

Global Carbon Budget 2016

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

Atmospheric CO₂ datasets

NOAA/ESRL (Dlugokencky and Tans 2016)
Scripps (Keeling et al. 1976)

Fossil Fuels and Industry

CDIAC (Boden et al. 2016)
USGS, 2016
UNFCCC, 2016
BP, 2016

Consumption Emission

Peters et al. 2011
GTAP (Narayanan et al. 2015)

Land-Use Change

Houghton et al. 2012
GFED4 (van der Werf et al. 2010)
FAO-FRA and FAOSTAT
HYDE (Klein Goldewijk et al. 2011)

Atmospheric inversions

CarbonTracker (Peters et al. 2010)
Jena CarboScope (Rödenbeck et al. 2003)
MACC (Chevallier et al. 2005)

Land models

CABLE-POP | CLASS-CTEM | CLM4.5BGC | DLEM |
ISAM | JSBACH | JULES | LPJ-GUESS | LPJ | LPX |
OCNv2 | ORCHIDEE | SDGVM | VISIT
CRU (Harris et al. 2014)

Ocean models

NEMO-PlankTOM5 | NEMO-PISCES (IPSL) | CCSM-BEC
| MICOM-HAMMOC | NEMO-PISCES (CNRM) | CSIRO
| MITgem-REcoM2

Ocean Data products

Jena CarboScope (Rödenbeck et al. 2014)
Landschützer et al. 2015
SOCATv4 (Bakker et al. 2016)

Full references provided in [Le Quéré et al 2016](#)

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TA Boden USA | **PP Tans** USA | **RA Houghton** USA | **RF Keeling** USA

S Alin USA | **OD Andrews** UK | **P Anthoni** USA | **L Barbero** USA | **L Bopp** France | **F Chevallier** France | **LP Chini** USA | **K Currie** New Zealand | **C Delire** France | **SC Doney** USA | **S Fuss** Germany | **T Gkritzalis** Belgium | **I Harris** UK | **J Hauck** Germany | **V Haverd** Australia | **M Hoppema** Germany | **R Jackson** USA | **K Jain** USA | **E Kato** Japan | **K Klein Goldewijk** Netherlands | **A Körtzinger** Germany | **P Landschützer** Switzerland | **N Lefèvre** France | **A Lenton** Australia | **S Lienert** Switzerland | **D Lombardozzi** USA | **JR Melton** Canada | **N Metzl** France | **F Millero** USA | **PMS Monteiro** South Africa | **DR Munro** USA | **JEMS Nabel** Germany | **S-I Nakaoka** Japan | **N Nakicenovic** Austria | **K O'Brien** USA | **A Olsen** Norway | **AM Omar** Norway | **T Ono** Japan | **D Pierrot** USA | **B Poulter** USA | **C Rödenbeck** Germany | **J Rogelj** Austria | **J Salisbury** USA | **U Schuster** UK | **J Schwinger** Norway | **R Séférian** France | **I Skjelvan** Norway | **BD Stocker** UK | **AJ Sutton** USA | **T Takahashi** USA | **H Tian** USA | **B Tilbrook** Australia | **IT van der Laan-Luijkx** Netherlands | **GR van der Werf** Netherlands | **N Viovy** France | **AP Walker** USA | **AJ Wiltshire** UK | **S Zaehle** Germany

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Global Carbon Budget 2016

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GLOBAL CARBON ATLAS

The Global Carbon Atlas is a platform to explore and visualize the most up-to-date data on carbon fluxes resulting from human activities and natural processes.

Human impacts on the carbon cycle are the most important cause of climate change.

OUTREACH

Take a journey through the history and future of human development and carbon

GO



EMISSIONS

Explore and download global and country level carbon emissions from human activity.

GO

RESEARCH

Explore and visualize research carbon data, and get access through data providers

GO

More information, data sources and data files:

www.globalcarbonproject.org

Contact: c.lequere@uea.ac.uk

More information, data sources and data files:

www.globalcarbonatlas.org

(funded in part by BNP Paribas Foundation)

Contact: philippe.ciais@lscce.ipsl.fr

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

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

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

1 GtC = 3.664 billion tonnes CO₂ = 3.664 GtCO₂

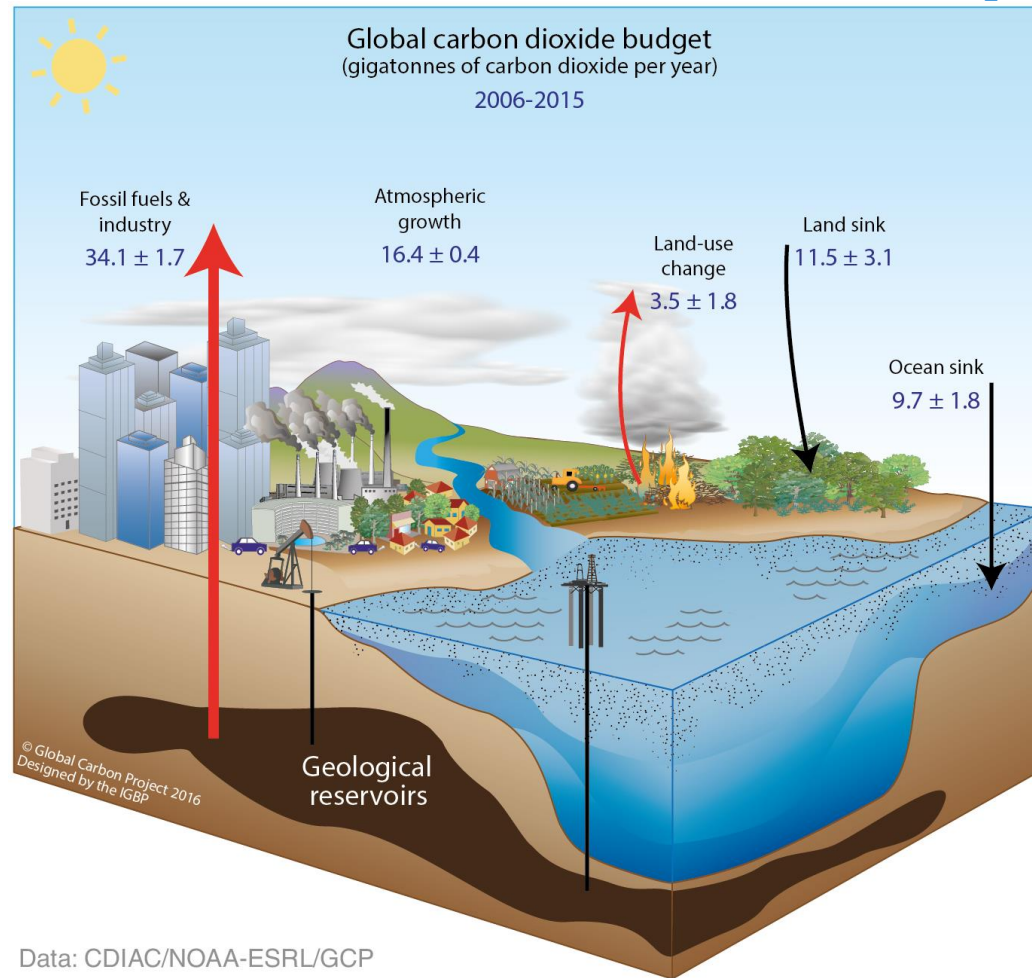
(Figures in units of GtC and GtCO₂ are available from <http://globalcarbonbudget.org/carbonbudget>)

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 2006–2015 (GtCO_2/yr)



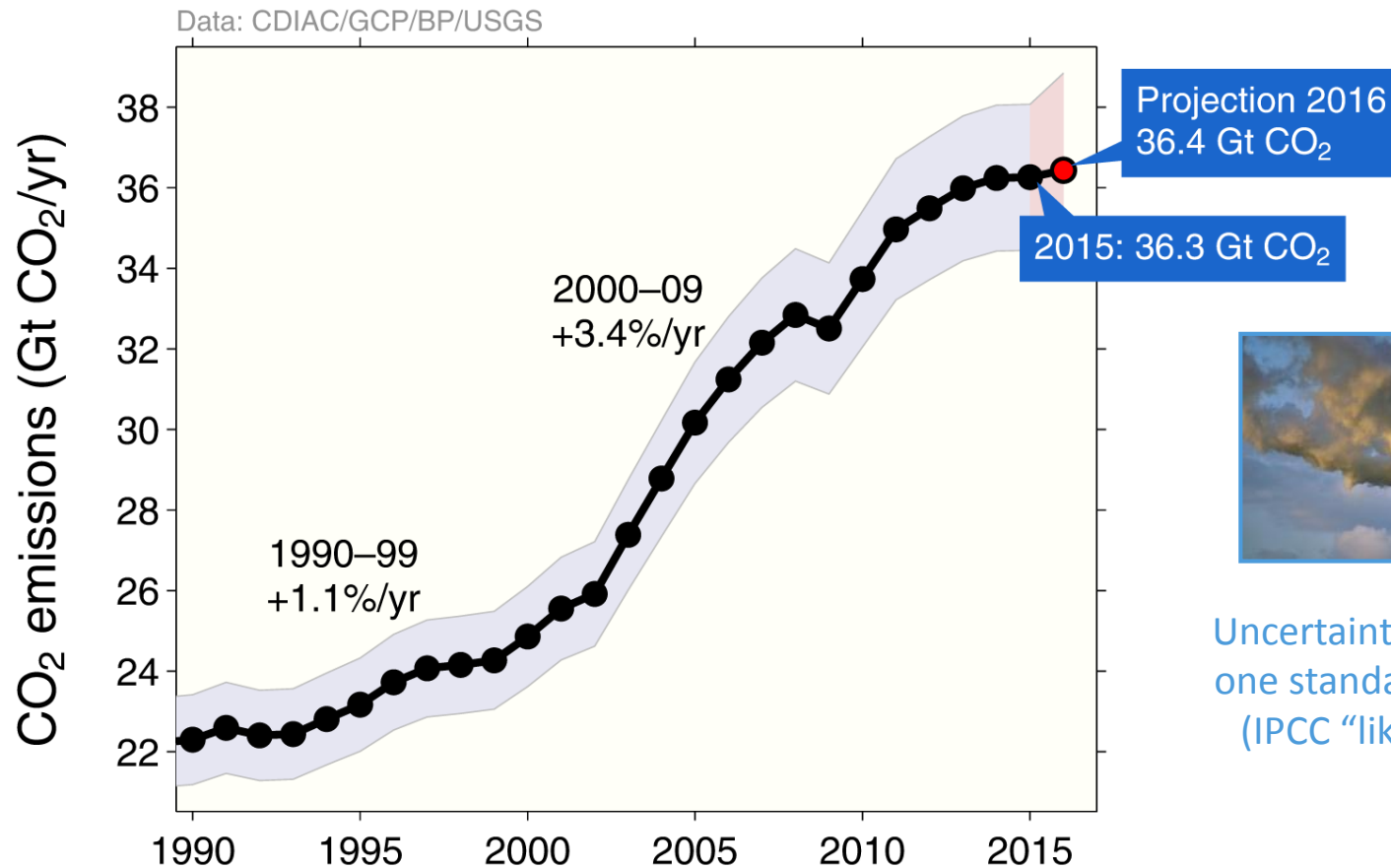
Source: [CDIAC](#); [NOAA-ESRL](#); [Le Quéré et al 2016](#); [Global Carbon Budget 2016](#)

Fossil Fuel and Industry Emissions

Emissions from fossil fuel use and industry

Global emissions from fossil fuel and industry: 36.3 ± 1.8 GtCO₂ in 2015, 63% over 1990

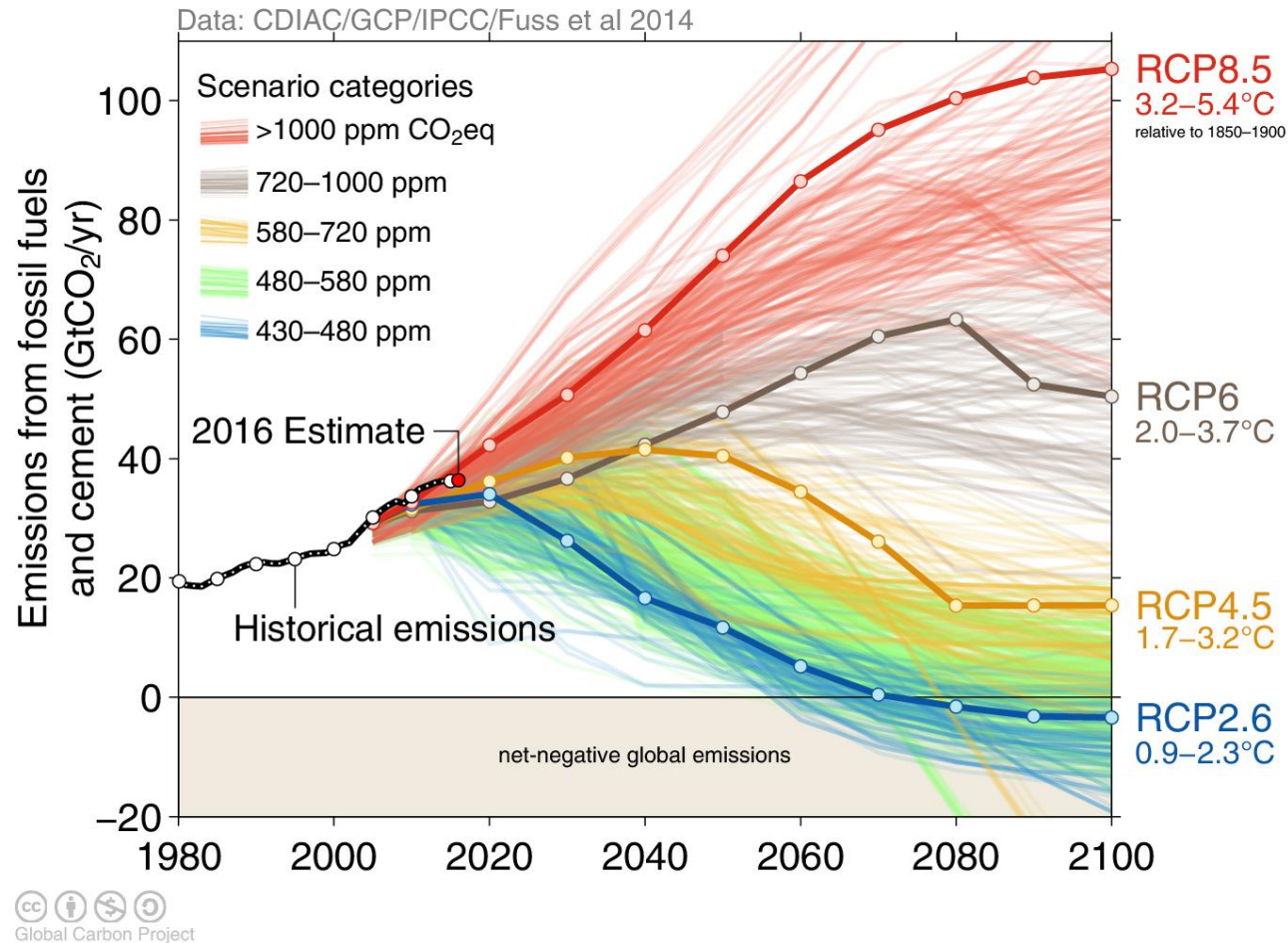
● Projection for 2016: 36.4 ± 2.3 GtCO₂, 0.2% higher than 2015



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

Observed emissions and emissions scenarios

The emission pledges to the Paris Agreement avoid the worst effects of climate change (4-5°C)
Most studies suggest the pledges give a likely temperature increase of about 3°C in 2100

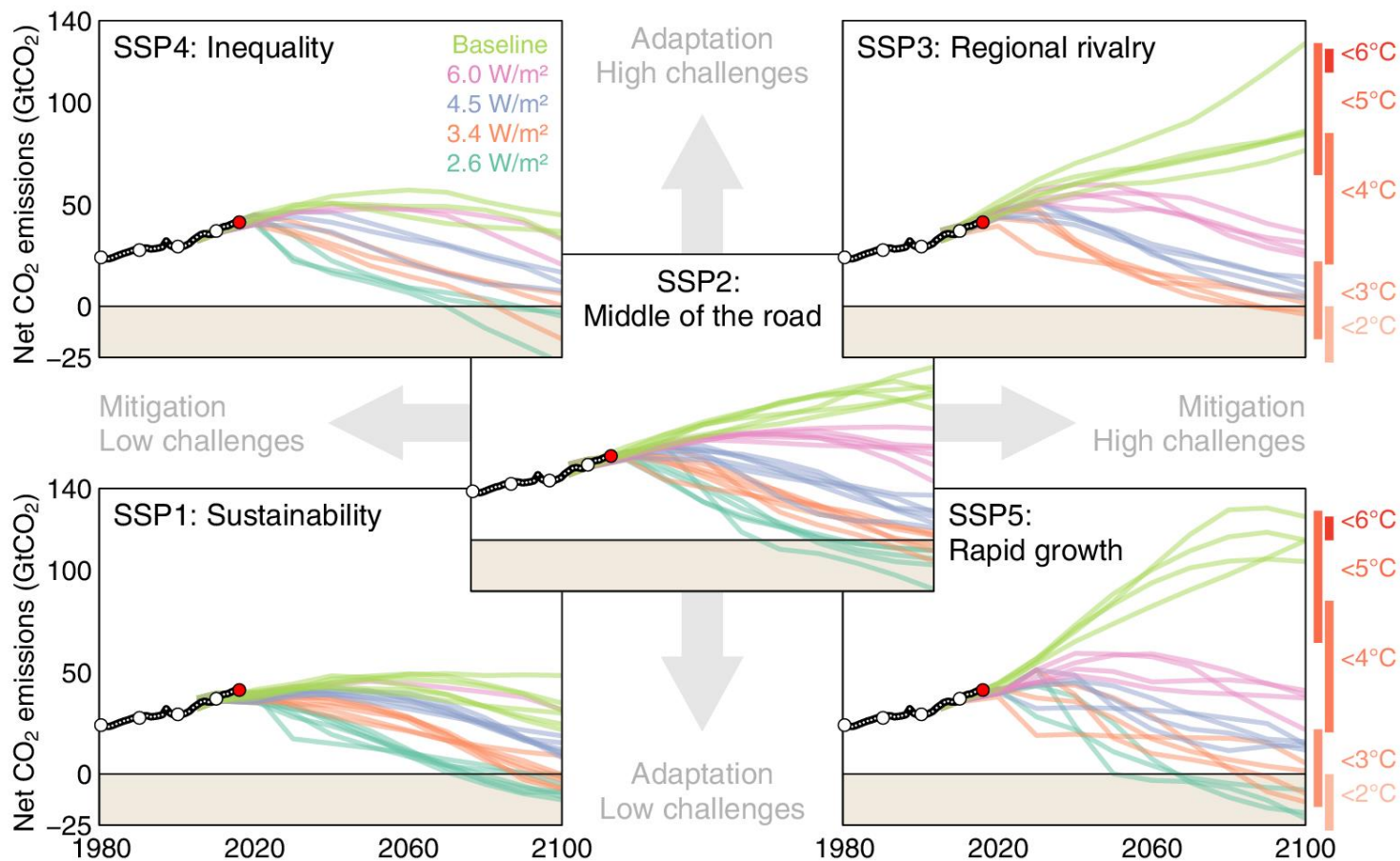


The IPCC Fifth Assessment Report assessed about 1200 scenarios with detailed climate modelling on four Representative Concentration Pathways (RCPs)

Source: [Fuss et al 2014](#); [CDIAC](#); [IIASA AR5 Scenario Database](#); [Global Carbon Budget 2016](#)

New generation of scenarios

In the lead up to the IPCC's Sixth Assessment Report new scenarios have been developed to more systematically explore key uncertainties in future socioeconomic developments

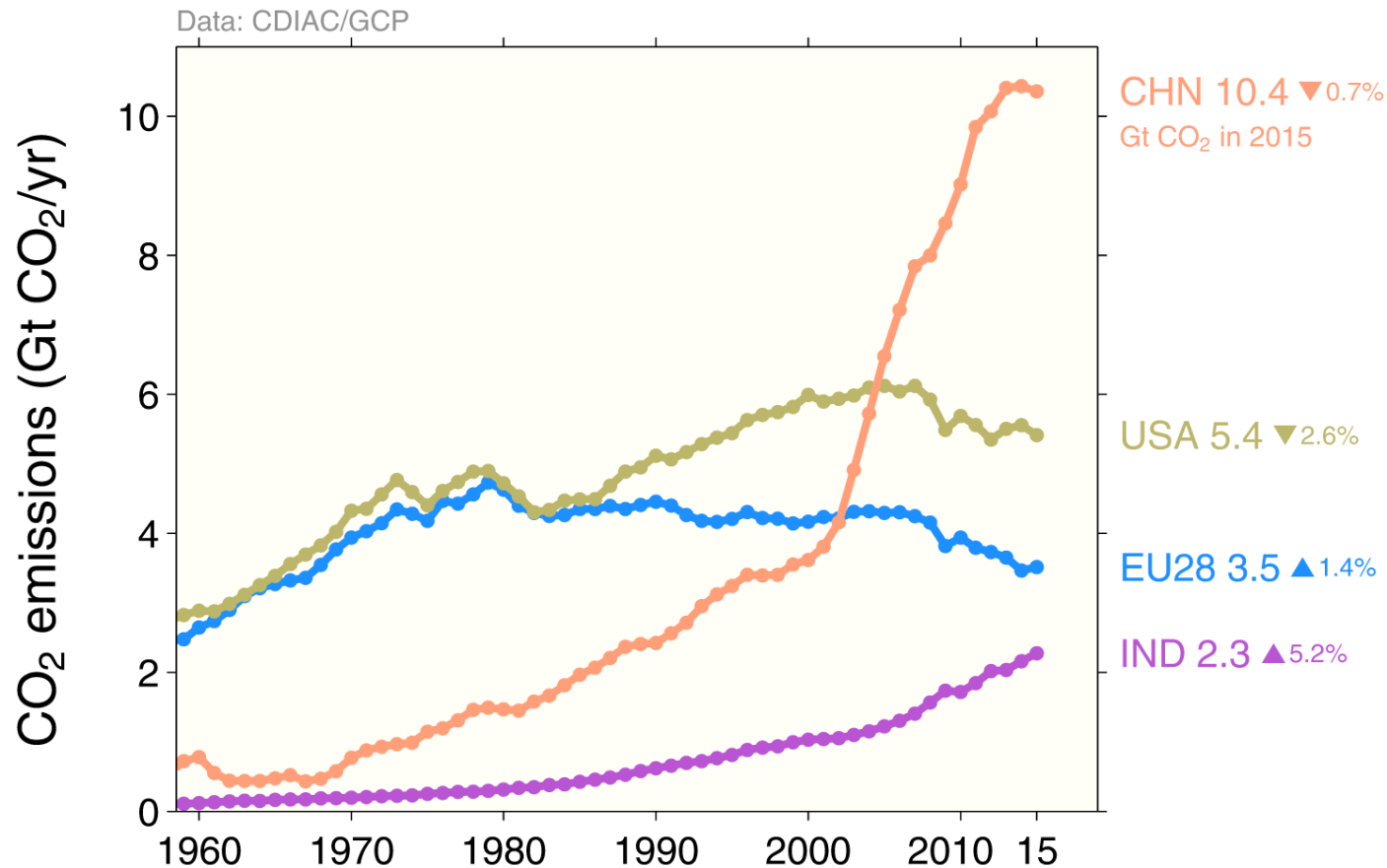


Five Shared Socioeconomic Pathways (SSPs) have been developed to explore challenges to adaptation and mitigation. Shared Policy Assumptions (SPAs) are used to achieve target forcing levels (W/m²).

