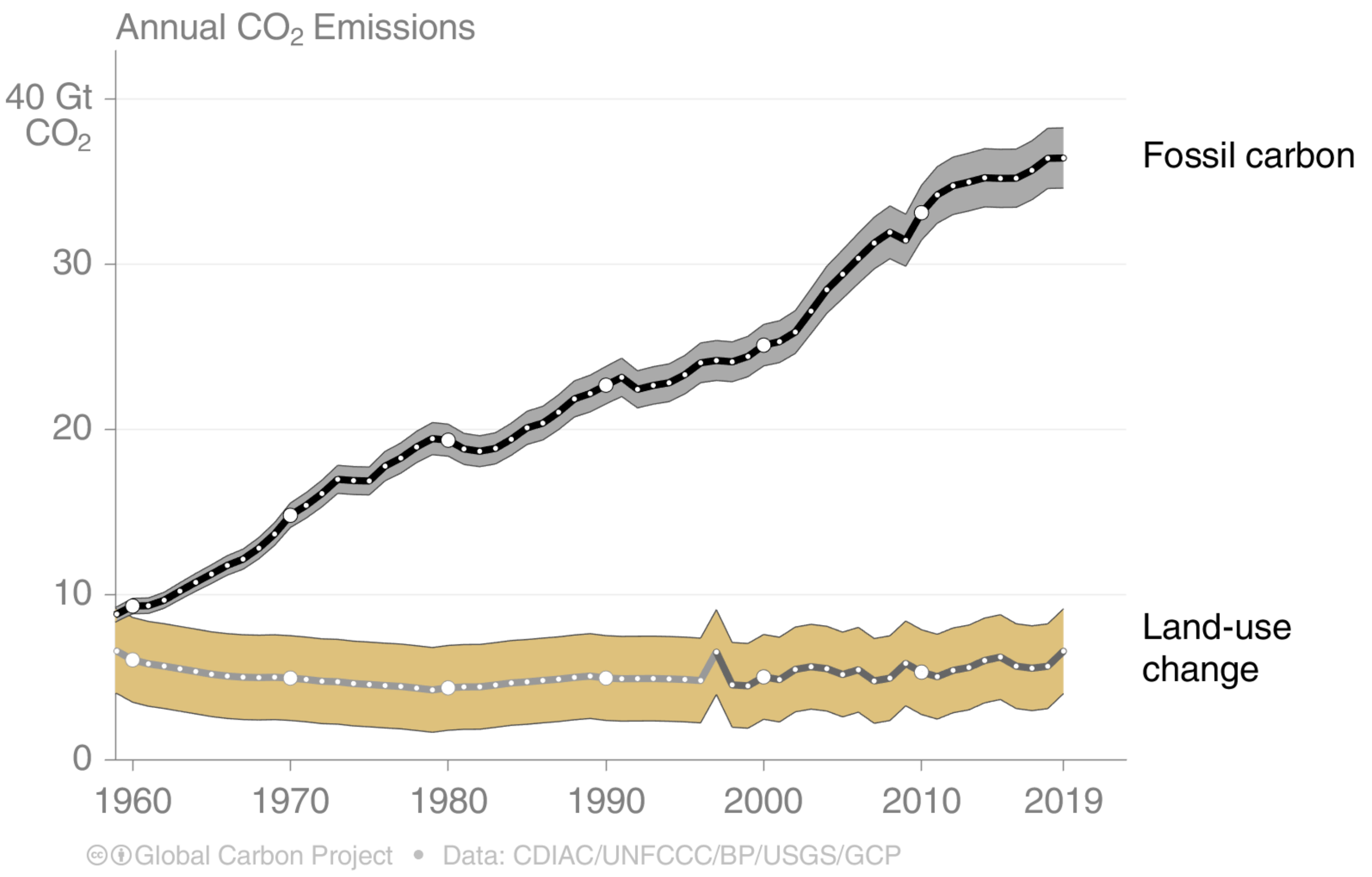
Total global emissions

Total global emissions: 43.0 ± 3.3 GtCO_2 in 2019, 56% over 1990
Percentage land-use change: 39% in 1960, 14% averaged 2010–2019



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

Source: CDIAC; Houghton and Nassikas 2017; Hansis et al 2015; Gasser et al 2020; van der Werf et al. 2017; Friedlingstein et al 2020; Global Carbon Budget 2020

Closing the Global Carbon Budget

GLOBAL CARBON PROJECT

Fate of anthropogenic CO_2 emissions (2010–2019)

