Climate Action Program

Part #2: An introduction to GHG mitigation

Overview of major GHG cycles and paths to mitigation

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Outline

1. An introduction to the Global Carbon Budget
2. Scrutinize anthropogenic CO_2 emissions
3. Anthropogenic CO_2 emissions and energy use
4. Global CH_4 emissions
5. Global N_2O emissions
6. How mitigation options are represented in mitigation pathways
7. Other players in global mitigation

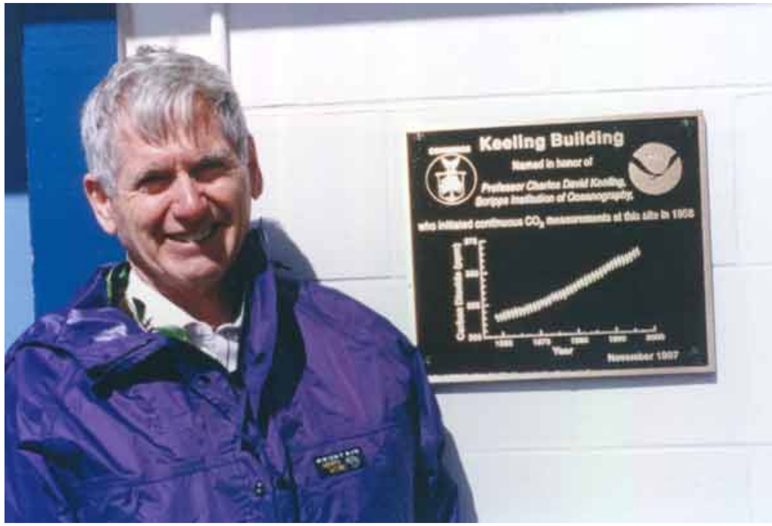
An introduction to the Global Carbon Budget

A long long time ago... Quiz ?

Who are those guys ?

A)

B)

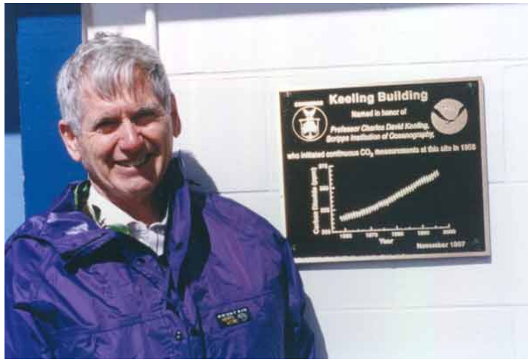


Your answers in **sli.do** :