Source: [Riahi et al. 2016](#); [IIASA SSP Database](#); [Global Carbon Budget 2016](#)

Top emitters: fossil fuels and industry (absolute)

The top four emitters in 2015 covered 59% of global emissions
China (29%), United States (15%), EU28 (10%), India (6%)



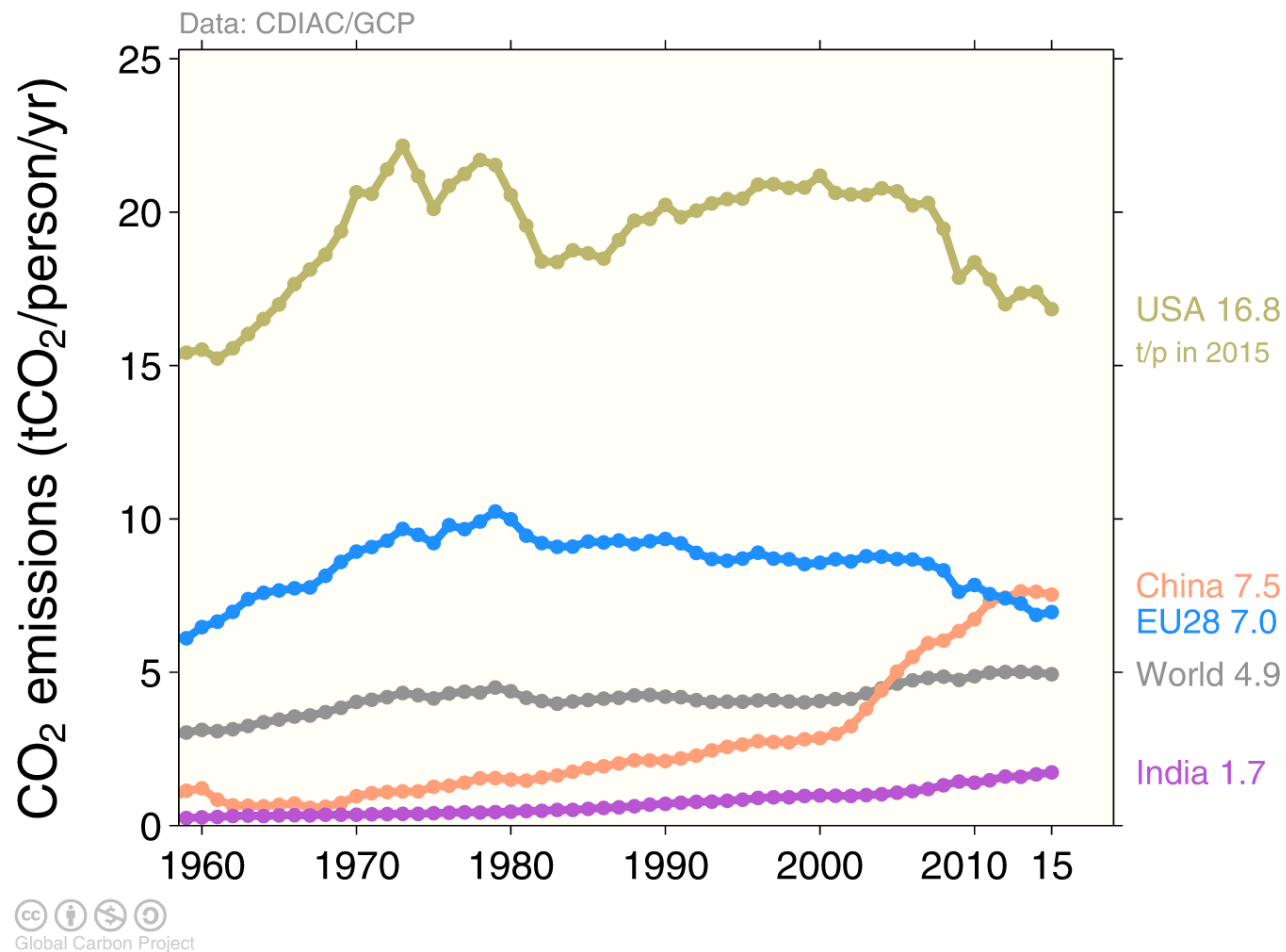
Bunker fuels are used for international transport is 3.1% of global emissions.

Statistical differences between the global estimates and sum of national totals are 1.2% of global emissions.

Source: [CDIAC](#); [Le Quéré et al 2016](#); [Global Carbon Budget 2016](#)

Top emitters: fossil fuels and industry (per capita)

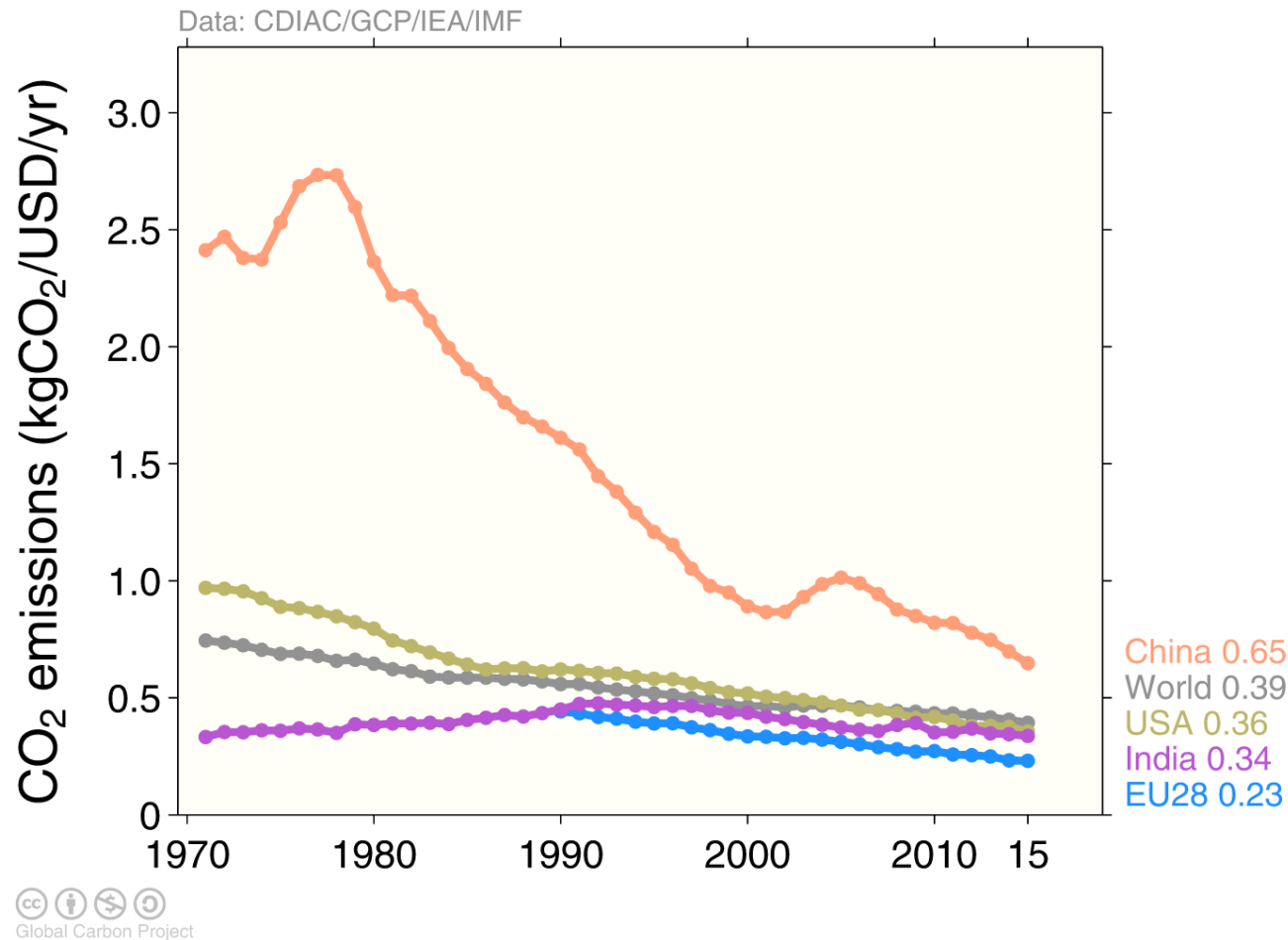
Countries have a broad range of per capita emissions reflecting their national circumstances



Source: [CDIAC](#); [Le Quéré et al 2016](#); [Global Carbon Budget 2016](#)

Top emitters: fossil fuels and industry (per dollar)

Emissions per unit economic output (emissions intensities) generally decline over time
China's intensity is declining rapidly, but is still much higher than the world average

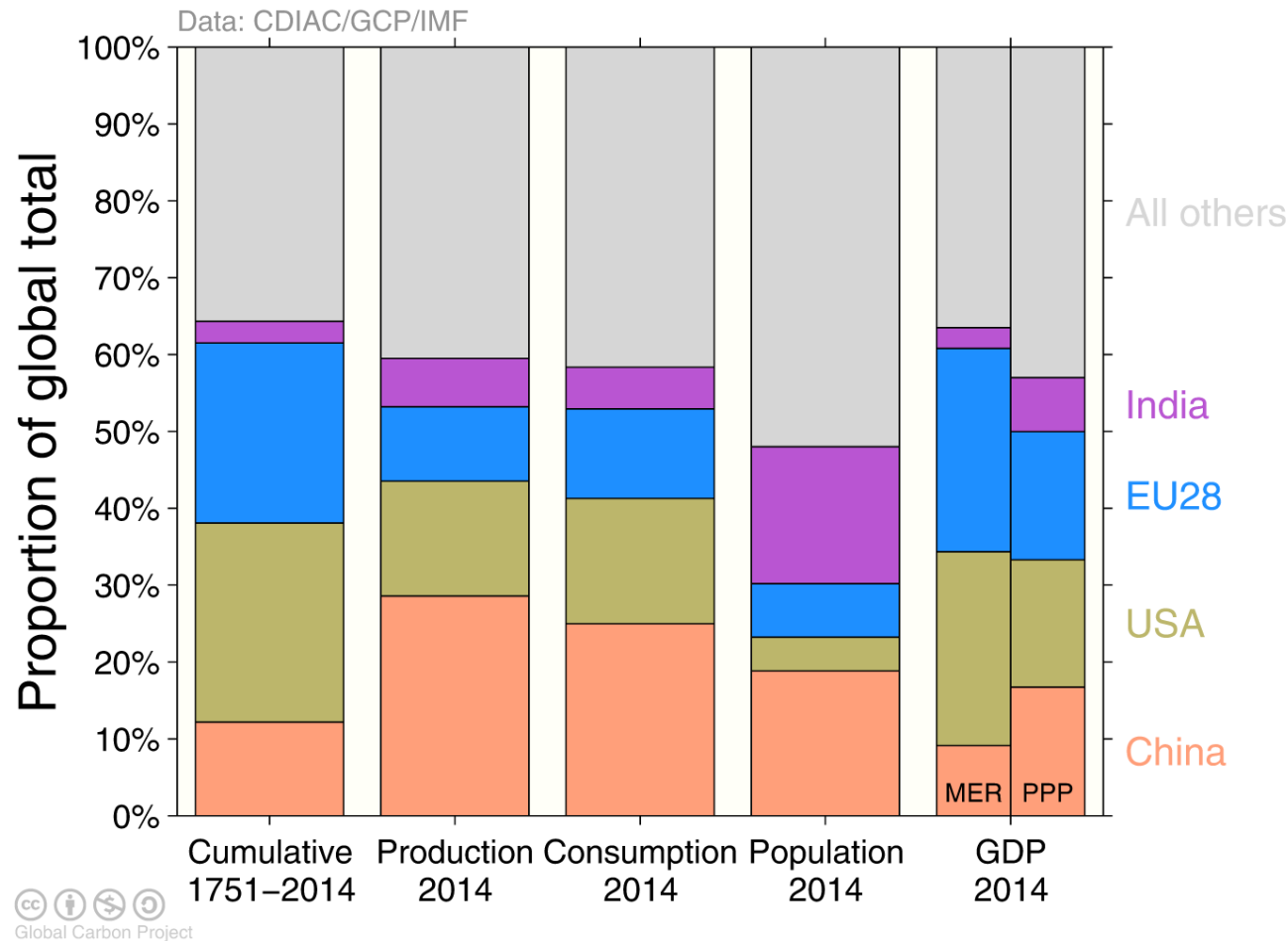


GDP are measured in purchasing power parity (PPP) terms in 2005 dollars.

Source: [CDIAC](#); [IEA 2015](#) GDP to 2013, [IMF 2016](#) growth rates to 2015; [Le Quéré et al 2016](#); [Global Carbon Budget 2016](#)

Alternative rankings of countries

Depending on perspective, the significance of individual countries changes

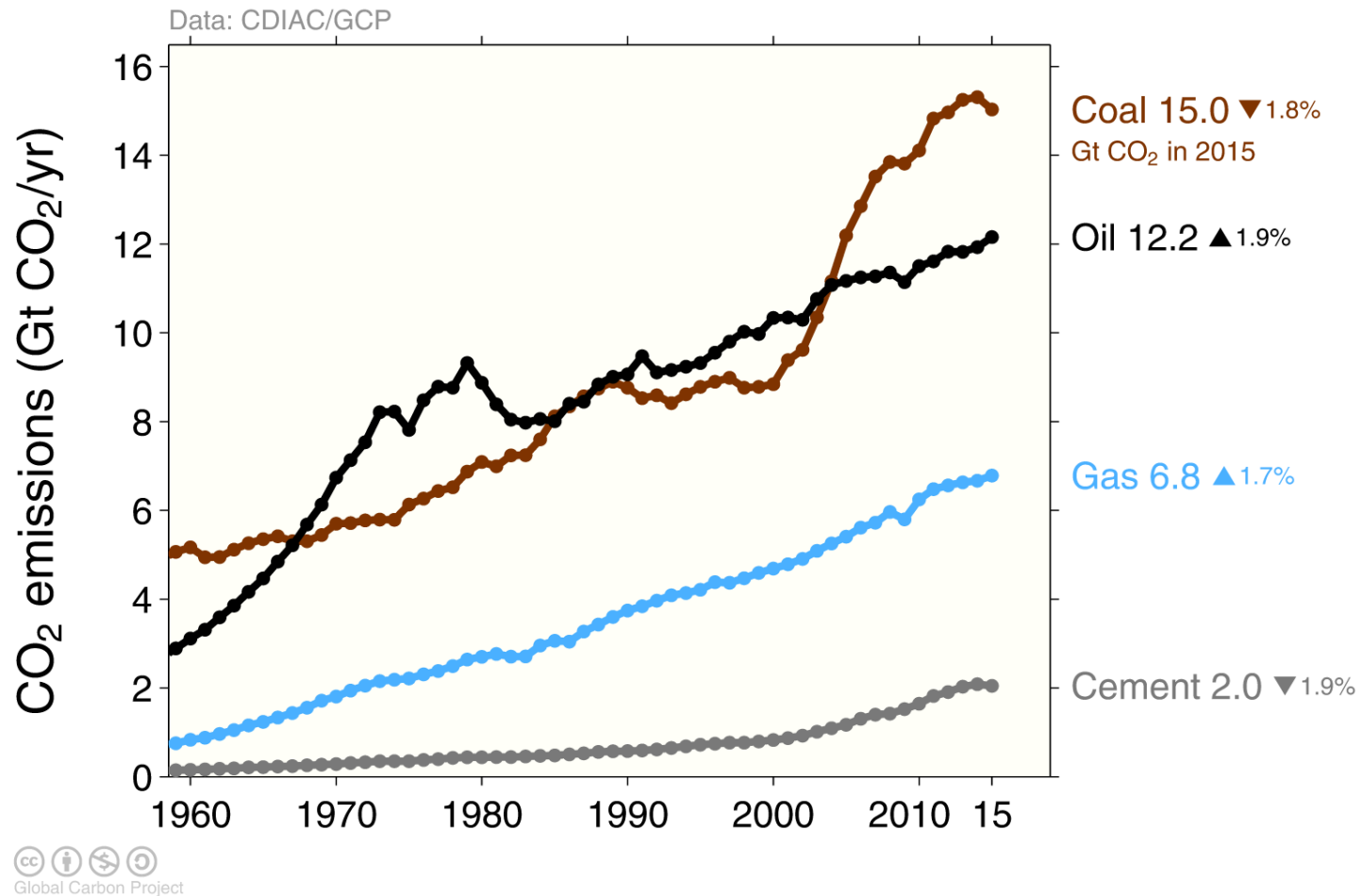


GDP: Gross Domestic Product in Market Exchange Rates (MER) and Purchasing Power Parity (PPP)

Source: [CDIAC](#); [United Nations](#); [Le Quéré et al 2016](#); [Global Carbon Budget 2016](#)

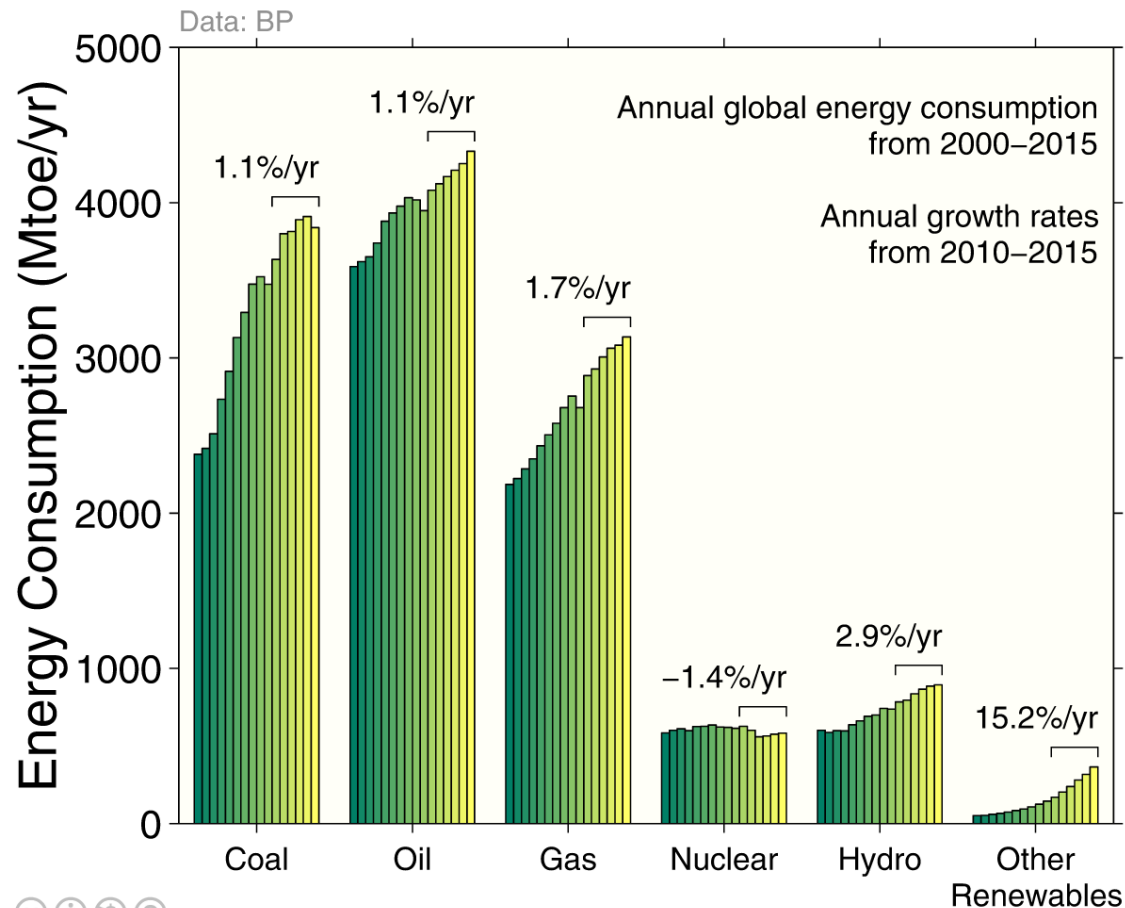
Emissions from coal, oil, gas, cement

Share of global emissions in 2015:
coal (41%), oil (34%), gas (19%), cement (6%), flaring (1%, not shown)