Sources = Sinks

34.4 $GtCO_2/yr$

86%

14%

5.7 $GtCO_2/yr$

18.6 $GtCO_2/yr$

46%

31%

12.5 $GtCO_2/yr$

23%

9.2 $GtCO_2/yr$

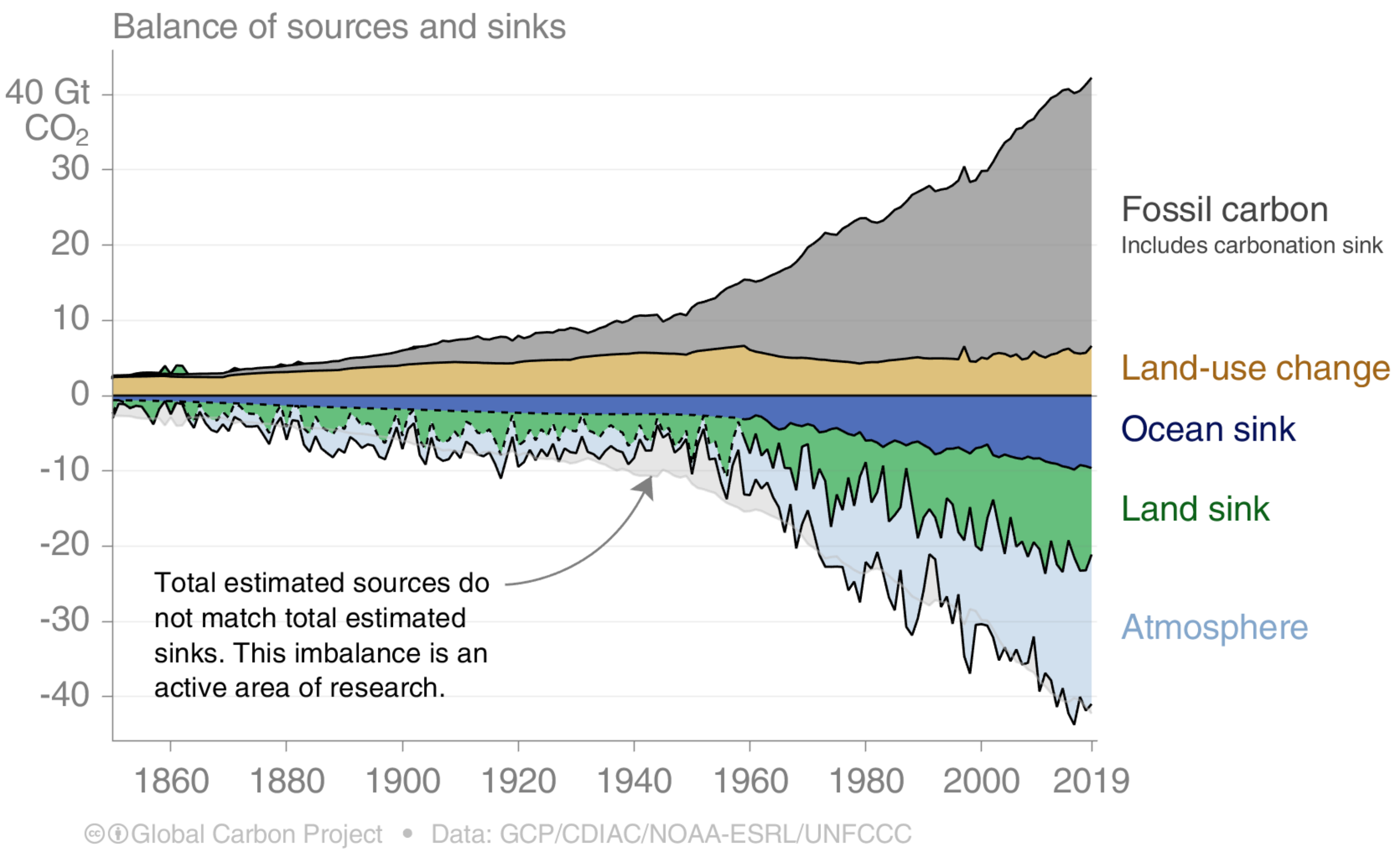
Budget Imbalance:
(the difference between estimated sources & sinks)

0.4%
0.2 $GtCO_2/yr$

Source: Friedlingstein et al 2020; Global Carbon Budget 2020

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 2020; Global Carbon Budget 2020

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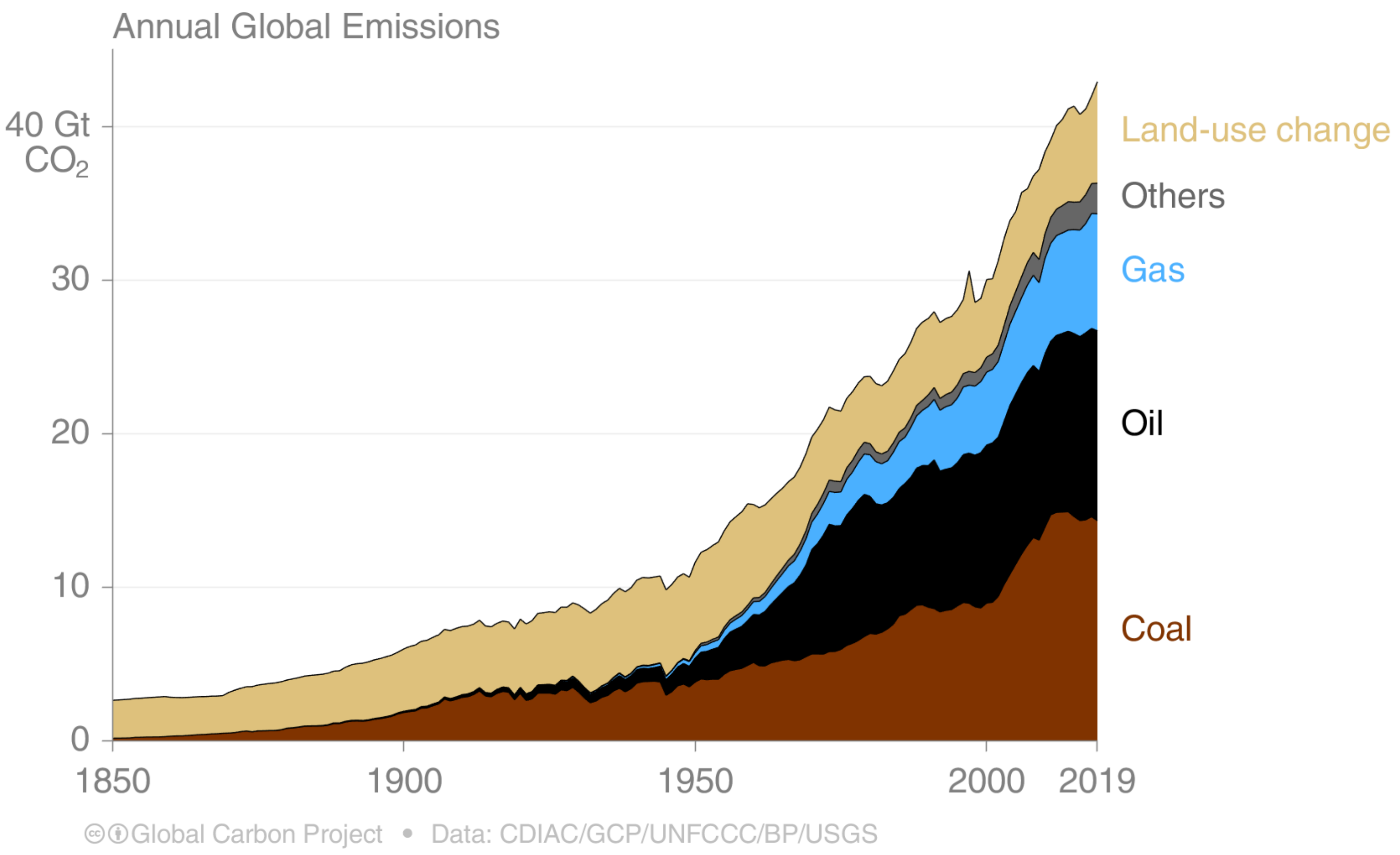
Additional Figures
Historical Emissions

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.