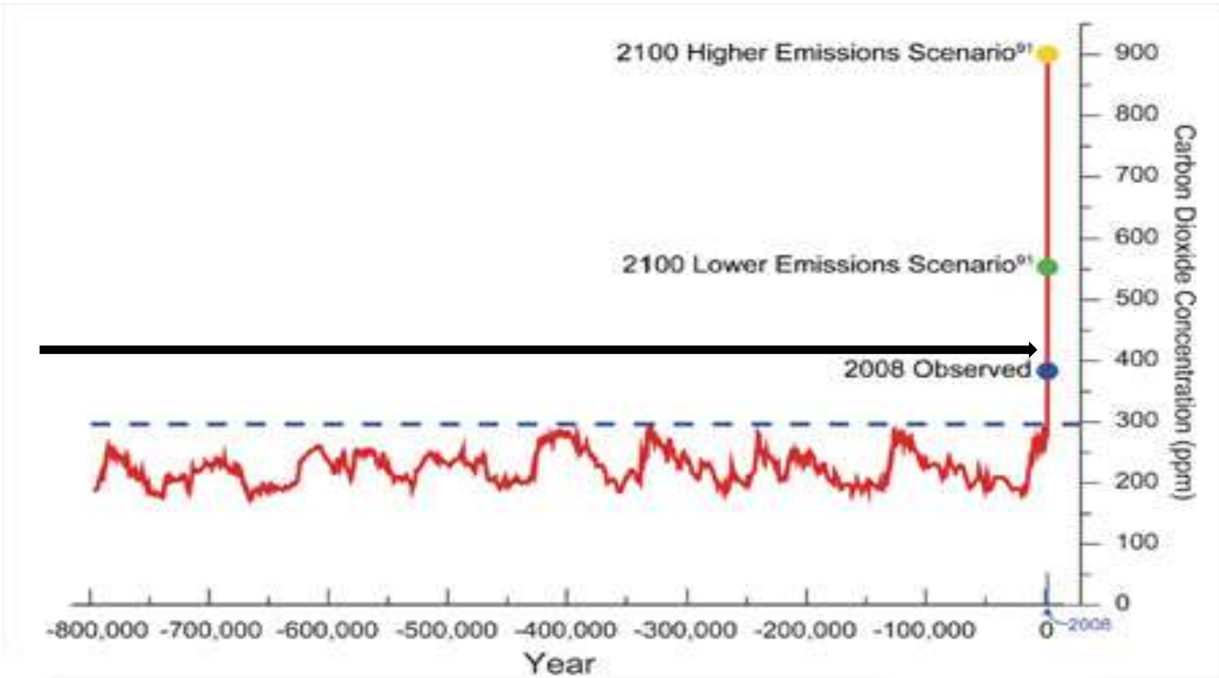
#31826

https://app.sli.do/event/0eyztlq(

A long long time ago... Quiz ?

- First measurement of atmospheric CO2 @Mona Loa in 1957 (Geophysical year)
-  and 

- This year (1957), atmospheric CO2 was 320 ppm, in 2020 it is greater than **400 ppm**



Global Carbon Project

Contributors 76 people
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All lines of evidence

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

Atmospheric CO_2 datasets
NOAA/ESRL (Dlugokencky and Tans 2019)
Scripps (Keeling et al. 1976)

Fossil Fuels and Industry
CDIAC (Gilfillan et al. 2019)
Andrew, 2019
UNFCCC, 2019
BP, 2019

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

Land-Use Change
Houghton and Nassikas 2017
BLUE (Hansis et al. 2015)
GFED4 (van der Werf et al. 2017)
FAO-FRA and FAOSTAT
HYDE (Klein Goldewijk et al. 2017)
LUH2 (Hurtt et al. in prep)

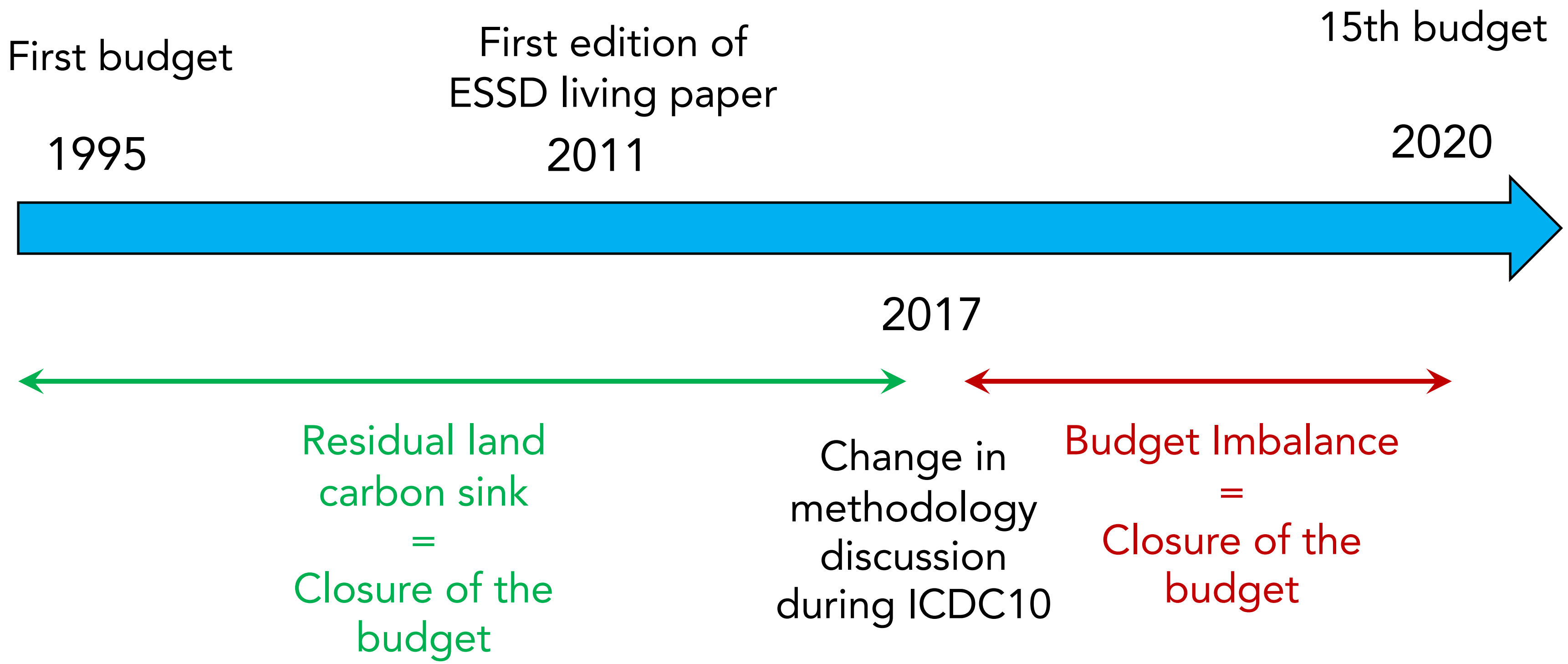
Atmospheric inversions
CarbonTracker Europe (van der Laan-Luijkx et al. 2017)
Jena CarboScope (Rödenbeck et al. 2003)
CAMS (Chevallier et al. 2005)