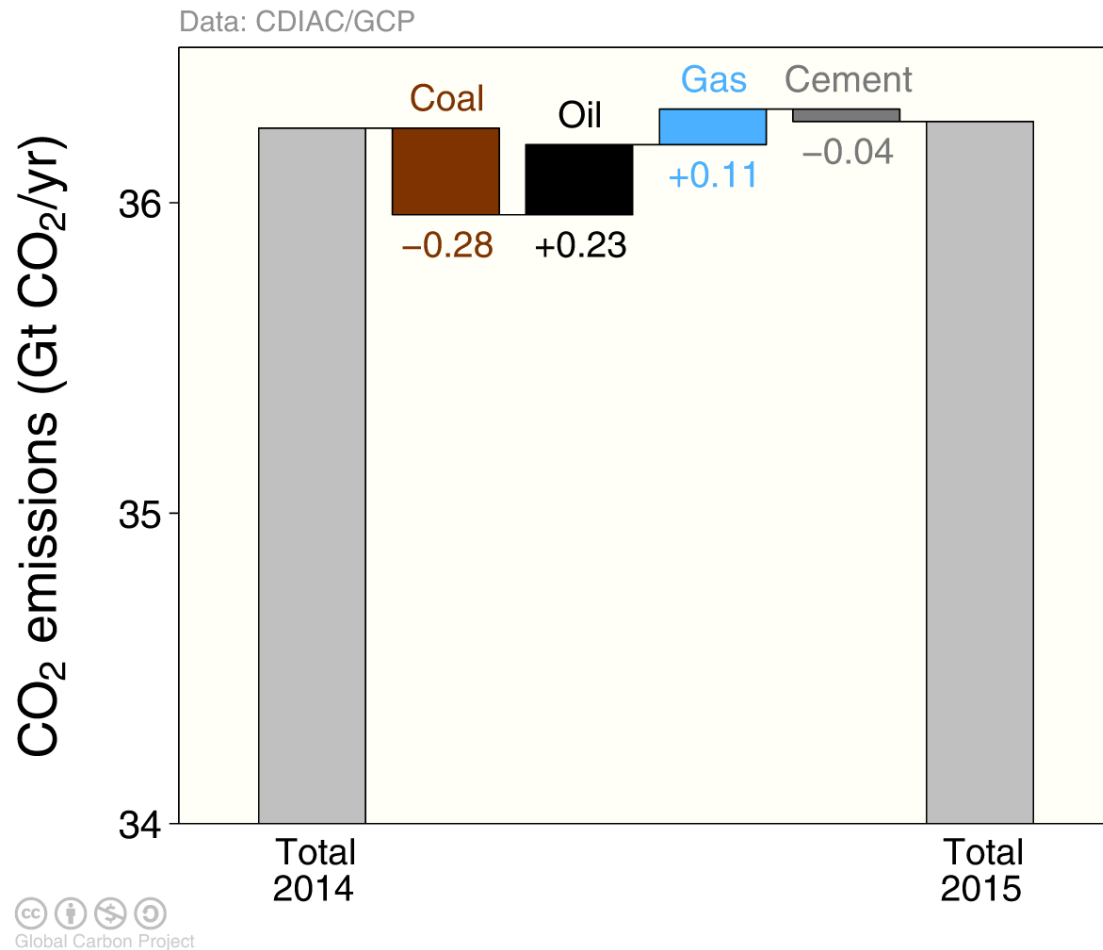
Energy consumption by energy type

Energy consumption by fuel source from 2000 to 2015, with growth rates indicated for the more recent period of 2010 to 2015



Fossil fuel and cement emissions growth

The biggest changes in emissions were from a decline in coal and an increase in oil



Fossil fuel and cement emissions growth

Emissions in the US, China and Russia declined

Emissions in India and all other countries combined increased

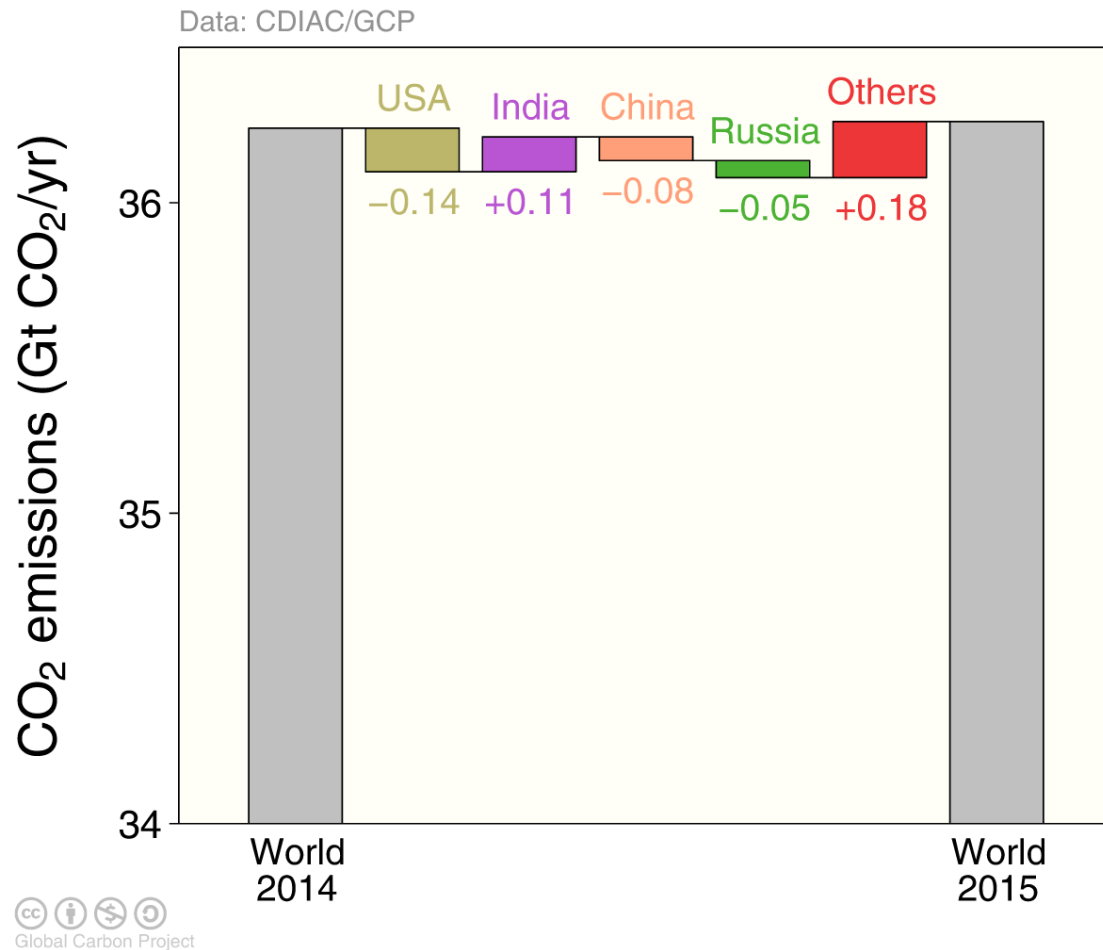
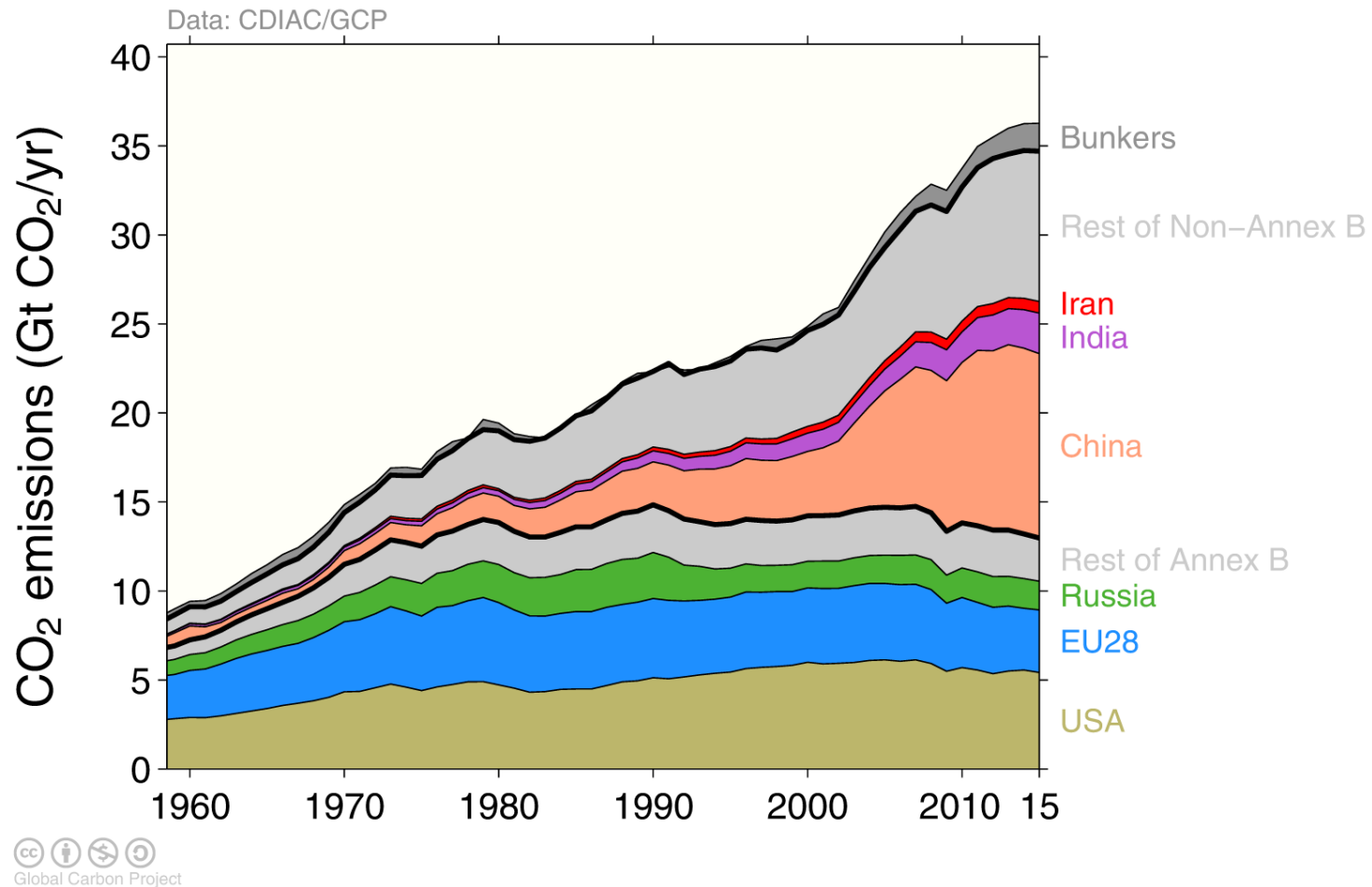


Figure shows the top four countries contributing to emissions changes in 2015

Source: [CDIAC](#); [Le Quéré et al 2016](#); [Global Carbon Budget 2016](#)

Breakdown of global emissions by country

Emissions from Annex B countries have slightly declined since 1990
Emissions from non-Annex B countries have increased rapidly in the last decade

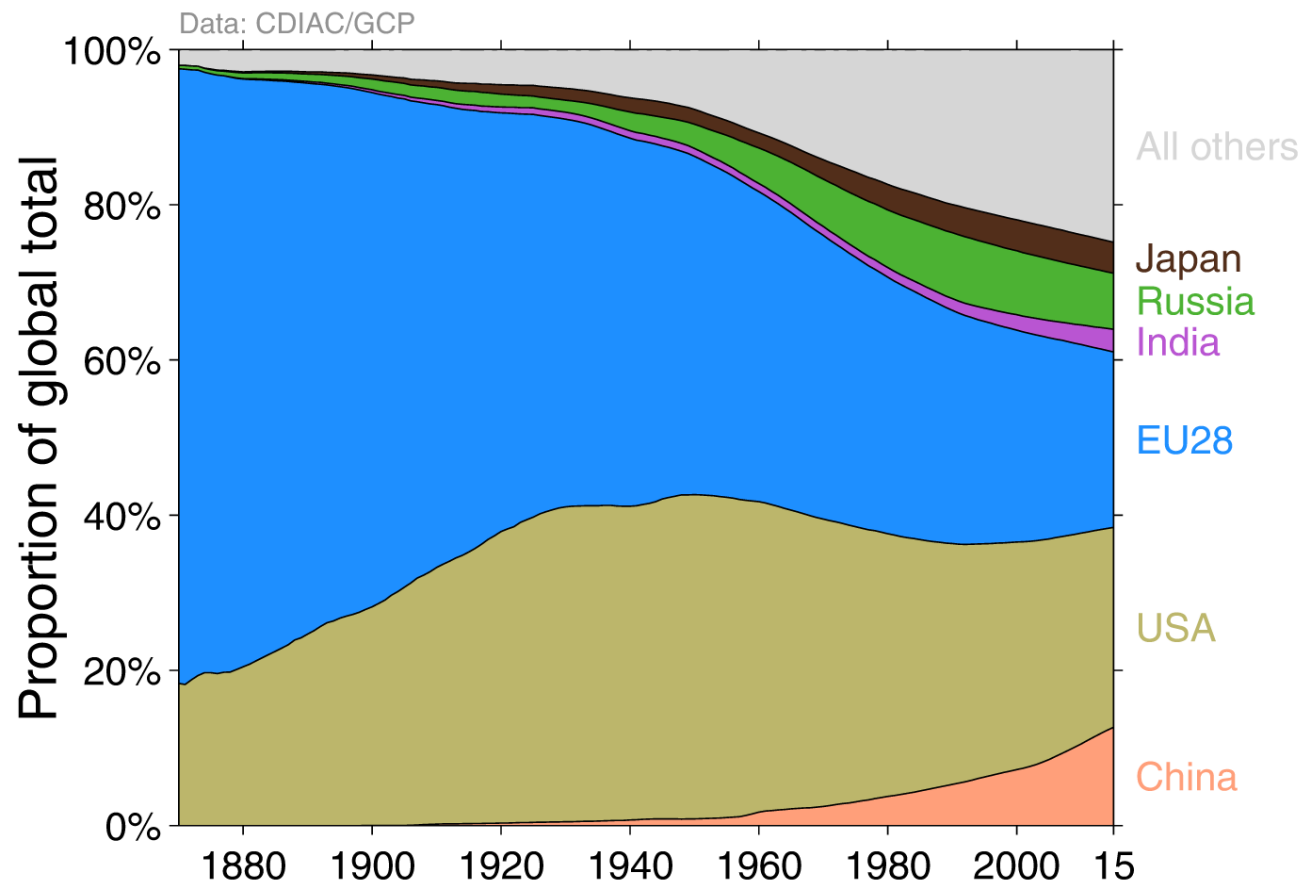


Annex B countries had emission commitments in the Kyoto Protocol (USA did not ratify, Canada withdrew)

Source: [CDIAC](#); [Le Quéré et al 2016](#); [Global Carbon Budget 2016](#)

Historical cumulative emissions by country

Cumulative emissions from fossil-fuel and cement were distributed (1870–2015):
USA (26%), EU28 (23%), China (13%), Russia (7%), Japan (4%) and India (3%)



Cumulative emissions (1990–2015) were distributed China (21%), USA (20%), EU28 (14%), Russia (6%), India/Japan (4%)

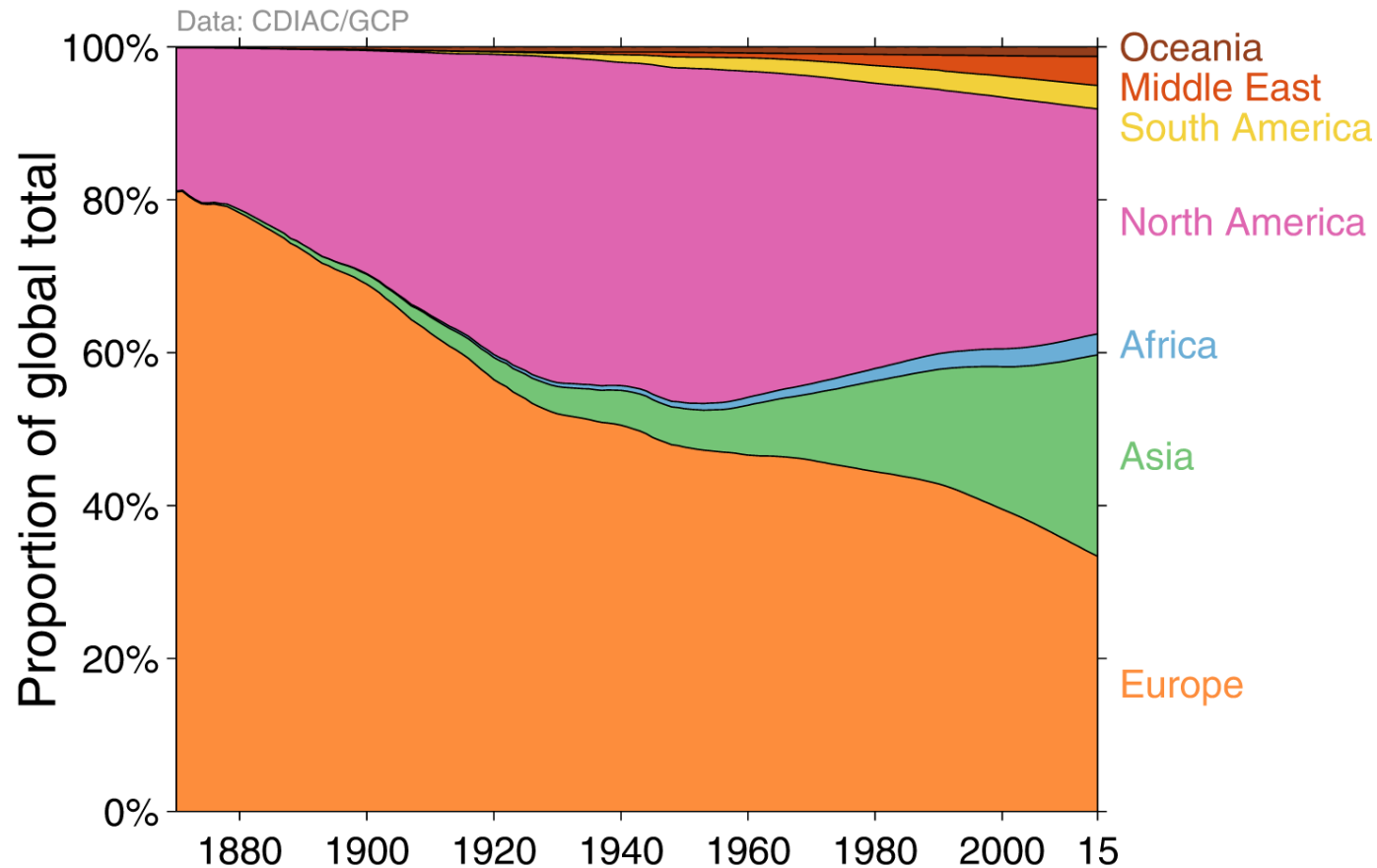
'All others' includes all other countries along with bunker fuels and statistical differences

Source: [CDIAC](#); [Le Quéré et al 2016](#); [Global Carbon Budget 2016](#)

Historical cumulative emissions by continent

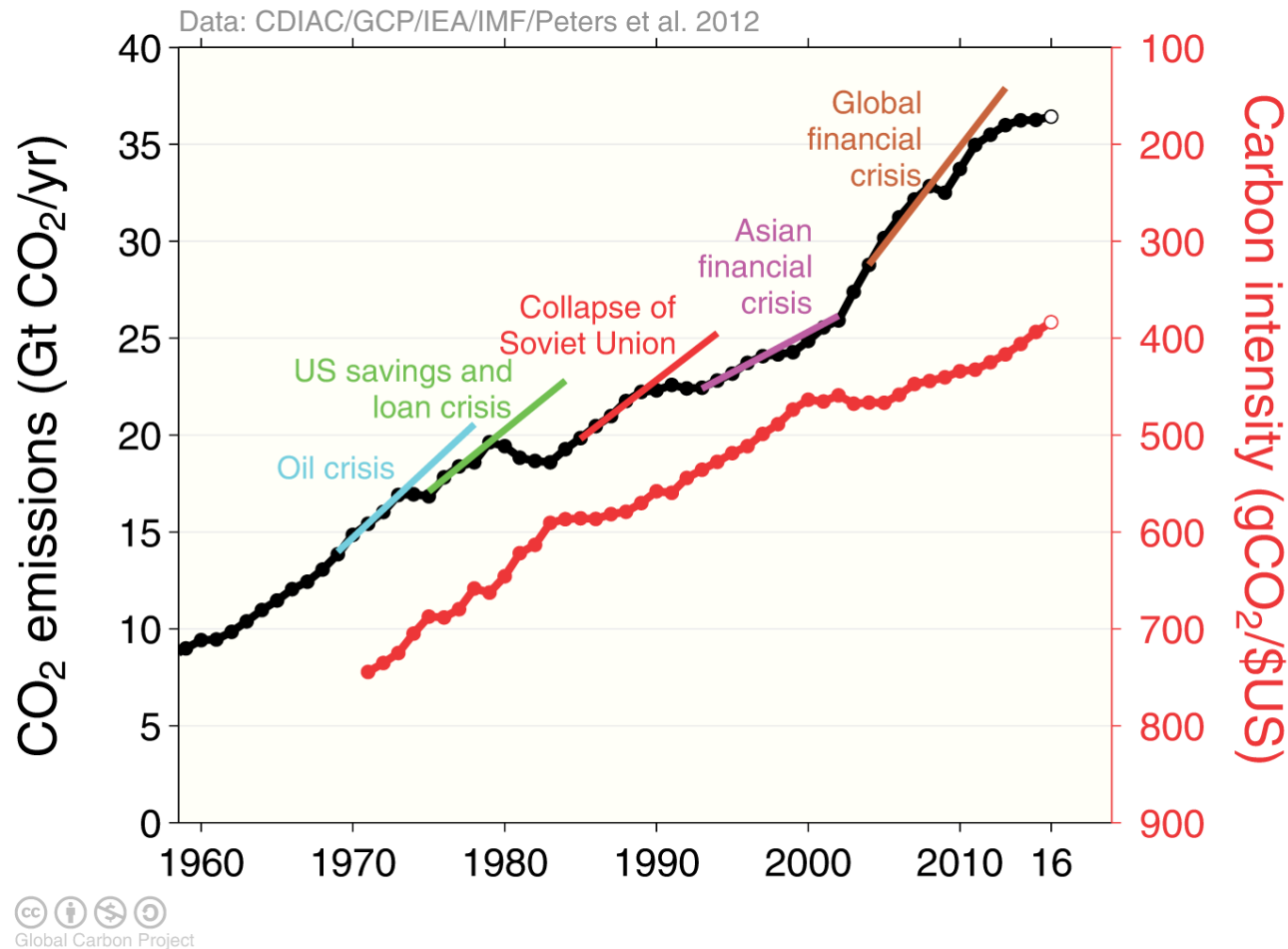
Cumulative emissions from fossil-fuel and cement (1870–2015)

North America and Europe responsible for most cumulative emissions, but Asia growing fast



Carbon intensity of economic activity

Global emissions growth has generally recovered quickly from previous financial crises
It is unclear if the recent slowdown in global emissions is related to the Global Financial Crisis