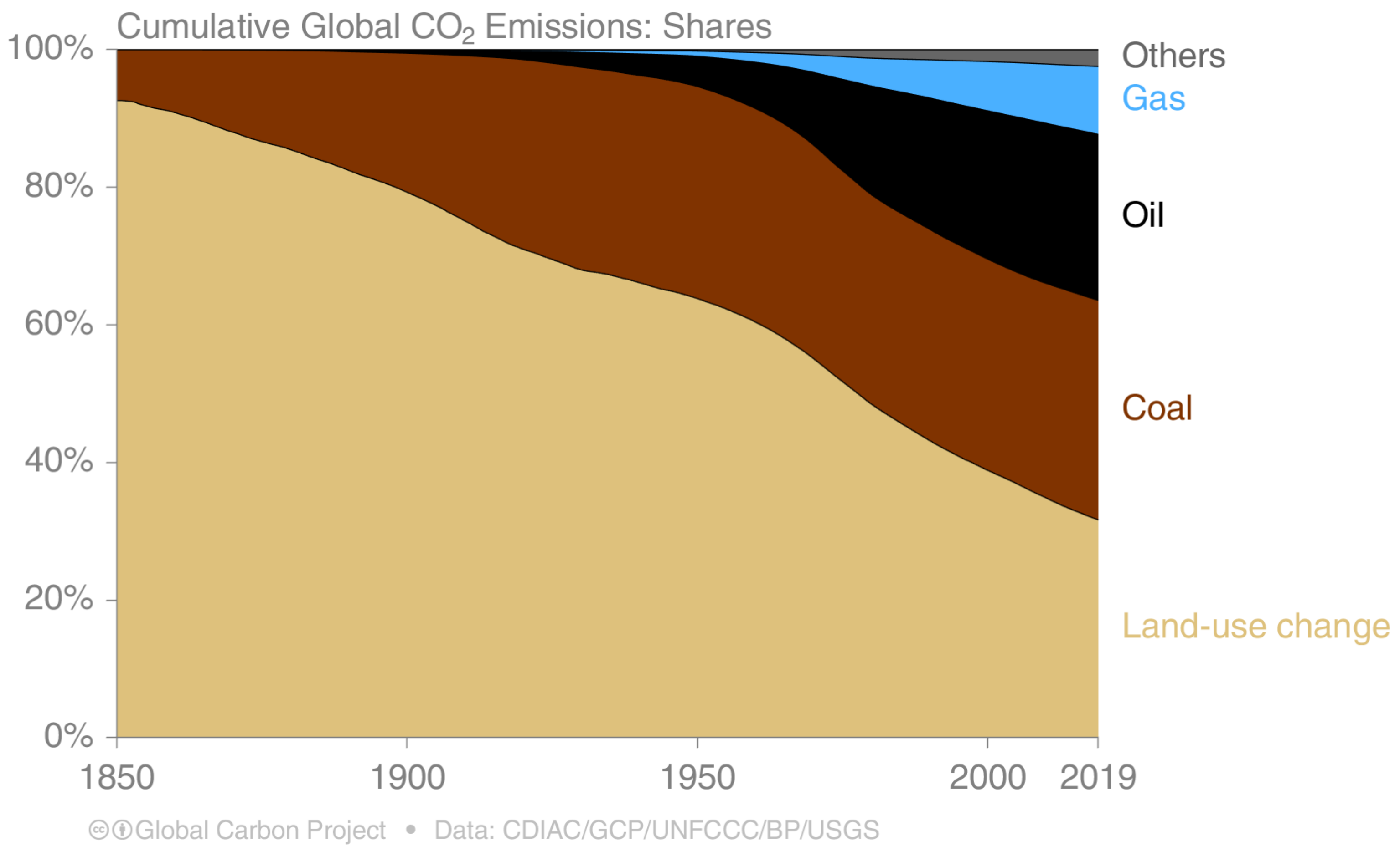


Others: Emissions from cement production and gas flaring

Source: CDIAC; Houghton and Nassikas 2017; Hansis et al 2015; Gasser et al 2020; Friedlingstein et al 2020; Global Carbon Budget 2020

Historical cumulative emissions by source

Land-use change represents about 32% of cumulative emissions over 1850–2019, coal 32%, oil 24%, gas 10%, and others 2%

