U LISBOA | UNIVERSIDADE DE LISBOA

Universidade Nova de Lisboa

Seminar on Energy and Climate Change

Global carbon budget

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CENSE
center for environmental and sustainability research

https://www.cense.fct.unl.pt/

1. Global Carbon Budget (GCP, 2019)

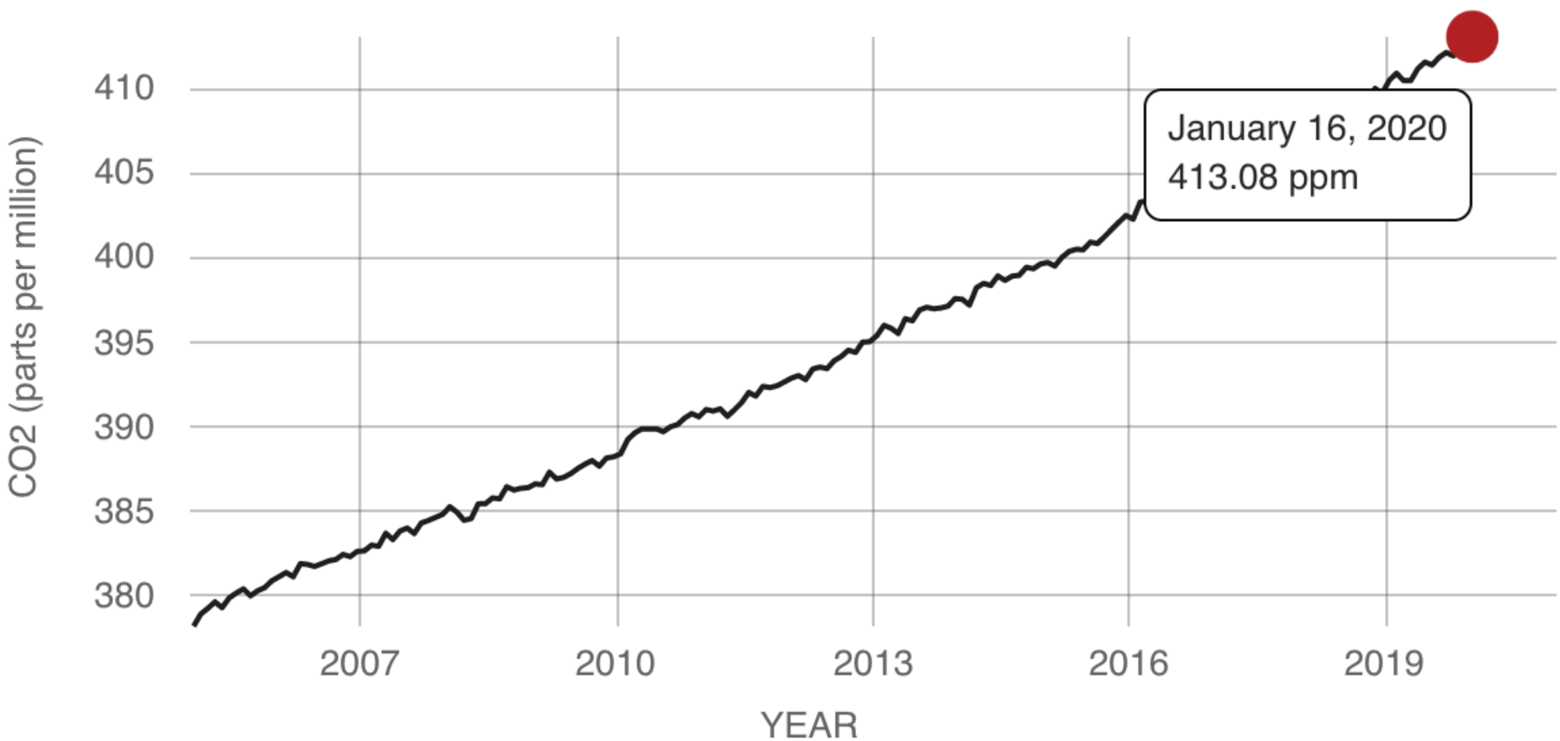
2. Global Methane Budget (CGP, 2016)

3. Emissions Scenarios

GLOBAL CLIMATE CHANGE
Vital Signs of the Planet

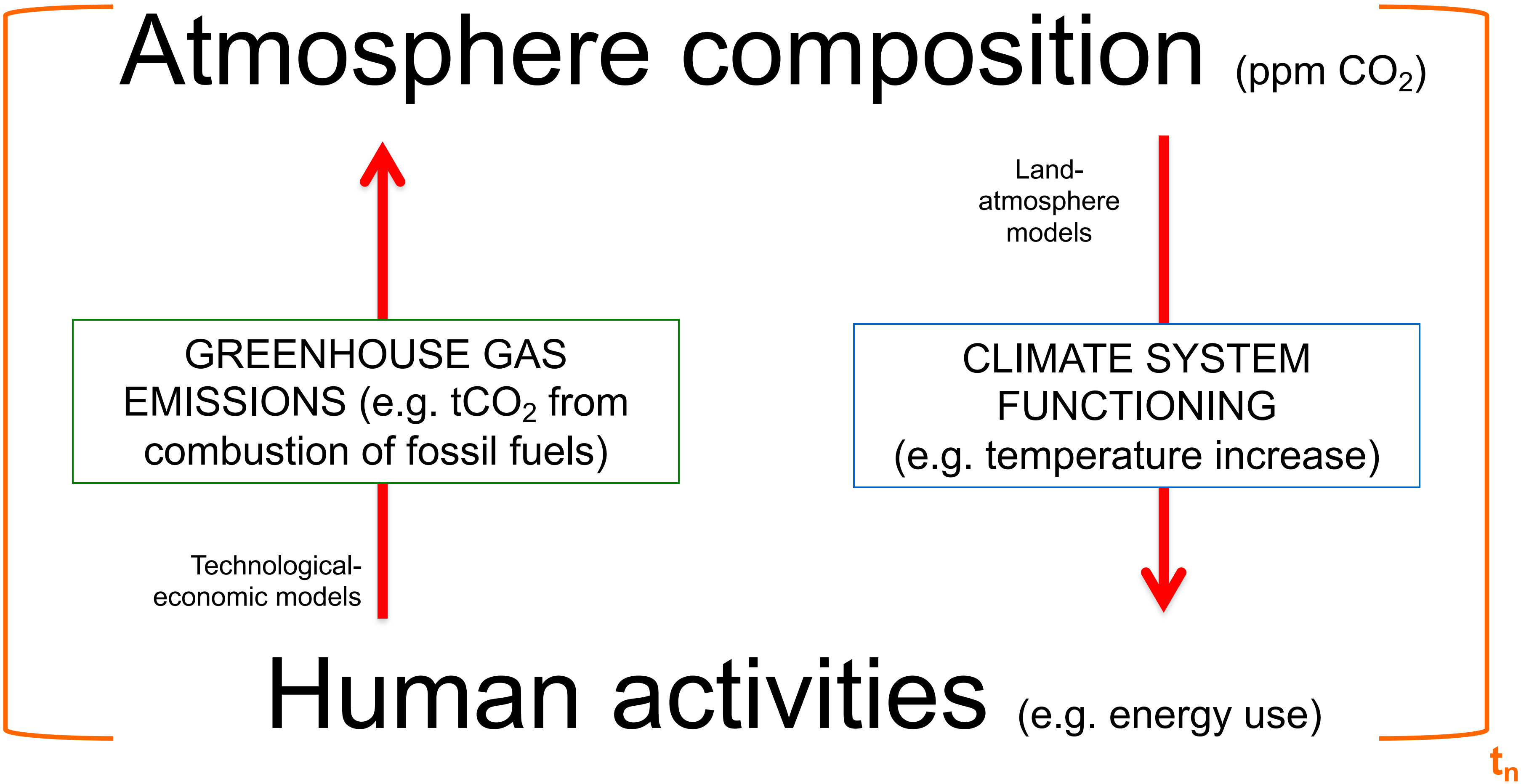
DIRECT MEASUREMENTS: 2005-PRESENT

Data source: Monthly measurements (average seasonal cycle removed). Credit: NOAA



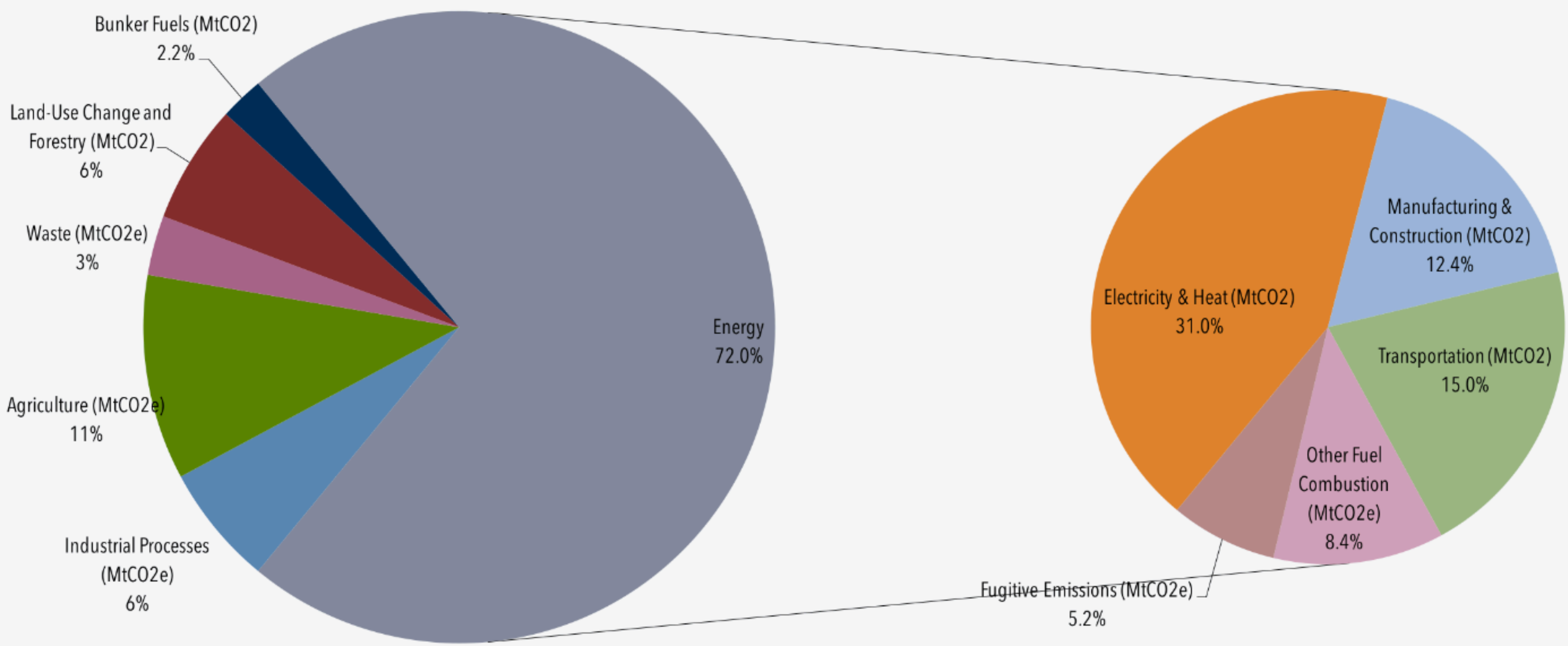
TIME SERIES: 2002-2016
Data source: Atmospheric Infrared Sounder (AIRS).
See the video here: http://climate.nasa.gov/vital-signs/carbon-dioxide/

Explore more at: https://climate.nasa.gov/



Meinshausen, M., S. J. Smith, K. V. Calvin, J. S. Daniel, M. L. T. Kainuma, J.-F. Lamarque, K. Matsumoto, S. A. Montzka, S. C. B. Raper, K. Riahi, A. M. Thomson, G. J. M. Velders and D. van Vuuren (2011). "The RCP Greenhouse Gas Concentrations and their Extension from 1765 to 2300." Climatic Change (Special Issue), DOI: 10.1007/s10584-011-0156-z, freely available online (PDF)

Global Manmade Greenhouse Gas Emissions by Sector, 2013



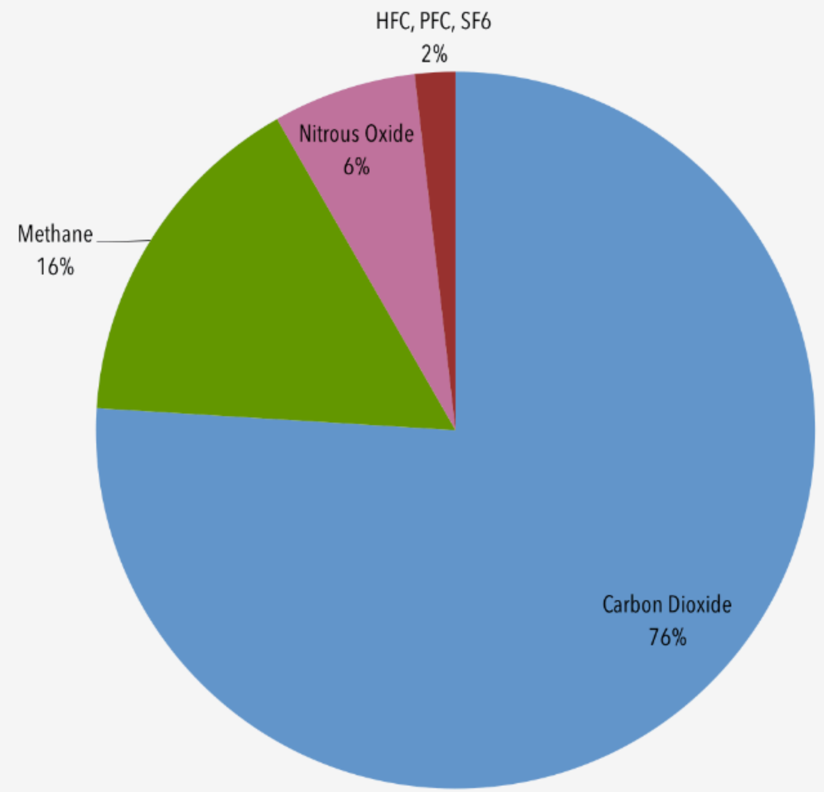
NOTES

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 Manmade Greenhouse Gas Emissions by Gas, 2015



NOTES

CO2 accounts for about 76 percent of total greenhouse gas emissions. Methane, primarily from agriculture, contributes 16 percent of greenhouse gas emissions and nitrous oxide, mostly from industry and agriculture, contributes 6 percent to global emissions. All figures here are expressed in CO2-equivalents.

SOURCE

Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2015 (EPA, 2017)

Global Carbon Budget

2019

http://www.globalcarbonproject.org/carbonbudget/index.htm

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 PDF or PNG from tinyurl.com/GCB17figs along with the data required to produce them.

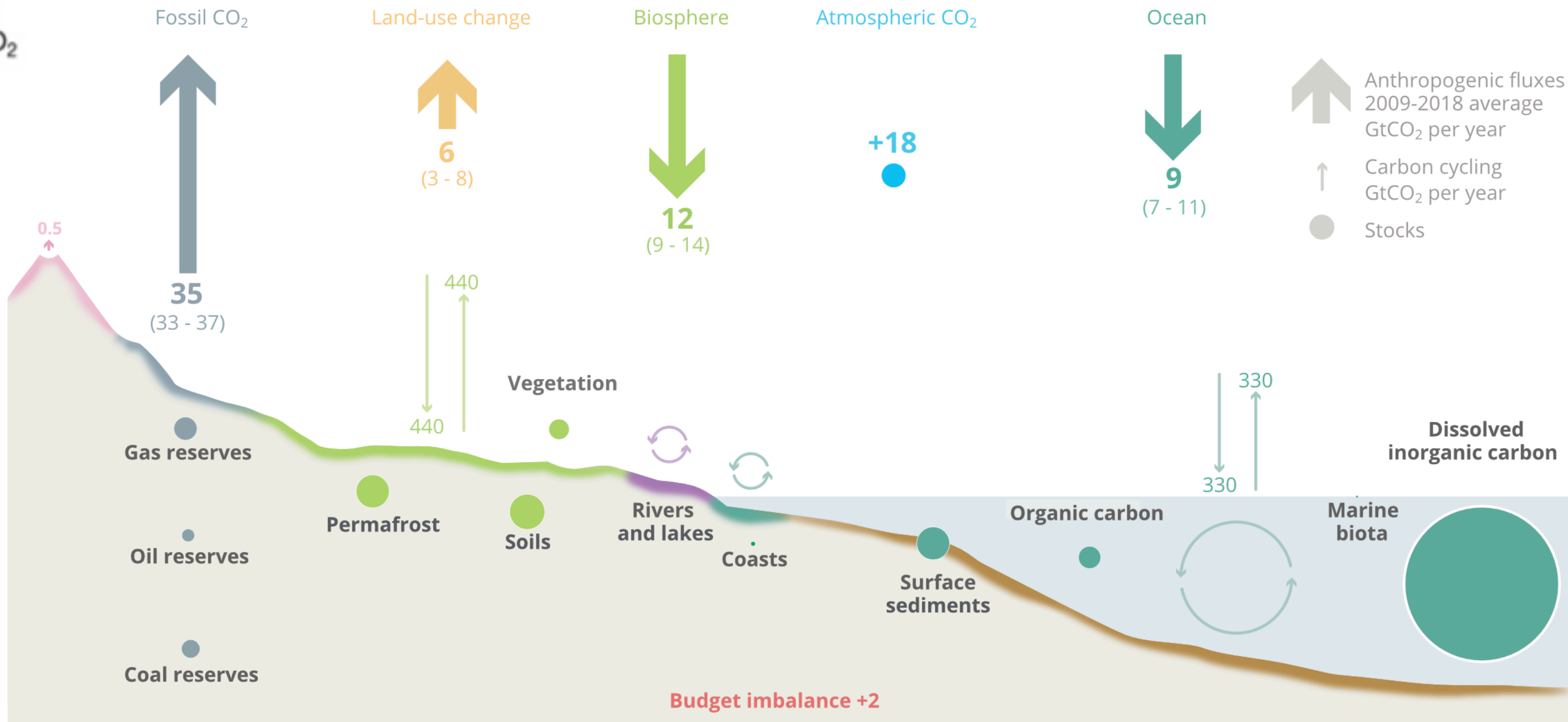
Disclaimer

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.

Perturbation of the global carbon cycle caused by anthropogenic activities, averaged globally for the decade 2009–2018 ($GtCO_2$/yr)

CO_2

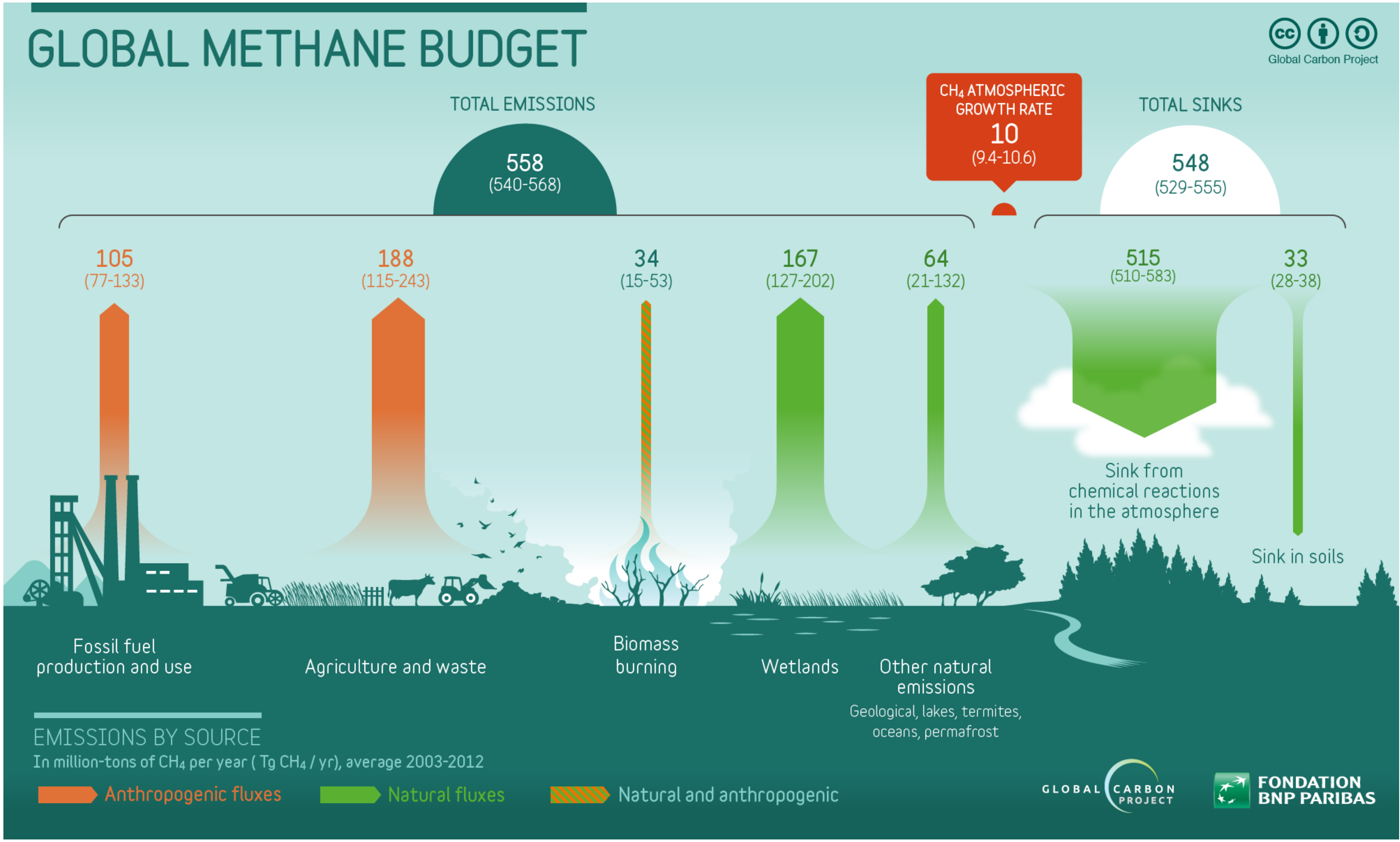
Climate sensitivity
2.5°C/doubling CO_2
67% greenhouse