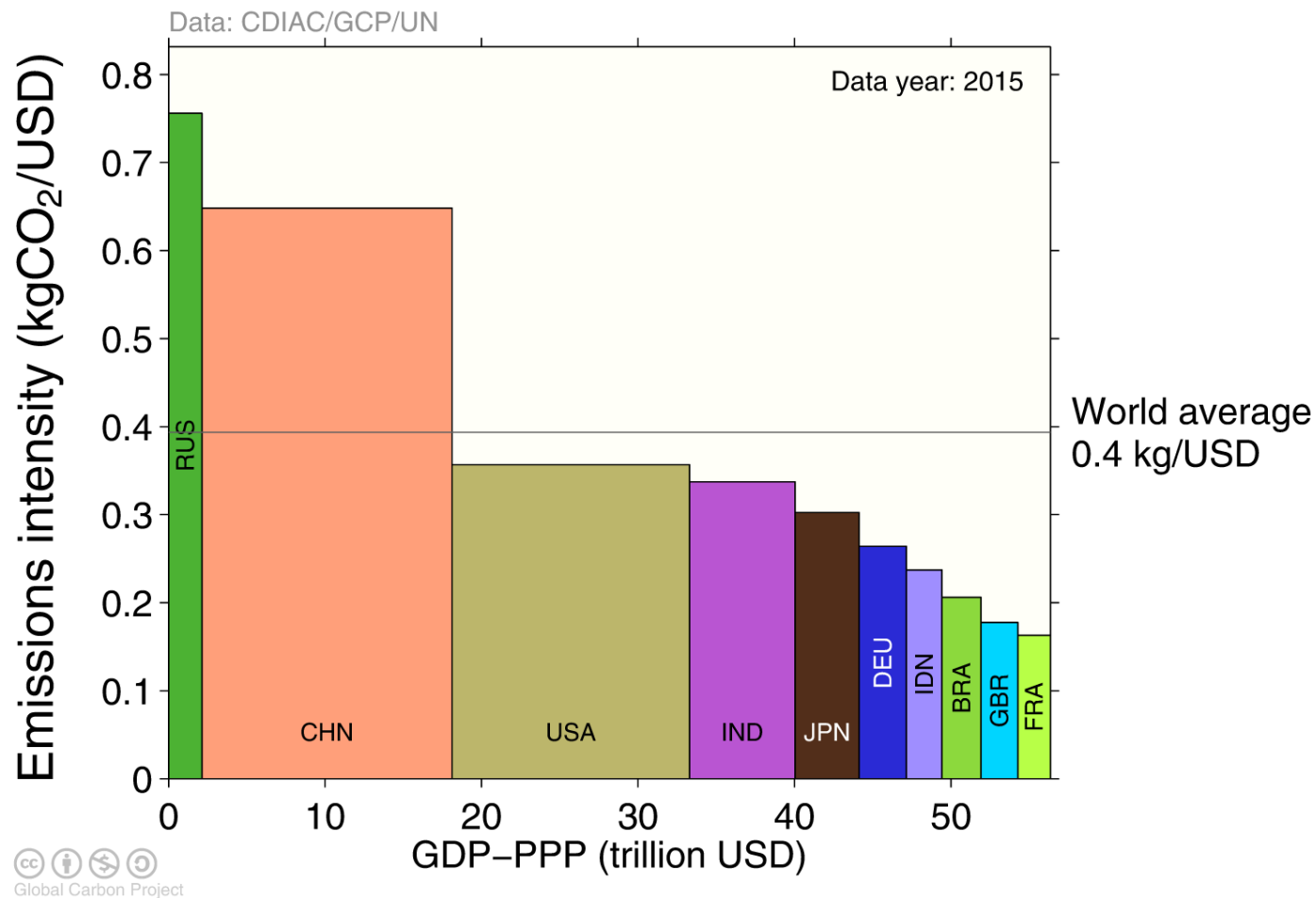


Economic activity is measured in Purchasing Power Parity

Source: [CDIAC](#); [Peters et al 2012](#); [Le Quéré et al 2016](#); [Global Carbon Budget 2016](#)

Emissions intensity per unit economic activity

The 10 largest economies have a wide range of emissions intensity of economic production

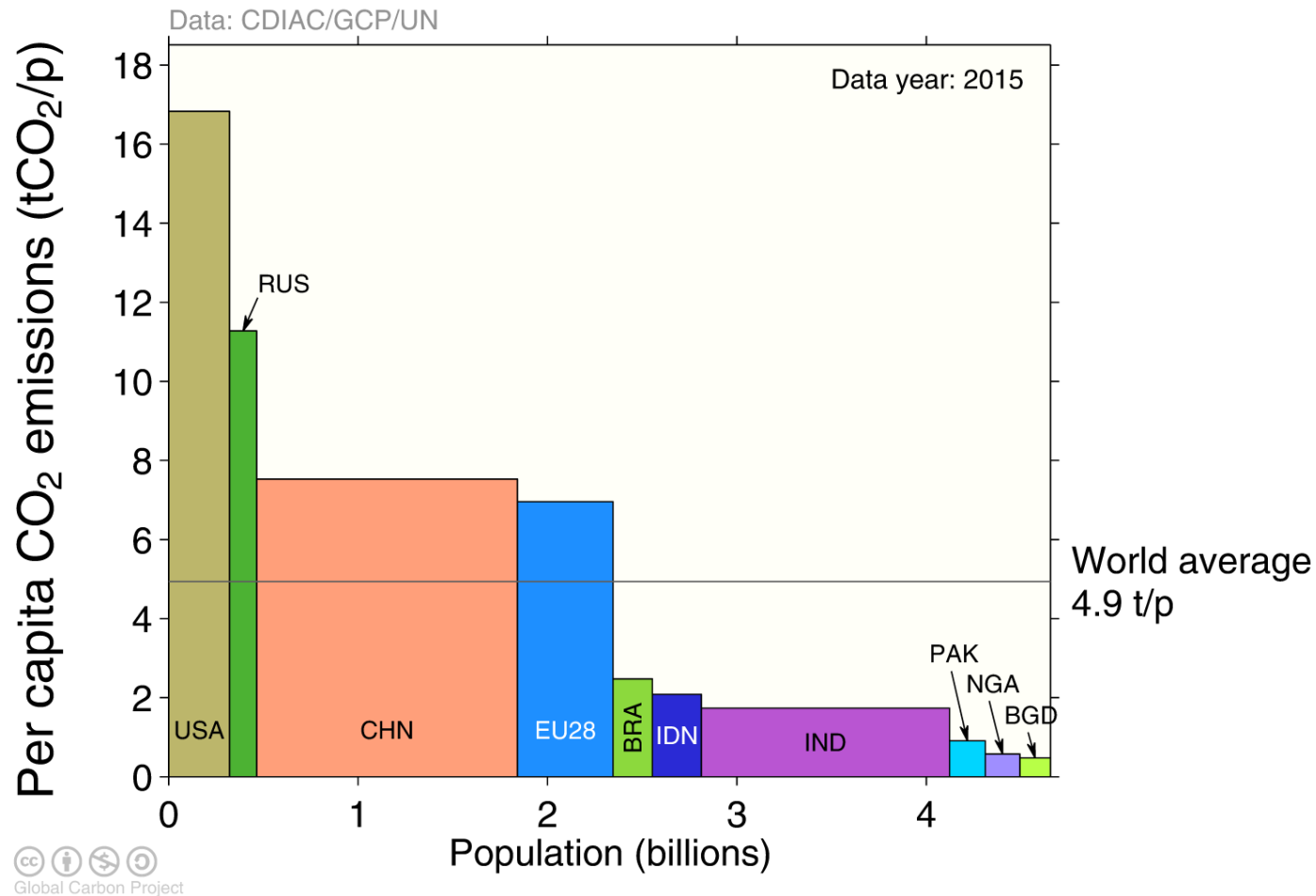


Emission intensity: CO₂ emissions from fossil fuel and industry divided by Gross Domestic Product

Source: [Global Carbon Budget 2016](#)

Emissions per capita

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



Emission per capita: CO₂ emissions from fossil fuel and industry divided by population

Source: [Global Carbon Budget 2016](#)

Key statistics

Region/Country	Emissions 2015				
	Per capita	Total		Growth 2014-15	
	tCO ₂ per person	GtCO ₂	%	GtCO ₂	%
Global (with bunkers)	4.9	36.26	100	0.021	0.0
Developed Countries (Annex B)					
Annex B	10.6	12.97	35.8	-0.228	-1.7
USA	16.8	5.42	14.9	-0.141	-2.6
EU28	7.0	3.51	9.7	0.048	1.4
Russia	11.3	1.62	4.5	-0.055	-3.3
Japan	9.8	1.24	3.4	-0.028	-2.2
Canada	12.9	0.46	1.3	-0.014	-3.0
Developing Countries (Non-Annex B)					
Non-Annex B	3.5	21.72	59.9	0.184	0.9
China	7.5	10.36	28.6	-0.077	-0.7
India	1.7	2.27	6.3	0.113	5.2
Iran	8.2	0.65	1.8	0.010	1.5
Saudi Arabia	19.0	0.60	1.7	0.026	4.4
South Korea	11.8	0.59	1.6	0.001	0.2
International Bunkers					
Aviation and Shipping	-	1.57	4.3	0.065	4.3

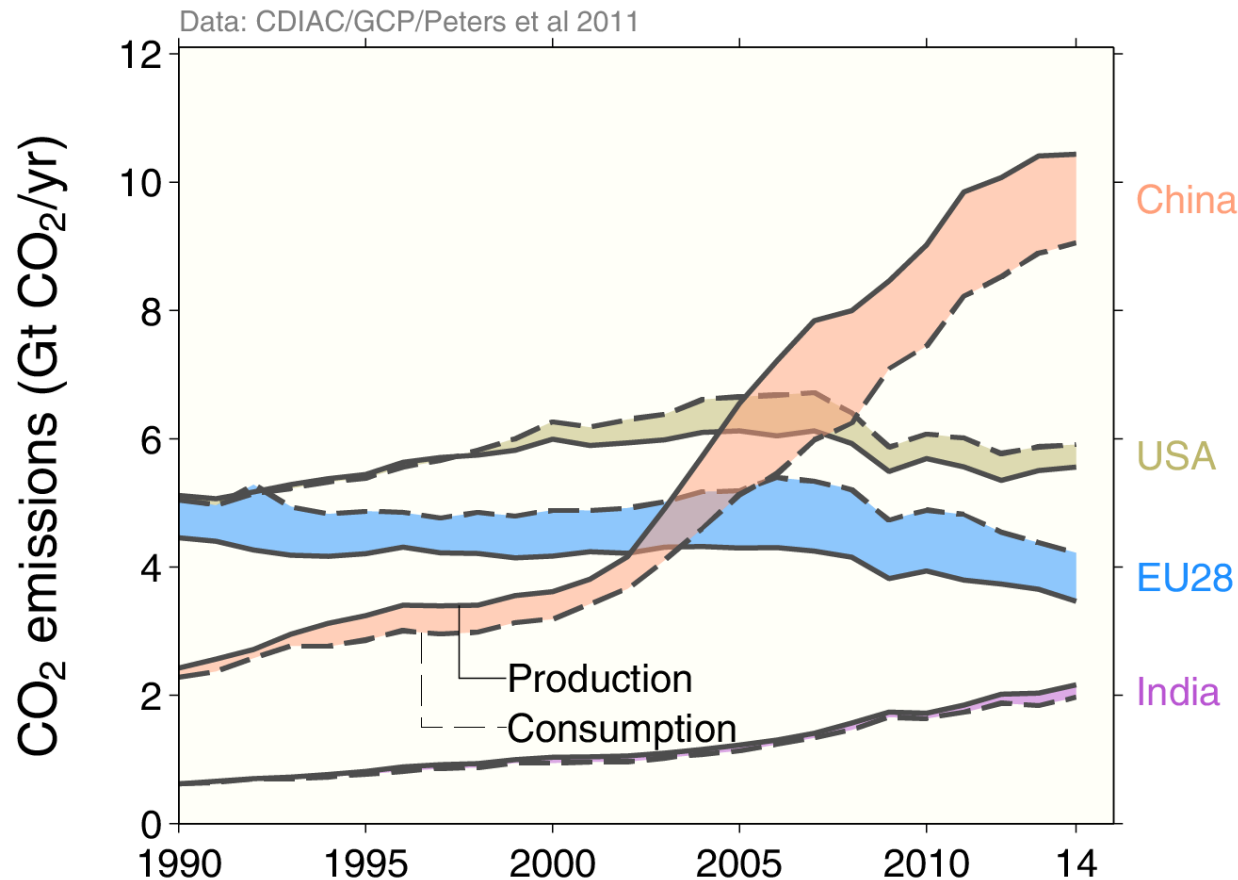
Consumption-based Emissions

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

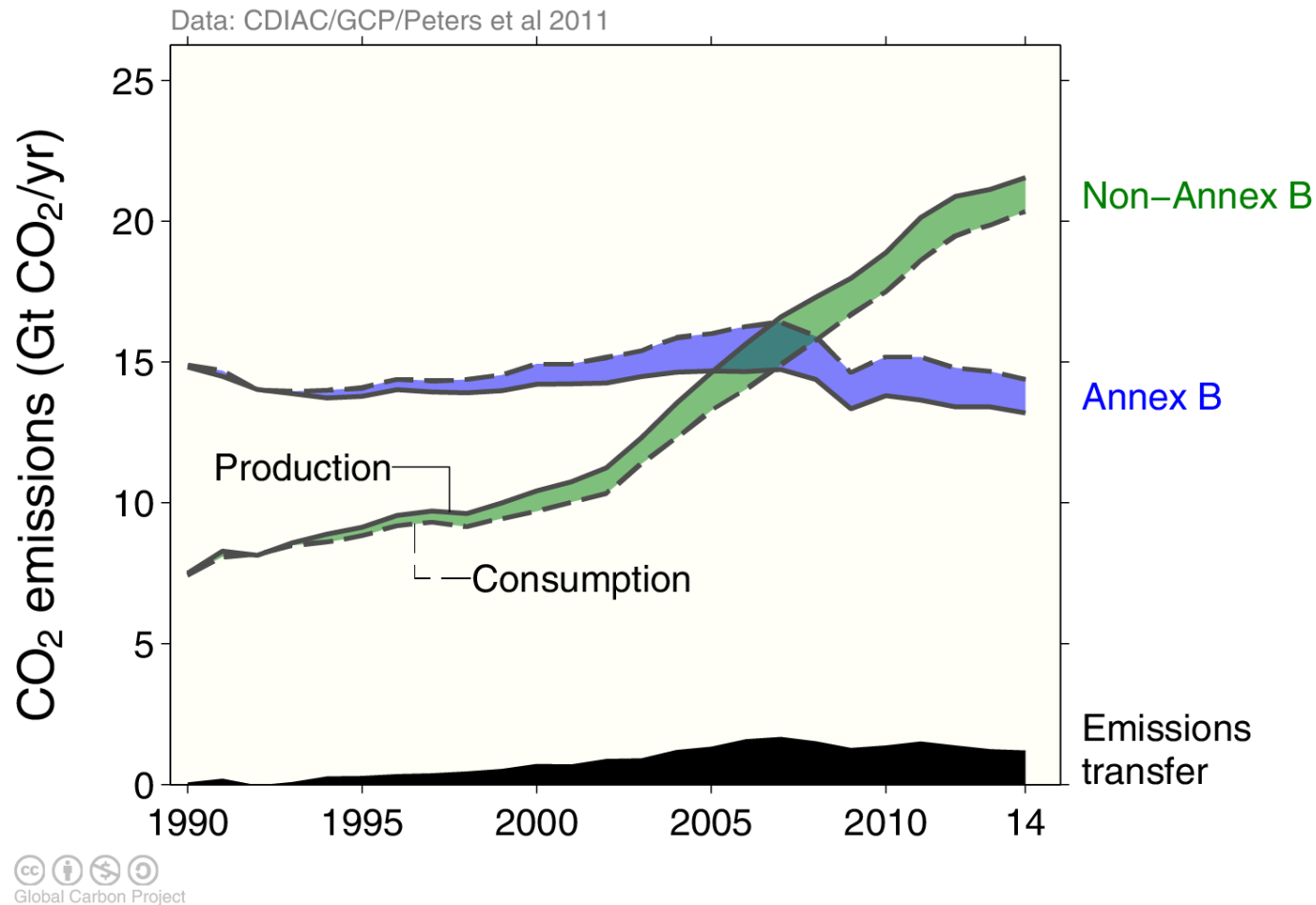
Consumption-based emissions (carbon footprint)

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



Consumption-based emissions

Transfers of emissions embodied in trade from non-Annex B countries to Annex B countries grew at about 19% per year between 1990 and 2007, but have since declined at nearly 4% per year.

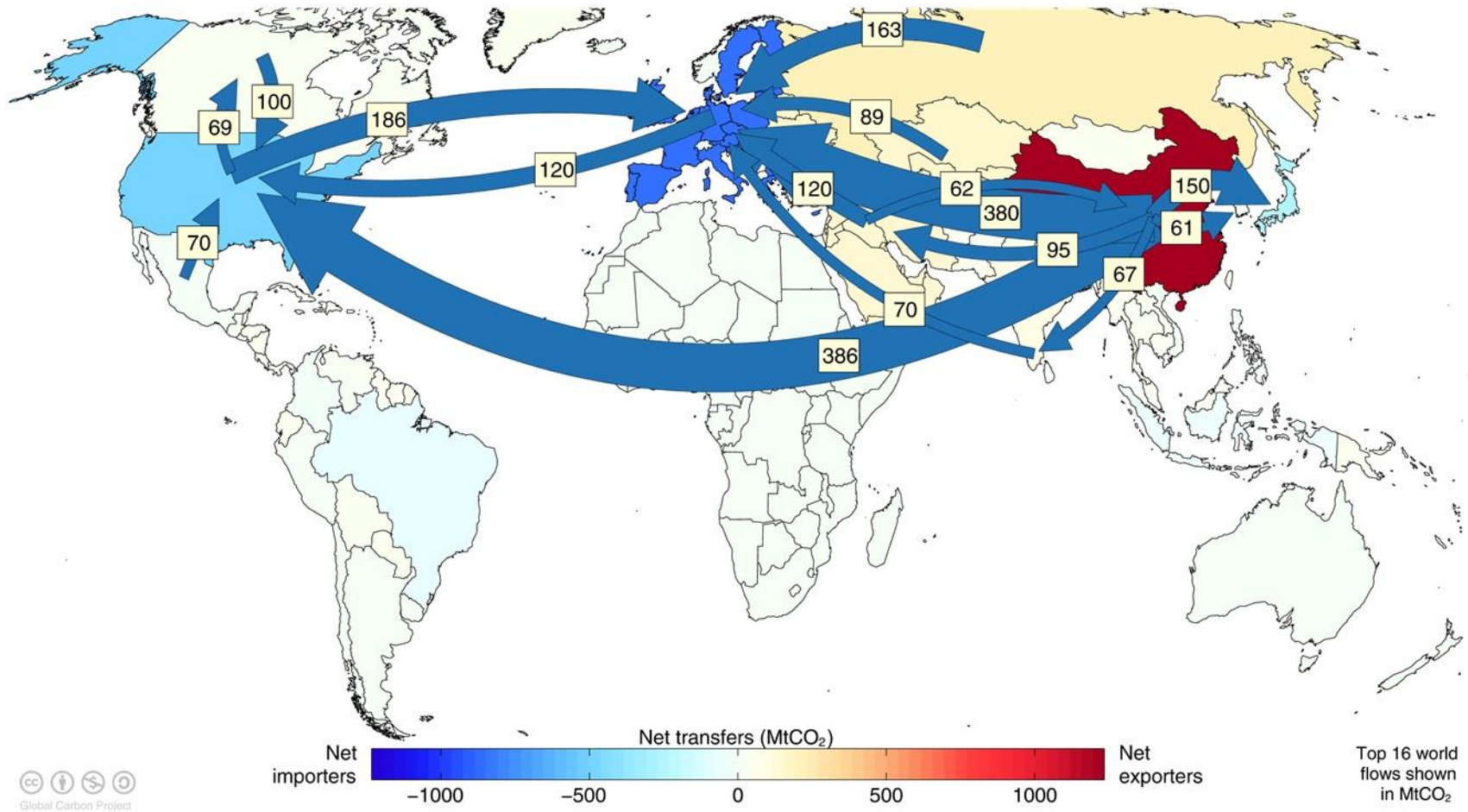


Annex B countries were used in the Kyoto Protocol, but this distinction is less relevant in the Paris Agreement

Source: [CDIAC](#); [Peters et al 2011](#); [Le Quéré et al 2016](#); [Global Carbon Budget 2016](#)