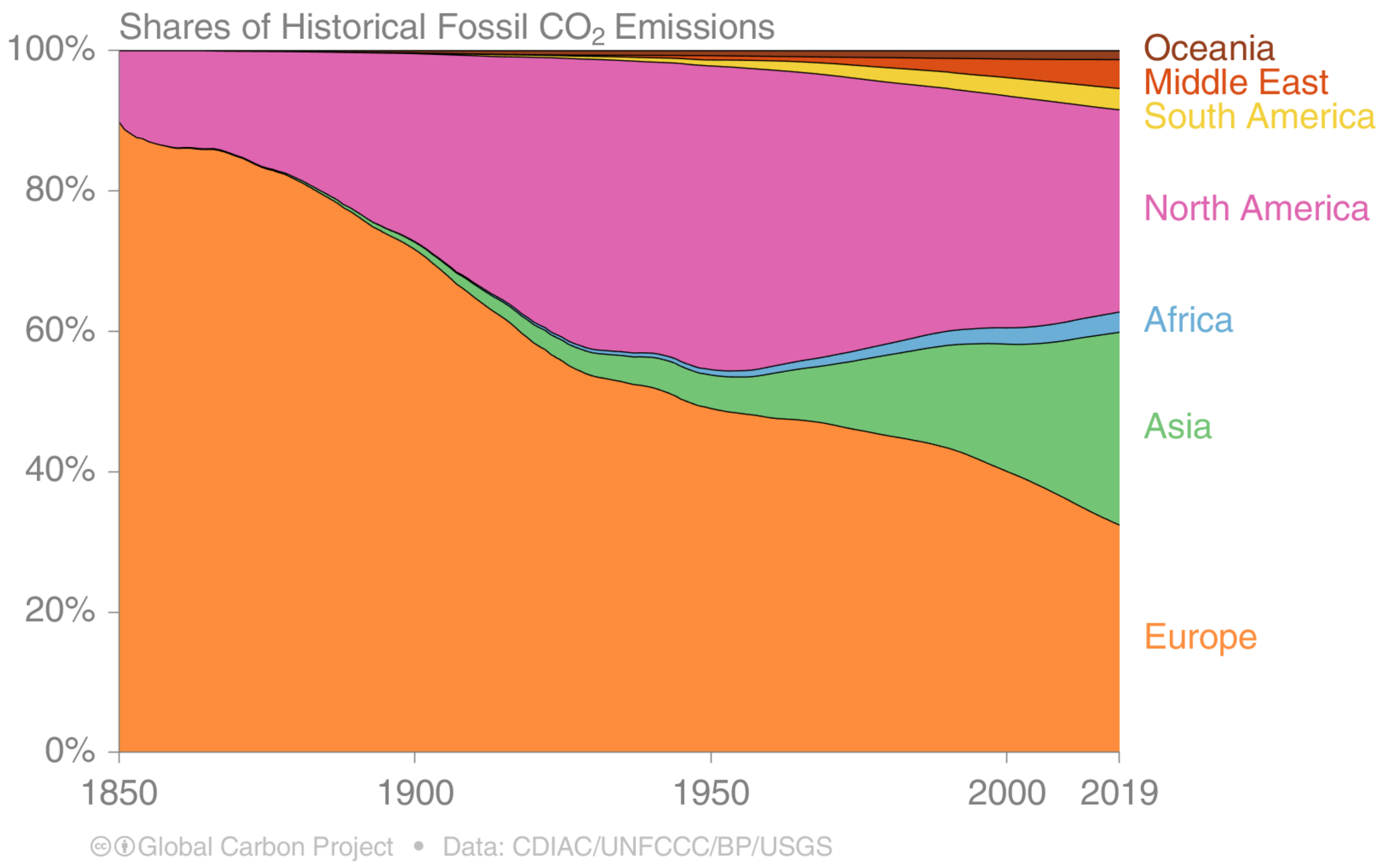


Others: Emissions from cement production and gas flaring

Source: CDIAC; Houghton and Nassikas 2017; Hansis et al 2015; Gasser et al 2020; Friedlingstein et al 2020; Global Carbon Budget 2020

Historical cumulative emissions by continent

Cumulative fossil CO_2 emissions (1850–2019). North America and Europe have contributed the most cumulative emissions, but Asia is growing fast



The figure excludes bunker fuels

Source: CDIAC; Friedlingstein et al 2020; Global Carbon Budget 2020

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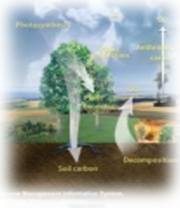
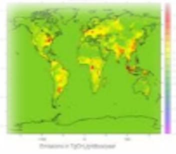
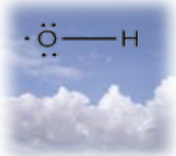






Global Methane Budget

2020

The Global Methane budget for 2000-2017

The GCP is a Global Research Project of futurearth Research. Innovation. Sustainability. and a Research Partner of WCRP World Climate Research Programme

Published on 15 July 2020

PowerPoint version 1.0 (released 15 July 2020)

All data are shown in

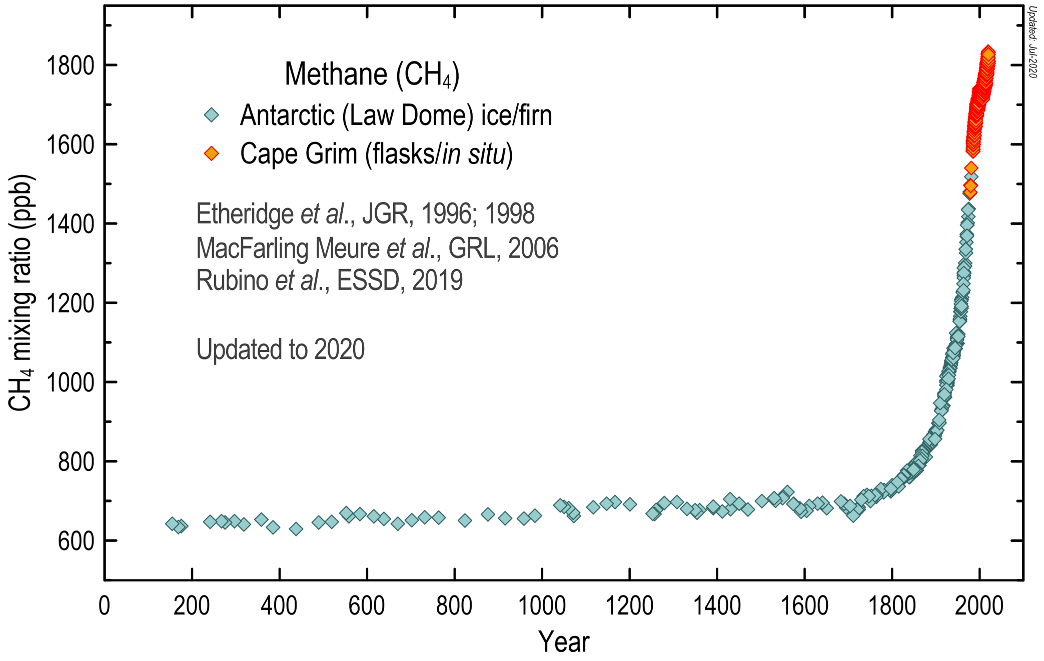
teragrams CH_4 ($TgCH_4$) for emissions and sinks
parts per billion (ppb) for atmospheric concentrations

1 teragram (Tg) = 1 million tonnes = 1×10^{12}g
2.78 Tg CH_4 per ppb

Disclaimer

The methane context

- After carbon dioxide (CO_2), methane (CH_4) is the most important greenhouse gas contributing to human-induced climate change.
- For a time horizon of 100 years, CH_4 has a Global Warming Potential 28 times larger than CO_2.
- Methane is responsible for 23% of the global warming produced by CO_2, CH_4 and N_2O.
- The concentration of CH_4 in the atmosphere is 150% above pre-industrial levels (cf. 1750).
- The atmospheric lifetime of CH_4 is 9±2 years, making it a good target for climate change mitigation