The budget imbalance is the difference between the estimated emissions and sinks.
Source: CDIAC; NOAA-ESRL; Friedlingstein et al 2019; Ciais et al. 2013; Global Carbon Budget 2019

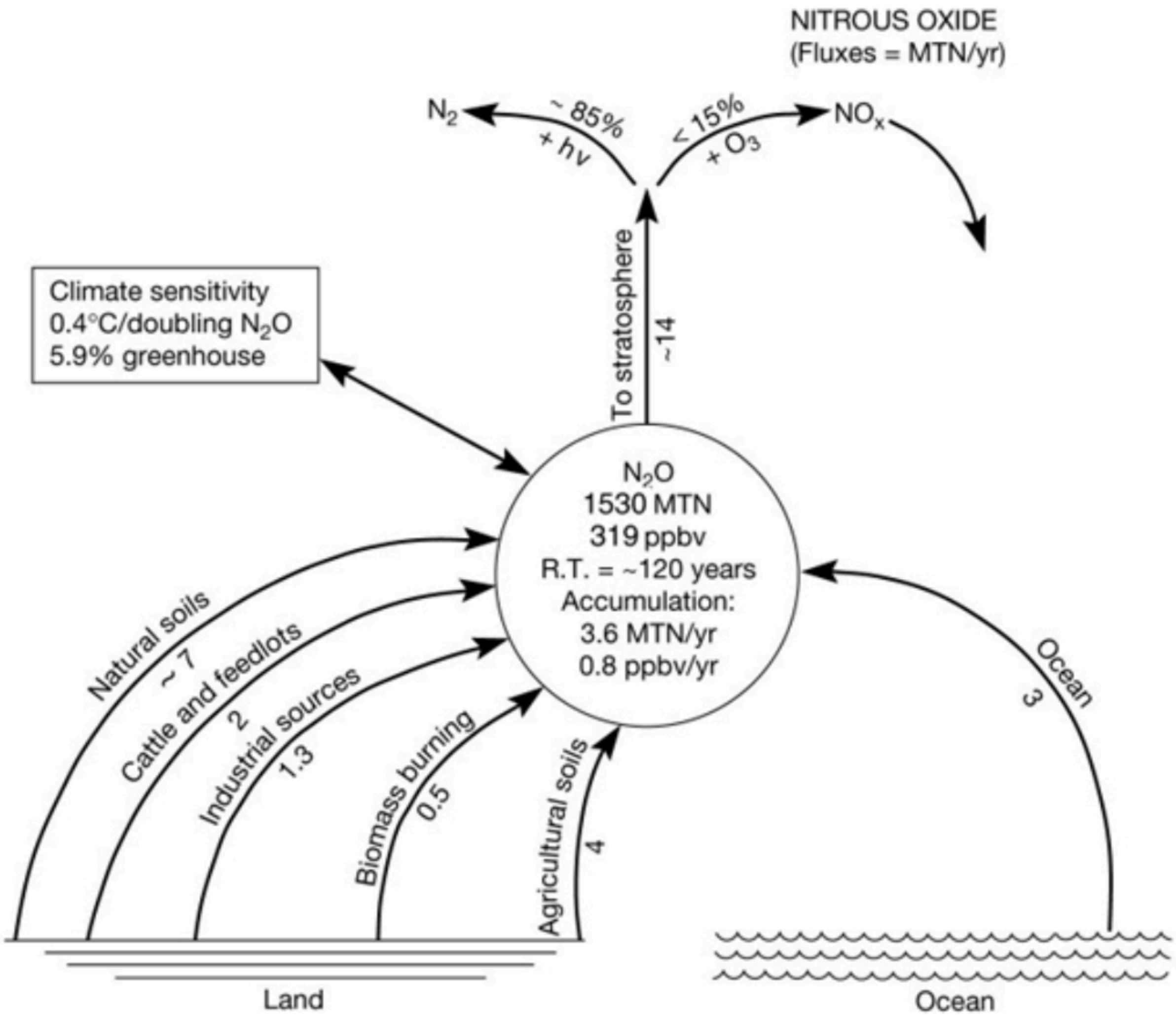
CH_4

Climate sensitivity
0.3°C/doubling CH_4
18% greenhouse

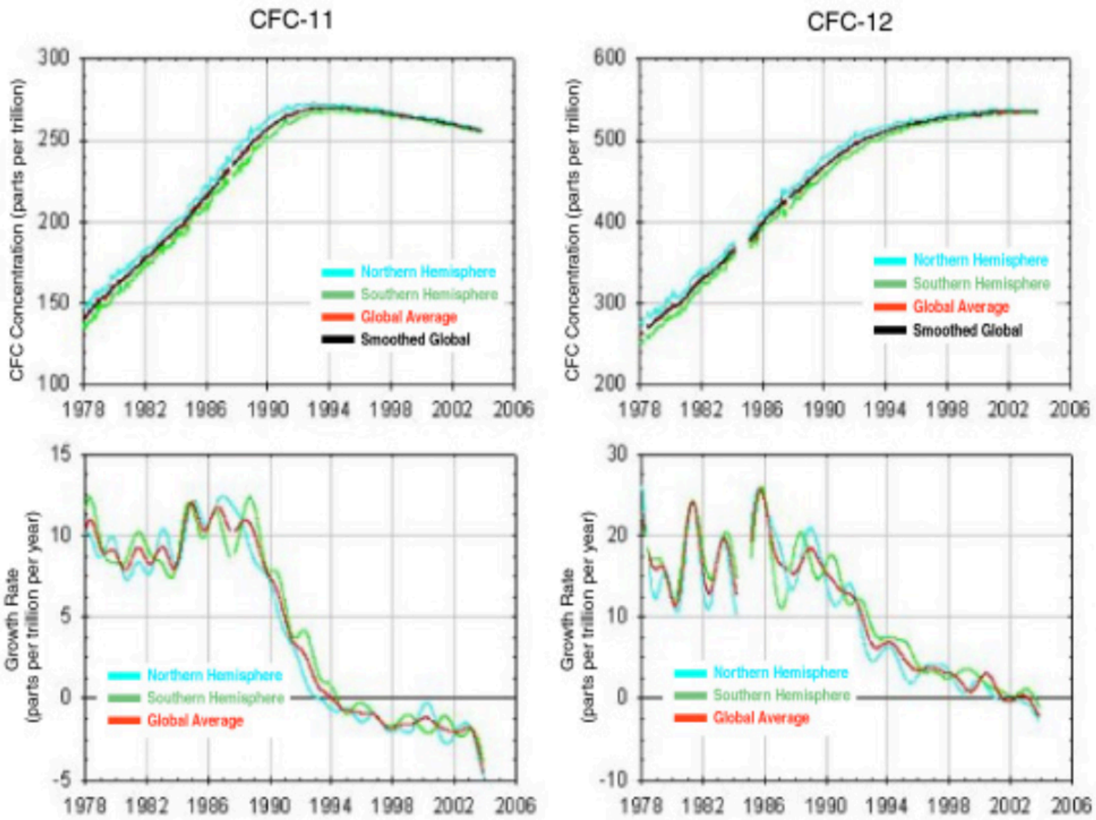


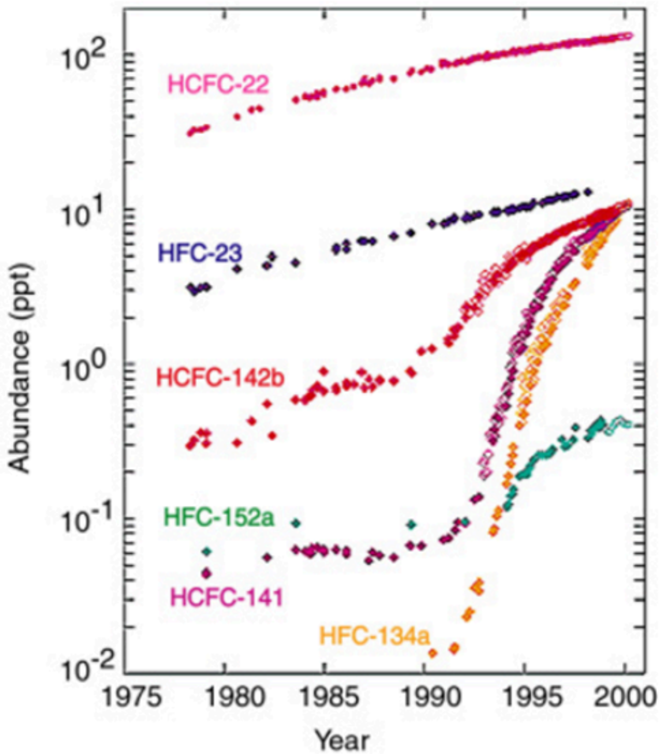
http://www.globalcarbonatlas.org

N2O Balance



MTN= millions of tons of nitrogen per year.


CFC-11
CFC-12
CFC Concentration (parts per trillion)
Northern Hemisphere
Southern Hemisphere
Global Average
Smoothed Global
Growth Rate (parts per trillion per year)
1978 1982 1986 1990 1994 1998 2002 2006


HCFC-22
HFC-23
HCFC-142b
HFC-152a
HCFC-141
HFC-134a
Abundance (ppt)
Year
1975 1980 1985 1990 1995 2000

(t, Mt, Gt | unidades de massa)

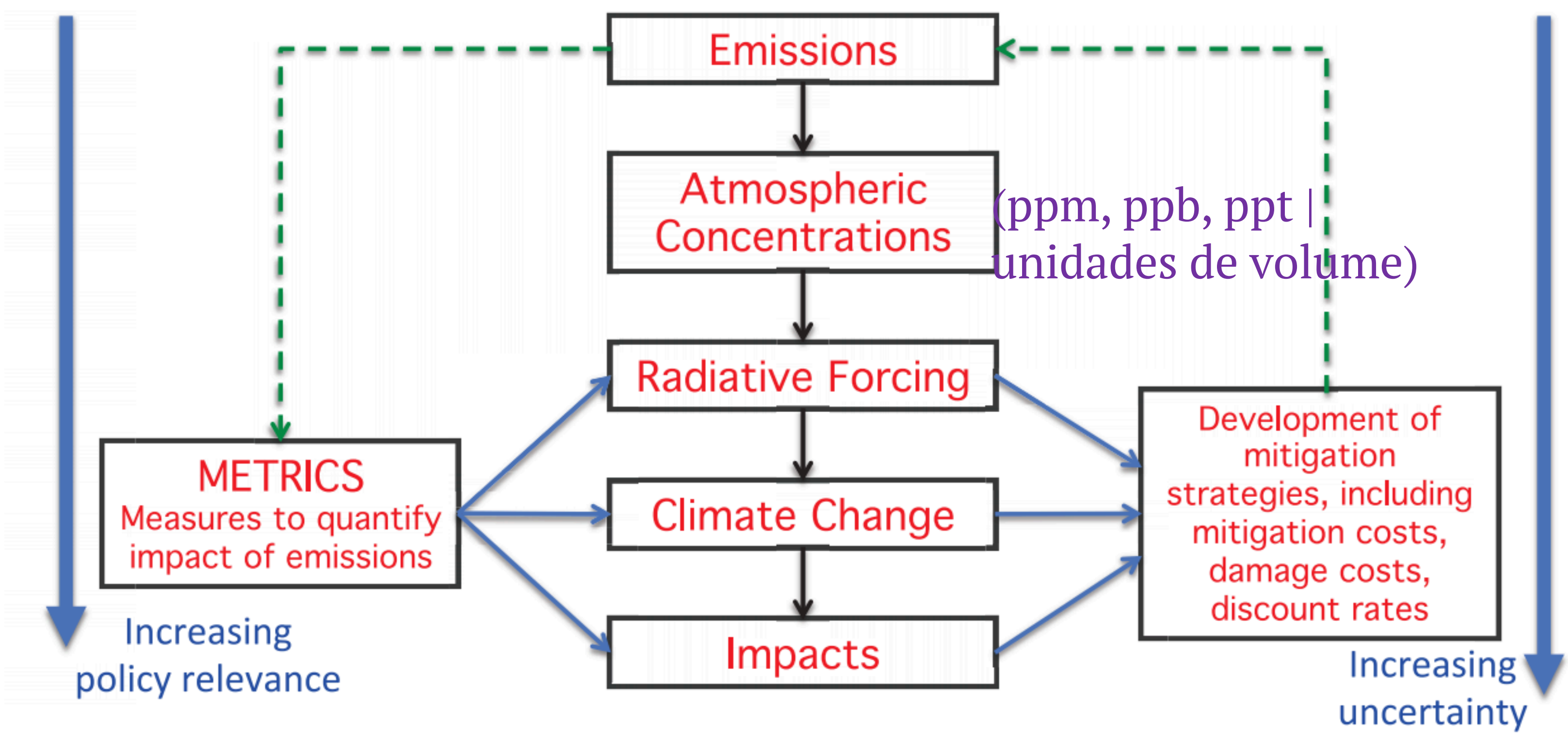


Figure 8.27 | The cause–effect chain from emissions to climate change and impacts showing how metrics can be defined to estimate responses to emissions (left) and for development of multi-component mitigation (right). The relevance of the various effects increases downwards but at the same time the uncertainty also increases. The dotted line on the left indicates that effects and impacts can be estimated directly from emissions, while the arrows on the right side indicate how these estimates can be used in development of strategies for reducing emissions. (Adapted from Fuglestvedt et al., 2003, and Plattner et al., 2009.)

Mt = milhão de toneladas (10^6 t)
Gt = mil milhões de toneladas (10^9 t)

IPCC, 2013

Fossil CO_2 Emissions

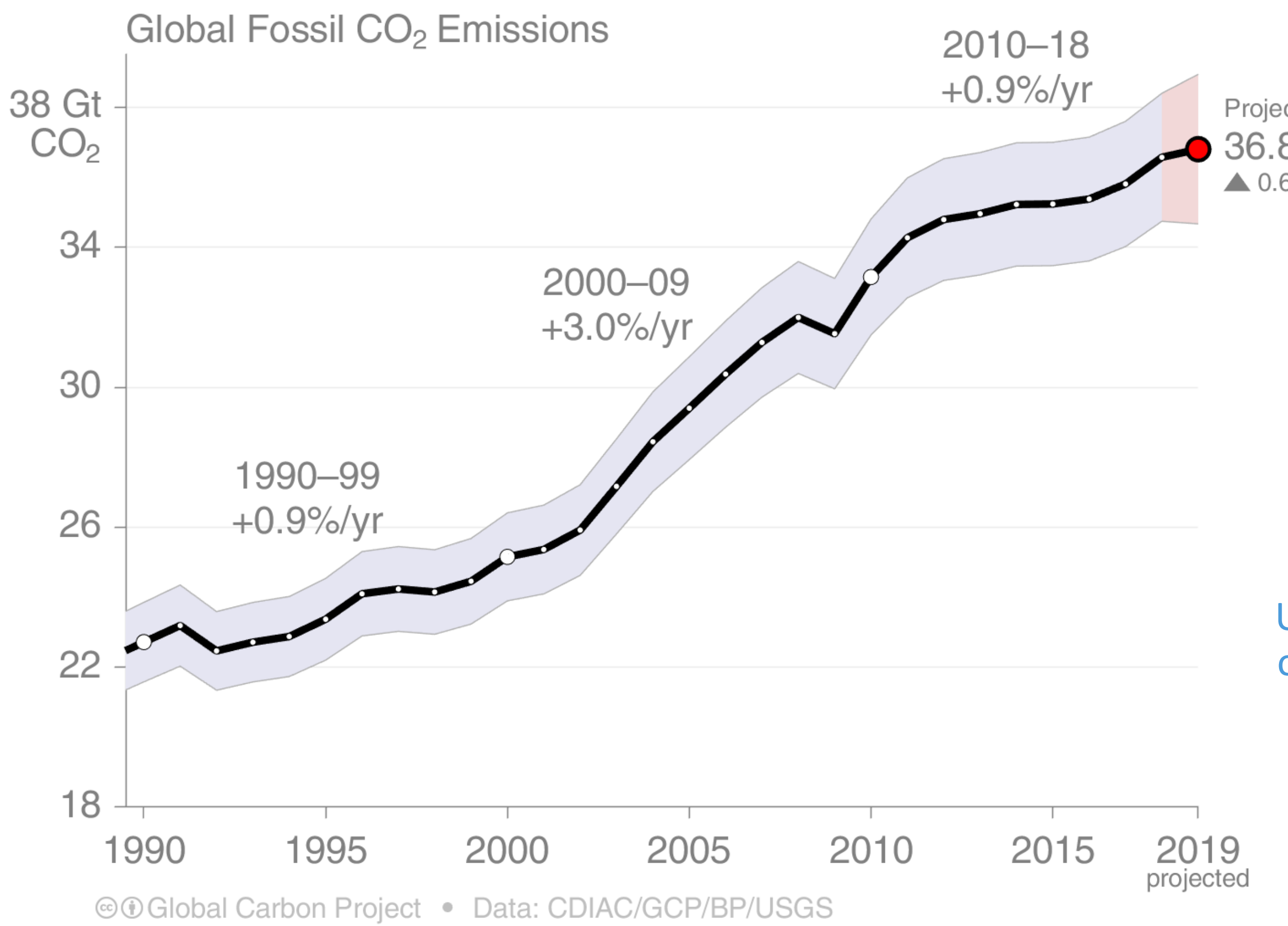
from fossil fuel use and industry

GLOBAL CARBON PROJECT

Global fossil CO_2 emissions: 36.6 ± 2 $GtCO_2$ in 2018, 61% over 1990

● Projection for 2019: 36.8 ± 2 $GtCO_2$, 0.6% higher than 2018 (range -0.2% to 1.5%)

Fossil CO_2 emissions will likely be more than 4% higher in 2019 than the year of the Paris Agreement in 2015

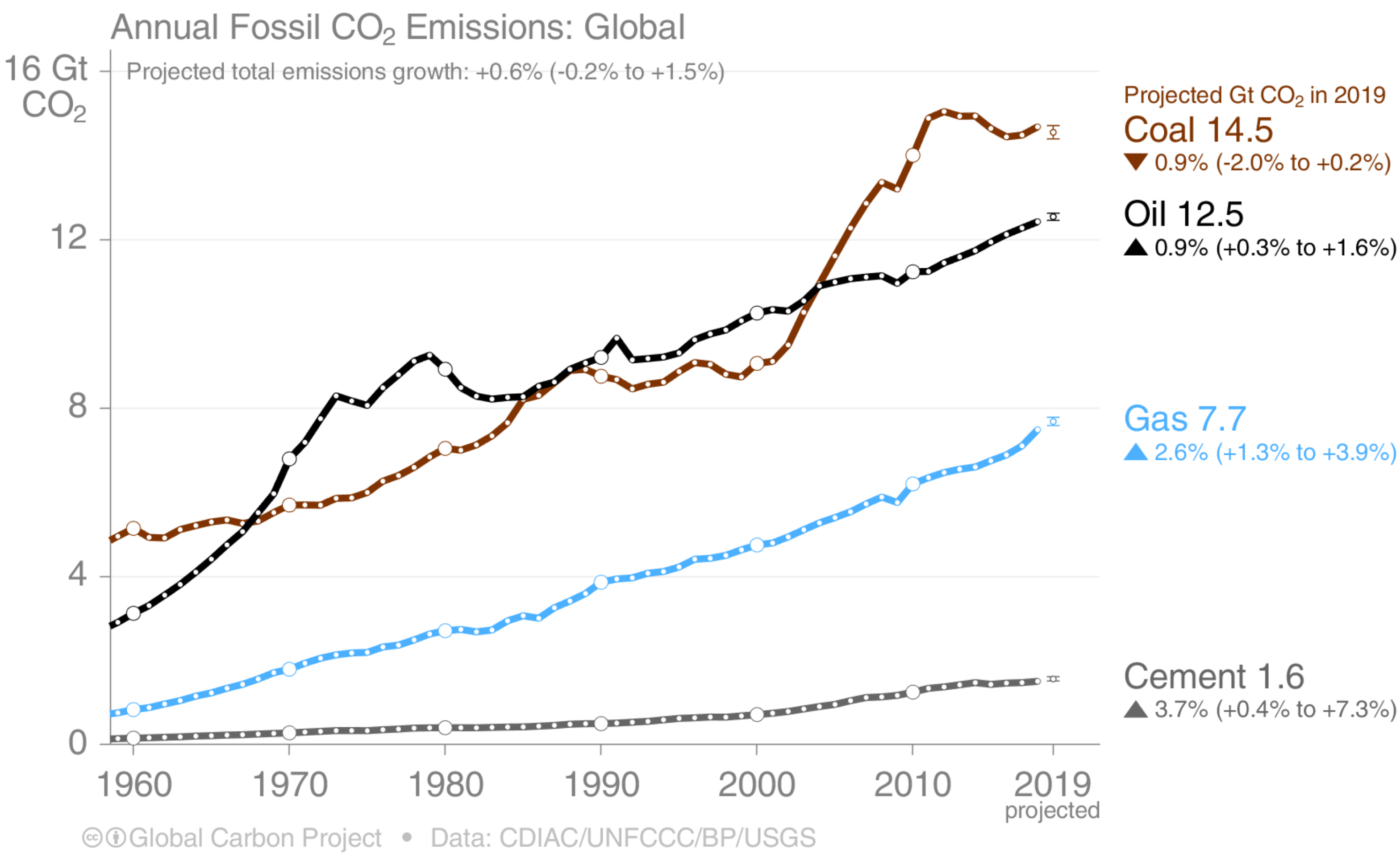


Uncertainty is ±5% for one standard deviation (IPCC "likely" range)