Land models
CABLE-POP | CLASS-CTEM | CLM5.0 | DLEM | ISAM | ISBA-CTRIP | JSBACH | JULES-ES | LPJ-GUESS | LPJ | LPX-Bern | OCN | ORCHIDEE-Trunk | ORCHIDEE-CNP | SDGVM | VISIT
CRU (Harris et al. 2014) JRA-55

Ocean models
CESM-ETHZ | CSIRO | MICOM-HAMOCC (NorESM-OC) | MITgem-REcoM2 | MOM6-COBALT (Princeton) | MPIOM-HAMOCC6 | NEMO3.6-PISCESv2-gas (CNRM) | NEMO-PISCES (IPSL) | NEMO-PlankTOM5

pCO_2-based ocean flux products
Jena-MLS | MPI-SOMFFN | CMEMS
SOCATv2019

Improved approaches to combine and assess the various lines of evidence



Fate of anthropogenic CO_2 emissions (2009–2018)

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)

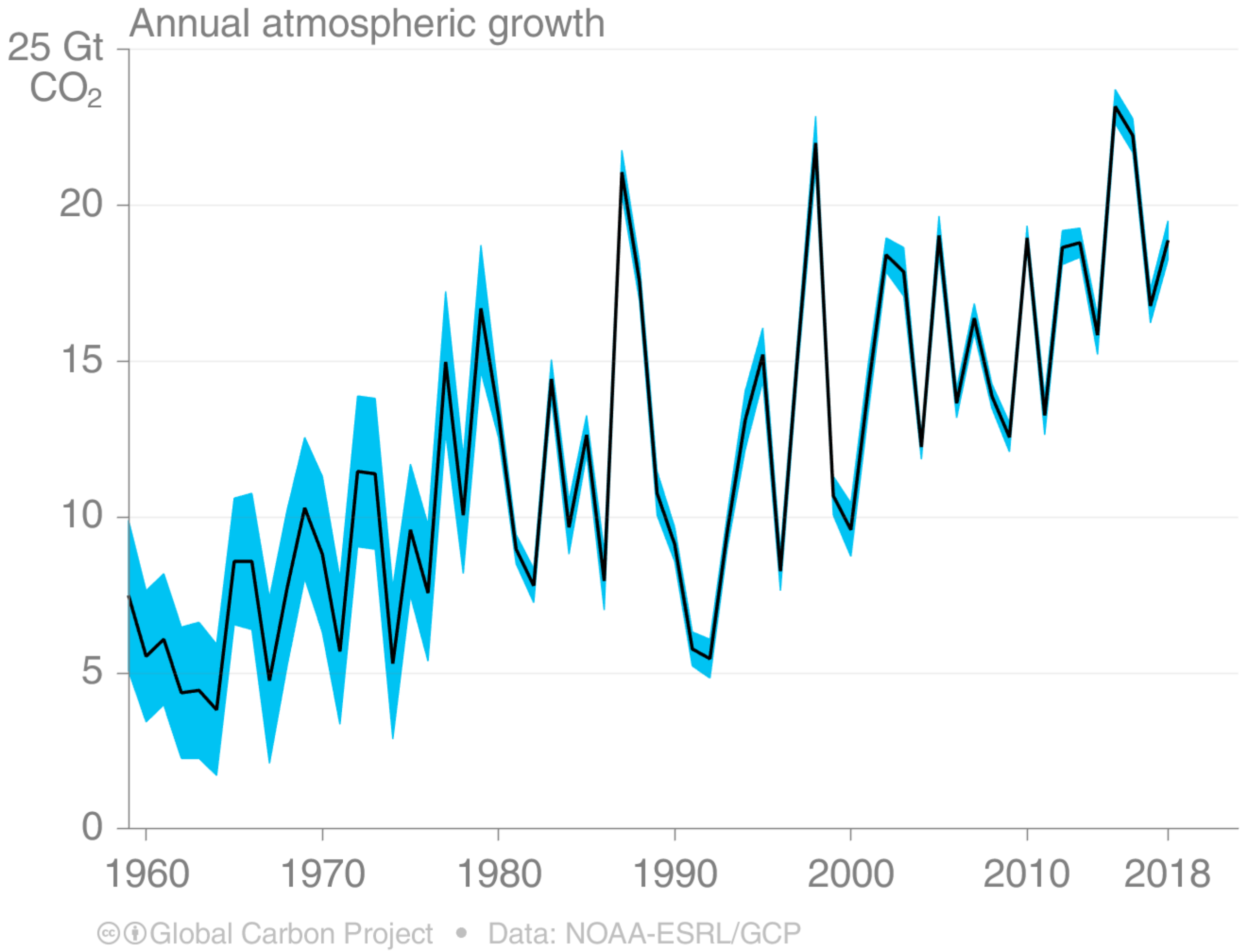
4%
1.6 $GtCO_2$/yr

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

Atmospheric growth rate

The atmospheric concentration growth rate has shown a steady increase

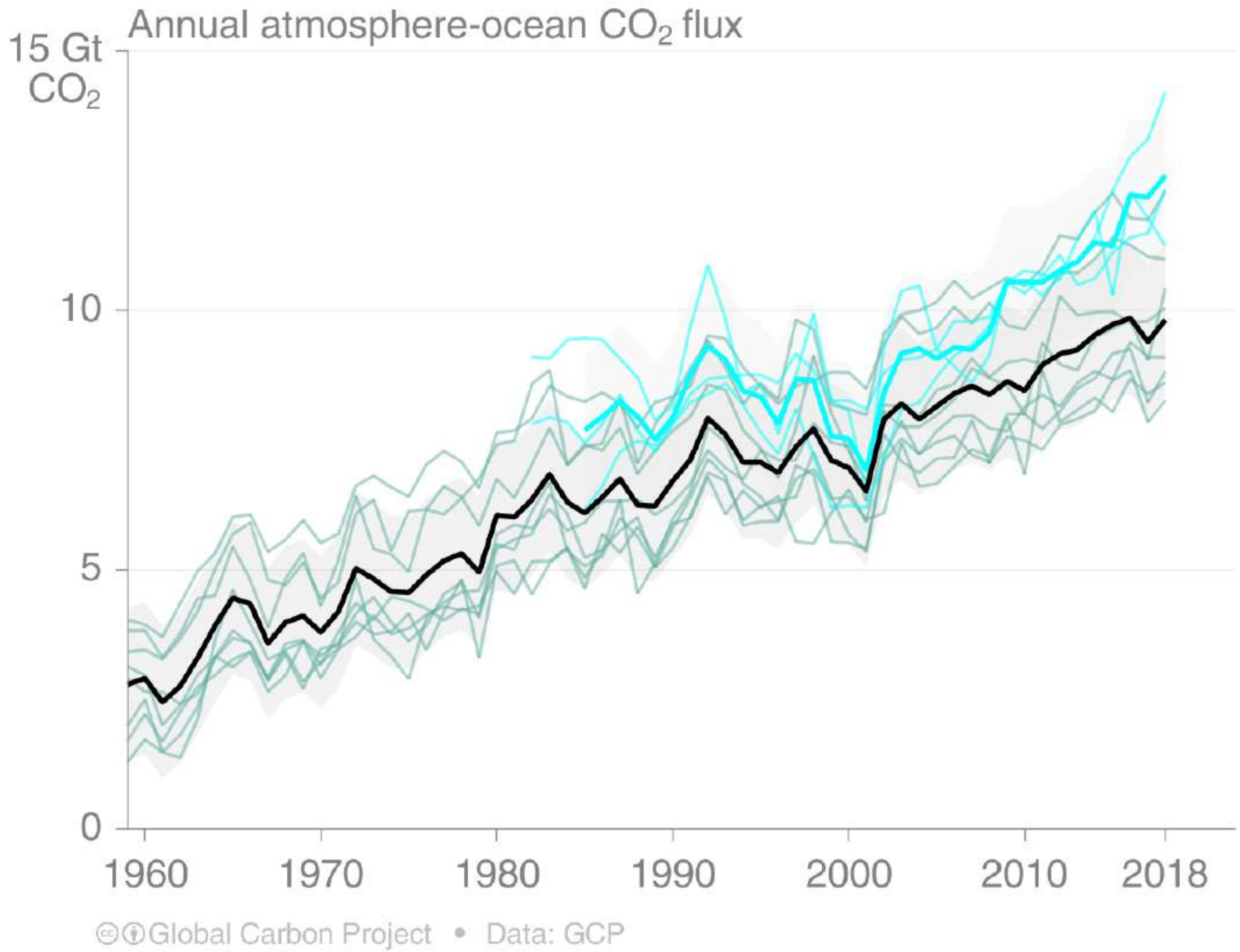
The high growth in 1987, 1998, & 2015–16 reflect a strong El