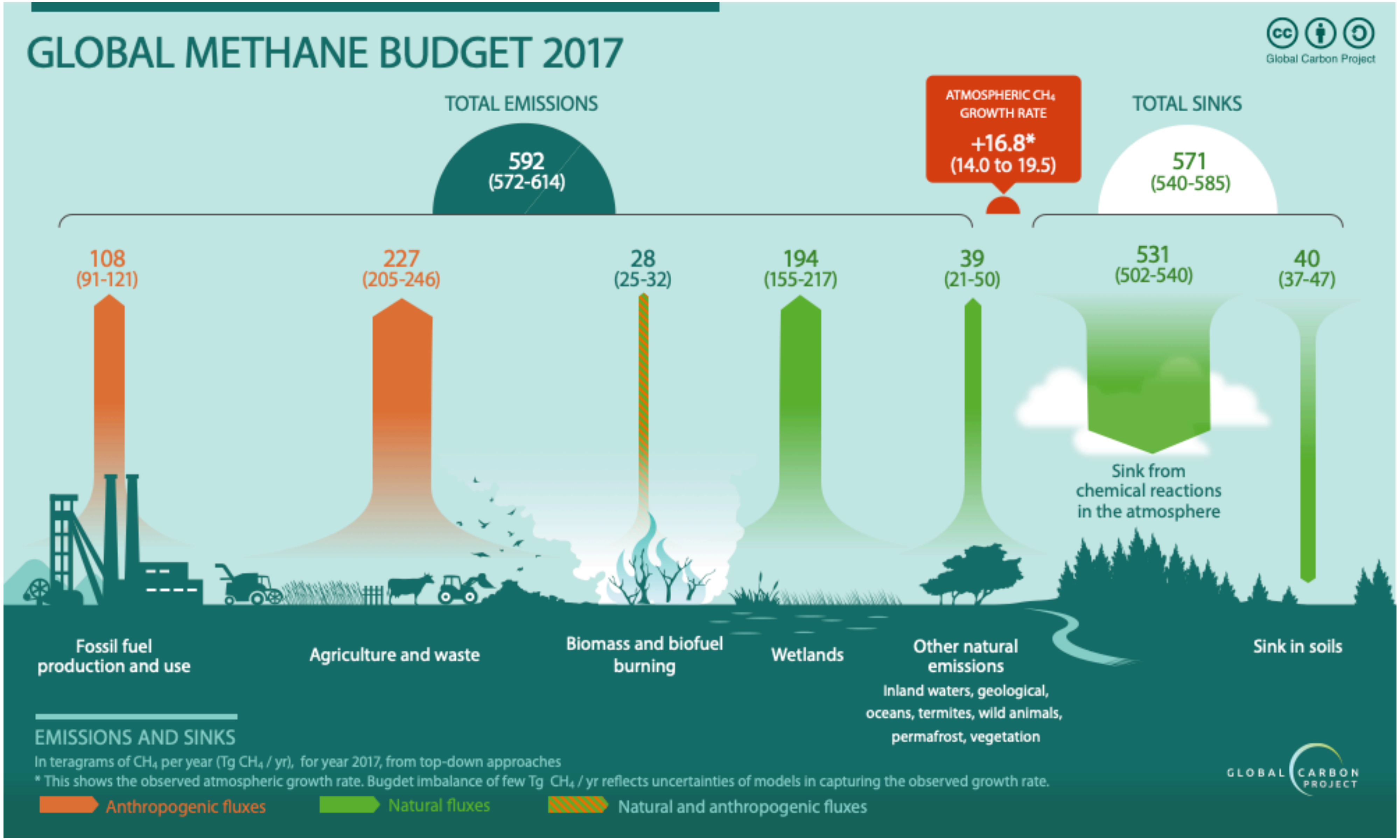


- Methane also contributes to tropospheric production of ozone, a pollutant that harms human health, food production and ecosystems.
- Methane also leads to production of water vapor in the stratosphere by chemical reactions, enhancing global warming.

Sources : Saunois et al. 2016; 2020, ESSD; IPCC 2013 5AR; Etminan et al. 2016

Global Methane Budget 2017

Top-down budget



Source: Jackson et al. 2020, ERL (Fig. 1)

Global Methane Emissions 2008-2017

Bottom-up budget | ($TgCH_4$/yr) | Top-down budget

Bottom-up budget		Top-down budget
149 [50%]	**Natural wetlands**	**181 [20%]**
206 [15%]	**Agriculture & waste**	**217 [15%]**
Rice 30 [40%]		
Enteric ferm & manure 111 [10%]		
Landfills & waste 65 [15%]		
128 [30%]	**Fossil fuel**	**111 [50%]**
Coal 42 [80%]		
Gas & oil 80 [30%]		
Industry and transport 7 [250 %]		
30 [30%]	**Biomass/biofuel burning**	**30 [50%]**
222 [70%]	**Other natural emissions**	**37 [80%]**
Inland waters 209 [70%]		
Geological 45 [100%]		
Termites 9 [100%]		
Oceans 6 [100%]		
Wild animals 2 [100%]		
Permafrost 1 [100%]		

Mean [uncertainty = min-max range %]

Mean [uncertainty= min-max range %]

Bottom-up budget
Process models, inventories, data driven methods
737 $TgCH_4$/yr [584-881]

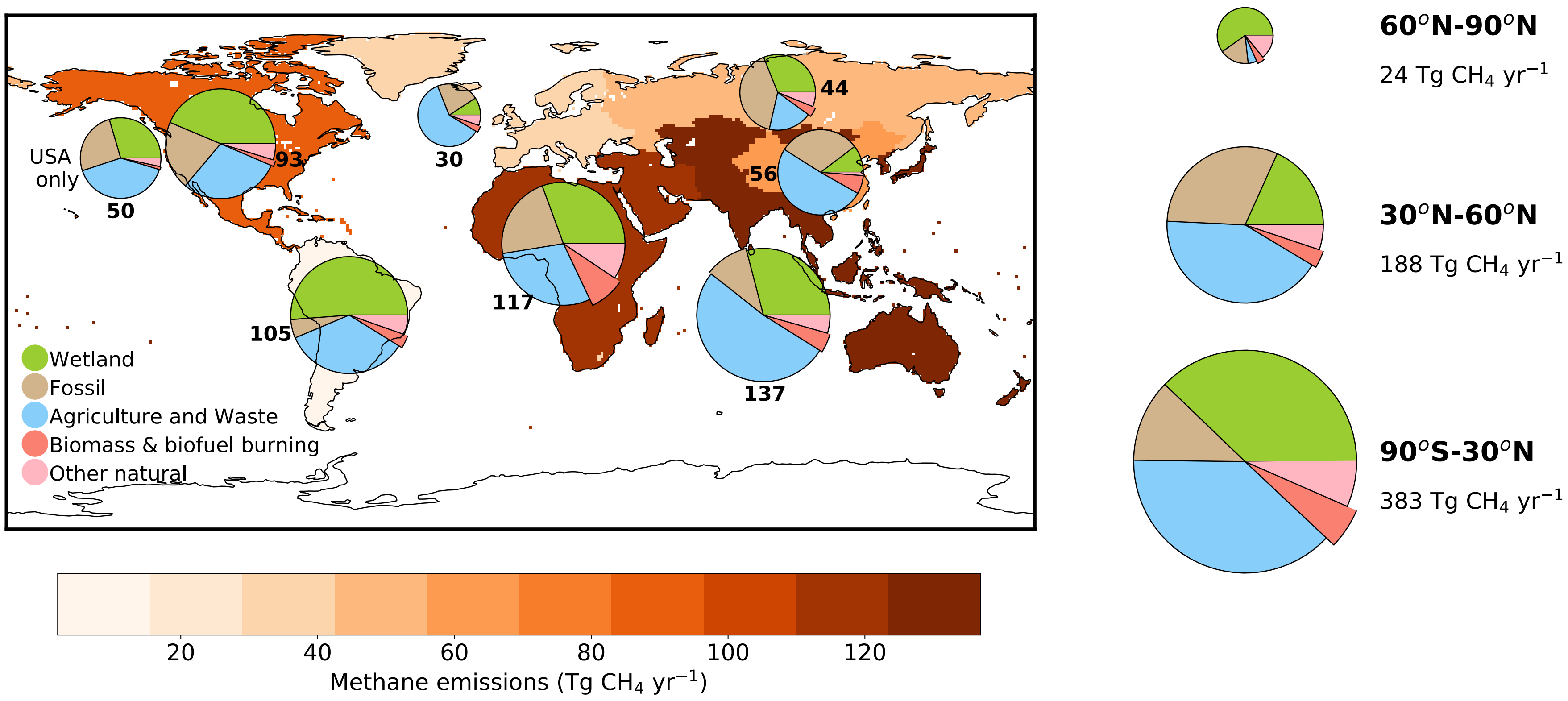
Mean [min-max range %]