The 2019 projection is based on preliminary data and modelling.
Source: CDIAC; Friedlingstein et al 2019; Global Carbon Budget 2019

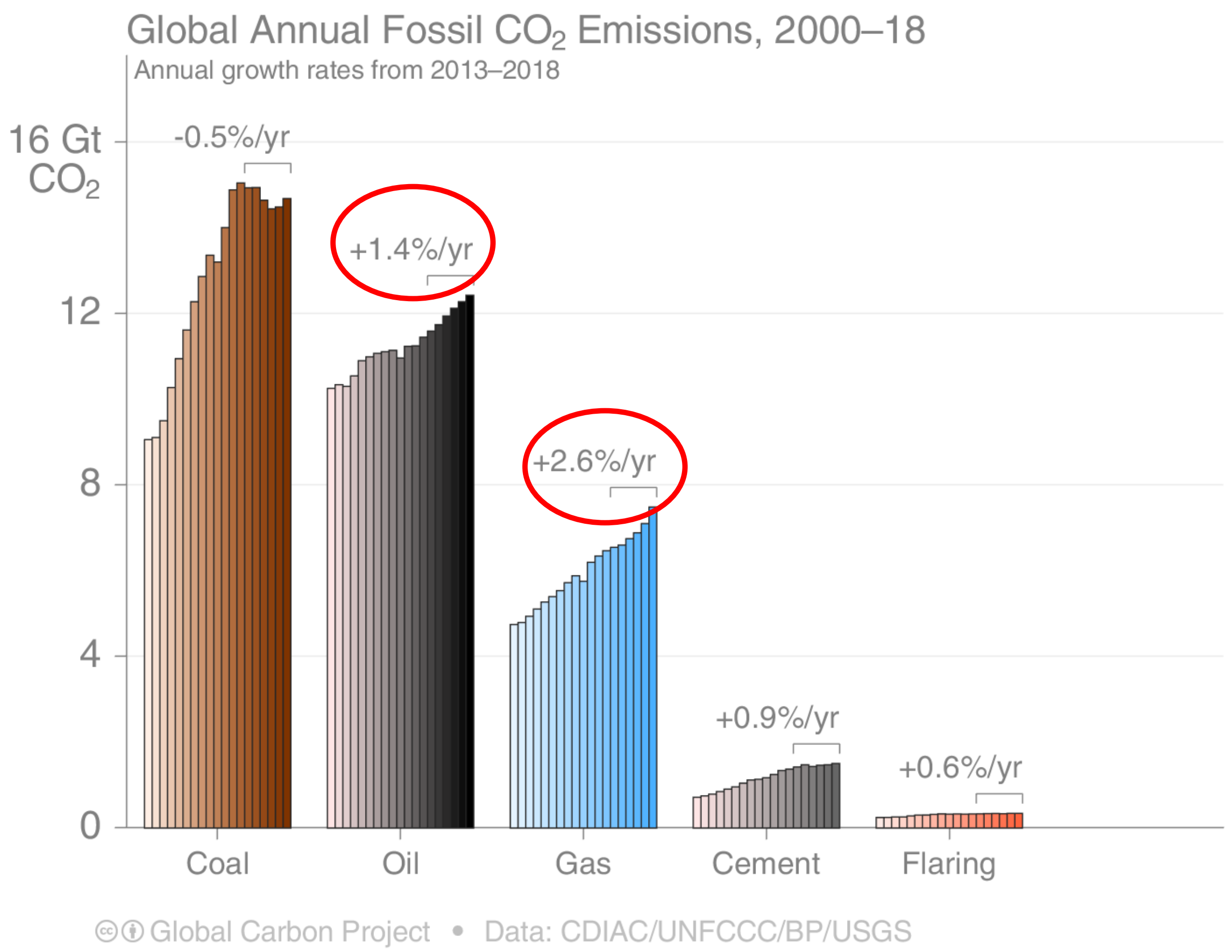
GLOBAL CARBON PROJECT

Share of global fossil CO_2 emissions in 2018: coal (40%), oil (34%), gas (20%), cement (4%), flaring (1%, not shown)



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

Emissions by category from 2000 to 2018, with growth rates indicated for the more recent period of 2013 to 2018

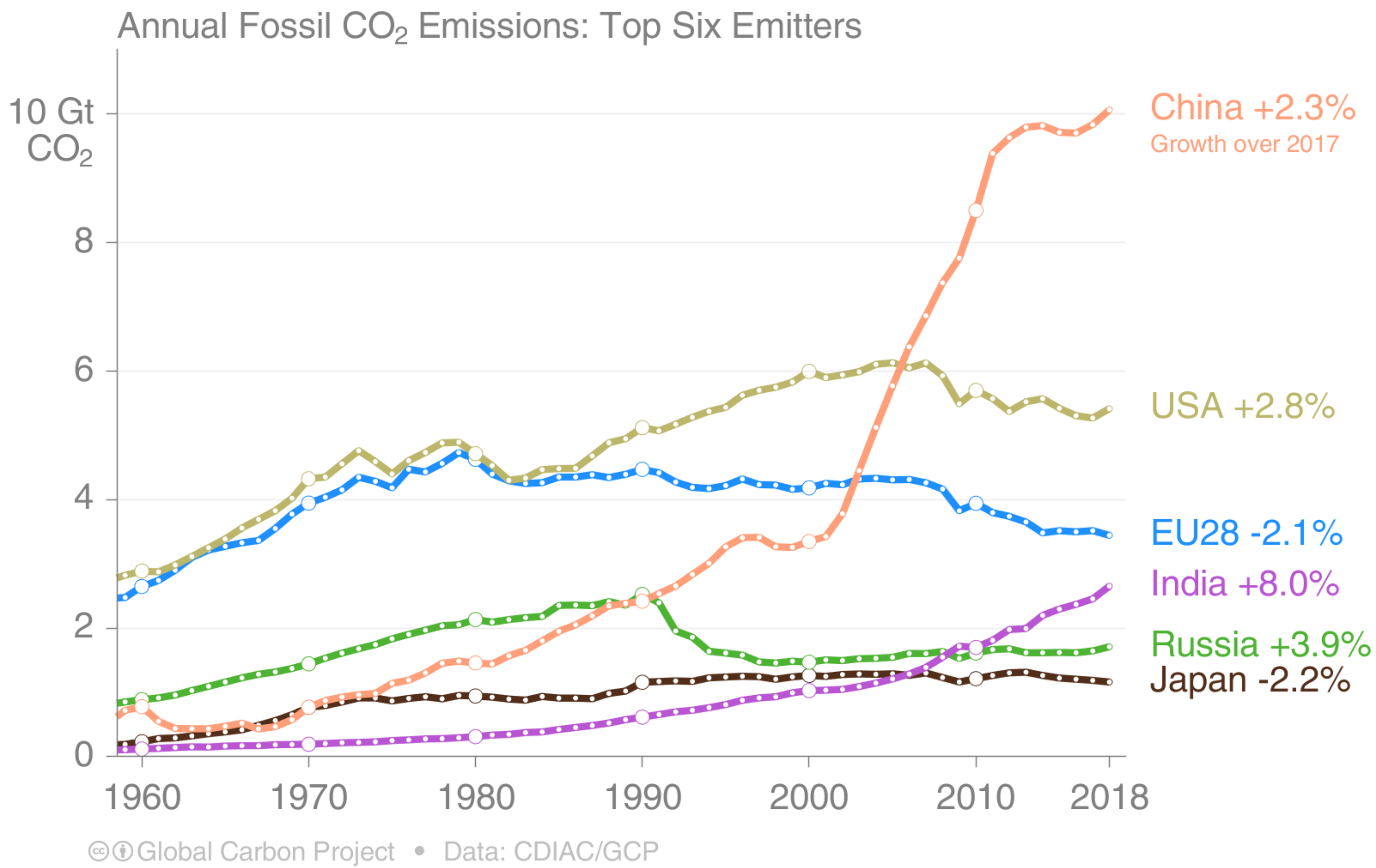


Source: CDIAC; Jackson et al 2019; Global Carbon Budget 2019

GLOBAL CARBON PROJECT

The top six emitters in 2018 covered 67% of global emissions

China 28%, United States 15%, EU28 9%, India 7%, Russia 5%, and Japan 3%

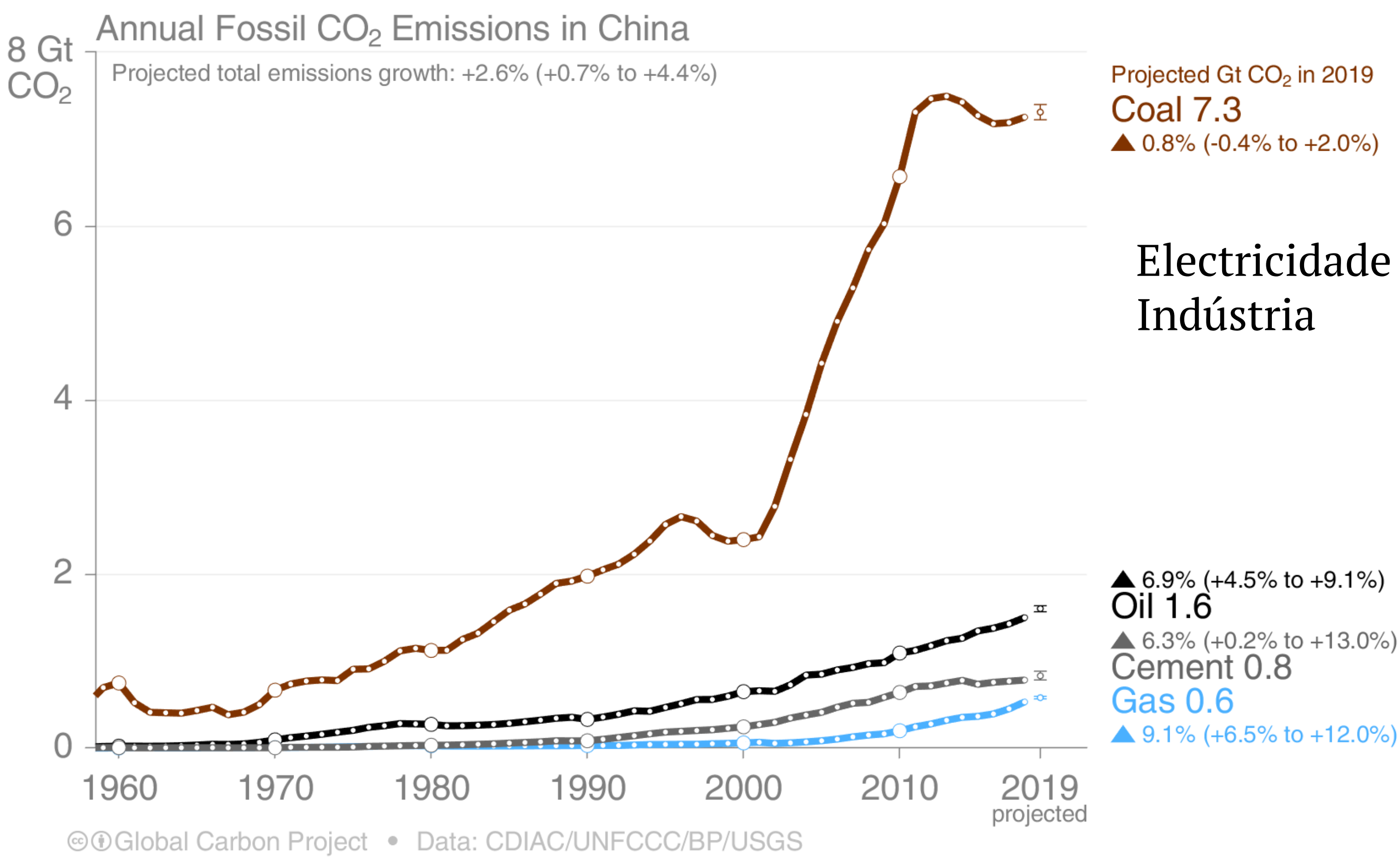


Bunker fuels, used for international transport, are 3.4% of global emissions.

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

GLOBAL CARBON PROJECT

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 to growth persists

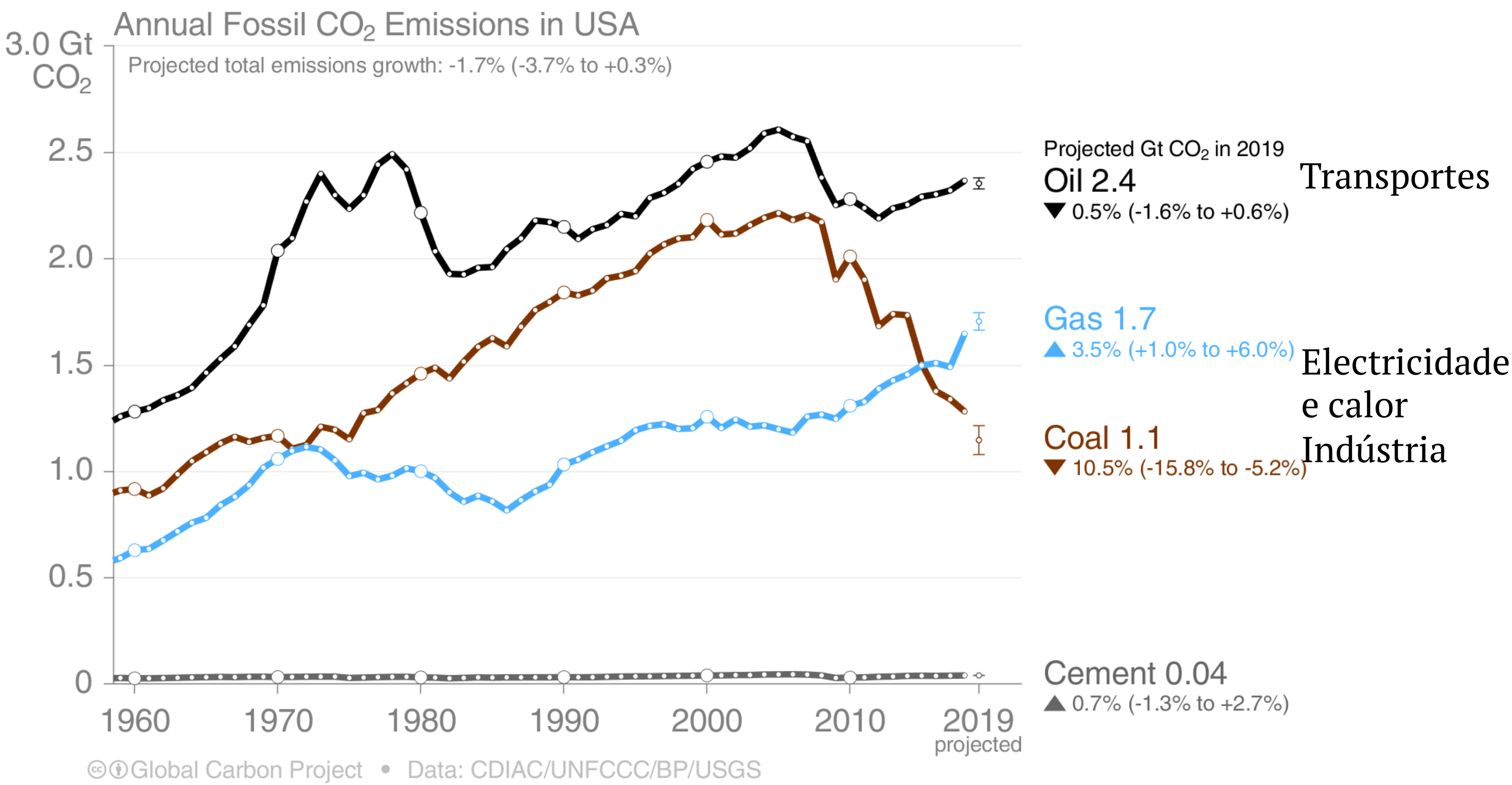


Electricidade e calor
Indústria

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

GLOBAL CARBON PROJECT

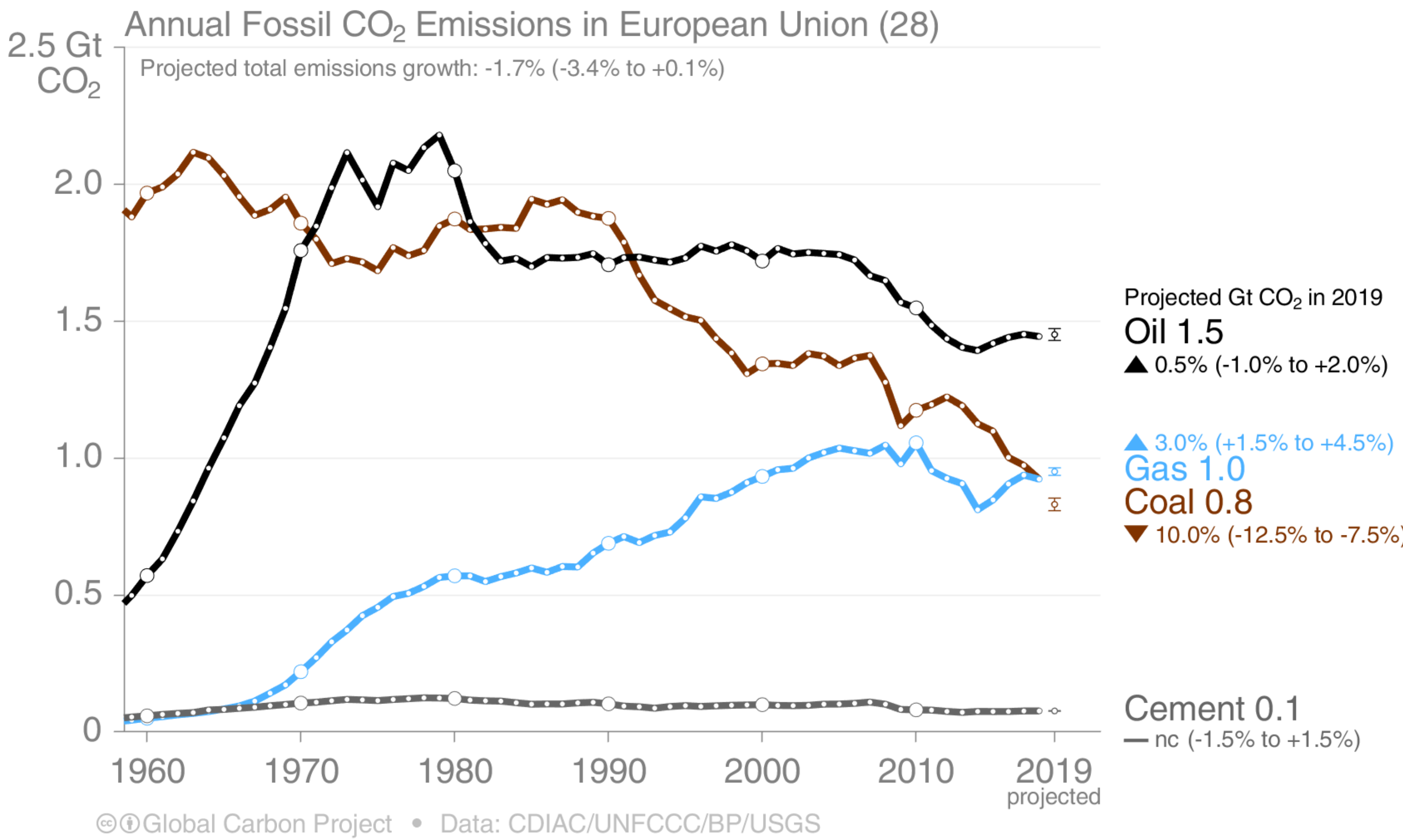
USA's CO_2 emissions have declined since 2007, driven by coal being displaced by gas, solar, & wind. Oil use has returned to growth. Emissions growth in 2018 was driven partly by weather.



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

GLOBAL CARBON PROJECT

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 2019.



Transportes

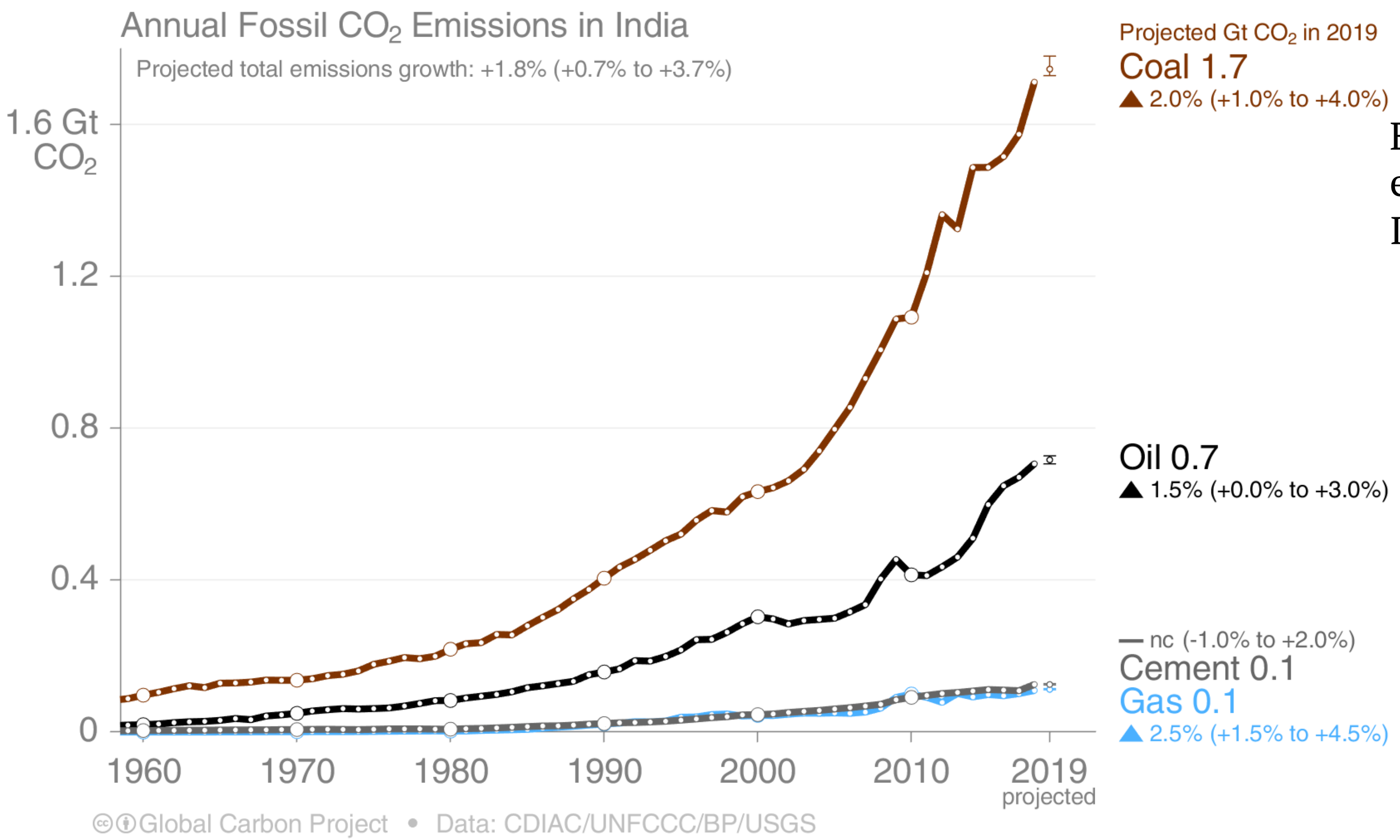
Electricidade e calor

Indústria

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

GLOBAL CARBON PROJECT

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.