Major flows from production to consumption

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

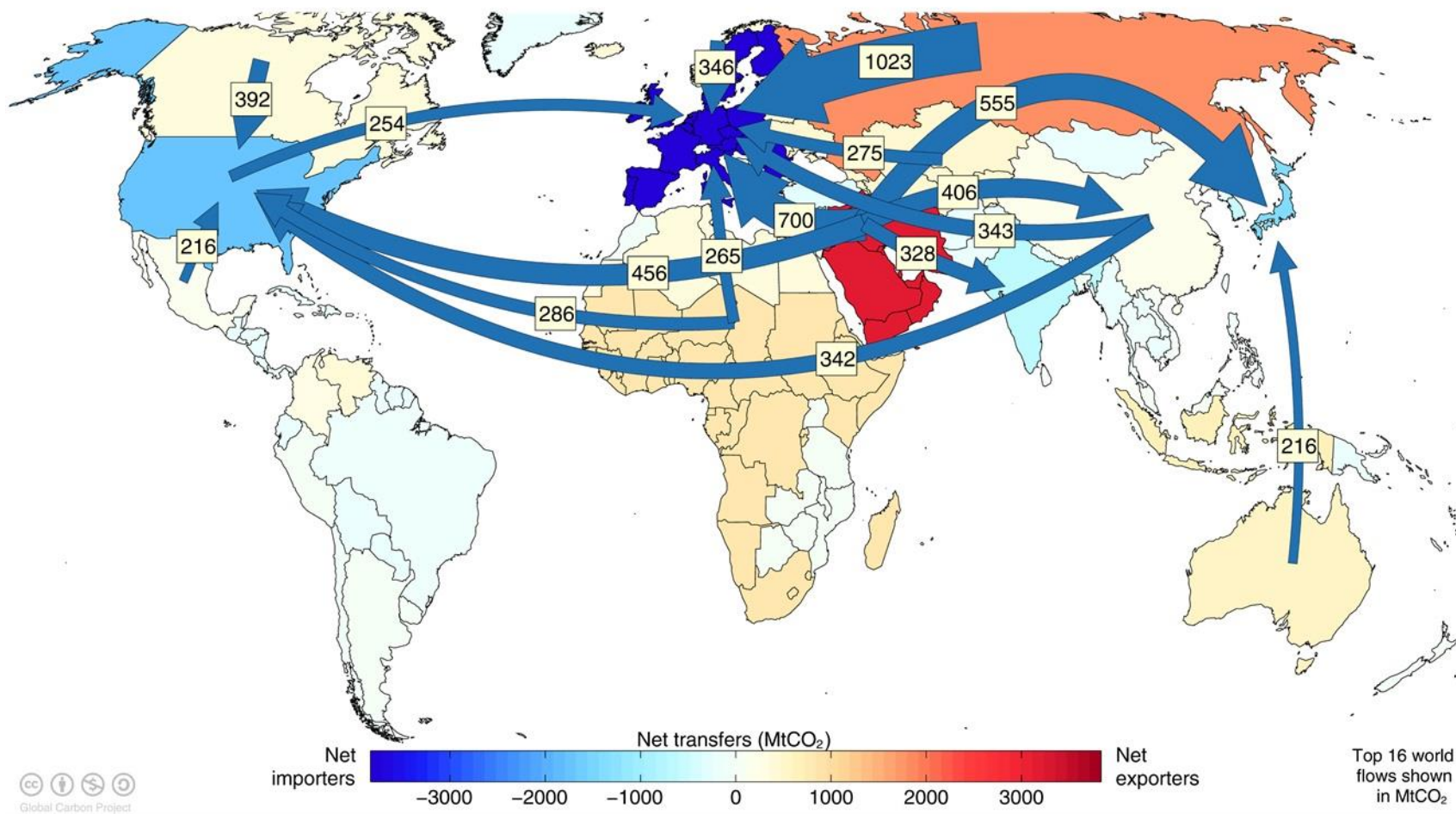


Values for 2011. EU is treated as one region. Units: MtCO₂

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



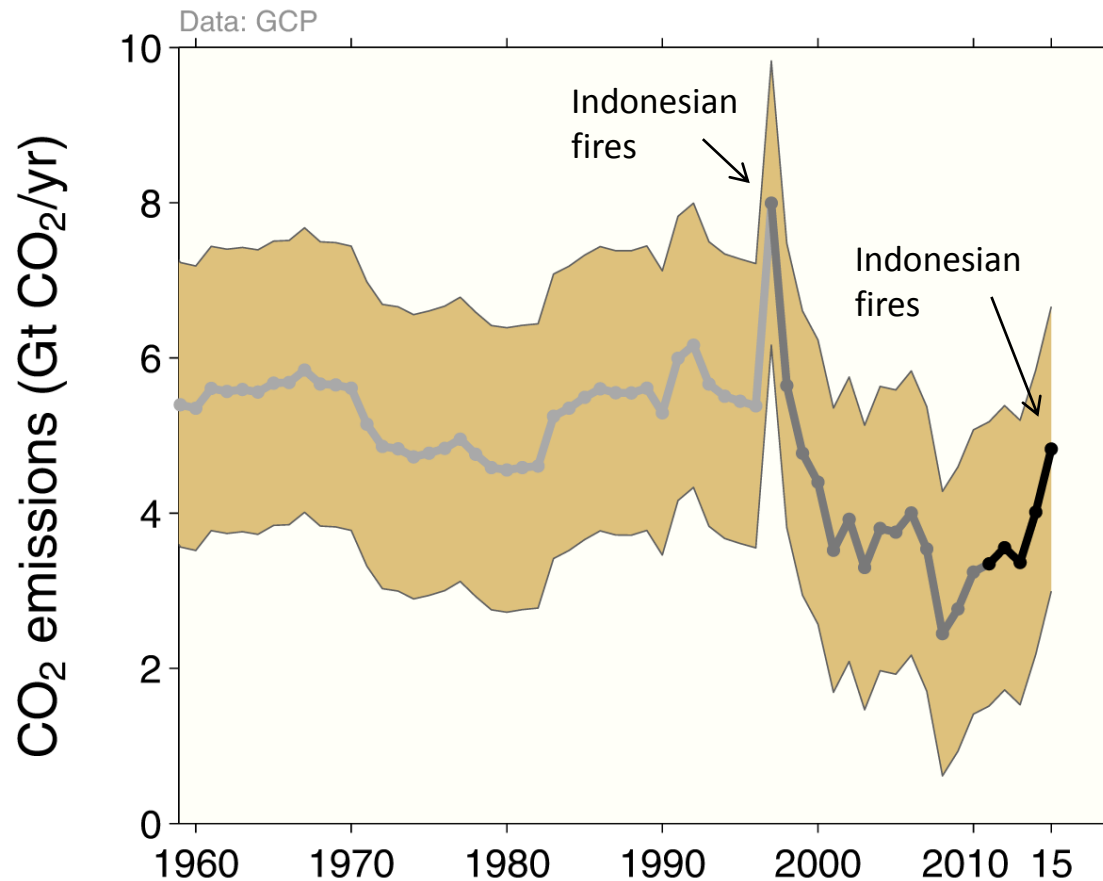
Values for 2011. EU is treated as one region. Units: MtCO₂

Source: [Andrew et al 2013](#)

Land-use Change Emissions

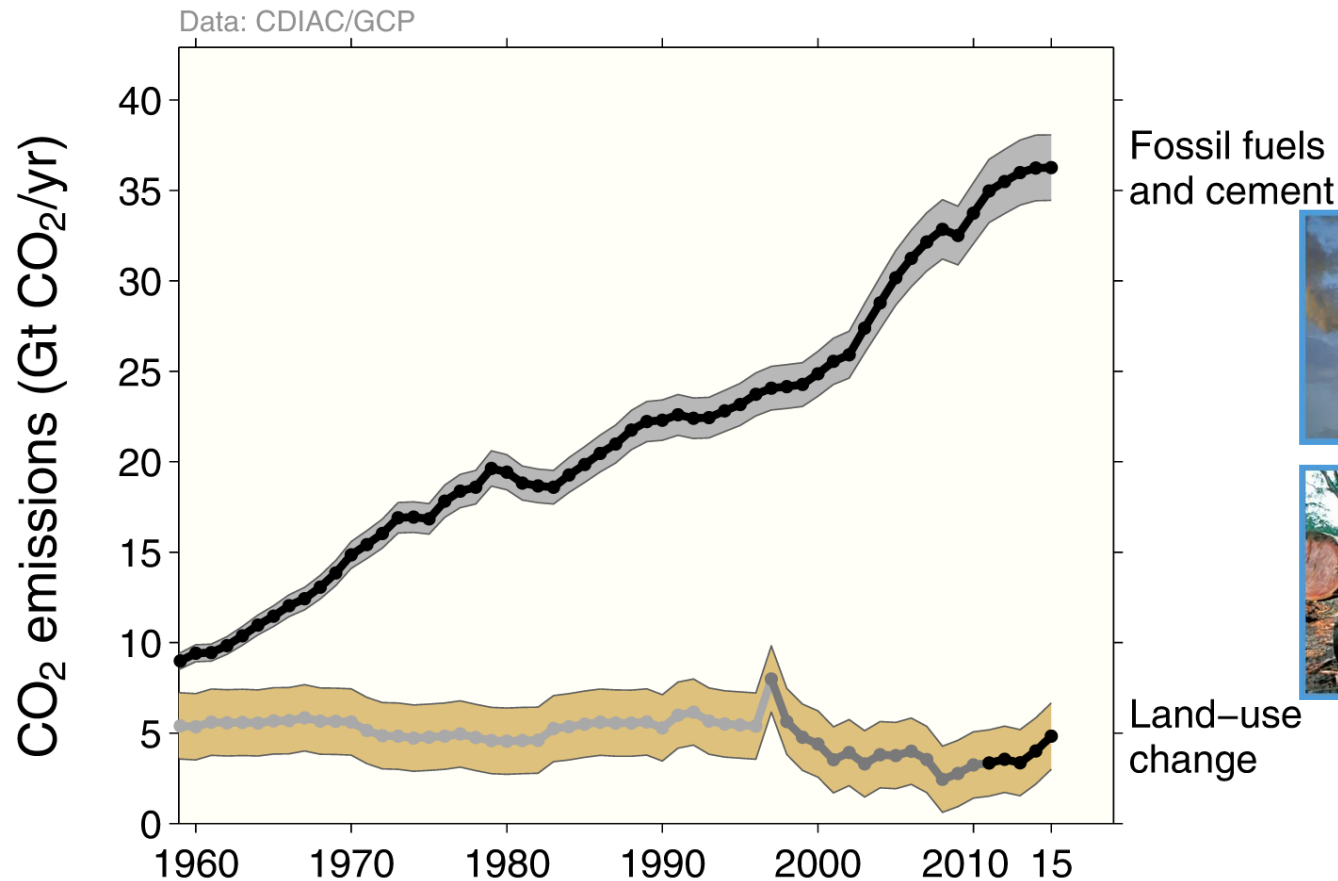
Land-use change emissions

Emissions in the 2000s were lower than earlier decades, but highly uncertain
Higher emissions in 2015 are linked to increased fires during dry El Niño conditions in Asia



Total global emissions

Total global emissions: 41.9 ± 2.8 GtCO₂ in 2015, 49% over 1990
 Percentage land-use change: 36% in 1960, 9% averaged 2006-2015

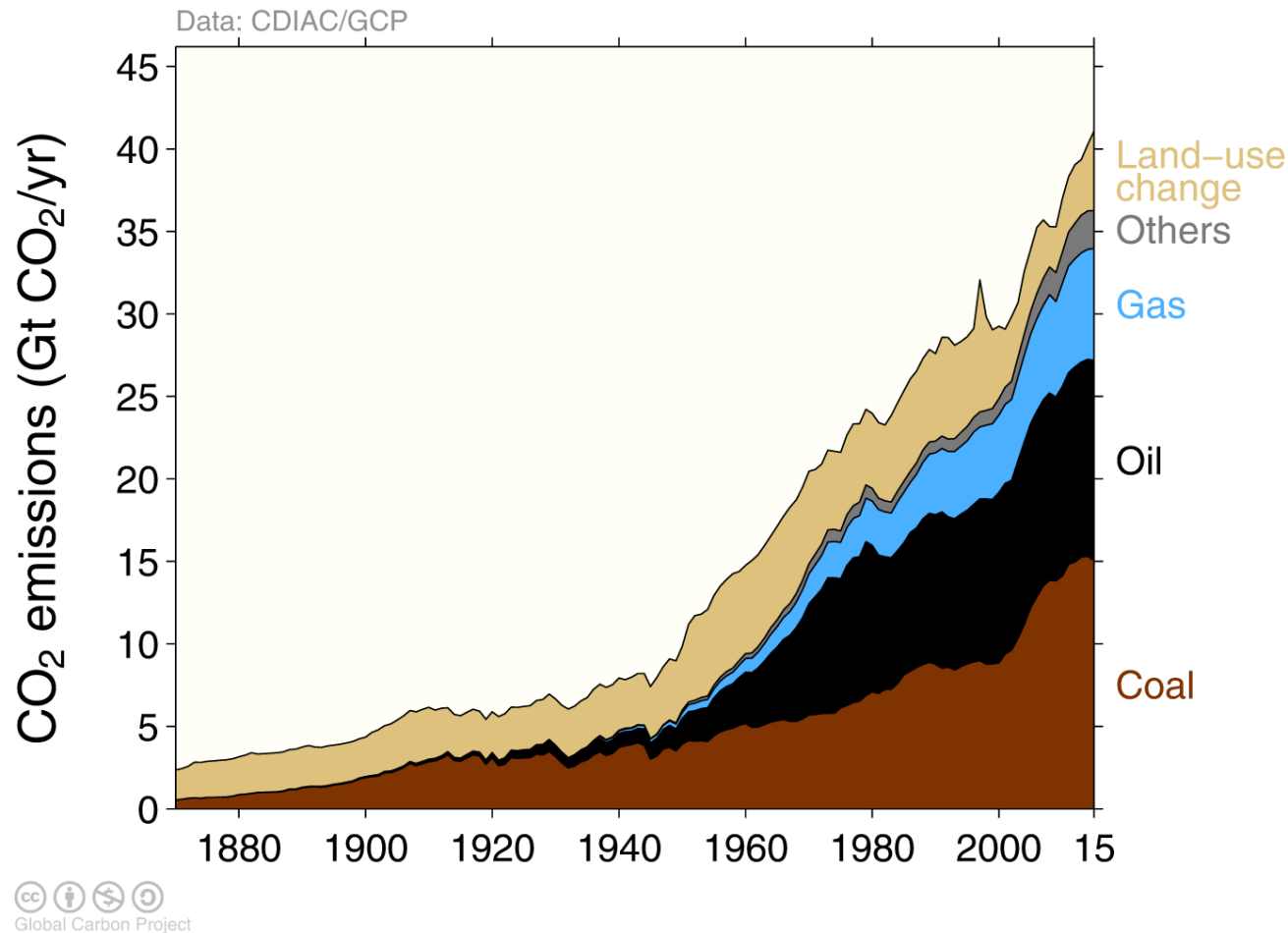


Three different methods have been used to estimate land-use change emissions, indicated here by different shades of grey

Source: [CDIAC](#); [Houghton et al 2012](#); [Giglio et al 2013](#); [Le Quéré et al 2016](#); [Global Carbon Budget 2016](#)

Total global emissions by source

Land-use change was the dominant source of annual CO₂ emissions until around 1950

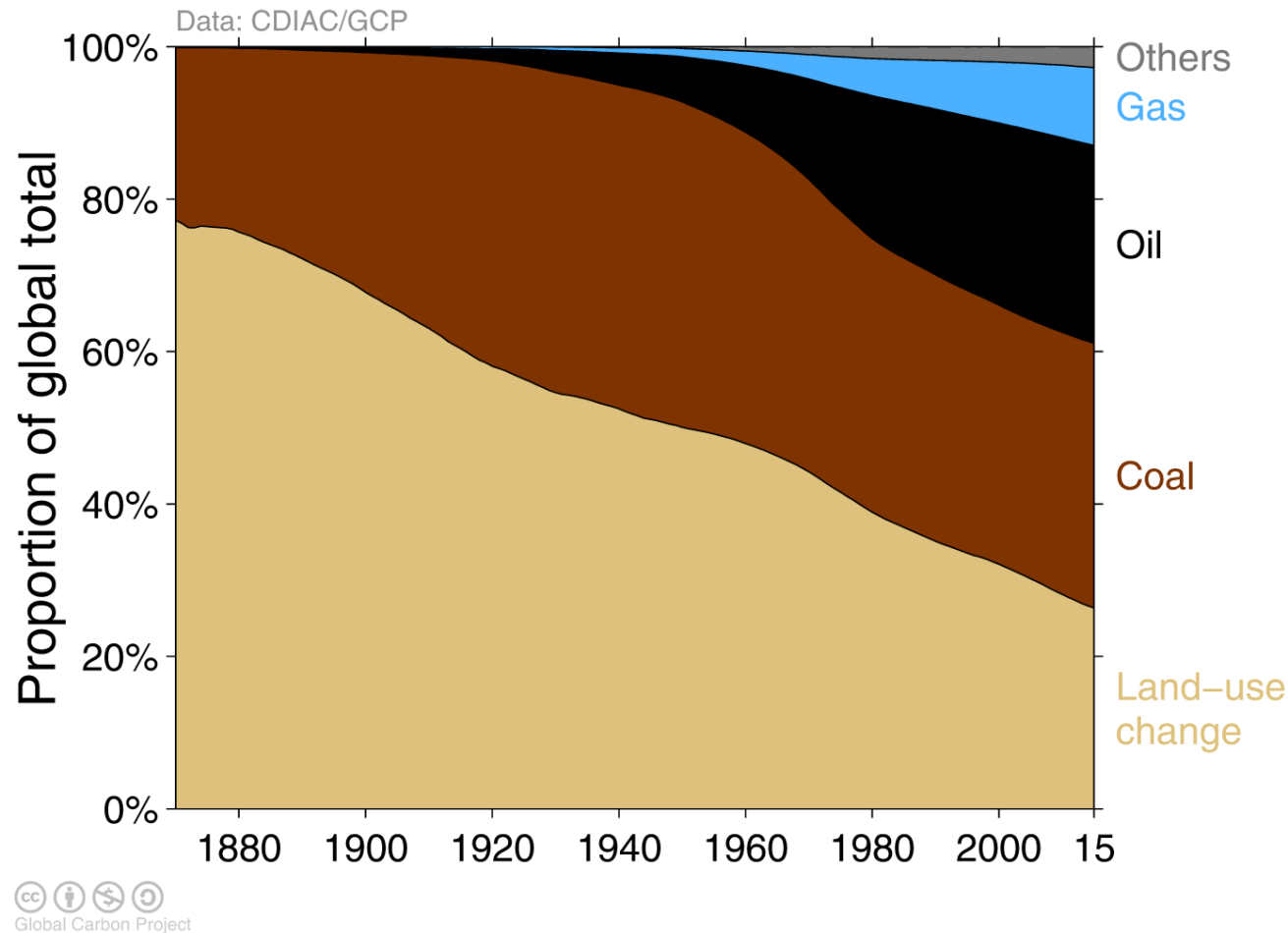


Others: Emissions from cement production and gas flaring

Source: [CDIAC](#); [Houghton et al 2012](#); [Giglio et al 2013](#); [Le Quéré et al 2016](#); [Global Carbon Budget 2016](#)

Historical cumulative emissions by source

Land-use change represents about 26% of cumulative emissions over 1870–2015, coal 35%, oil 26%, gas 10%, and others 3%



Others: Emissions from cement production and gas flaring

Source: [CDIAC](#); [Houghton et al 2012](#); [Giglio et al 2013](#); [Le Quéré et al 2016](#); [Global Carbon Budget 2016](#)

Closing the Global Carbon Budget

Fate of anthropogenic CO₂ emissions (2006-2015)



34.1 GtCO₂/yr
91%



9%
3.5 GtCO₂/yr

Sources = Sinks

16.4 GtCO₂/yr
44%



31%
11.6 GtCO₂/yr

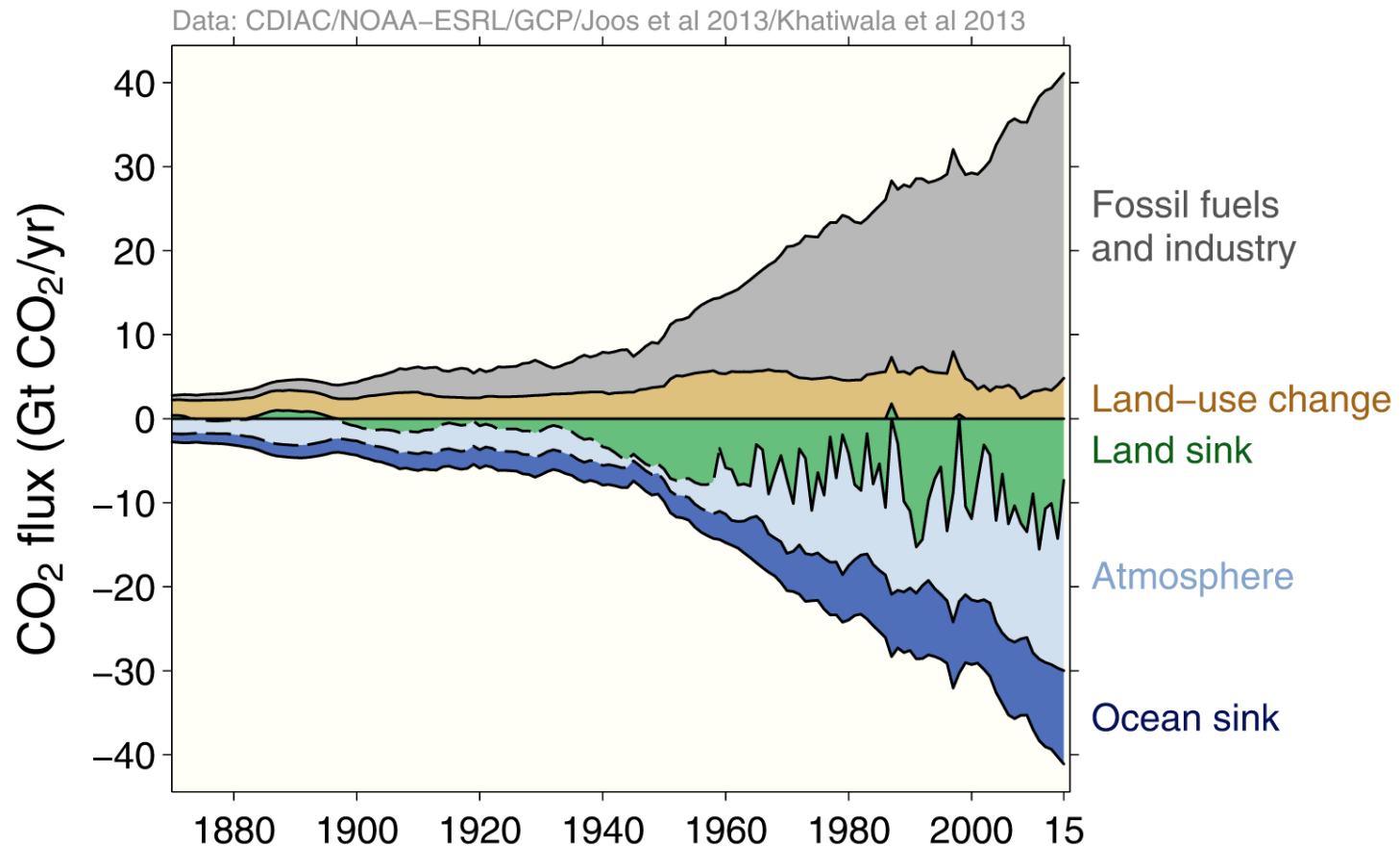


26%
9.7 GtCO₂/yr



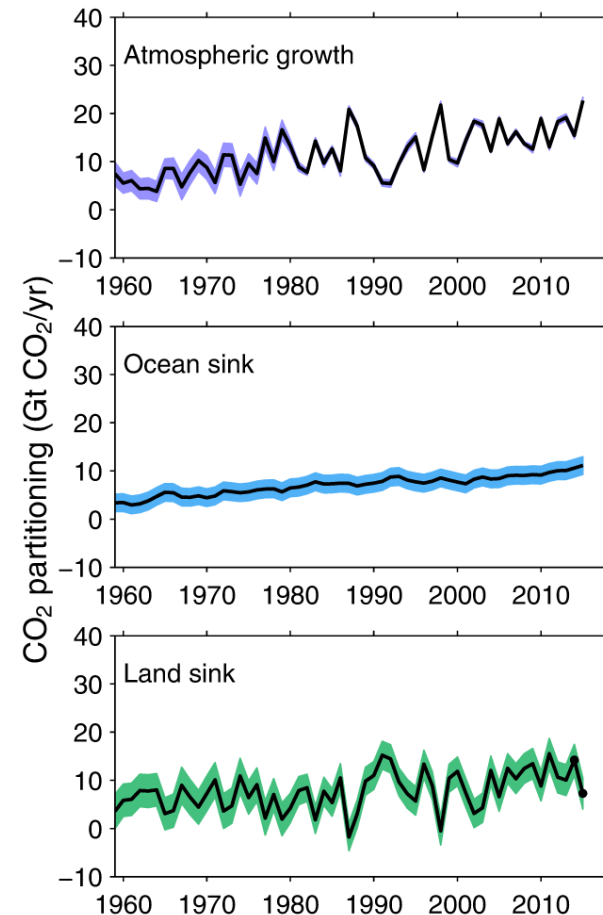
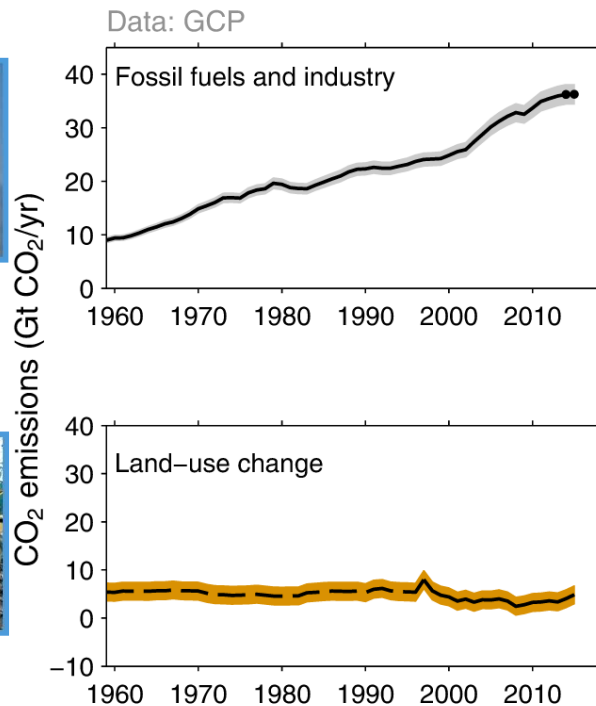
Global carbon budget