Top-down budget
Atmospheric inversions
576 $TgCH_4$/yr [550-594]

Source : *Saunois et al. 2020, ESSD*

Regional Methane Sources (2017)

Top-down budget



- 64% of global methane emissions come mostly from tropical sources
- Anthropogenic sources are responsible for about 60% of global emissions.
- Largest emissions in South America, Africa, South-East Asia and China (50% of global emissions)
- Dominance of wetland emissions in the tropics and boreal regions
- Dominance of agriculture & waste in Asia
- Balance between agriculture & waste and fossil fuels at mid-latitudes

Source: Jackson et al. 2020 ERL (Fig 2)

Inverse models

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In partnership with International Nitrogen Initiative

Global Nitrous Oxide Budget

2020

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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N_2O Basics

- N_2O is both a powerful greenhouse gas (GHG) and a ozone-depleting substance.
- Per unit of mass, N_2O is considered 298 times as effective as a greenhouse gas as CO_2 when integrating over 100-years.
- Once emitted, N_2O stays in the atmosphere for longer than a human life, about 116 ±9 years.
- N_2O is the third most important GHG contributing to human-induced global warming, after carbon dioxide (CO_2) and methane (CH_4).
- N_2O is responsible for 6.5% of the global warming due to three most important GHGs (CO_2, CH_4 and N_2O) (Updated to 2019 from Etminan et al. 2016, GRL)
- N_2O concentration in the atmosphere reached 331 parts per billion (ppb) in 2018 (WMO 2020, United in Science), about 22% above levels around the year 1750, before the industrial era began.

Highlights

- Global N_2O emissions were about 17.0 (15.9–17.7) Tg N yr^{-1} over the 10-year period 2007-2016 (based on two approaches).

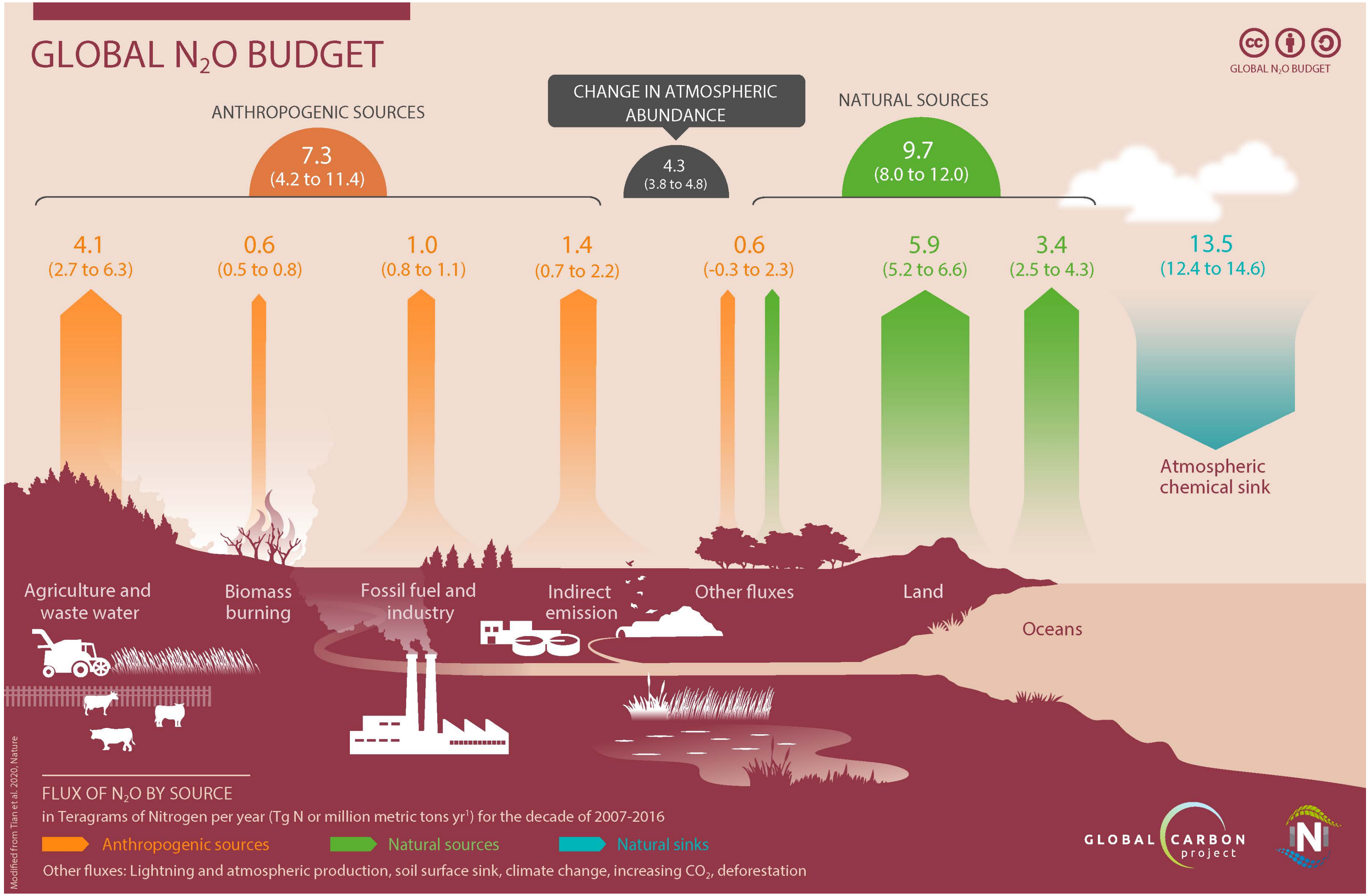
- Global anthropogenic emissions increased by 30% since 1980, dominated by nitrogen fertilization in croplands. The anthropogenic emission increase is almost exclusively responsible for the growth in atmospheric N_2O.