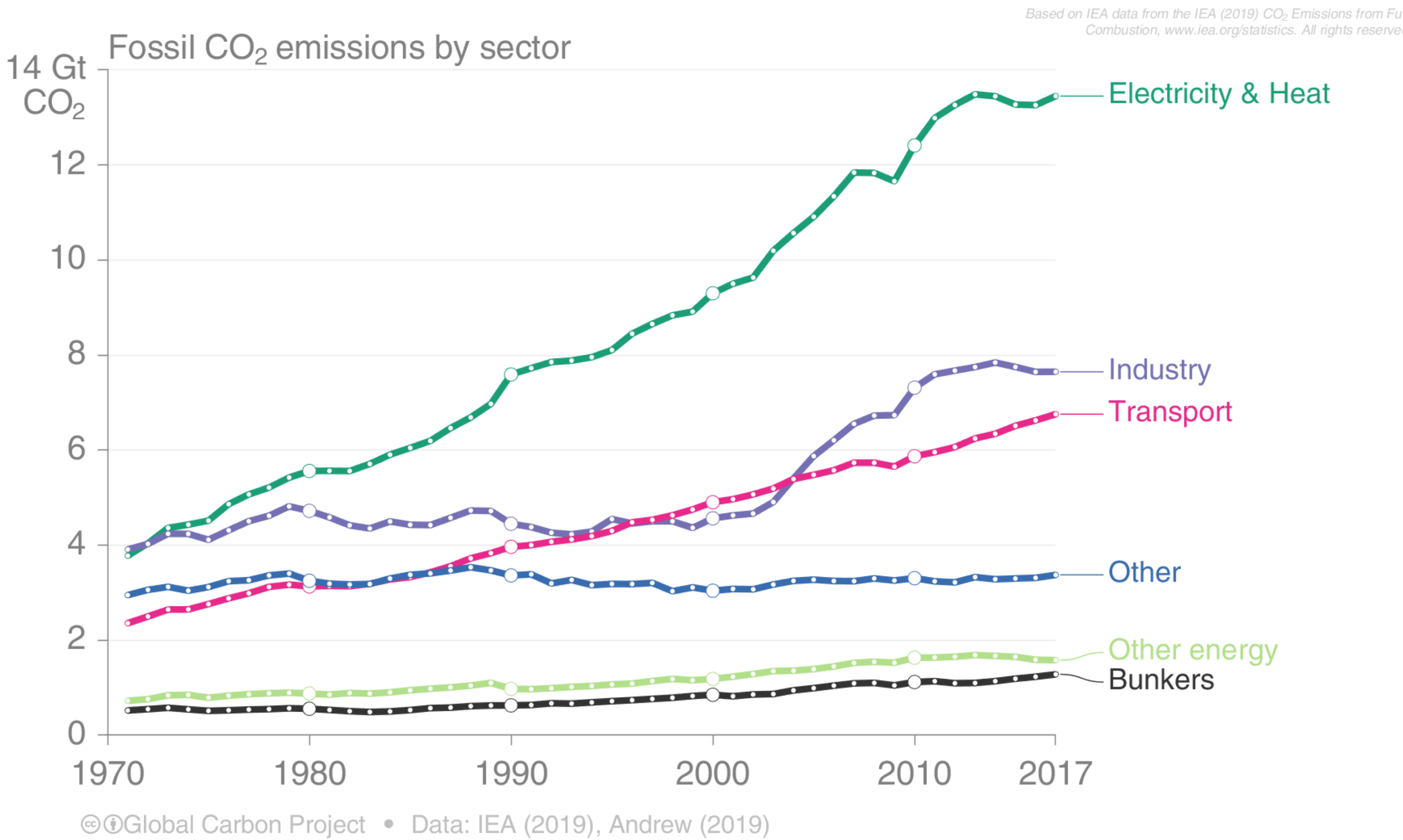


Electricidade e calor
Indústria

Indústria
Transportes

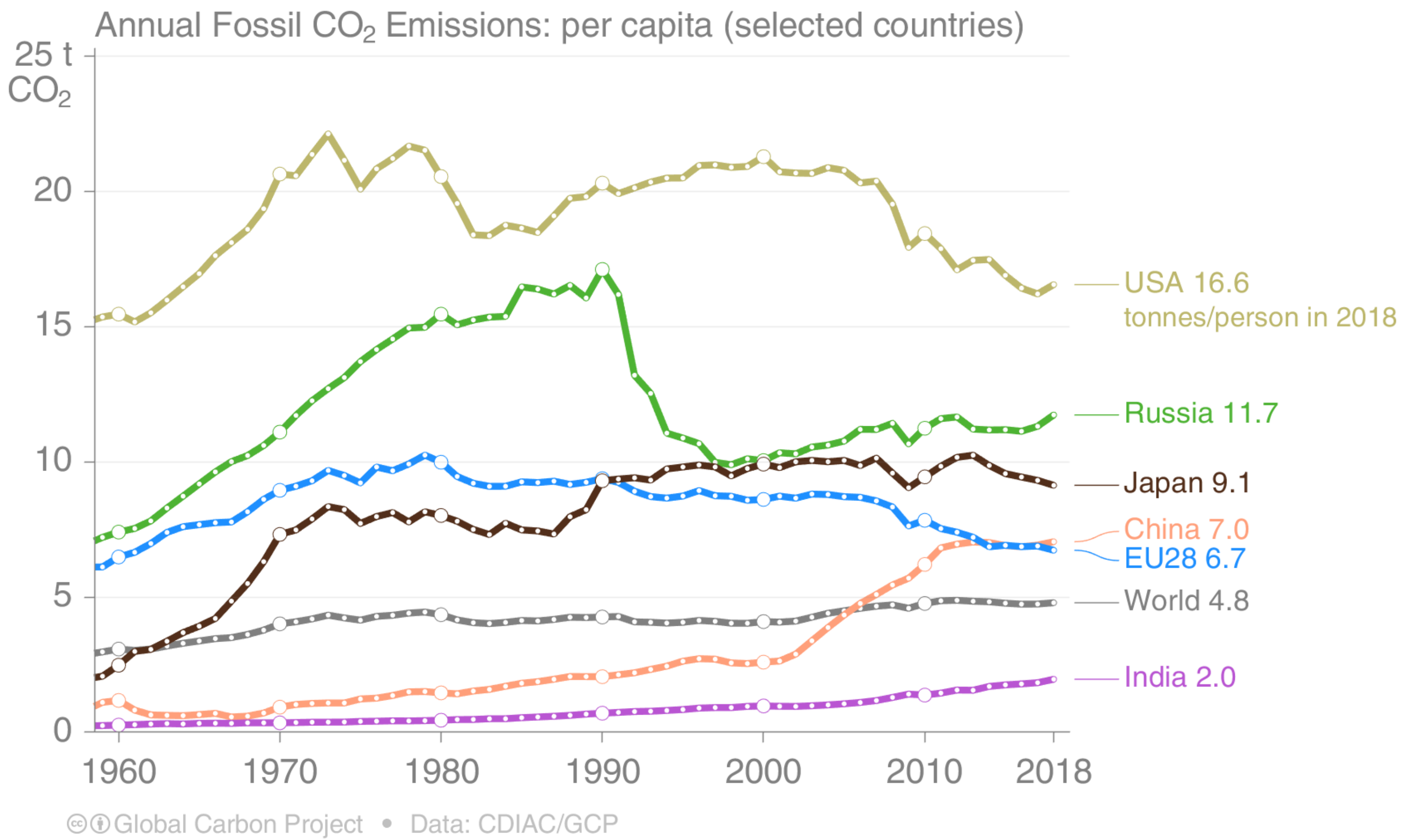
Source: CDIAC; Friedlingstein et al 2019; Global Carbon Budget 2019

Global fossil CO_2 emissions are dominated by electricity, heat, & energy (45%), industry (23%), & national transport (19%). International aviation and marine bunkers are 3.5% & remaining sectors 10%.



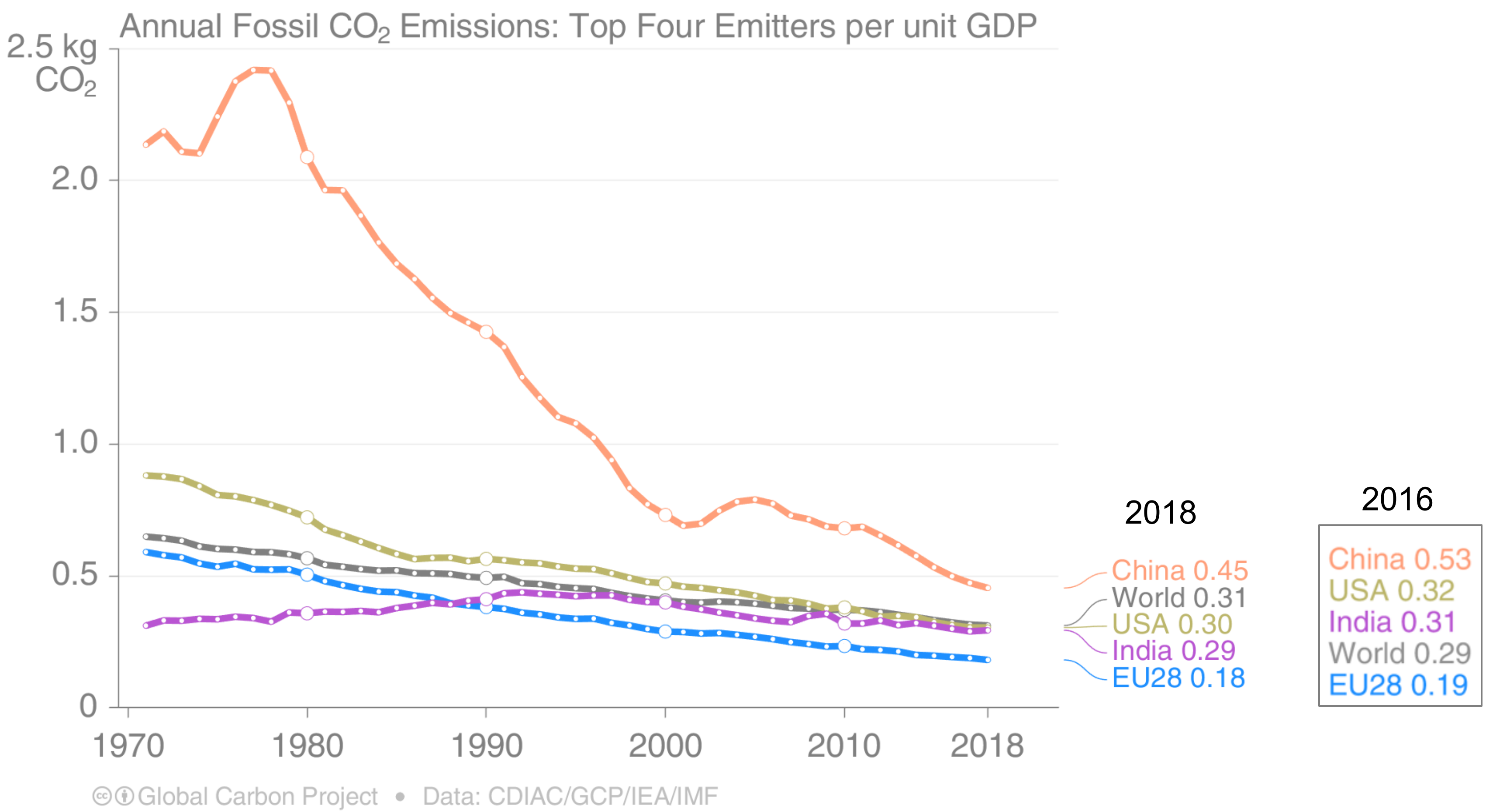
Source: IEA 2019; Peters et al 2019; Global Carbon Budget 2019

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



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

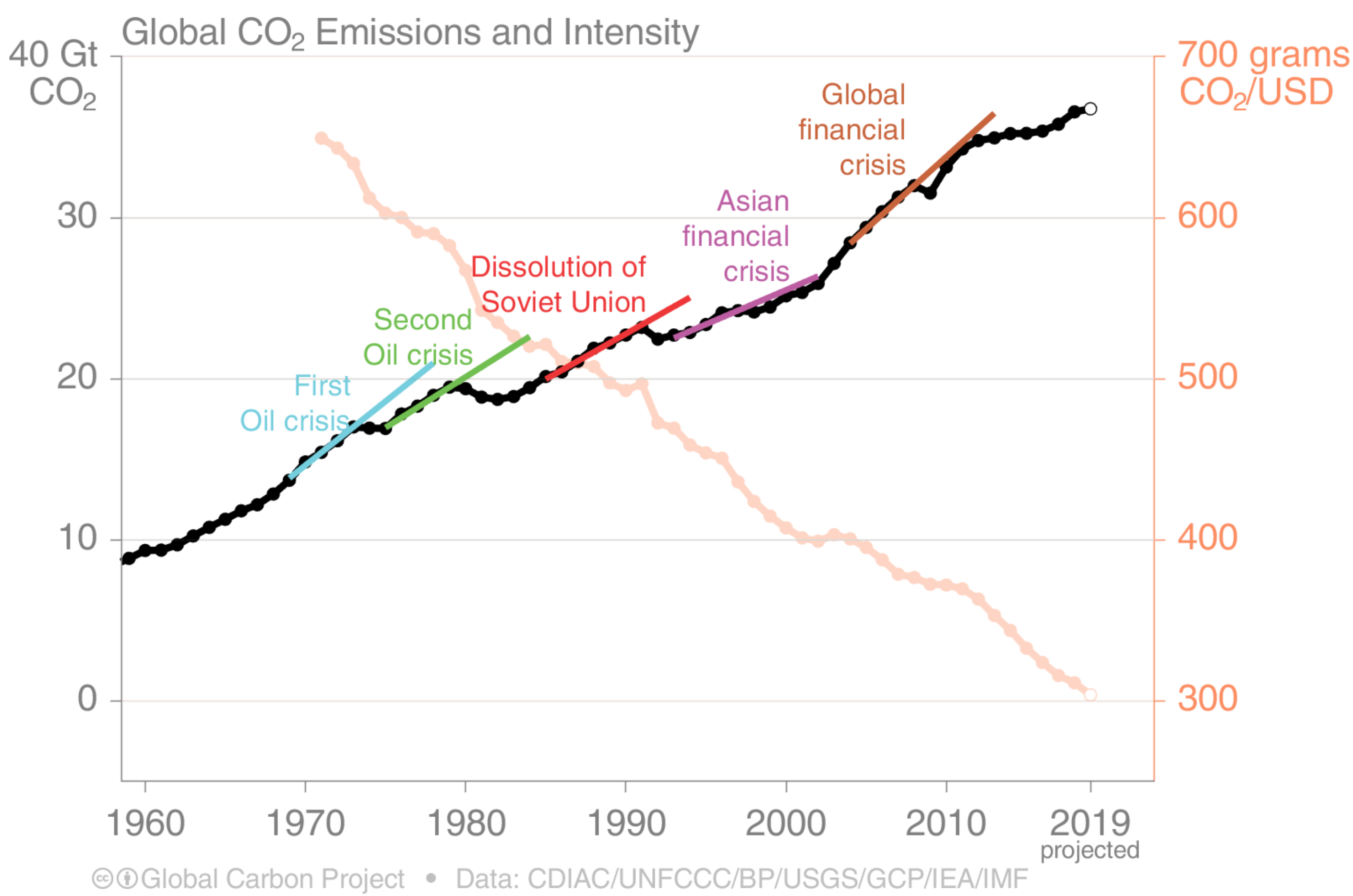
Emission intensity (emission per unit economic output) generally declines over time. In many countries, these declines are insufficient to overcome economic growth.



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

Source: CDIAC; IEA 2018 GDP to 2016, IMF 2019 growth rates to 2018; Friedlingstein et al 2019; Global Carbon Budget 2019

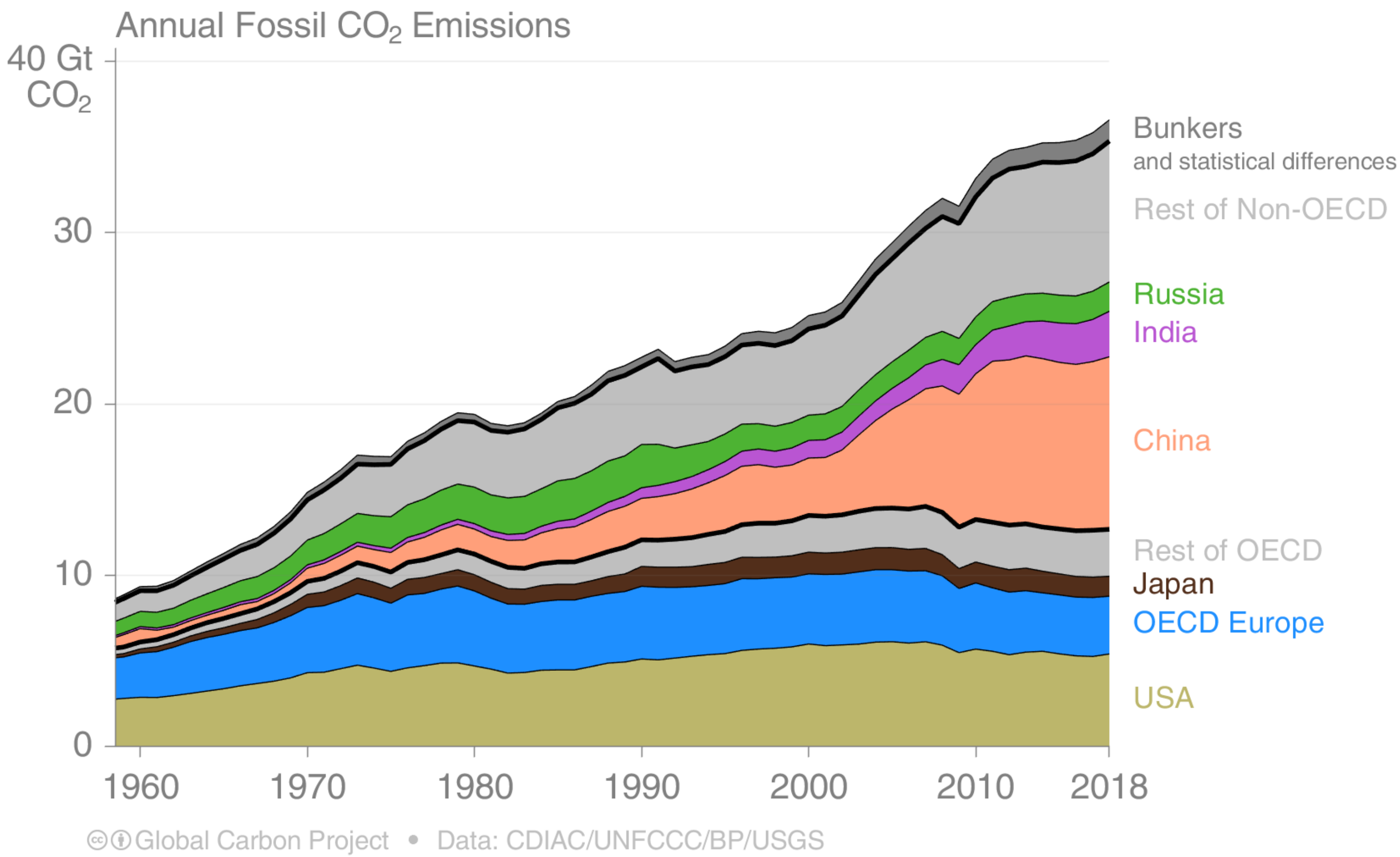
Global CO_2 emissions growth has generally resumed quickly from financial crises.
Emission intensity has steadily declined but not sufficiently to offset economic growth.