The carbon sources from fossil fuels, industry, and land use change emissions are balanced by the atmosphere and carbon sinks on land and in the ocean



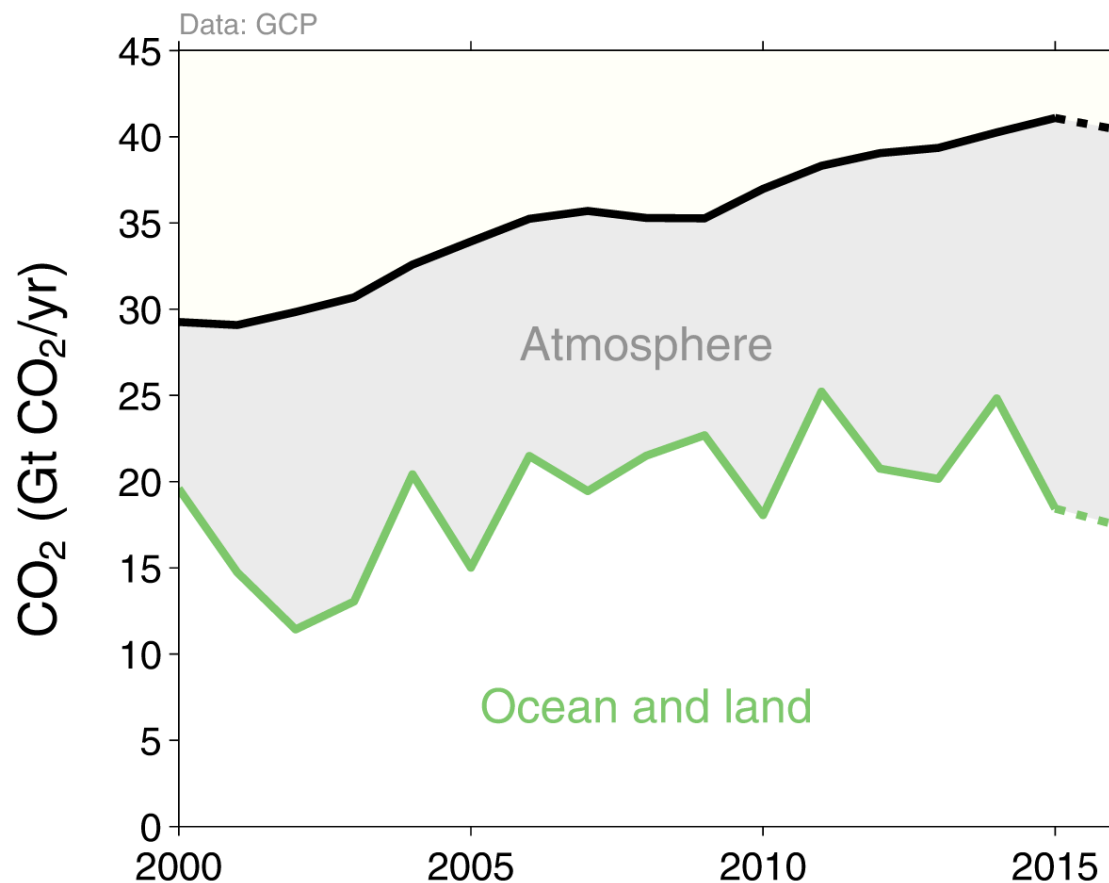
Changes in the budget over time

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



Partitioning of total CO₂ emissions

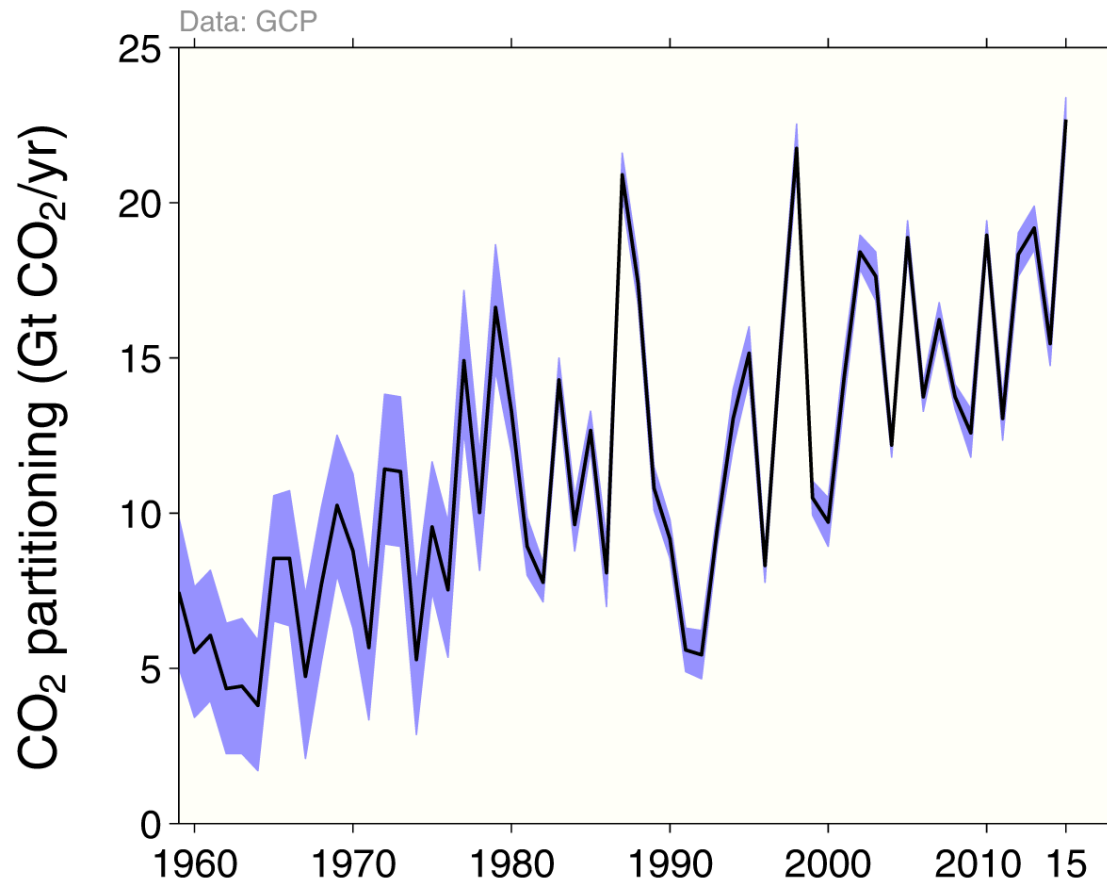
Atmospheric CO₂ growth rate was a record high in 2015 in spite of no growth in fossil fuel and industry emissions because of a weaker CO₂ sink on land from hot & dry El Niño conditions



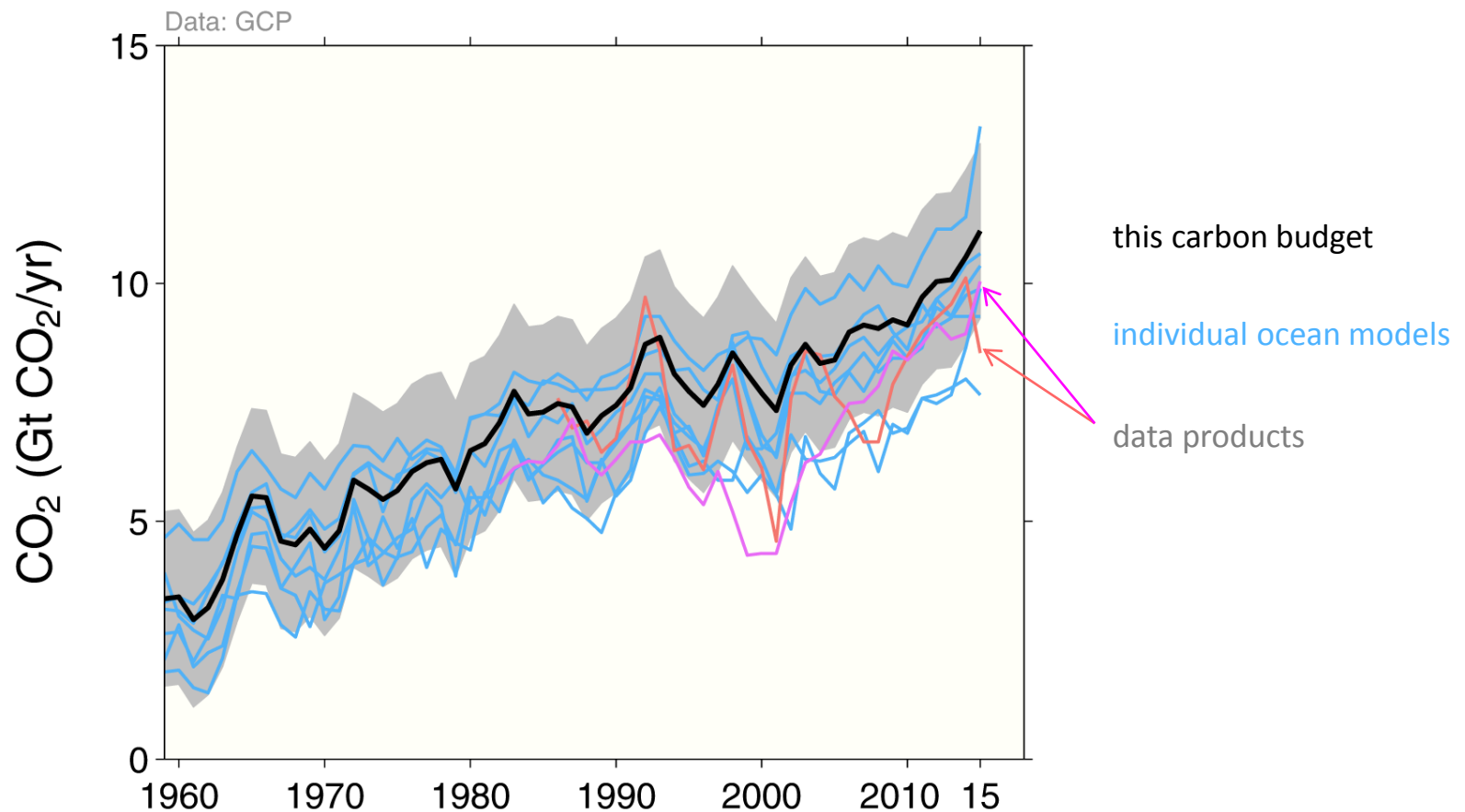
The emissions (shown in black) include fossil fuels and industry and land-use change

Source: [CDIAC](#); [NOAA-ESRL](#); [Houghton et al 2012](#); [Giglio et al 2013](#); [Joos et al 2013](#); [Khatiwala et al 2013](#); [Le Quéré et al 2016](#); [Global Carbon Budget 2016](#)

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



The ocean carbon sink continues to increase
 $9.7 \pm 1.8 \text{ GtCO}_2/\text{yr}$ for 2006-2015 and $11.1 \pm 1.8 \text{ GtCO}_2/\text{yr}$ in 2015

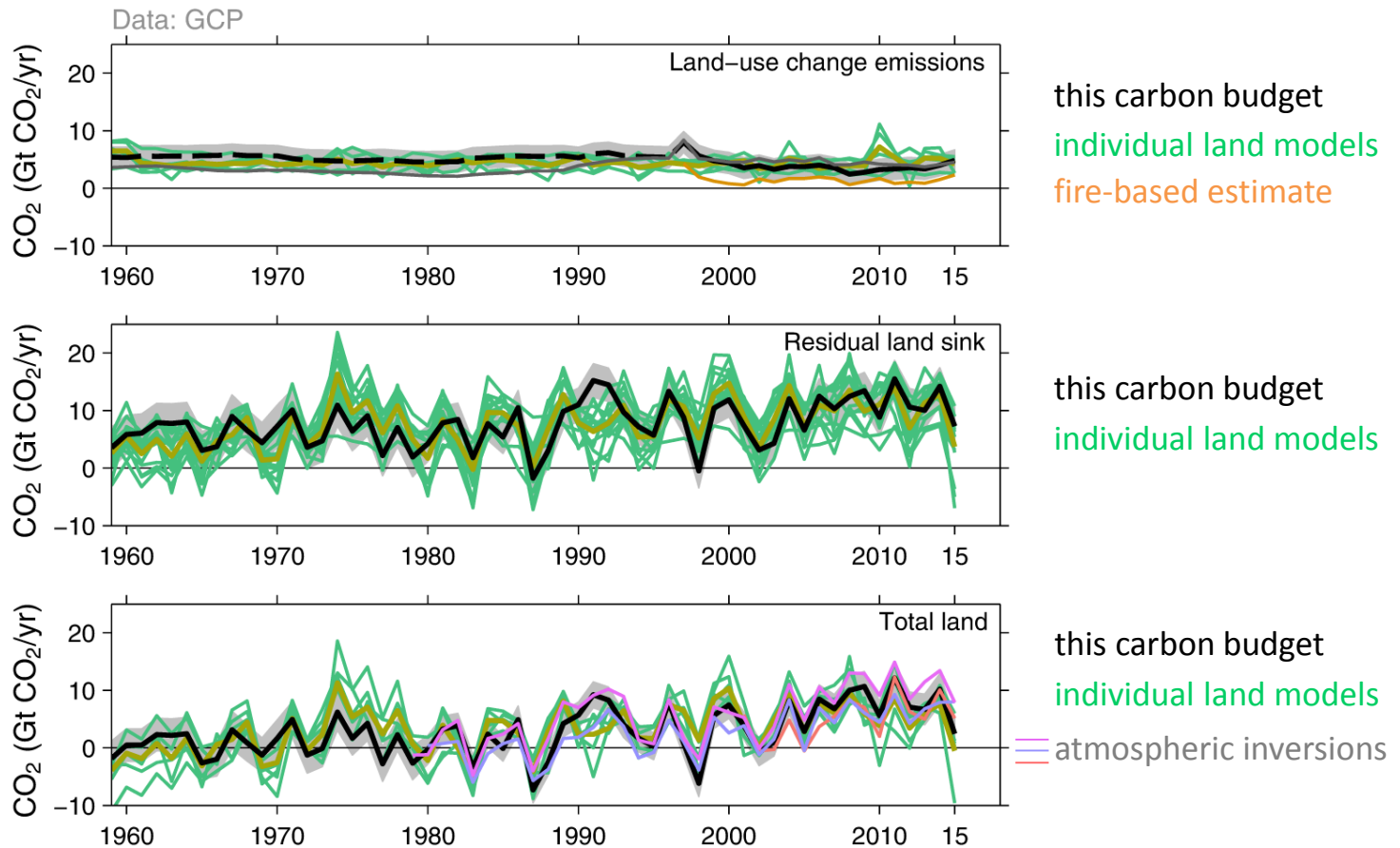


Source: [Le Quéré et al 2016](#); [Global Carbon Budget 2016](#)

Individual estimates from: Aumont and Bopp (2006); Buitenhuis et al. (2010); Doney et al. (2009); Hauck et al. (2016); Landschützer et al. (2015); Oke et al. (2013); Rödenbeck et al. (2014); Sérian et al. (2013); Schwinger et al. (2016). Full references provided in Le Quéré et al. (2016).

Terrestrial sink

The residual land sink decreased to 6.9 ± 3.2 GtCO₂/yr in 2015, due to El Niño conditions
Total CO₂ fluxes on land (including land-use change) are constrained by atmospheric inversions

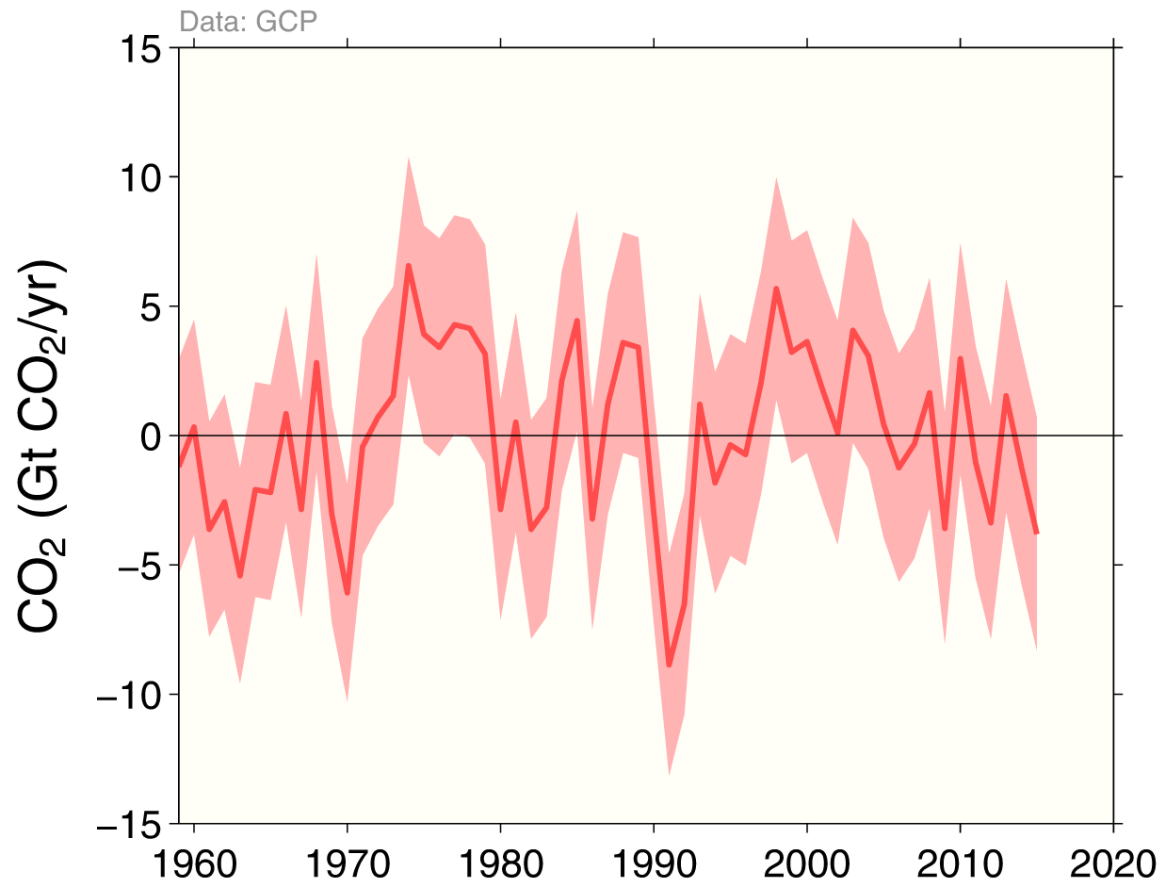


Source: [Le Quéré et al 2016](#); [Global Carbon Budget 2016](#)

Individual estimates from: Chevallier et al. (2005); Clarke et al. (2011); Jain et al. (2013); Kato et al. (2013); Krinner et al. (2005); Melton and Arora (2016); Oleson et al. (2013); Peters et al. (2010); Reick et al. (2013); Rodenbeck et al. (2003); Sitch et al. (2003); Smith et al. (2014); Stocker et al. (2013); Tian et al. (2010); Woodward et al. (1995); Zaehle and Friend (2010); Zhang et al. (2013). Full references provided in Le Quéré et al. (2016).