- Soil N_2O emissions are increasing due to interactions between nitrogen inputs and global warming, constituting an emerging positive N_2O-climate feedback.

- The recent increase in global N_2O emissions exceeds the emission trends of the least optimistic scenarios developed by the Intergovernmental Panel on Climate Change (IPCC), underscoring the urgent need to mitigate N_2O emissions.

The Global N_2O Budget (simplified)

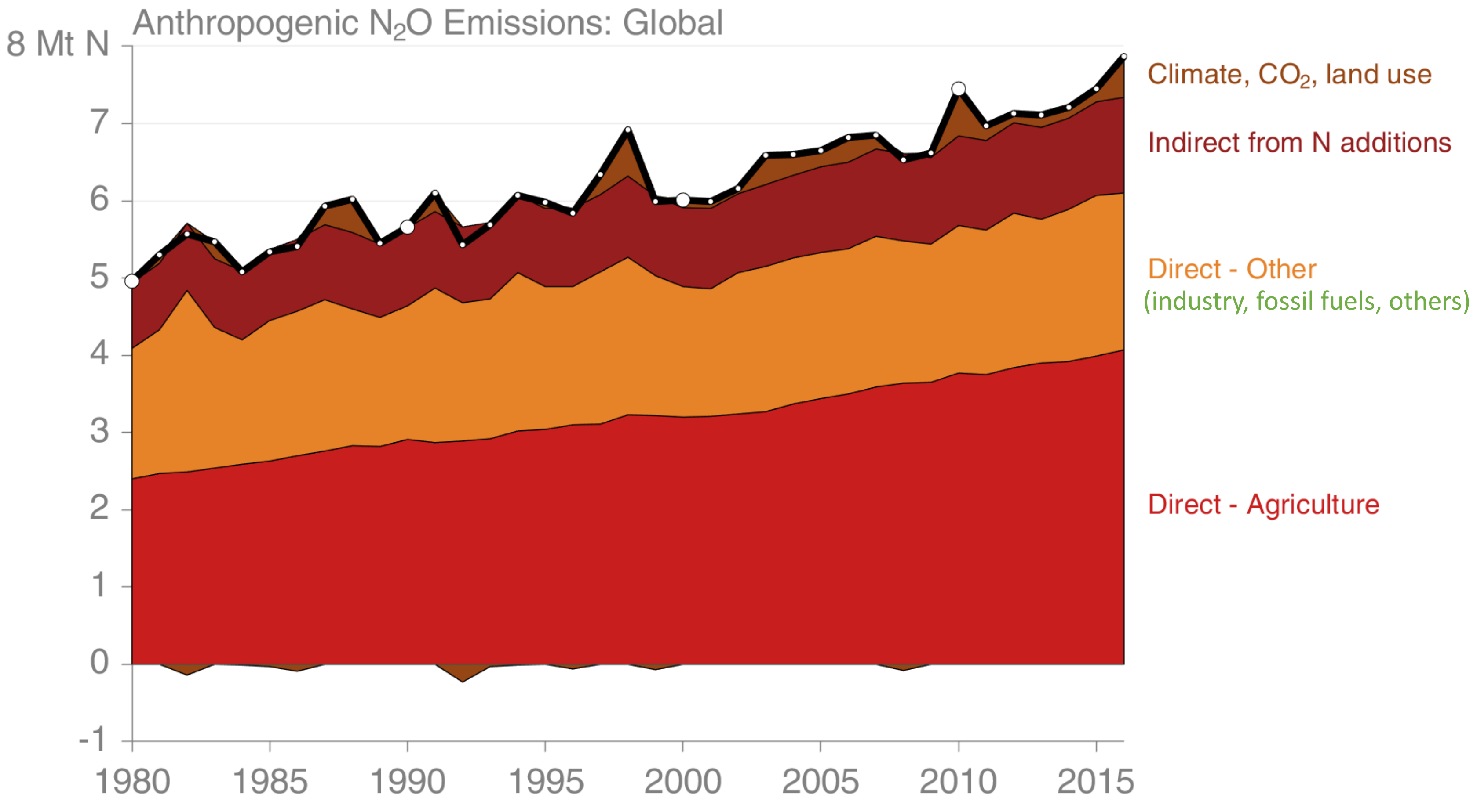
Anthropogenic sources contribute, for the central estimate, 43% to total global N_2O emissions.