Economic activity is measured in purchasing power parity (PPP) terms in 2010 US dollars.
Source: CDIAC; Peters et al 2012; Friedlingstein et al 2019; Global Carbon Budget 2019

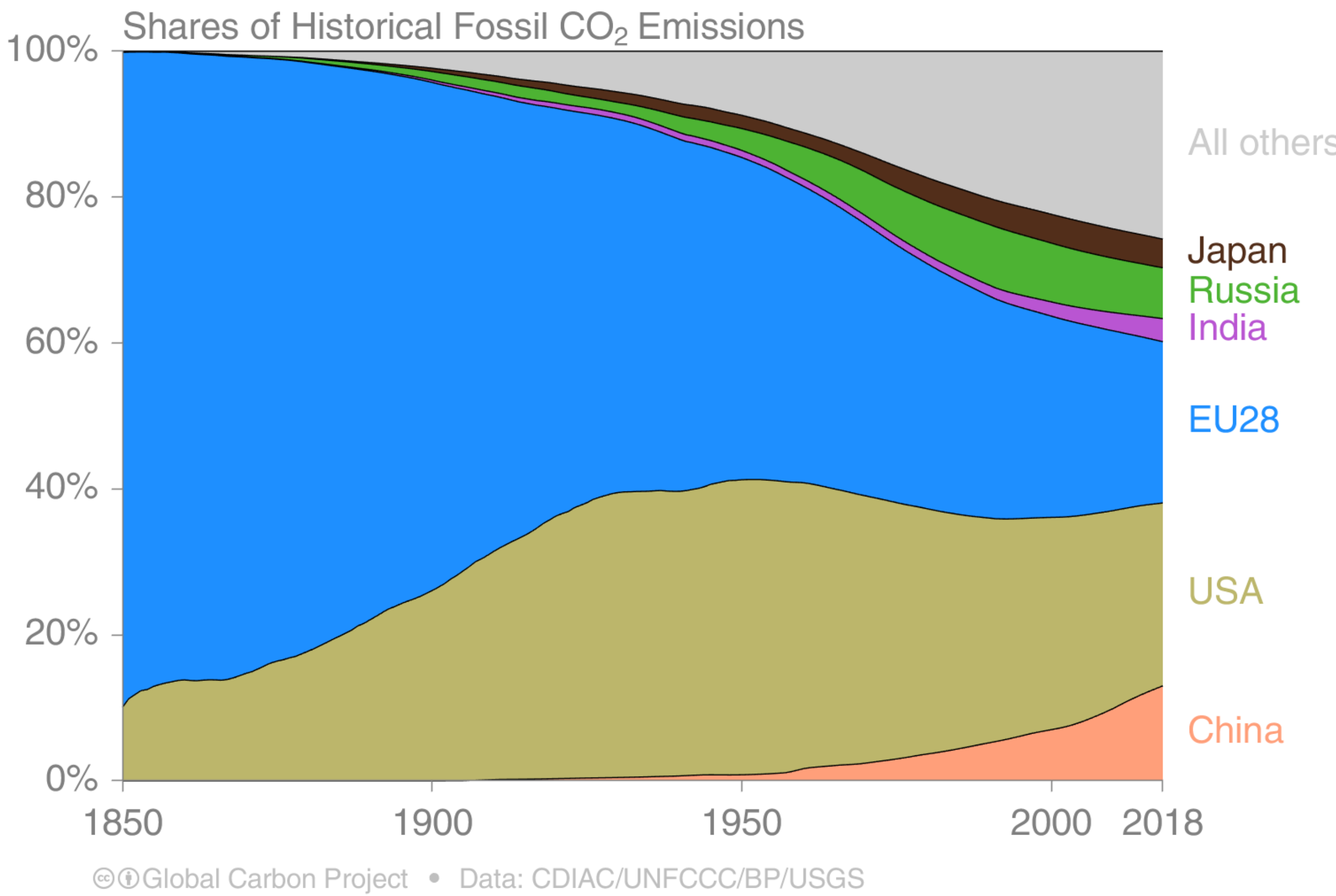
GLOBAL CARBON PROJECT

Emissions in OECD countries have increased by 5% since 1990, despite declining 10% from their maximum in 2007. Emissions in non-OECD countries & from international shipping and aviation (bunkers) have more than doubled since 1990



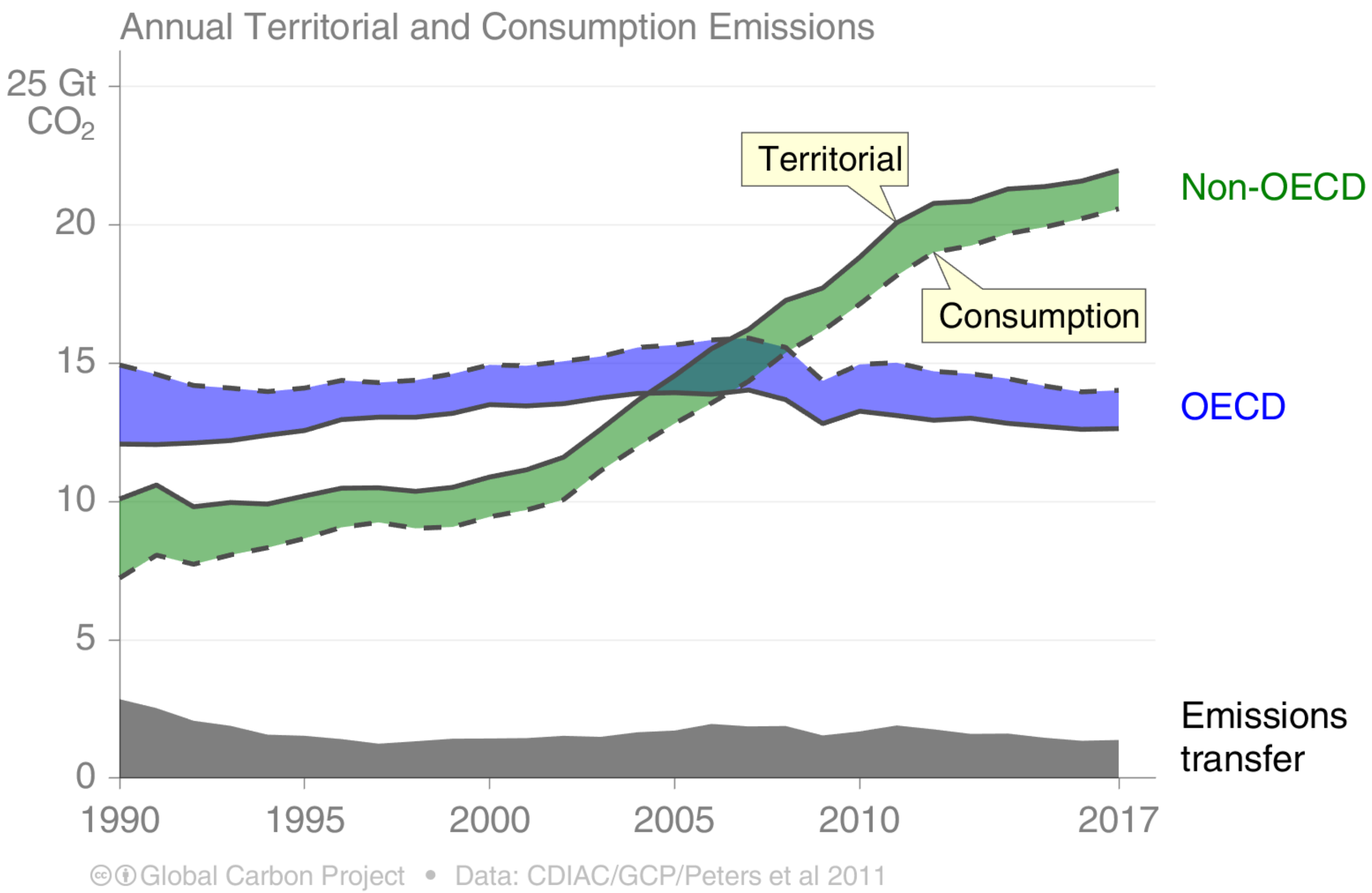
Source: CDIAC; Friedlingstein et al 2019; Global Carbon Budget 2019

Cumulative fossil CO_2 emissions were distributed (1870–2018):
USA 25%, EU28 22%, China 13%, Russia 7%, Japan 4% and India 3%



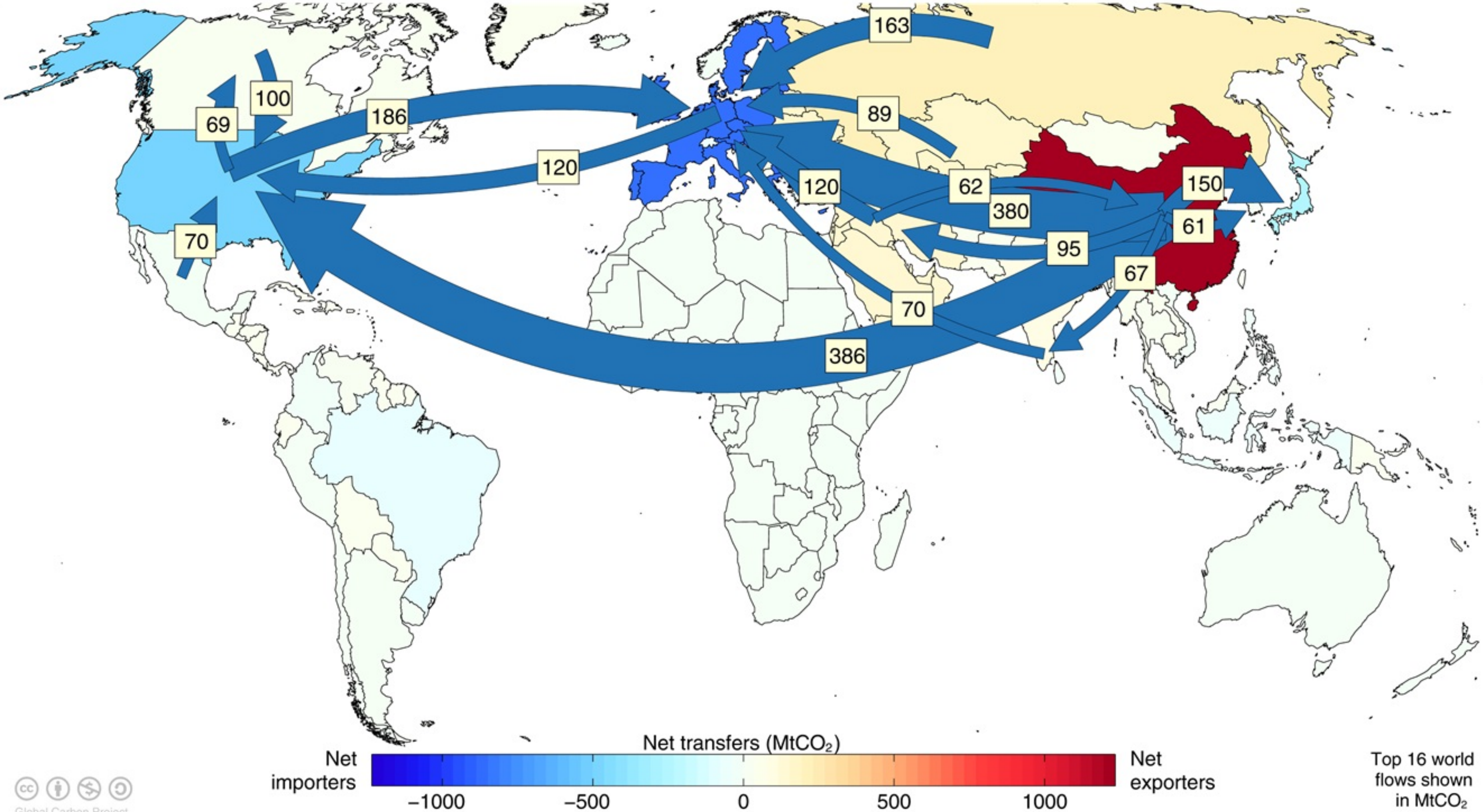
Cumulative emissions (1990–2018) were distributed China 20%, USA 20%, EU28 14%, Russia 6%, India 5%, Japan 4%
'All others' includes all other countries along with international bunker fuels
Source: CDIAC; Friedlingstein et al 2019; Global Carbon Budget 2019

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; Friedlingstein et al 2019; Global Carbon Budget 2019

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

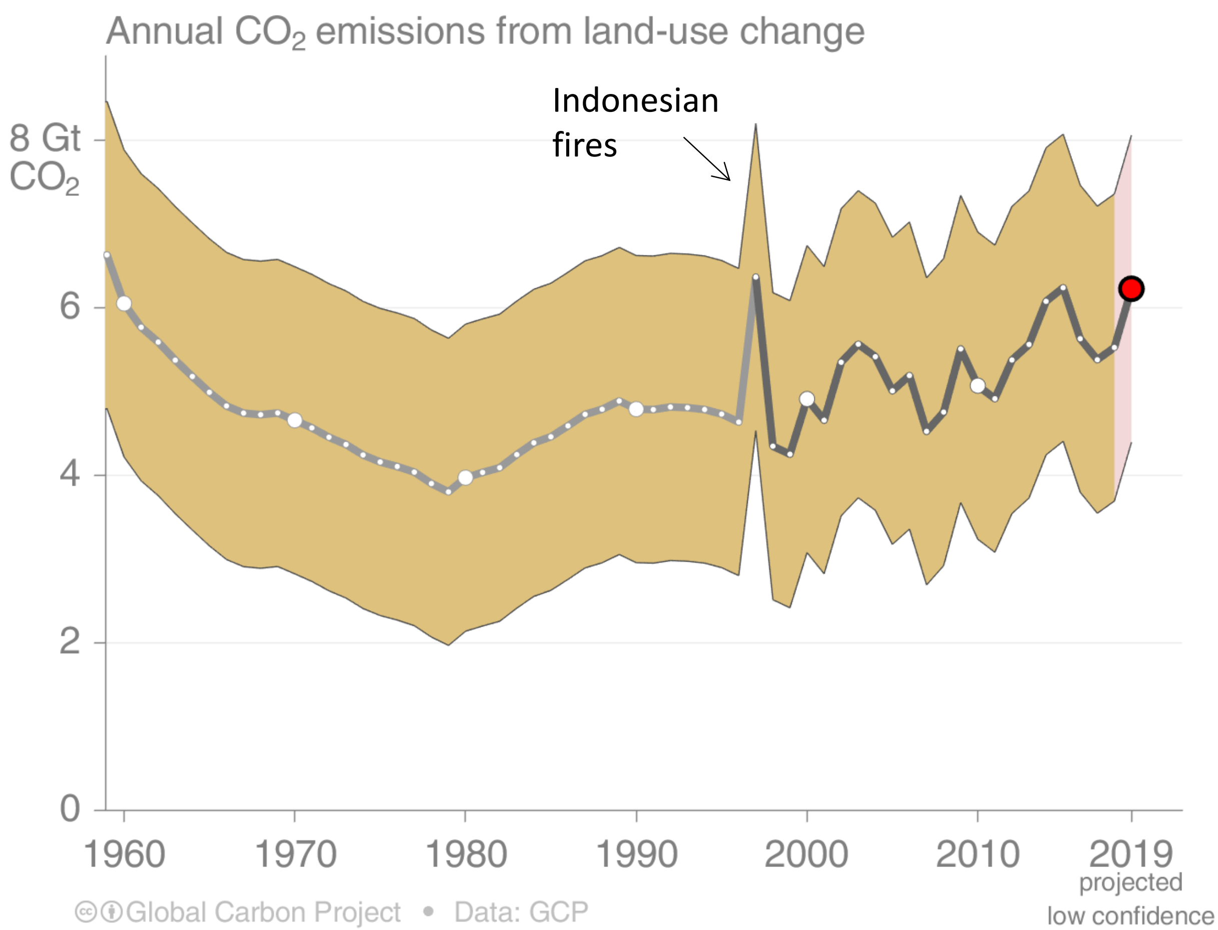


Values for 2011. EU is treated as one region. Units: $MtCO_2$
Source: Peters et al 2012

Land-use Change Emissions

GLOBAL CARBON PROJECT

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

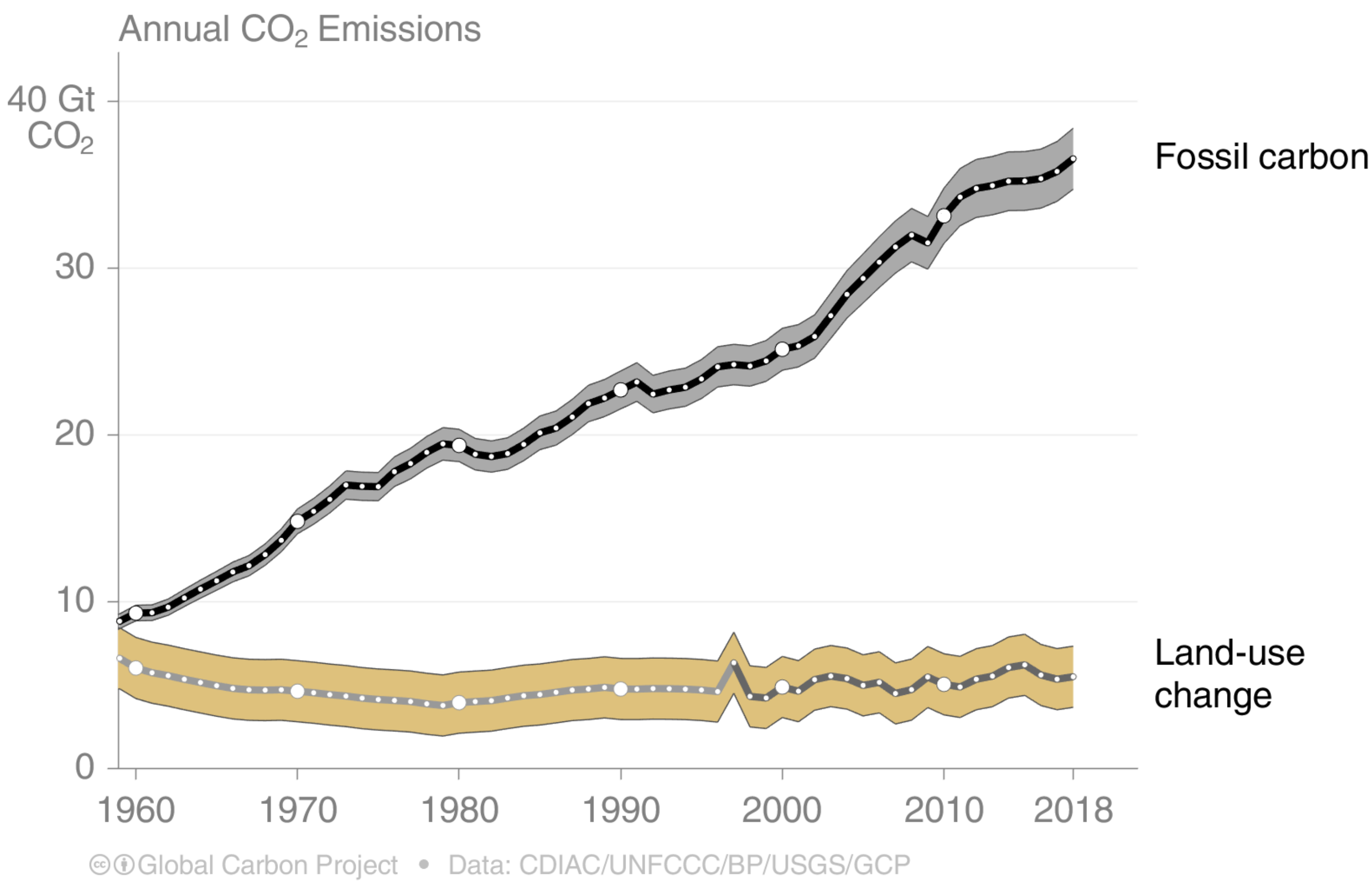


Estimates from two bookkeeping models, using fire-based variability from 1997

Source: Houghton and Nassikas 2017; Hansis et al 2015; van der Werf et al. 2017; Friedlingstein et al 2019; Global Carbon Budget 2019

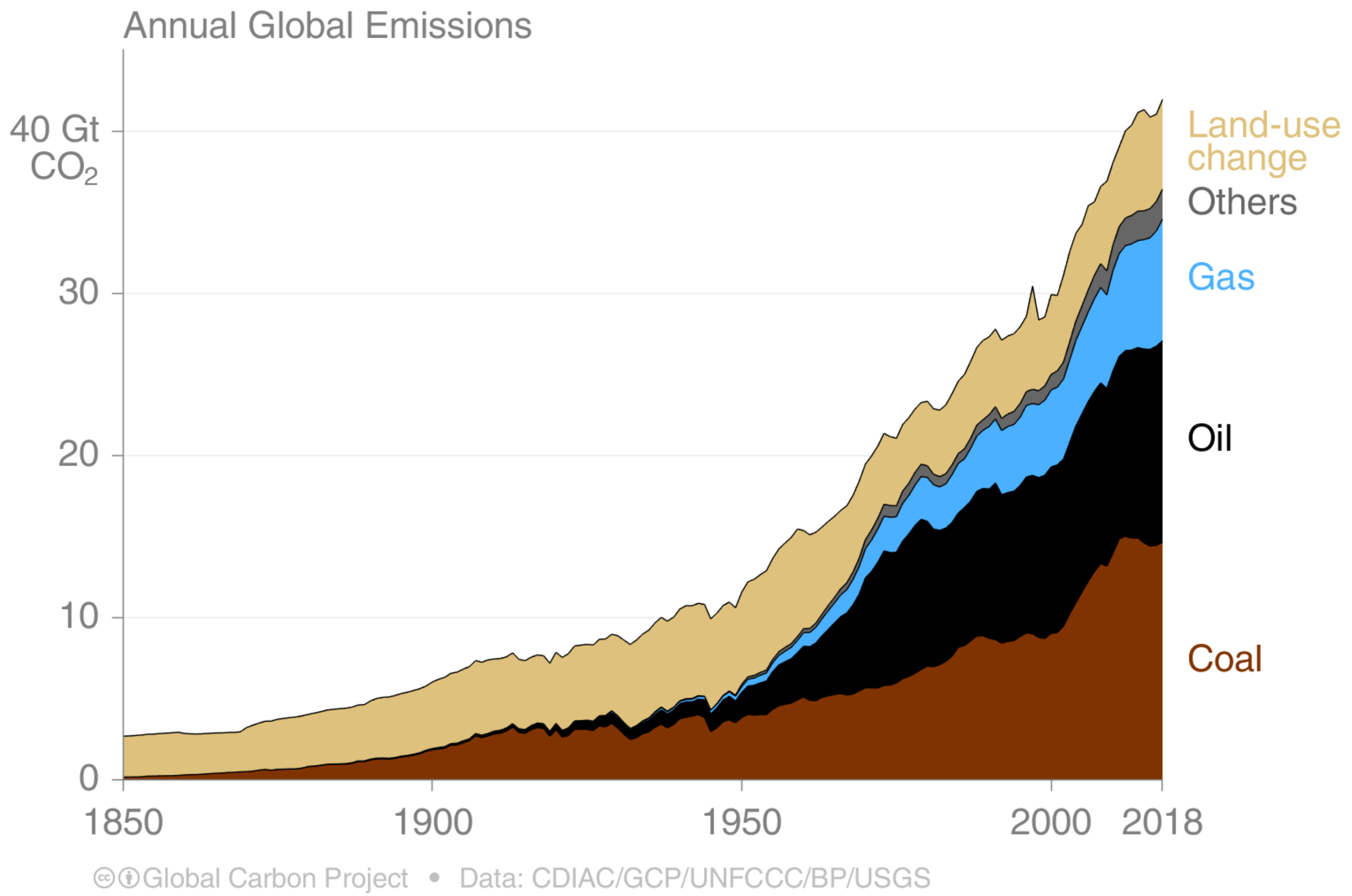
GLOBAL CARBON PROJECT

Total global emissions: 42.1 ± 2.8 GtCO_2 in 2018, 55% over 1990
Percentage land-use change: 39% in 1960, 14% averaged 2009–2018