Remaining uncertainty in the global carbon balance

Large uncertainties in the global carbon balance remain and hinder independent verification of reported CO₂ emissions



The remaining uncertainty is the carbon left after adding independent estimates for total emissions, the atmospheric growth rate, and model-based estimates for the land and ocean carbon sinks

Source: [Le Quéré et al 2016](#); [Global Carbon Budget 2016](#)

The cumulative contributions to the global carbon budget from 1870

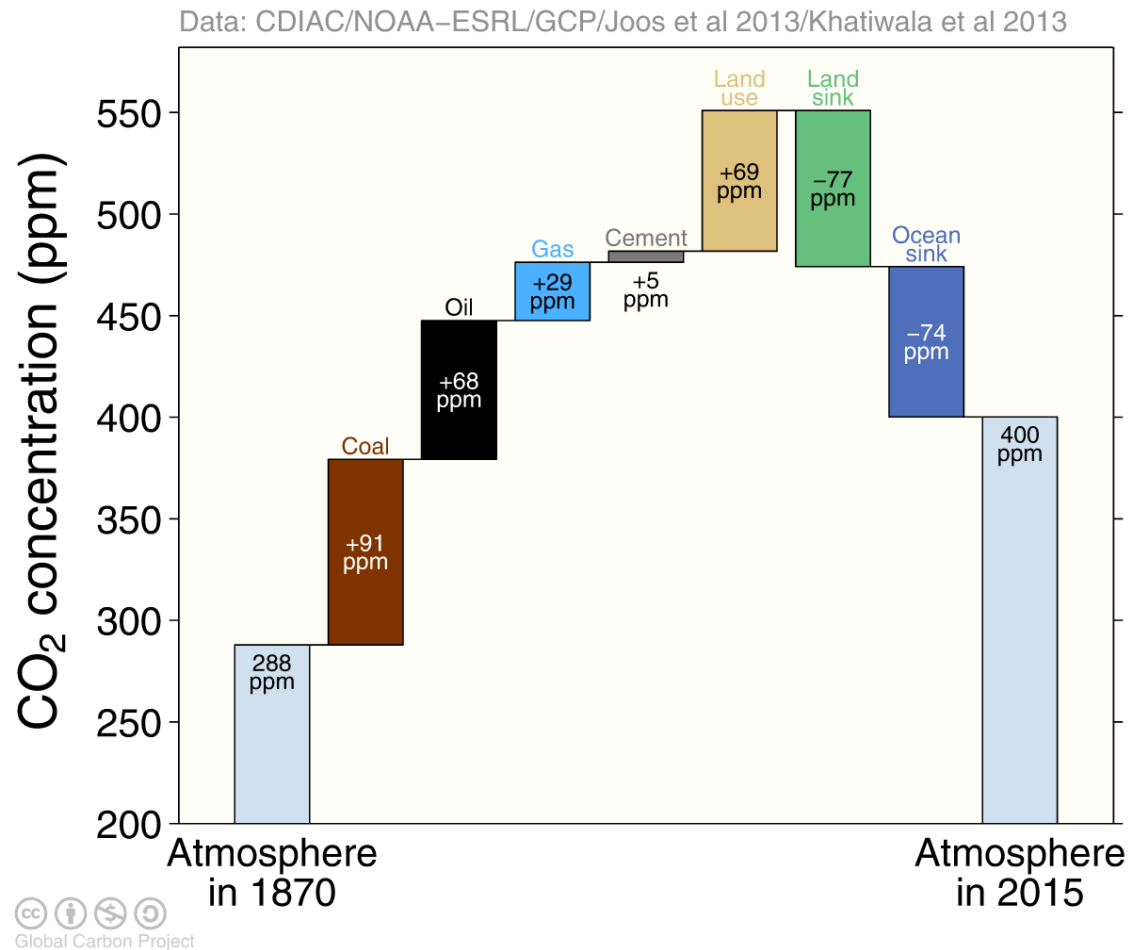
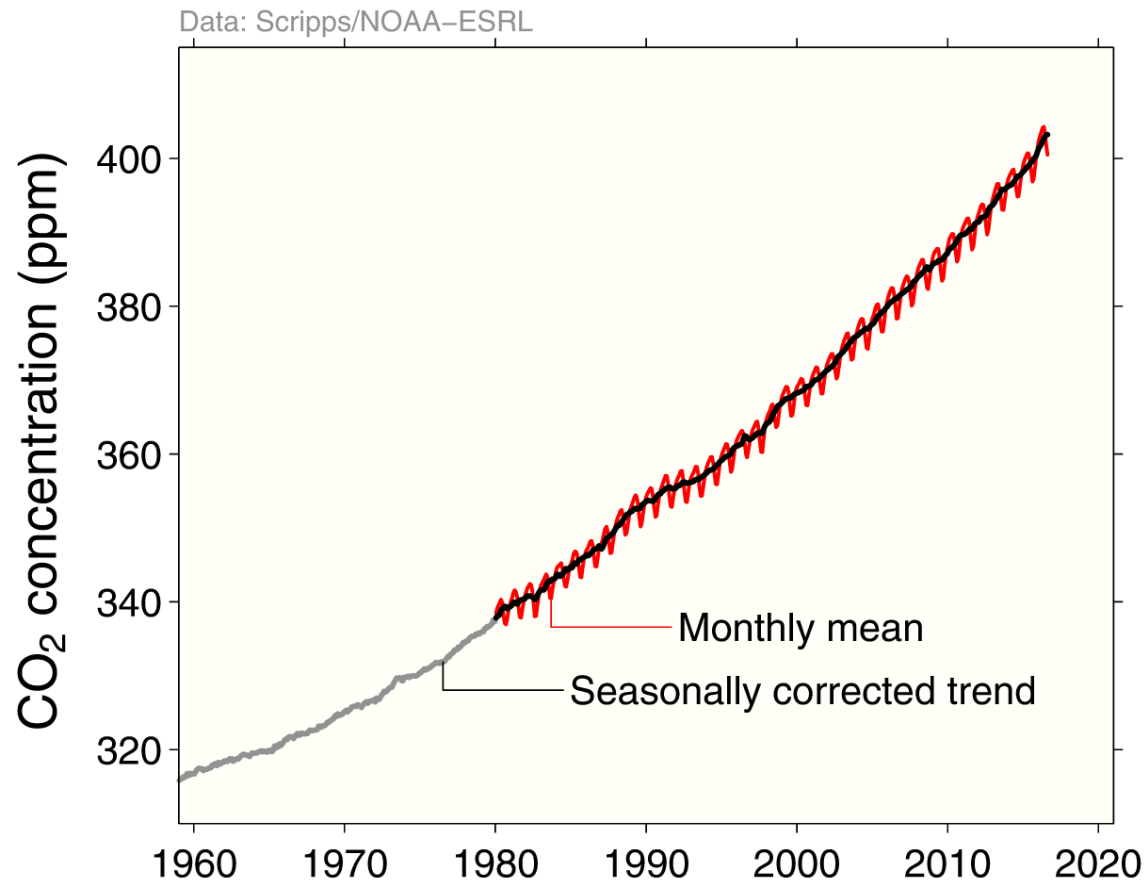


Figure concept from [Shrink That Footprint](#)

Source: [CDIAC](#); [NOAA-ESRL](#); [Houghton et al 2012](#); [Giglio et al 2013](#); [Joos et al 2013](#); [Khatiwala et al 2013](#); [Le Quéré et al 2016](#); [Global Carbon Budget 2016](#)

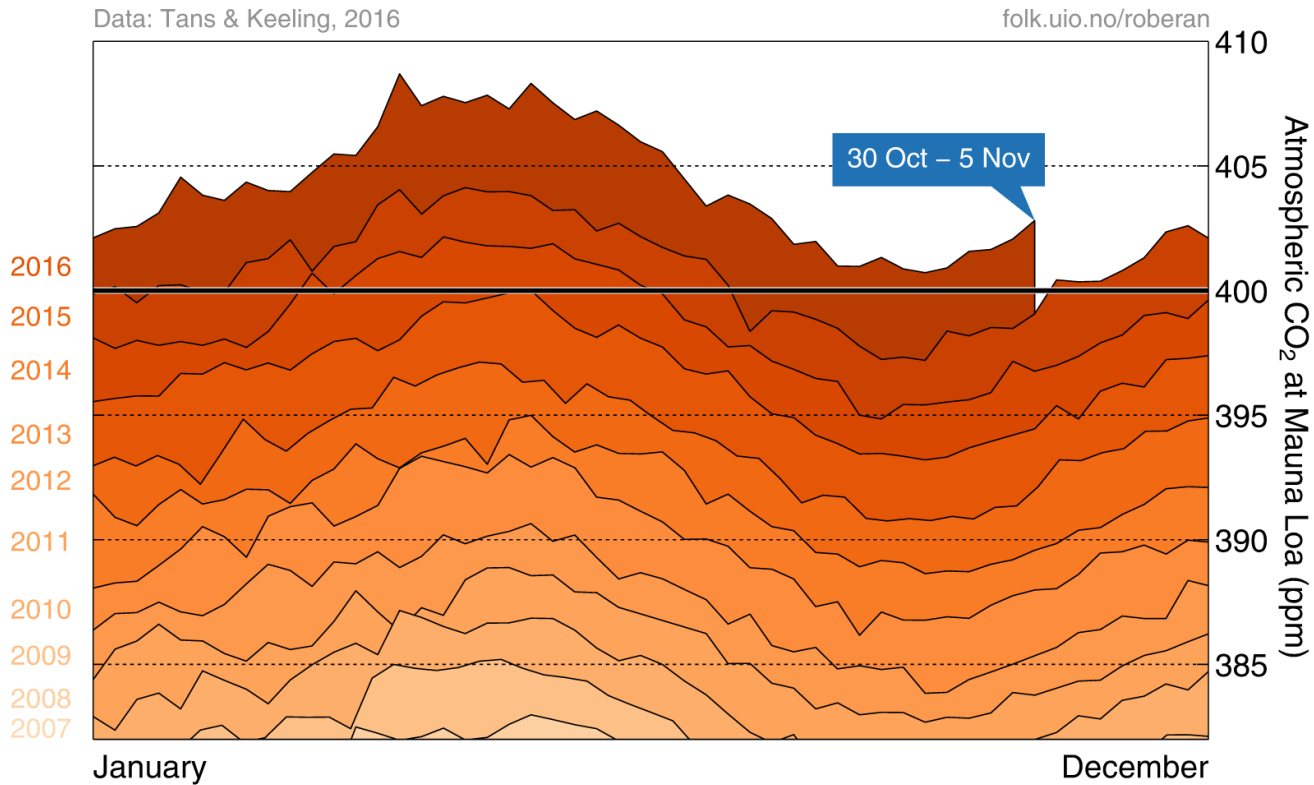
Atmospheric concentration

The global CO₂ concentration increased from ~277ppm in 1750 to 399ppm in 2015 (up 44%)
2016 will be the first full year with concentration above 400ppm



Seasonal variation of atmospheric CO₂ concentration

Weekly CO₂ concentration measured at Mauna Loa will stay above 400ppm throughout 2016



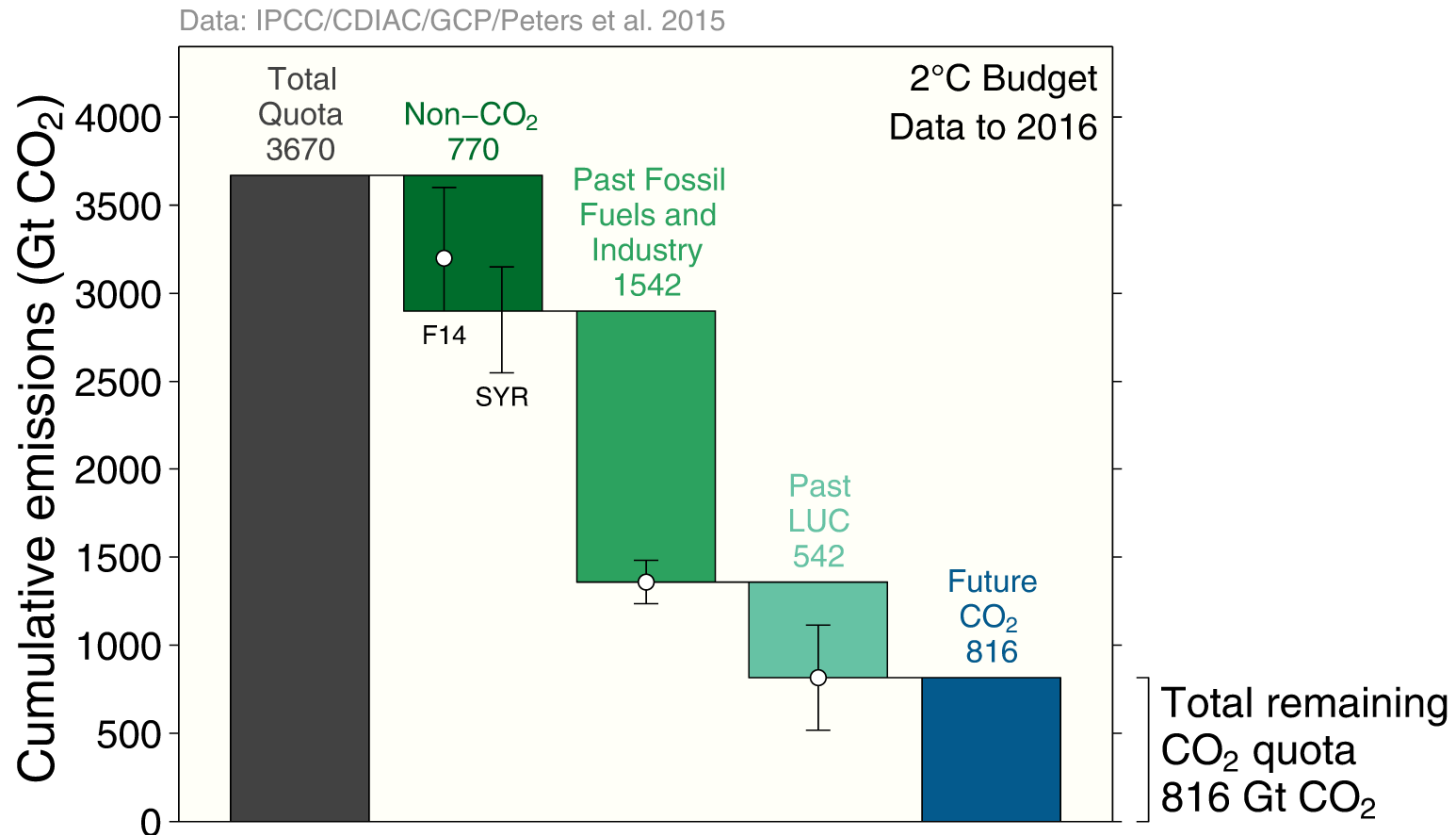
An animation of [this figure](#) is available, and [another](#) on the drivers of the atmospheric growth

Source: Tans and Keeling (2016), [NOAA-ESRL](#), [Scripps Institution of Oceanography](#)

Carbon Quotas to Climate Stabilization

Carbon quota for a 66% chance to keep below 2°C

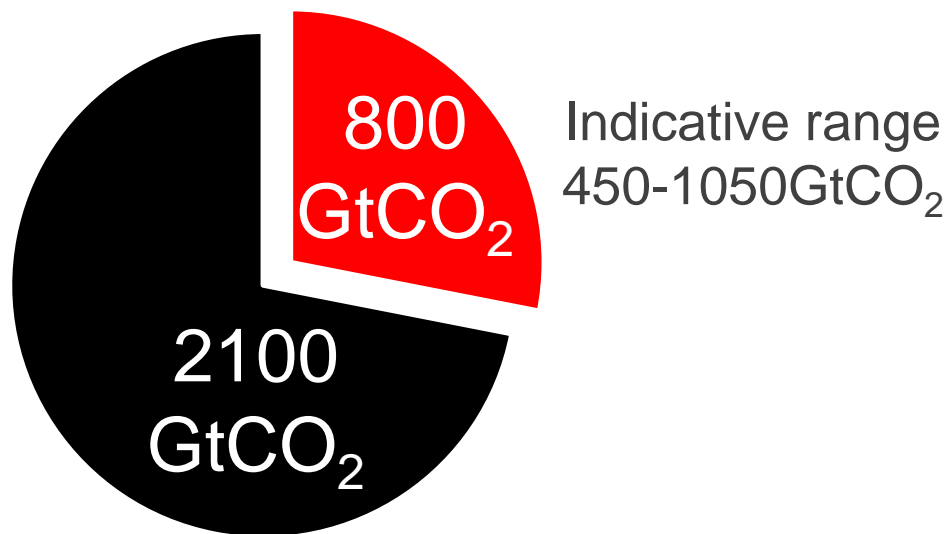
The total remaining emissions from 2017 to keep global average temperature below 2°C (800GtCO₂) will be used in around 20 years at current emission rates



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

For a >66% chance to keep global average temperature below 2°C above pre-industrial levels, society can emit 2900 billion tonnes CO₂ from 1870 or about 800 billion tonnes CO₂ from 2017

<2.0°C, >66%



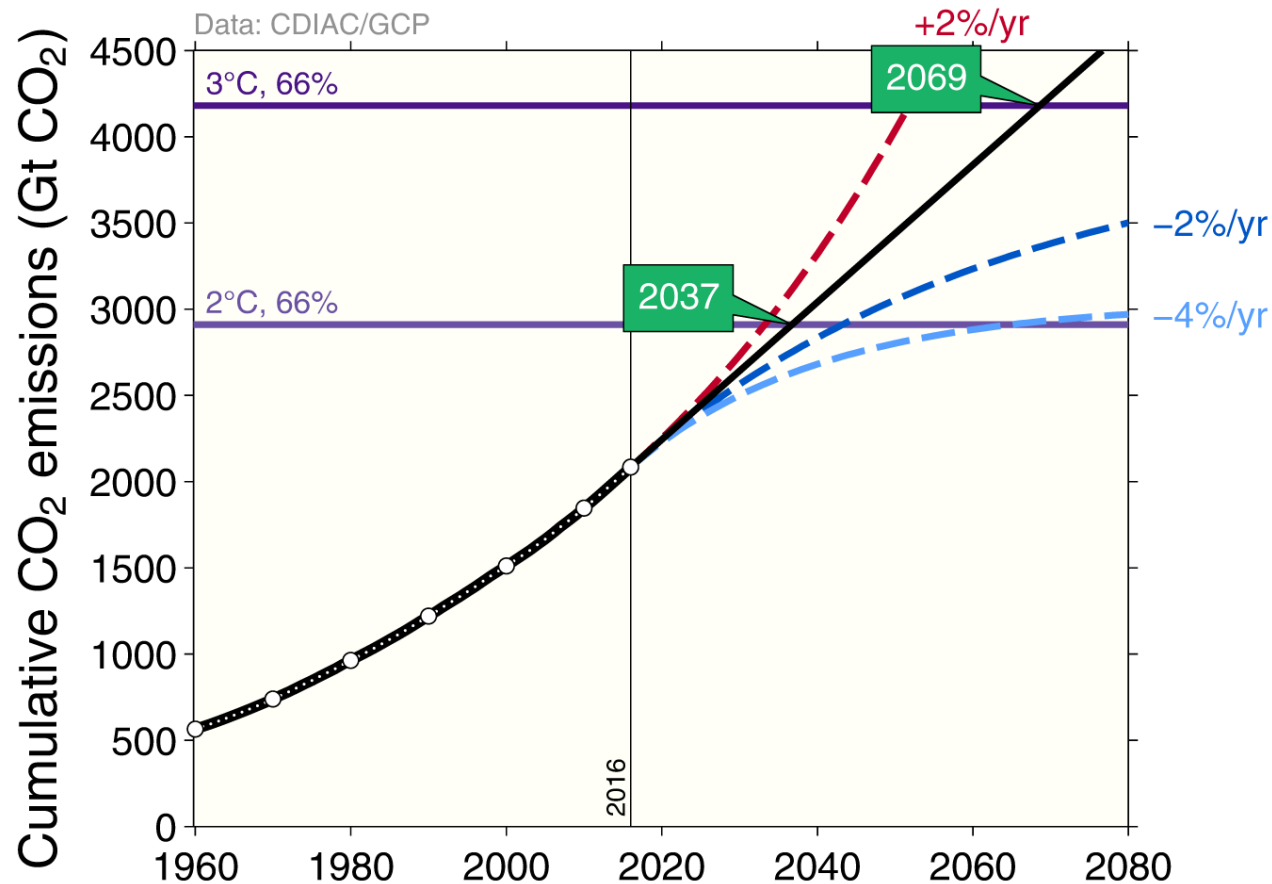
Historical emissions 1870-2016: 2100GtCO₂. All values rounded to the nearest 50 GtCO₂

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](#)

Cumulative global CO₂ emissions and temperature

Cumulative global CO₂ emissions from fossil fuels, industry, and land use change and four simplified future pathways compared to probability of exceeding different temperatures



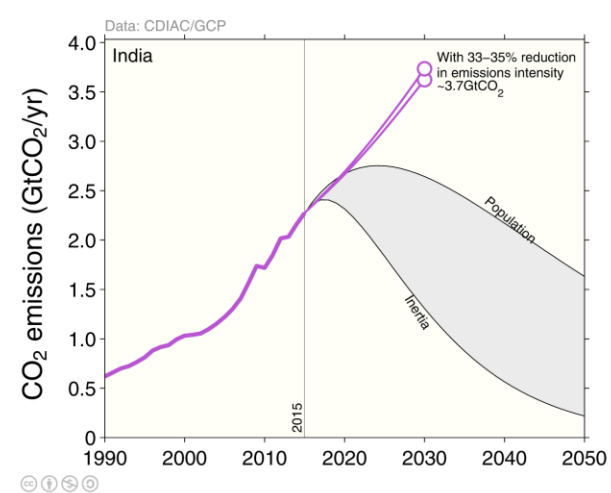
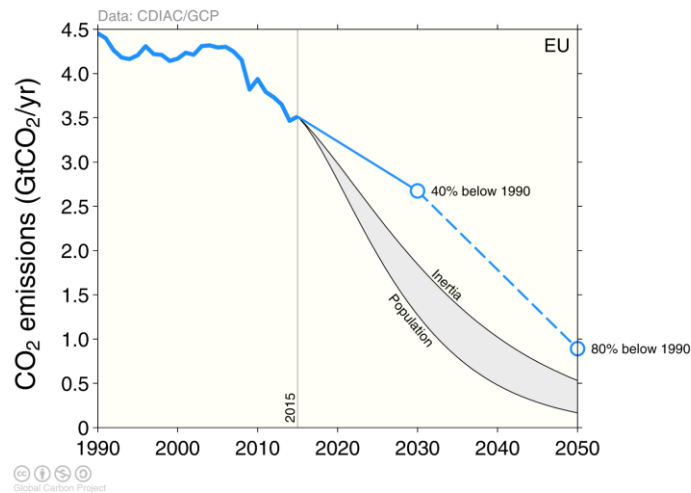
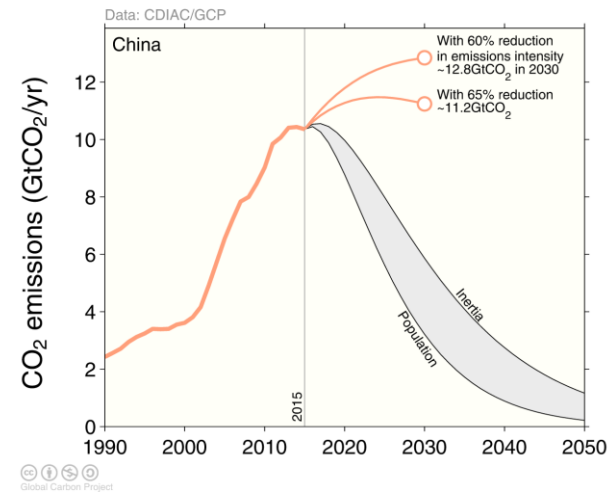
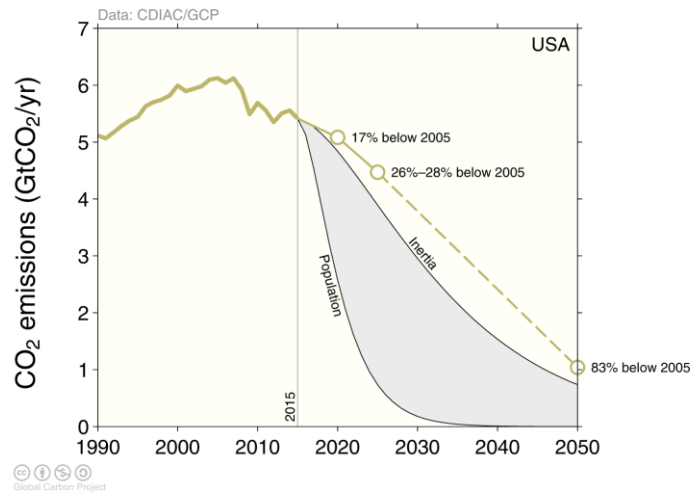
The green boxes show the year that the exceedance budgets are exceeded assuming constant 2016 emission levels