Read the full paper here https://doi.org/10.1038/s41586-020-2780-0

Global Anthropogenic N_2O Emissions

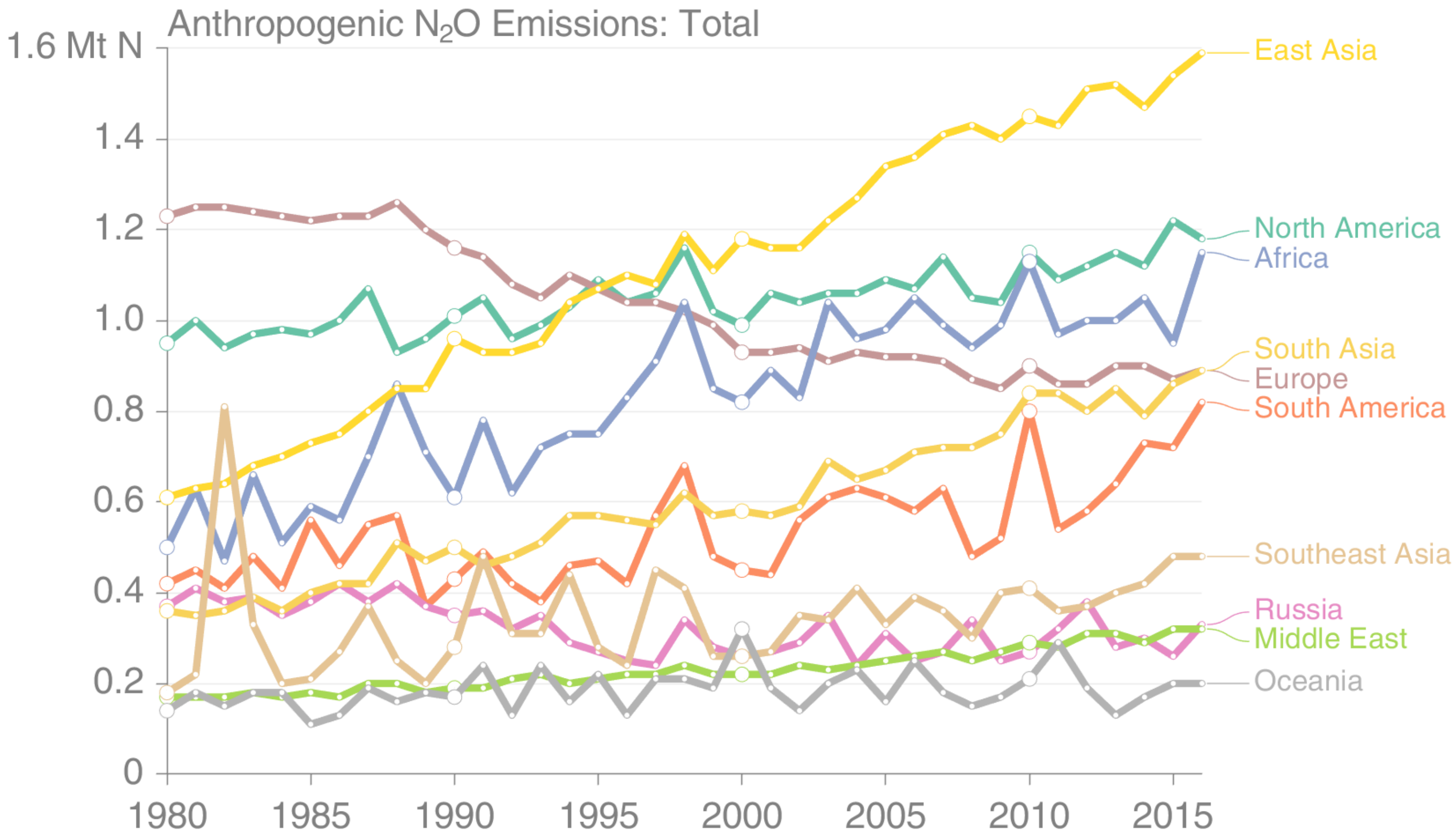
Global anthropogenic N_2O emissions are growing at over 1% pear year.
Agriculture is the single largest anthropogenic source of N_2O emissions.



Direct sources are those occurring where nitrogen additions are made, while indirect sources are those occurring down-stream or downwind

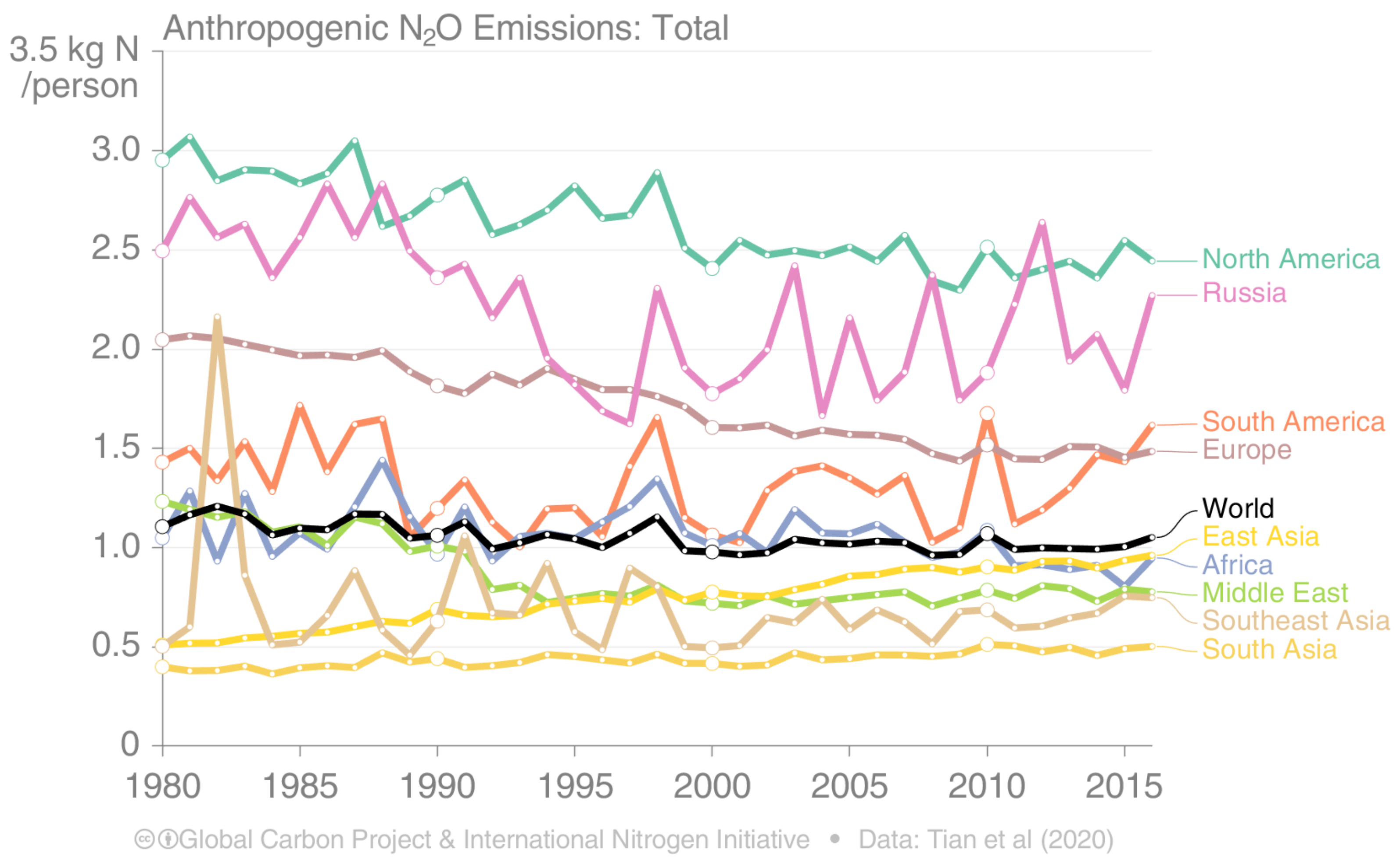
Anthropogenic Emissions by World Region

The recent global increase in N_2O emissions is driven by Asia, followed by South America and Africa, while emissions in Europe have decreased since 1990



Anthropogenic Emissions per Person by World Region

There is a broad range of N_2O emissions per person, with wealthier regions generally above the world average



Oceania excluded to make figure clearer. Oceania emits around 6kgN per person