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; Friedlingstein et al 2019; Global Carbon Budget 2019

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

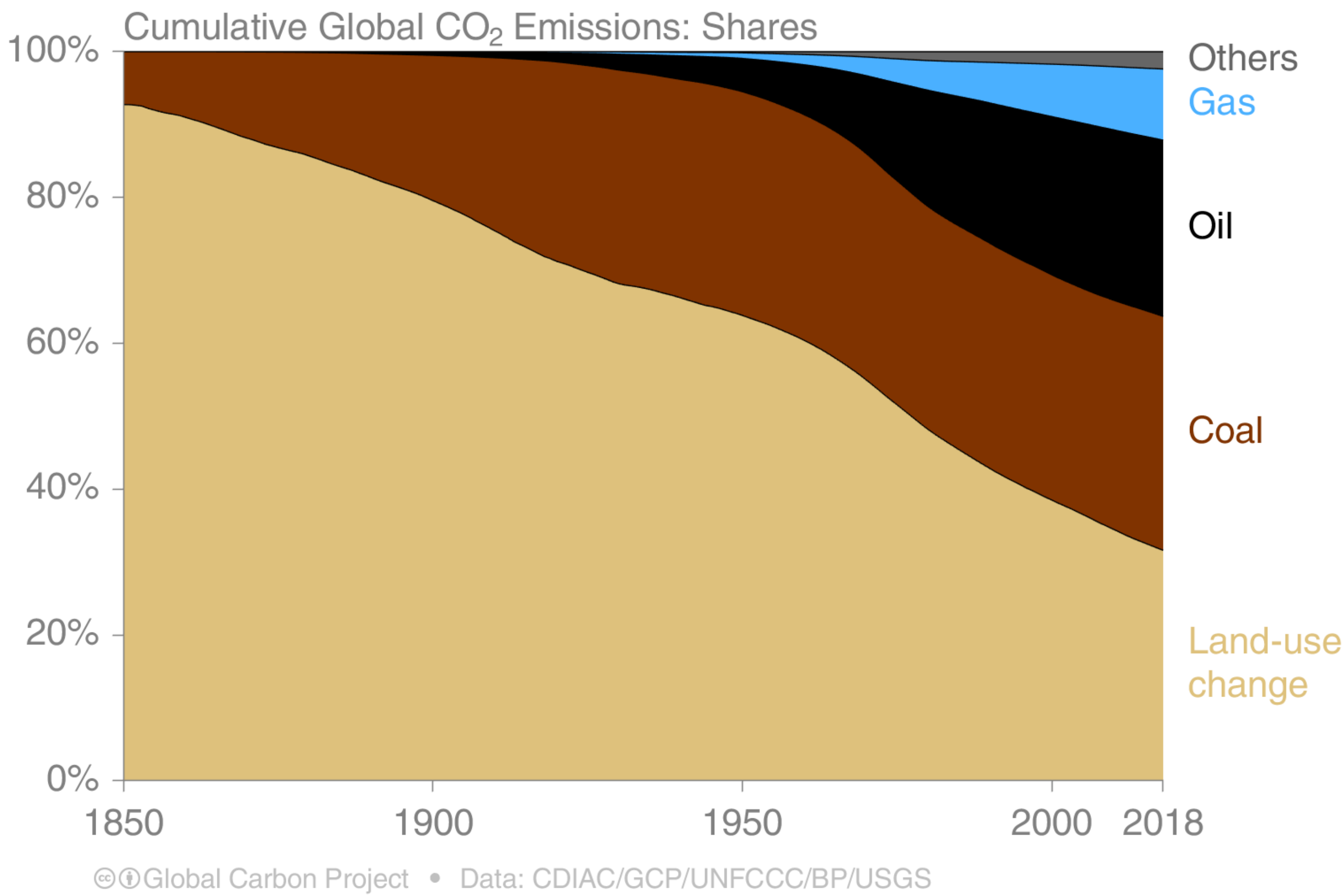


Others: Emissions from cement production and gas flaring

Source: CDIAC; Houghton and Nassikas 2017; Hansis et al 2015; Friedlingstein et al 2019; Global Carbon Budget 2019

GLOBAL CARBON PROJECT

Land-use change represents about 30% of cumulative emissions over 1870–2018, coal 33%, 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; Friedlingstein et al 2019; Global Carbon Budget 2019

Closing the Global Carbon Budget

Sources = Sinks

34.7 $GtCO_2$/yr

86%

14%

5.5 $GtCO_2$/yr

17.9 $GtCO_2$/yr

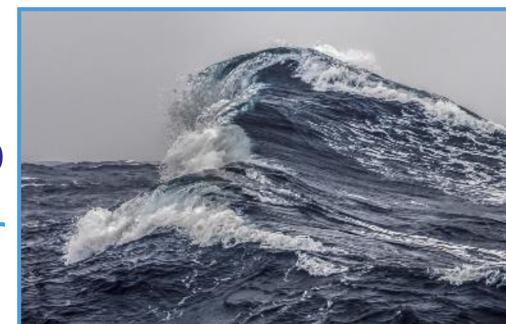
44%

29%

11.5 $GtCO_2$/yr

23%

9.2 $GtCO_2$/yr

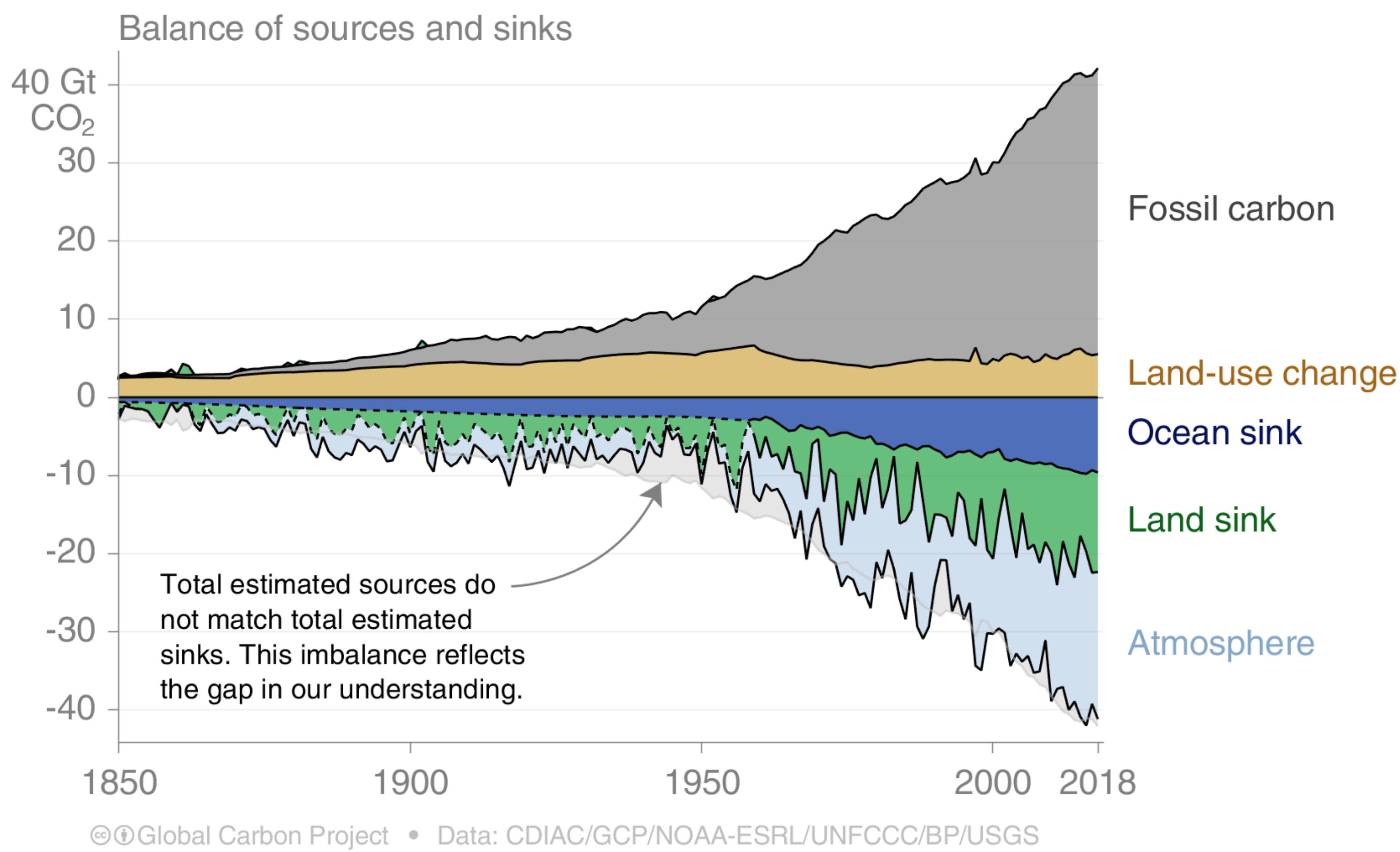


Budget Imbalance:
(the difference between estimated sources & sinks)

4%
1.6 $GtCO_2$/yr

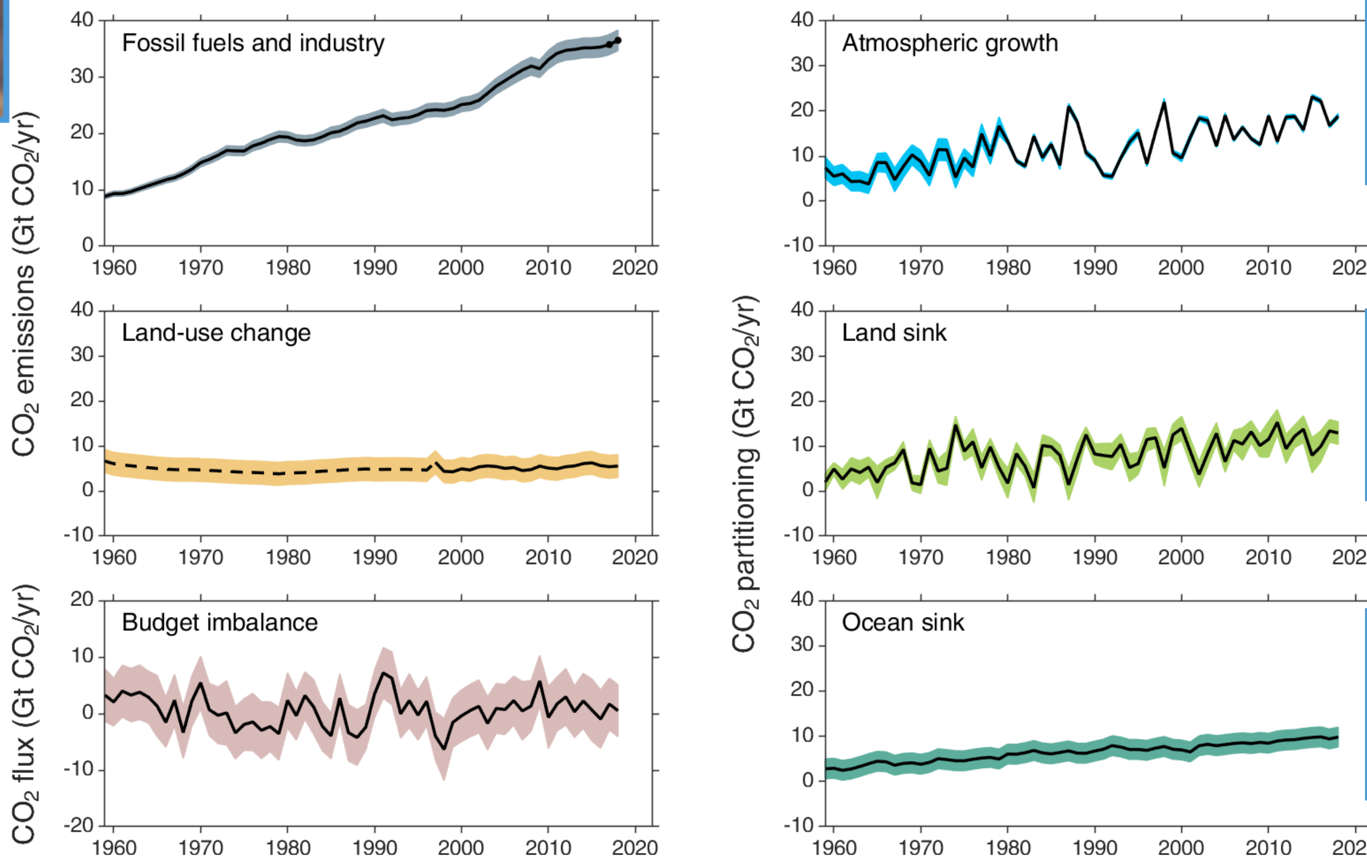
Carbon emissions are partitioned among the atmosphere and carbon sinks on land and in the ocean

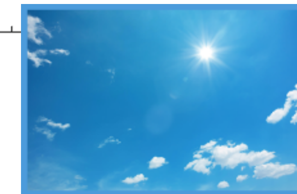
The "imbalance" between total emissions and total sinks reflects the gap in our understanding

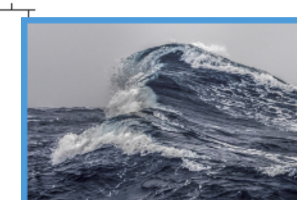


Source: CDIAC; NOAA-ESRL; Houghton and Nassikas 2017; Hansis et al 2015; Joos et al 2013; Khatiwala et al. 2013; DeVries 2014; Friedlingstein et al 2019; Global Carbon Budget 2019

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





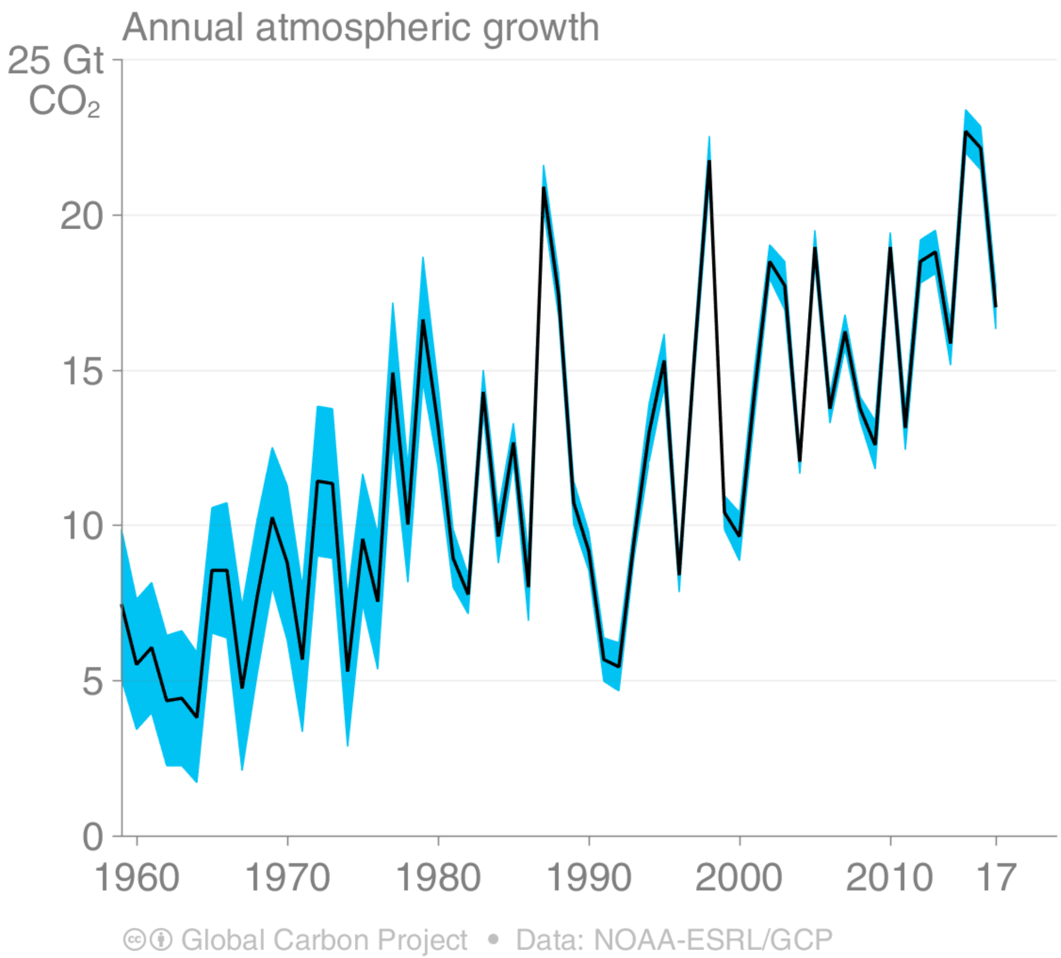


The budget imbalance is the total emissions minus the estimated growth in the atmosphere, land and ocean.
It reflects the limits of our understanding of the carbon cycle.
Source: CDIAC; NOAA-ESRL; Houghton and Nassikas 2017; Hansis et al 2015; Friedlingstein et al 2019; Global Carbon Budget 2019

GLOBAL CARBON PROJECT

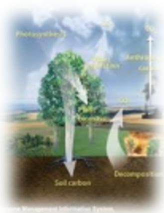
The atmospheric concentration growth rate has shown a steady increase

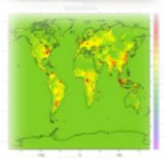
The high growth in 1987, 1998, & 2015–16 reflect a strong El Niño, which weakens the land sink