The years are indicative and vary depending on definition and methodology

Source: [Jackson et al 2015b](#); [Global Carbon Budget 2016](#)

The emission pledges (INDCs) of the top-4 emitters

The emission pledges compared to different ways of sharing the remaining 2°C quota

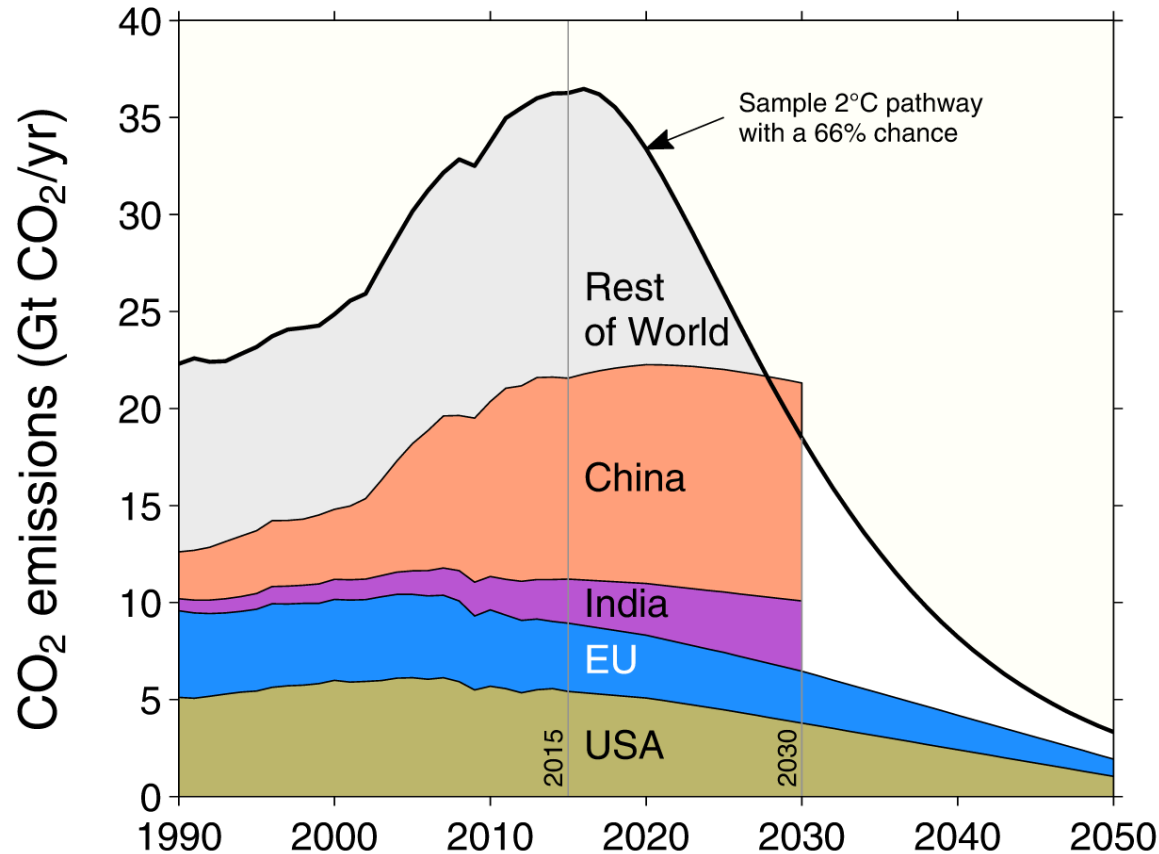


Equity: Remaining quota shared by current population. Inertia: The remaining quota shared by current emissions.

Source: [Peters et al 2015](#); [Global Carbon Budget 2016](#)

The emission pledges (INDCs) of the top-4 emitters

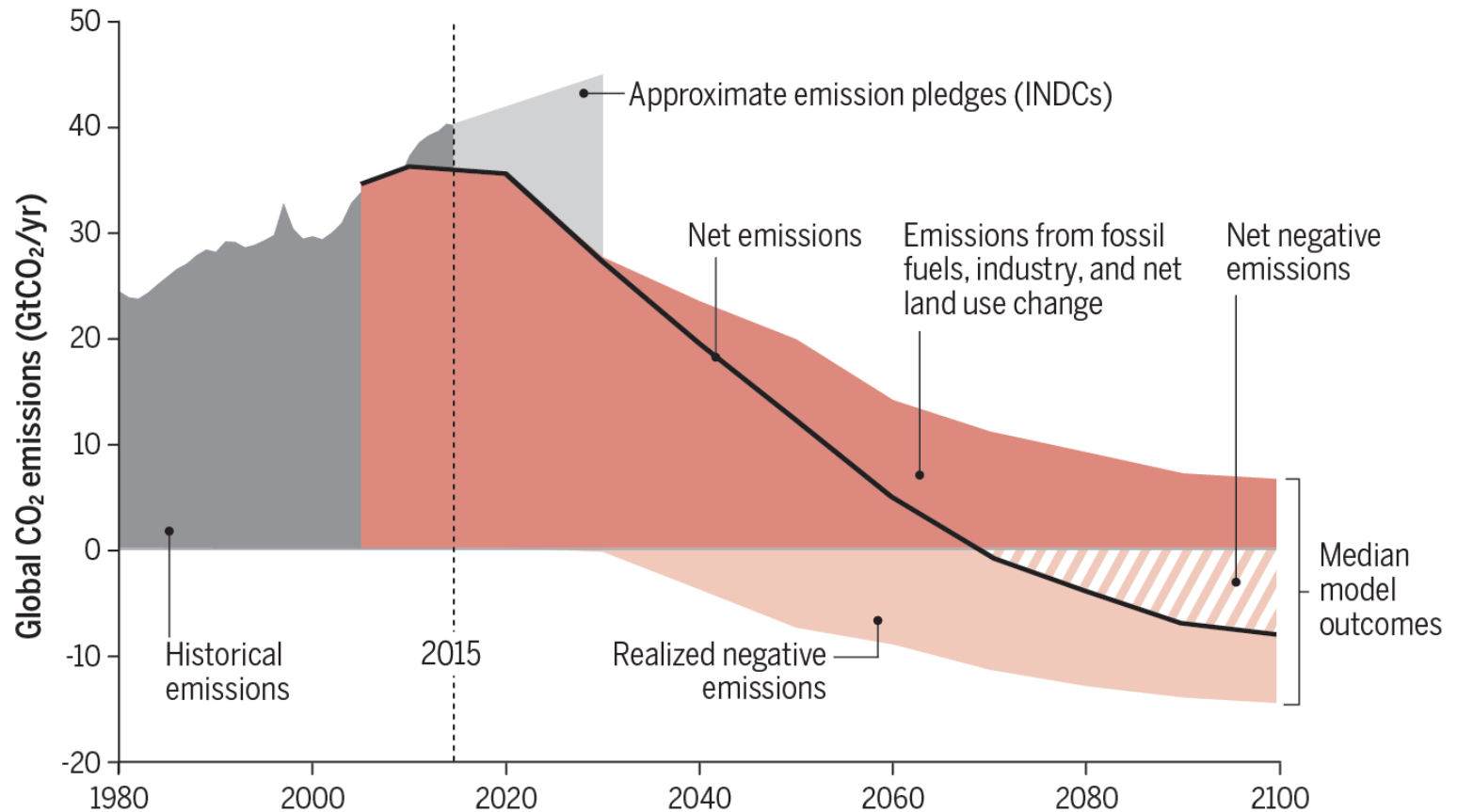
The emission pledges from the US, EU, China, and India leave no room for other countries to emit in a 2°C emission budget (66% chance)



Additional Papers

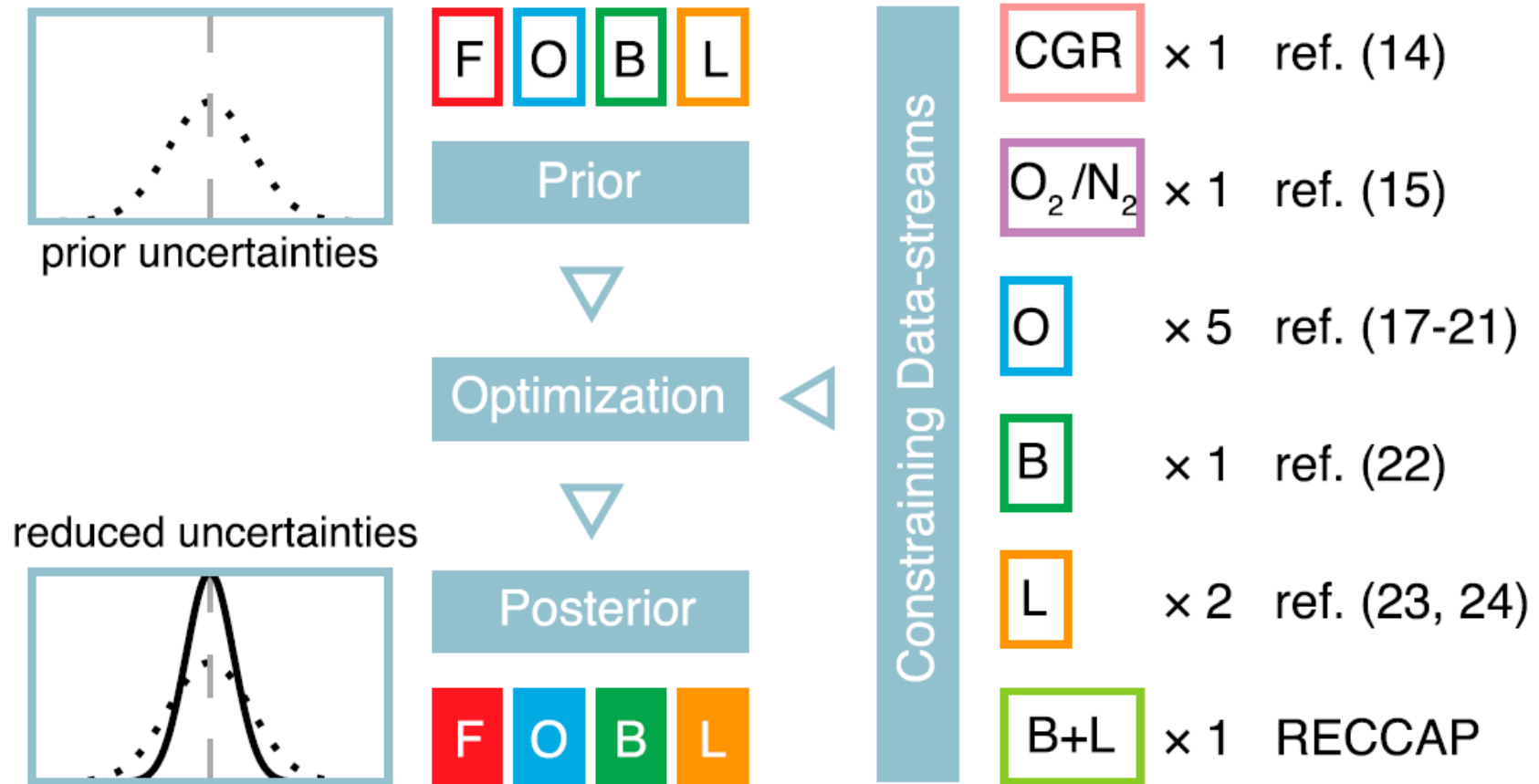
Negative emissions required for 2°C

To achieve net-negative emissions globally after 2050 requires deployment as early as 2020-2030
 If negative emission technologies do not work at scale, society is locked into higher temperatures



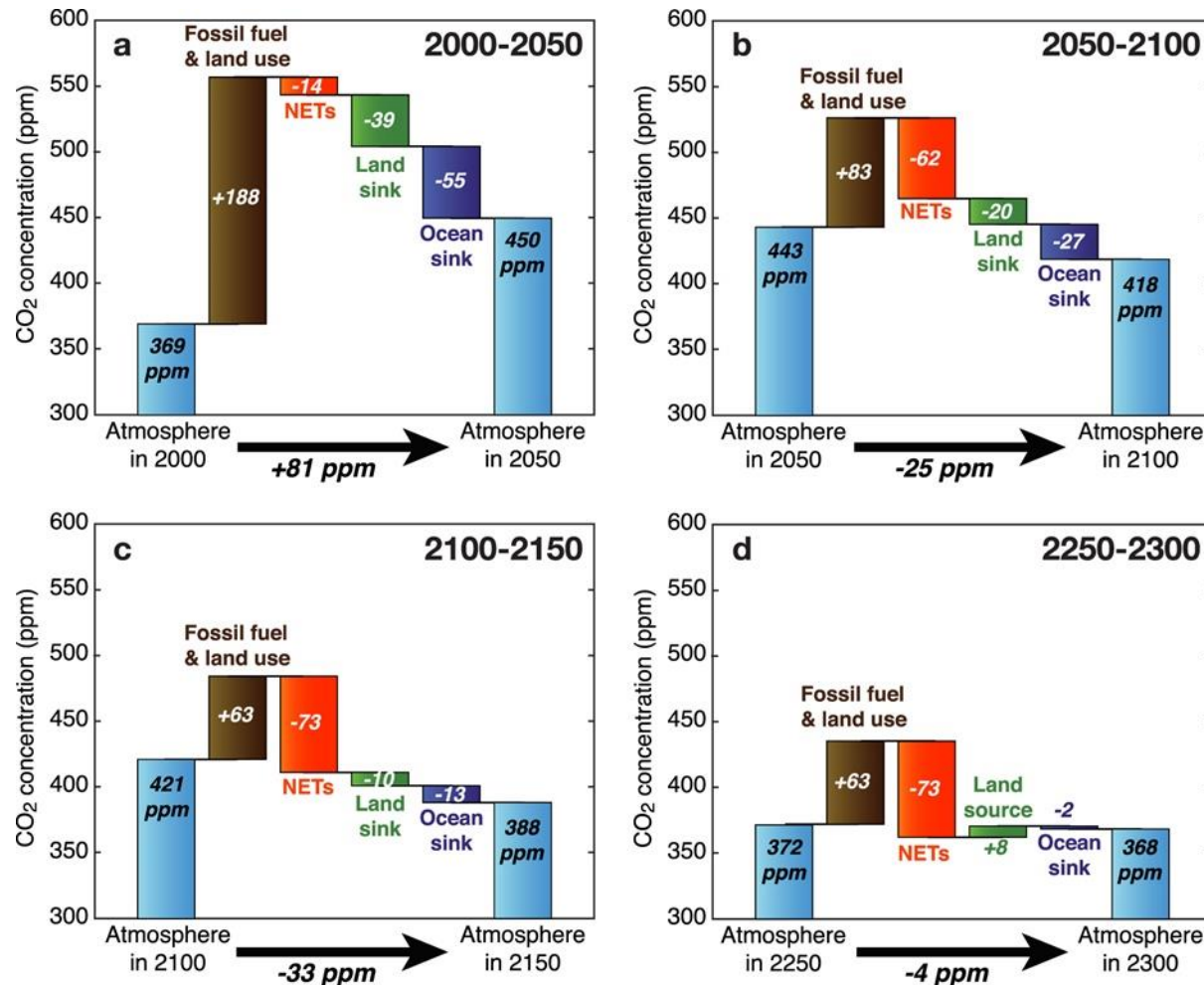
Reducing uncertainty through Bayesian analysis

Bayesian optimization decreases the uncertainty in the land sink by 41%, ocean sink by 46%, land-use change by 47%, while fossil fuel uncertainty is marginally improved



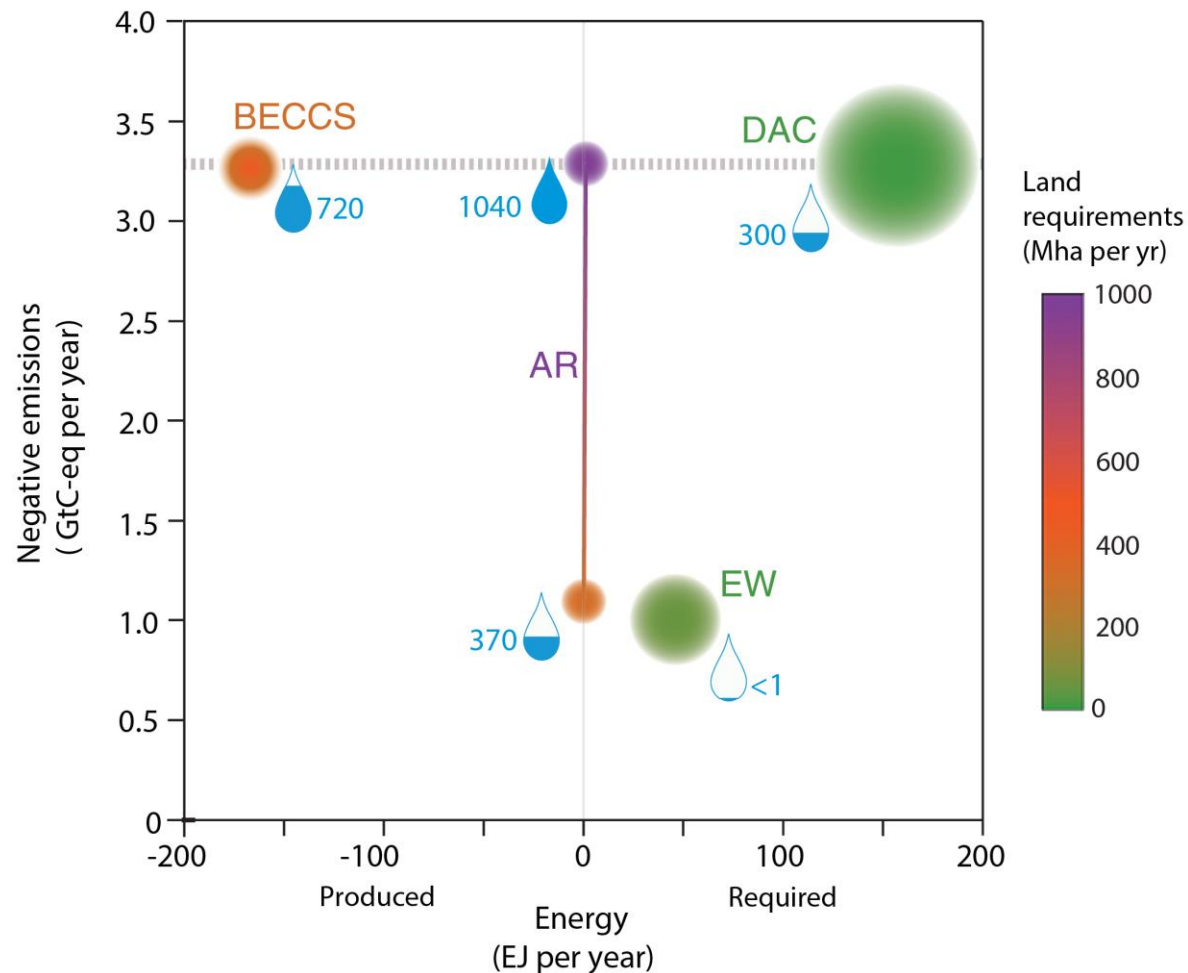
The Earth system response to negative emissions

Earth system models suggest significant weakening, even potential reversal, of the ocean and land sinks under future low emission scenarios



Impact/limit summary for Negative Emission Technologies

The impacts and investment requirements of Negative Emissions Technologies to limit warming to 2°C



Water requirement is shown as water droplets, with quantities in km³ per year.

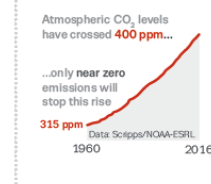
All values are for the year 2100 except relative costs, which are for 2050

Source: [Smith et al 2015](#); [Global Carbon Budget 2016](#)

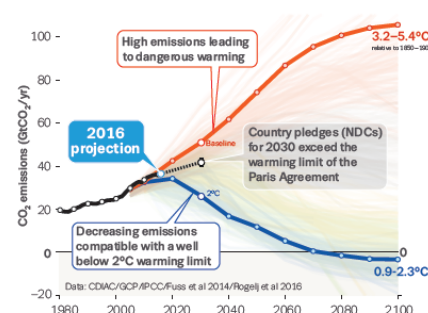
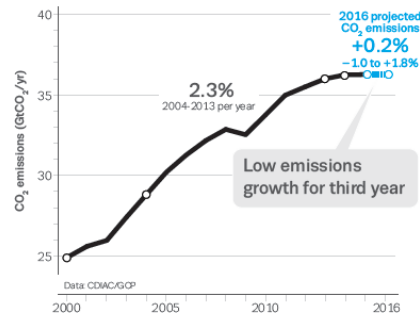
Global Carbon Budget 2016

Global emissions from fossil fuels and industry did not grow in 2015 and are projected to **rise slightly in 2016**.

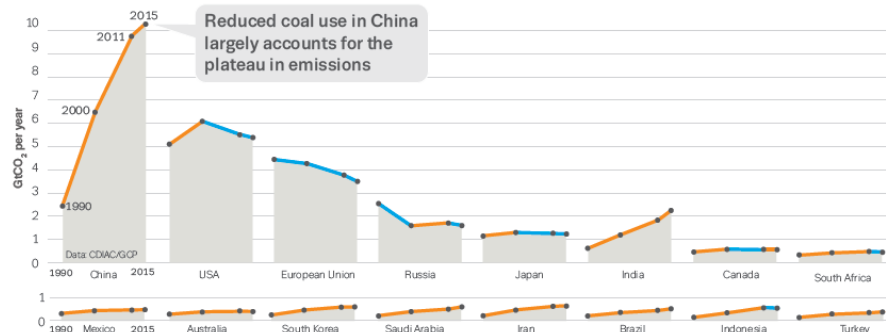
This is the third year in a row where global emissions are below 1% growth while global GDP exceeds 3% growth



Between the Paris agreement and the Marrakesh plan of action, we are [here](#)

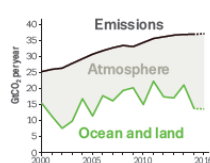


Emissions trends vary among countries

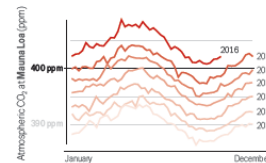


While atmospheric CO2 moves permanently above 400ppm

The big El Niño in 2015-2016 led to smaller CO₂ uptake by plants and left much more emissions in the atmosphere than usual



Atmospheric CO₂ concentration will continue to rise until CO₂ emissions are cut down to near zero



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