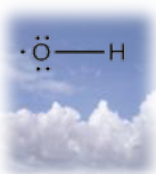


Source: NOAA-ESRL; Global Carbon Budget 2018

GLOBAL CARBON PROJECT





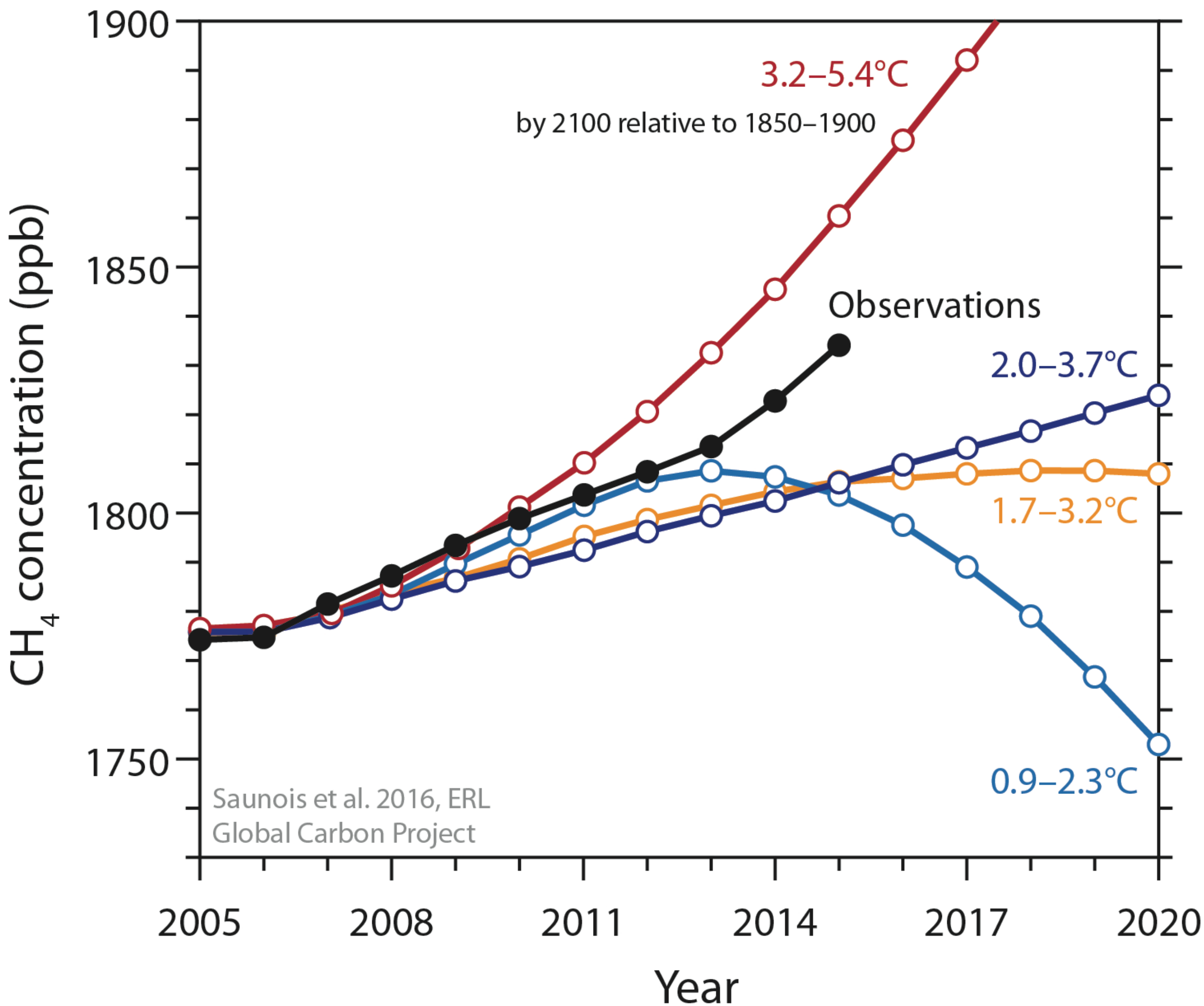


Global Methane Budget 2016

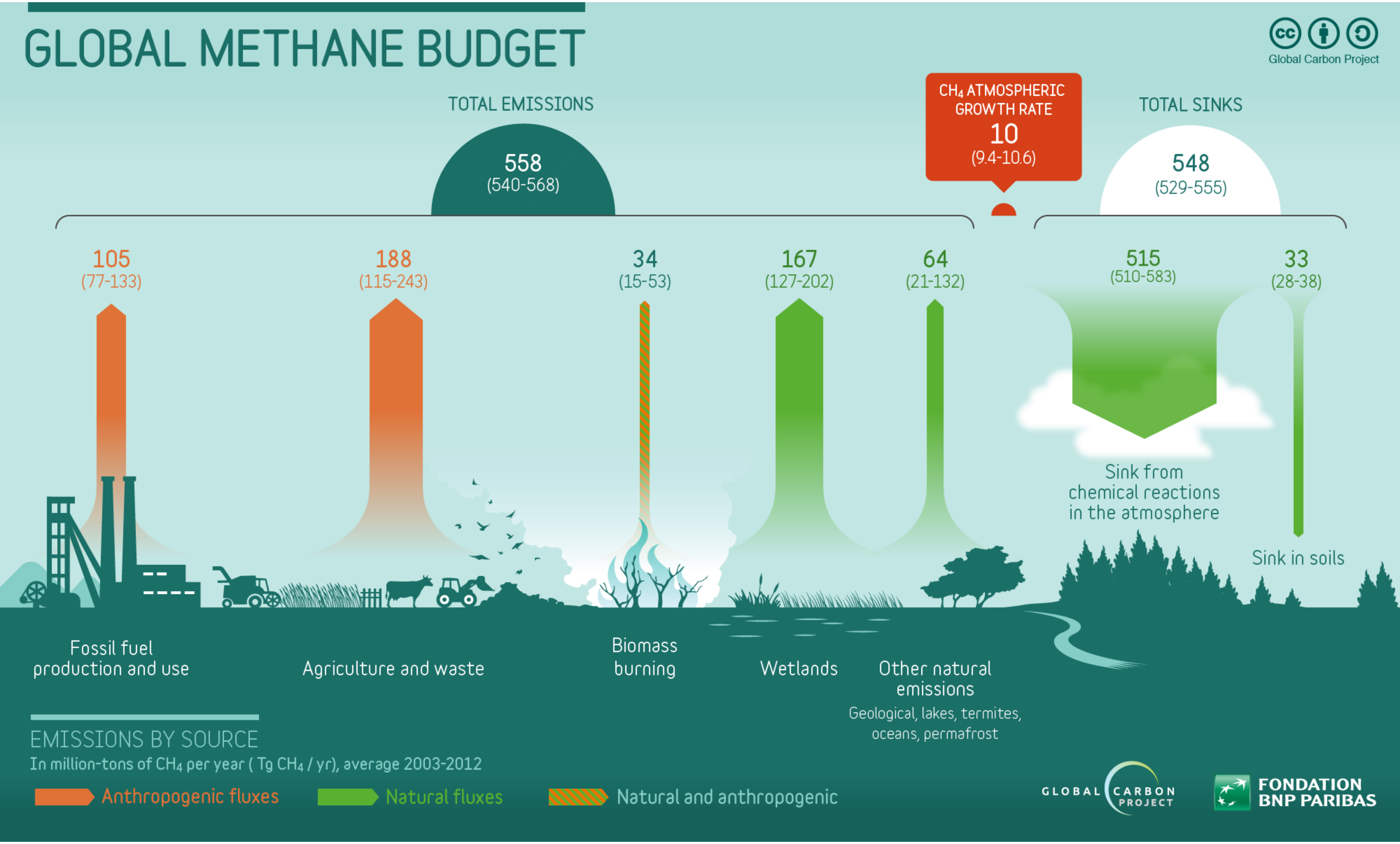
The Global Methane budget for 2000-2012

futurearth
research for global sustainability

Published on 12 December 2016
PowerPoint version 1.0 (released 12 December 2016)



1900
1850
1800
1750
CH_4 concentration (ppb)
3.2–5.4°C
by 2100 relative to 1850–1900
Observations
2.0–3.7°C
1.7–3.2°C
0.9–2.3°C
Saunois et al. 2016, ERL
Global Carbon Project
2005
2008
2011
2014
2017
2020
Year



http://www.globalcarbonatlas.org

GLOBAL CARBON PROJECT

Bottom-up budget	(TgCH$_4$/yr)	Top-down budget
185 [40%]	Natural wetlands	167 [80%]
195 [15%]	Agriculture & waste	188 [65%]
30 [10%]	Rice	
106 [20%]	Enteric ferm & manure	
59 [20%]	Landfills & waste	
121 [20%]	Fossil fuel use	105 [50%]
42 [80%]	Coal	
79 [10%]	Gas & oil	
30 [30%]	Biomass/biofuel burning	34 [55%]
199 [90%]	Other natural emissions	64 [150%]
122 [100%]	Fresh waters	
10 [100%]	Wild animals	
3 [100%]	Wild fires	
9 [120%]	Termites	
40 [50%]	Geological	
3 [100%]	Oceans	
1 [100%]	Permafrost	

Mean [uncertainty= min-max range %] (bottom-up)

Mean [uncertainty= min-max range %] (top-down)

Bottom-up budget

Process models, inventories, data driven methods

734 TgCH$_4$/yr [596-884]

Mean [min-max range %]

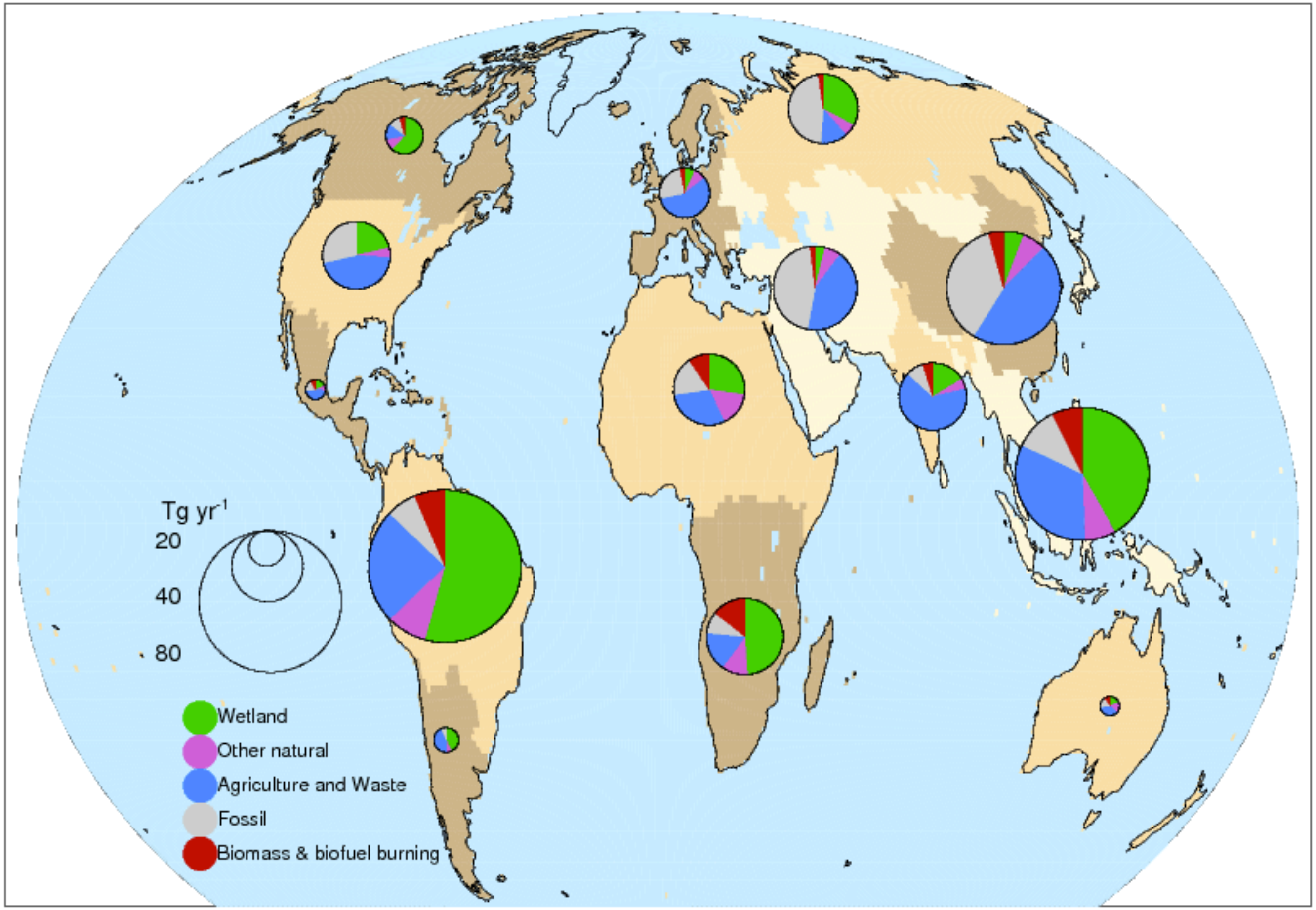
Source : *Saunois et al. 2016, ESSD*

Top-down budget

Atmospheric inversions

559 TgCH$_4$/yr [540-568]

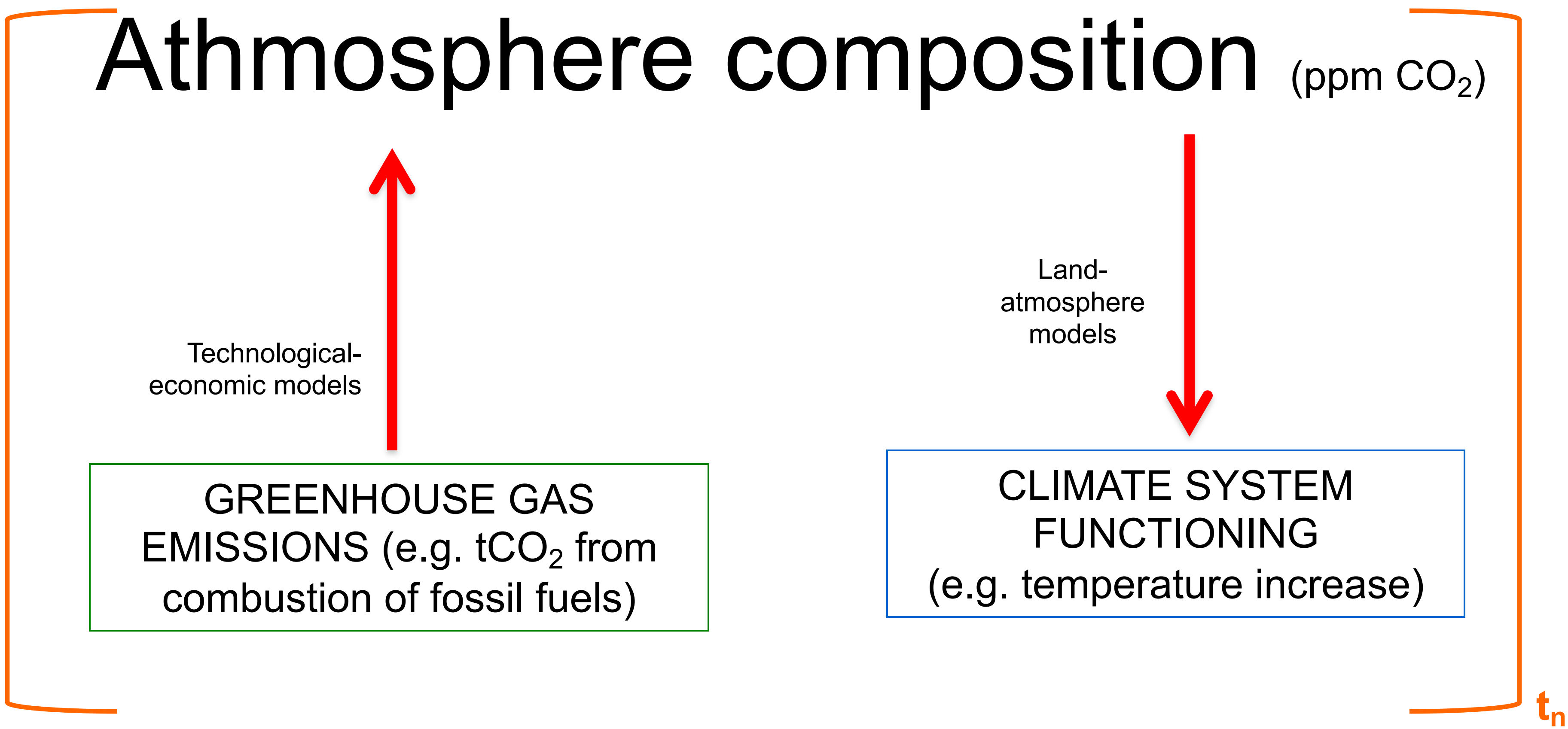
Top-down budget



- 60% of global methane emissions come from tropical sources
- Anthropogenic sources are responsible for 60% of global emissions.

Inverse models

Source: Saunois et al. 2016 ERL (Fig 2)


Athmosphere composition (ppm CO_2)
Technological-economic models
Land-atmosphere models
GREENHOUSE GAS EMISSIONS (e.g. tCO_2 from combustion of fossil fuels)
CLIMATE SYSTEM FUNCTIONING (e.g. temperature increase)
t_n

How will the future look like?
Emission scenarios

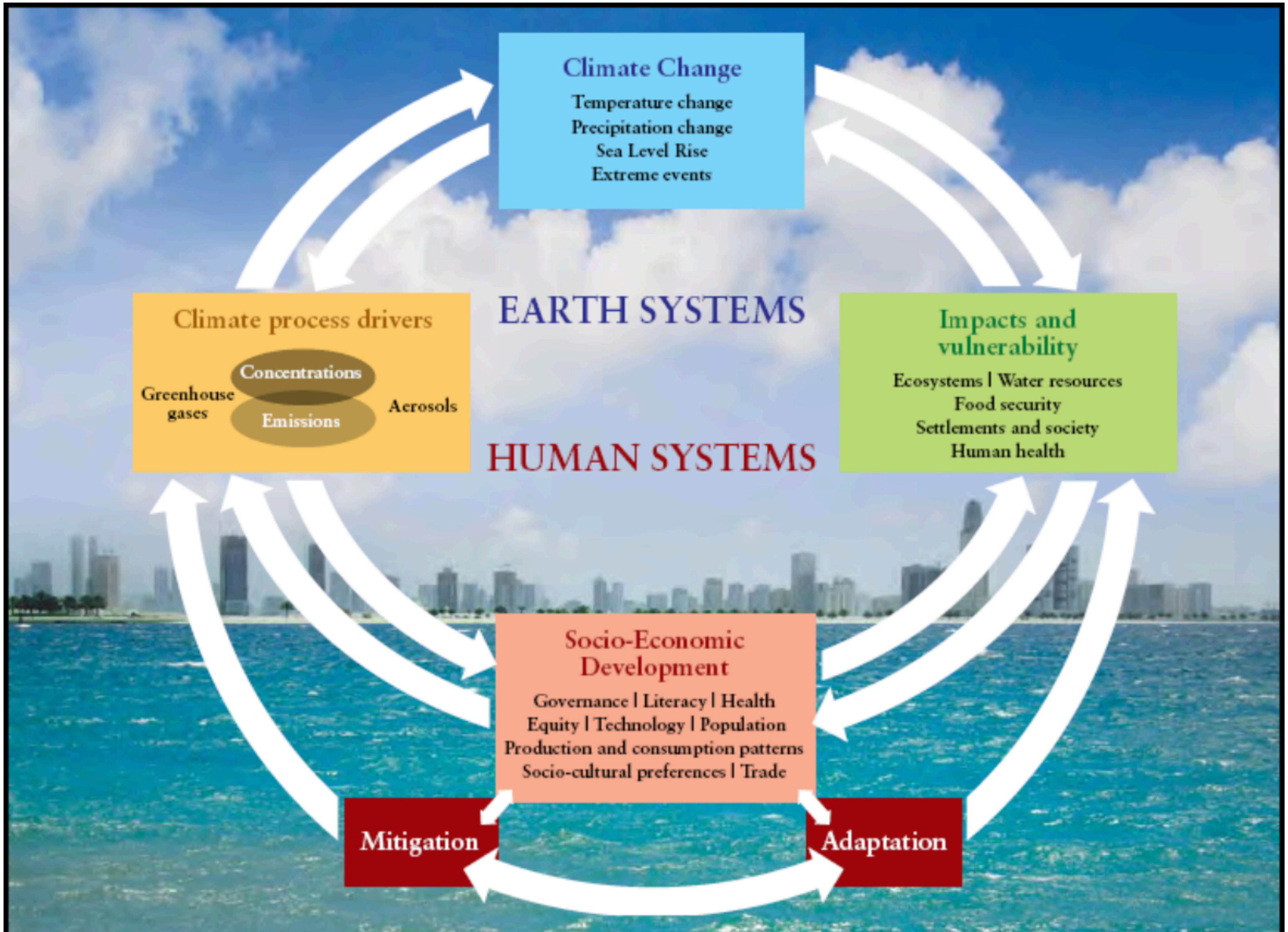
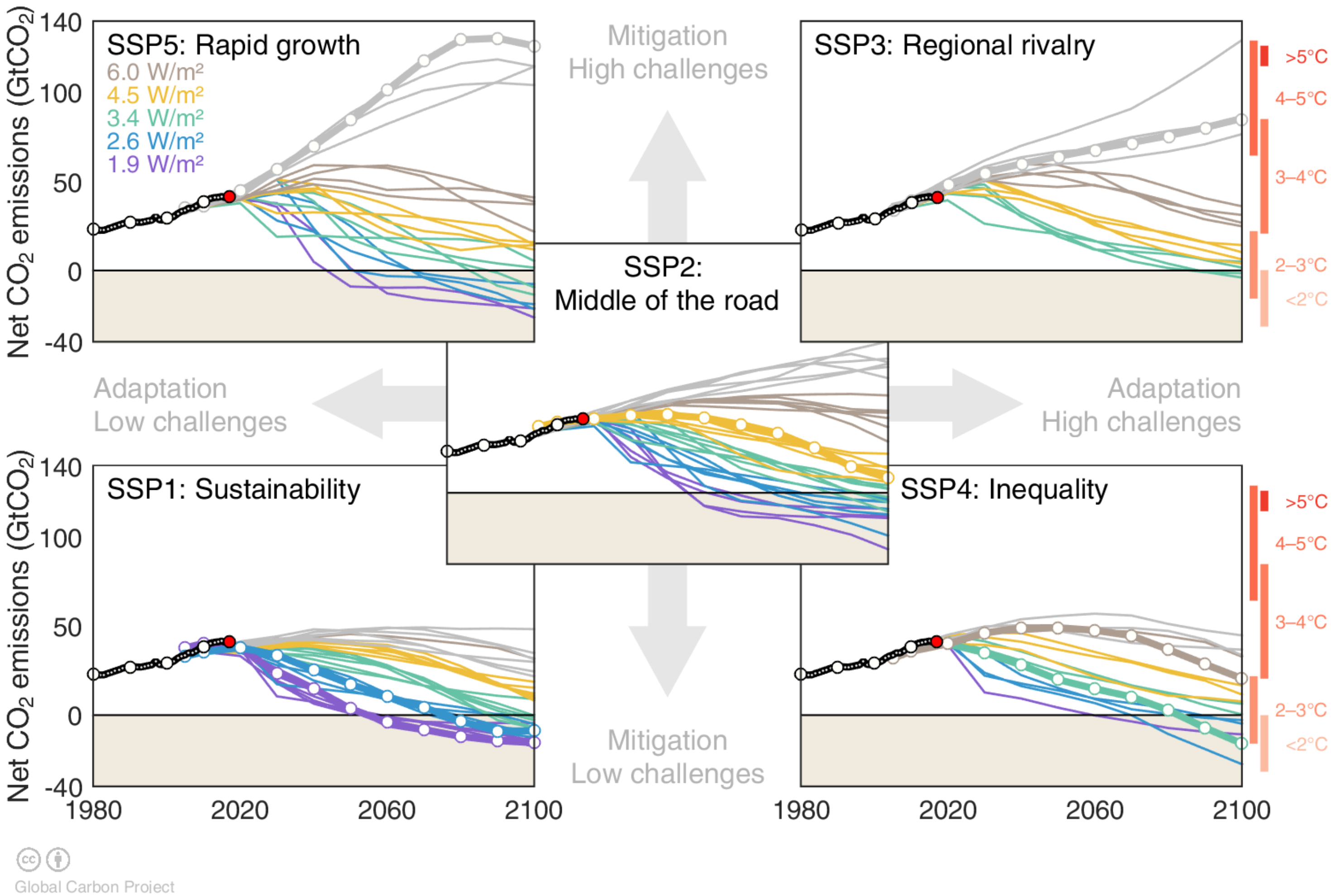


Figure 1. *From the IPCC Expert Meeting Report: Towards New Scenarios - Technical Summary*

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

Emissions Scenarios

“The radiative forcing trajectories were thus termed “Representative Concentration Pathways” (RCPs). The RCPs are not associated with unique socioeconomic assumptions or emissions scenarios (including land-cover changes) but can result from different combinations of economic, technological, demographic, policy, and institutional futures”.
(Source: IPCC Scenario Process for AR5)

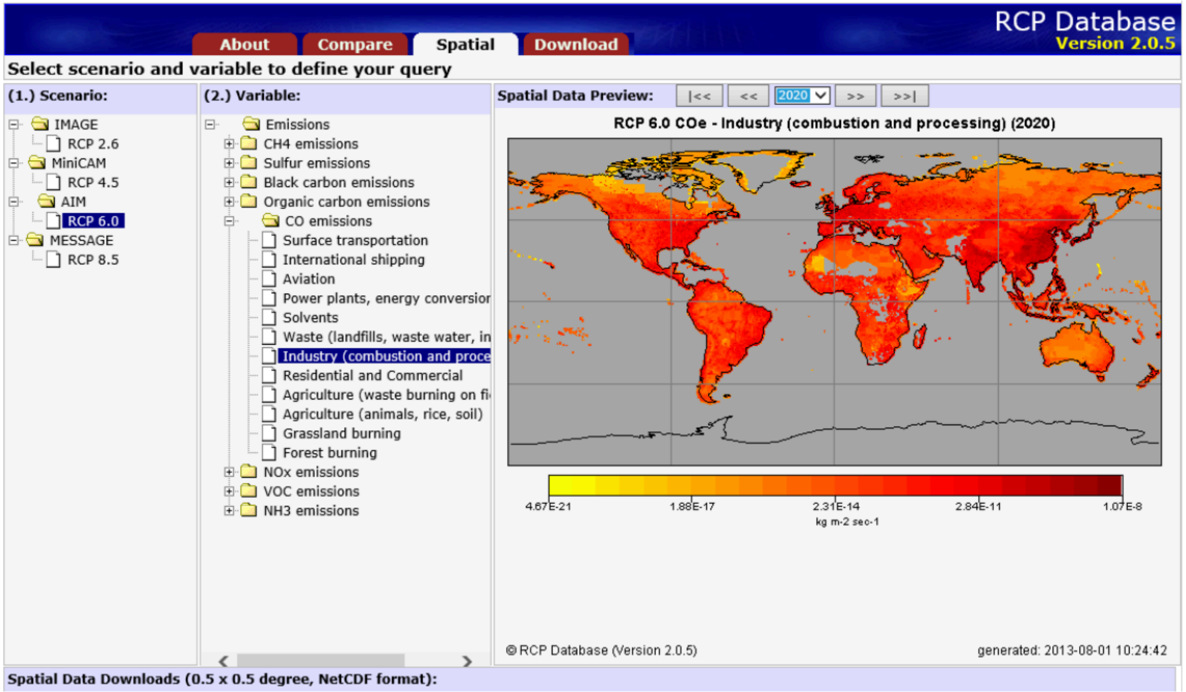
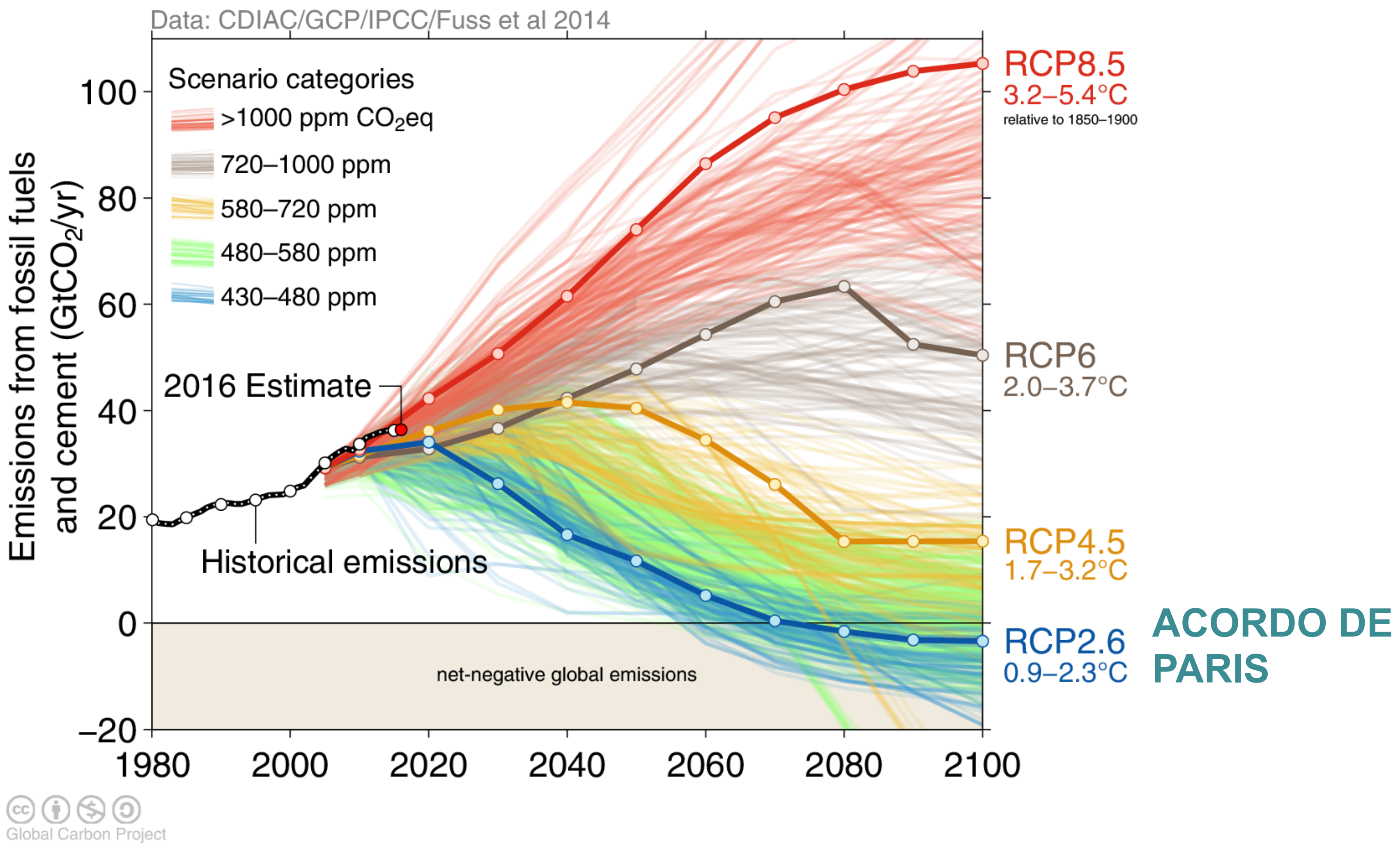


***Figure 2**: RCP on-line database showing RPC6 spatial data for industry COe emissions for the year 2020.*

http://www.iiasa.ac.at/web-apps/tnt/RcpDb/dsd?Action=htmlpage&page=welcome

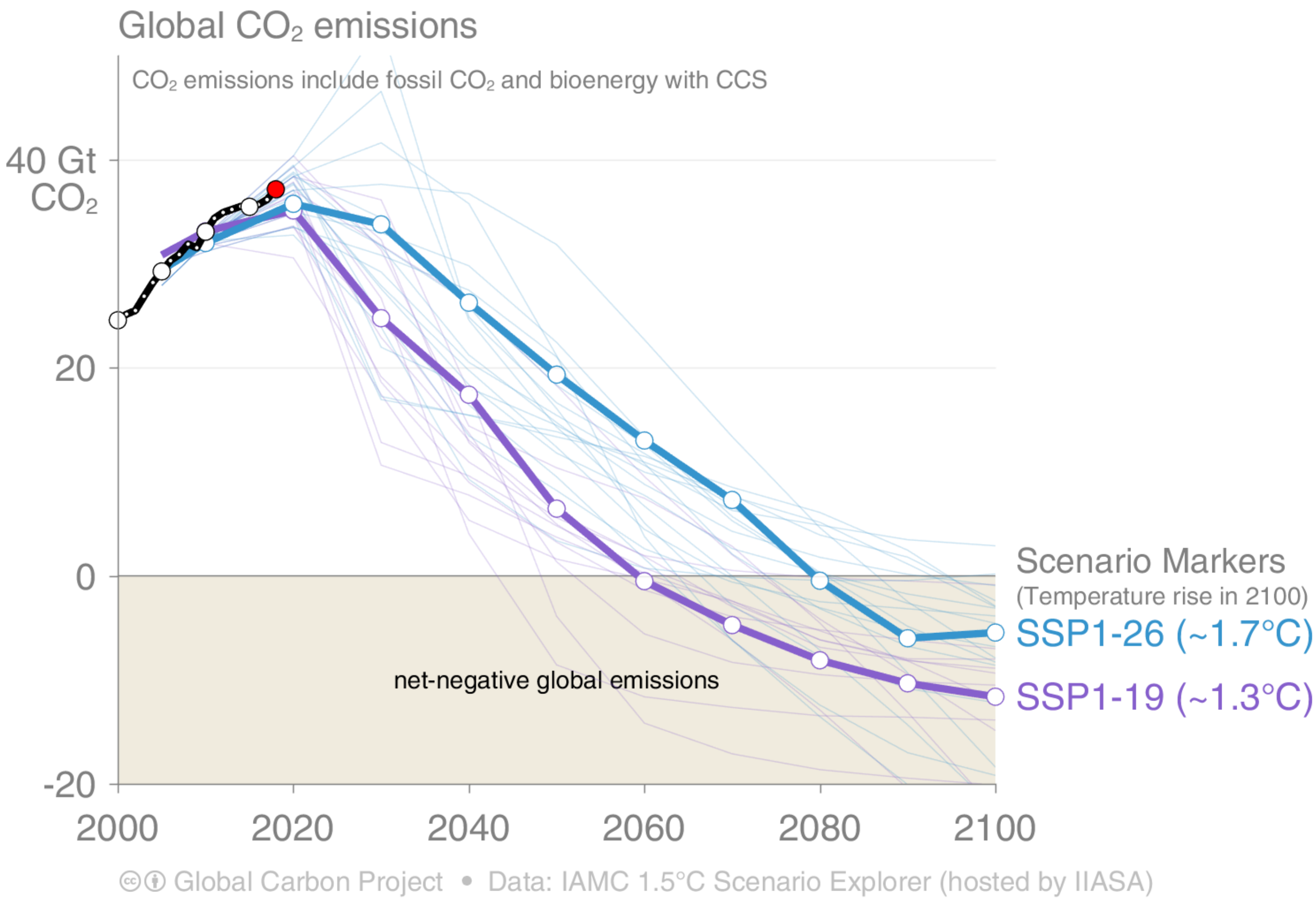
Observed emissions and emissions scenarios



To know more on RCPs please read Meinshausen et al (2011)

Emissions must decline rapidly

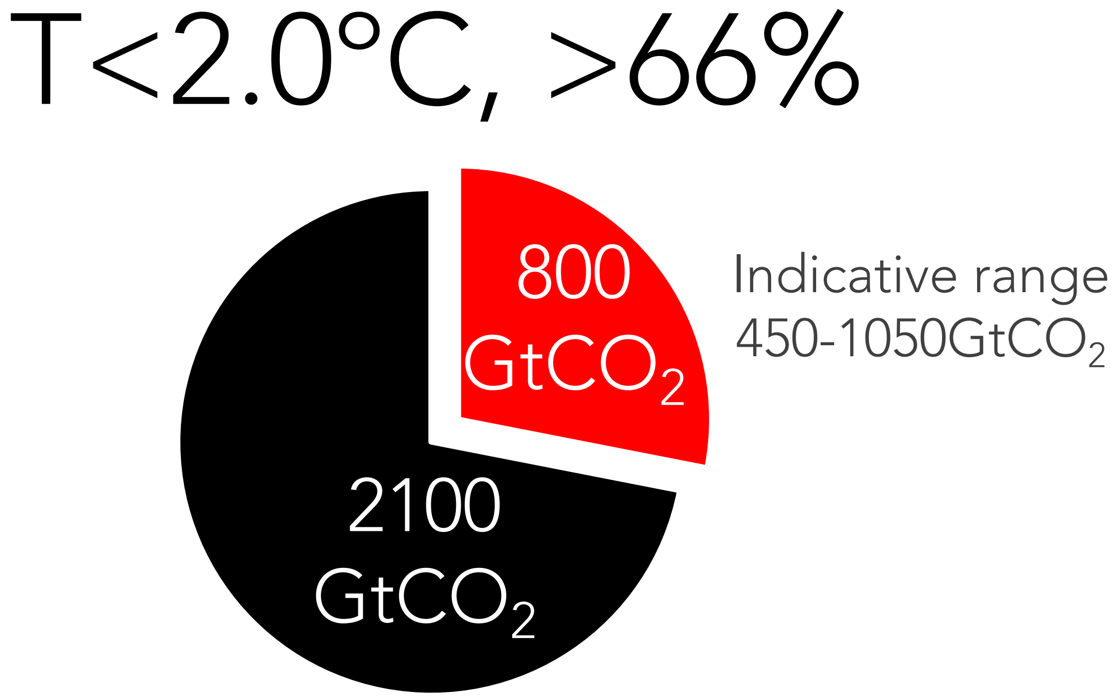
CO_2 emissions need to rapidly decline to follow pathways consistent with the **Paris targets**
(Projection for 2018 emissions in red)



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

Carbon quota for a >66% chance to keep below 2ºC

For a >66% chance to keep global average temperature below 2º C above pre-industrial levels, society can emit 2900 billion tonnes CO_2 from 1870 or about 800 billion tonnes CO_2 from 2017



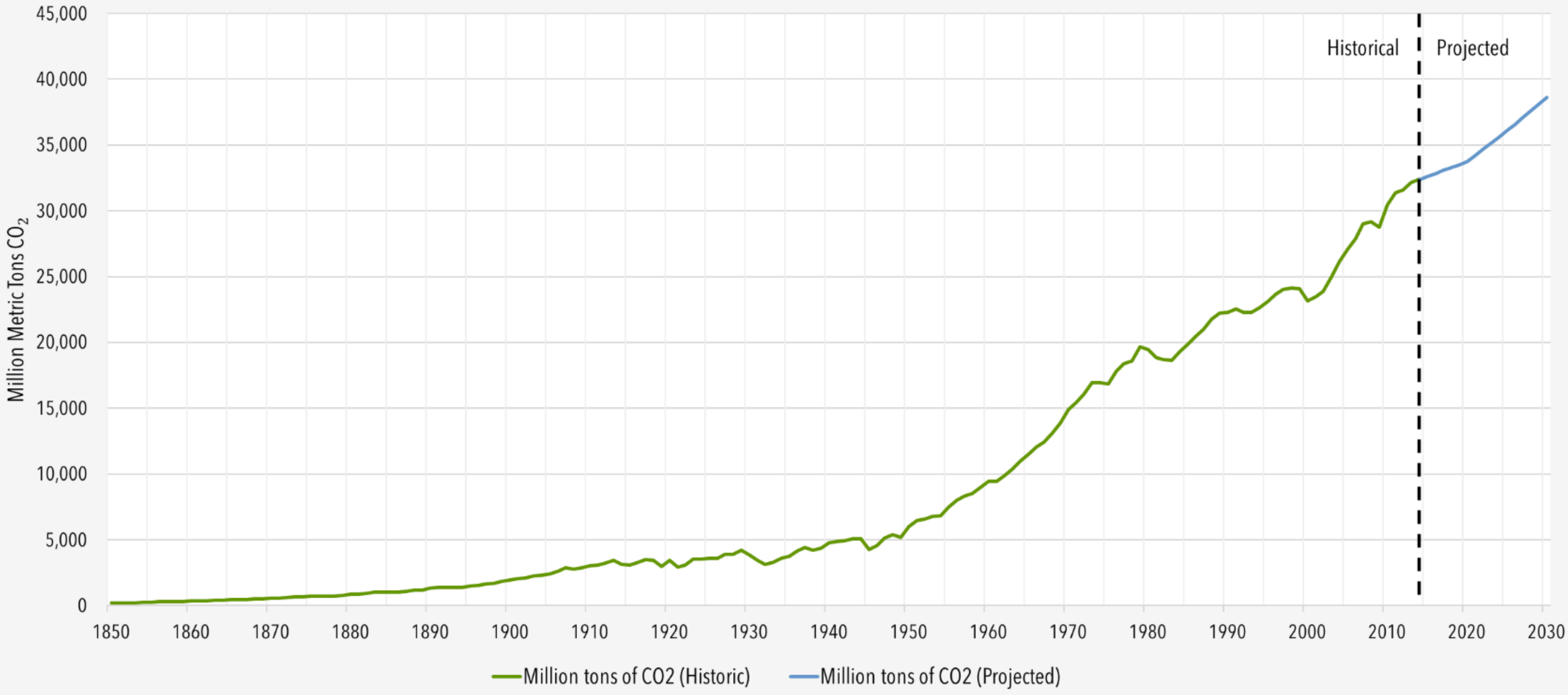
Historical emissions 1870-2016: 2100$GtCO_2$. All values rounded to the nearest 50 $GtCO_2$

The remaining quotas are indicative and vary depending on definition and methodology (Rogelj et al 2016).

Source: IPCC AR5 SYR (Table 2.2); Le Quéré et al 2016; Global Carbon Budget 2016

Emissions Scenarios (put in a past perspective)

Global Carbon Dioxide Emissions, 1850–2030



SOURCE

Carbon Dioxide Information Analysis Center (Oak Ridge National Laboratory, 2017)

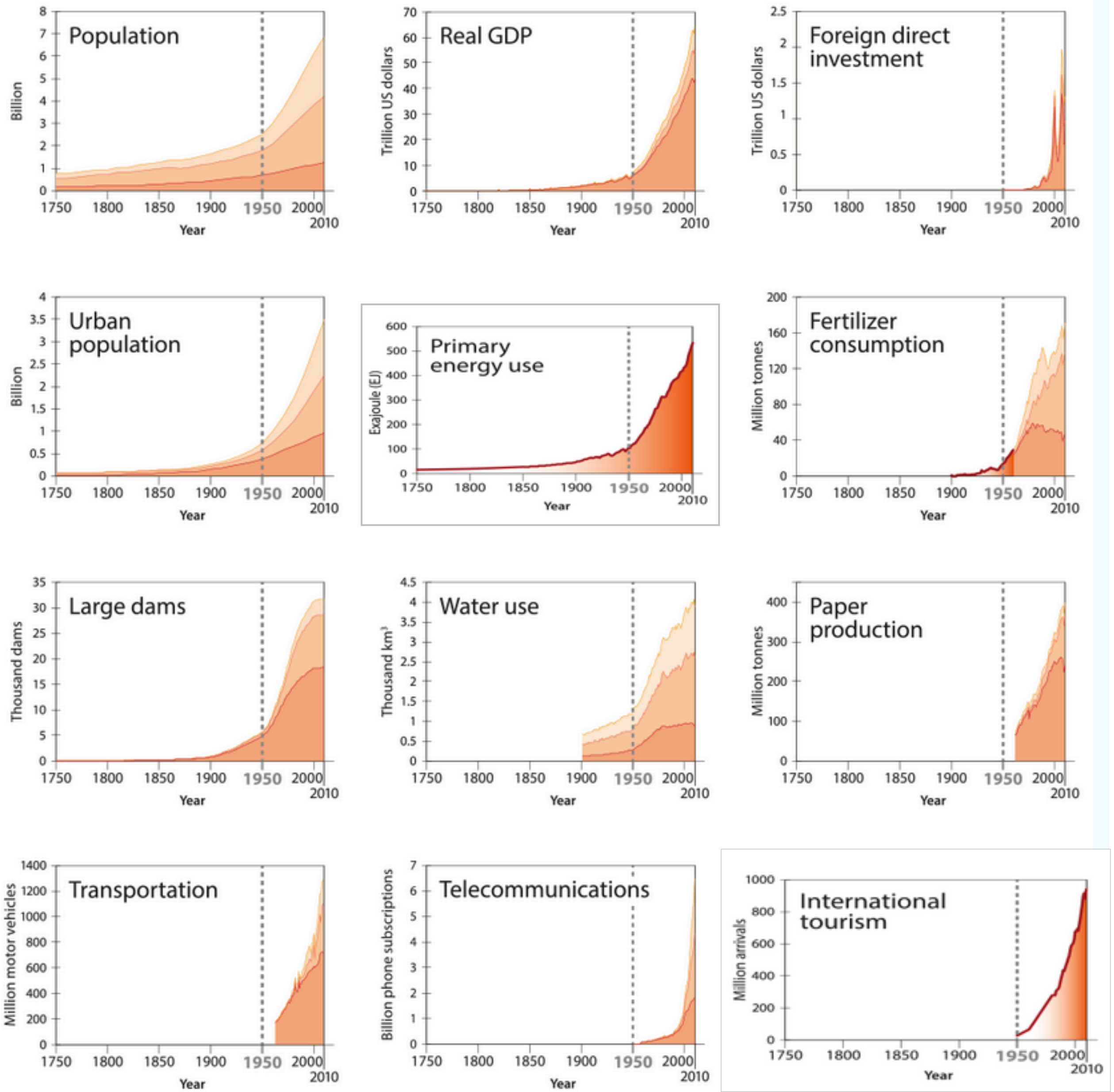
World Energy Outlook (International Energy Agency, 2016).

GREAT ACCELERATION

Socio-economic trends

OECD BRICS Others

Increasing rates of change in human activity since the beginning of the Industrial Revolution.



Steffen *et al.* The trajectory of the Anthropocene: The Great Acceleration (*Anthropocene Review)* 16 January 2015. Design: Globaia