Source: NOAA-ESRL; Friedlingstein et al 2019; Global Carbon Budget 2019

Ocean Carbon Sink

The ocean carbon sink continues to increase
9.2±2.2 GtCO_2/yr for 2009–2018 and 9.6±2.2 GtCO_2/yr in 2018



Source: SOCATv6; Bakker et al 2016; Friedlingstein et al 2019; Global Carbon Budget 2019

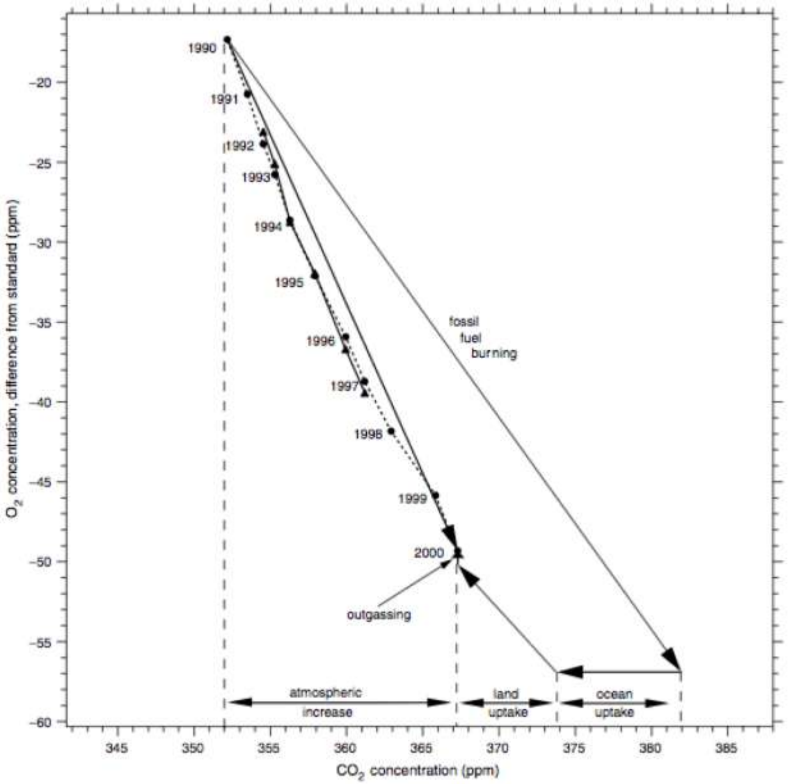
Ocean Carbon Sink

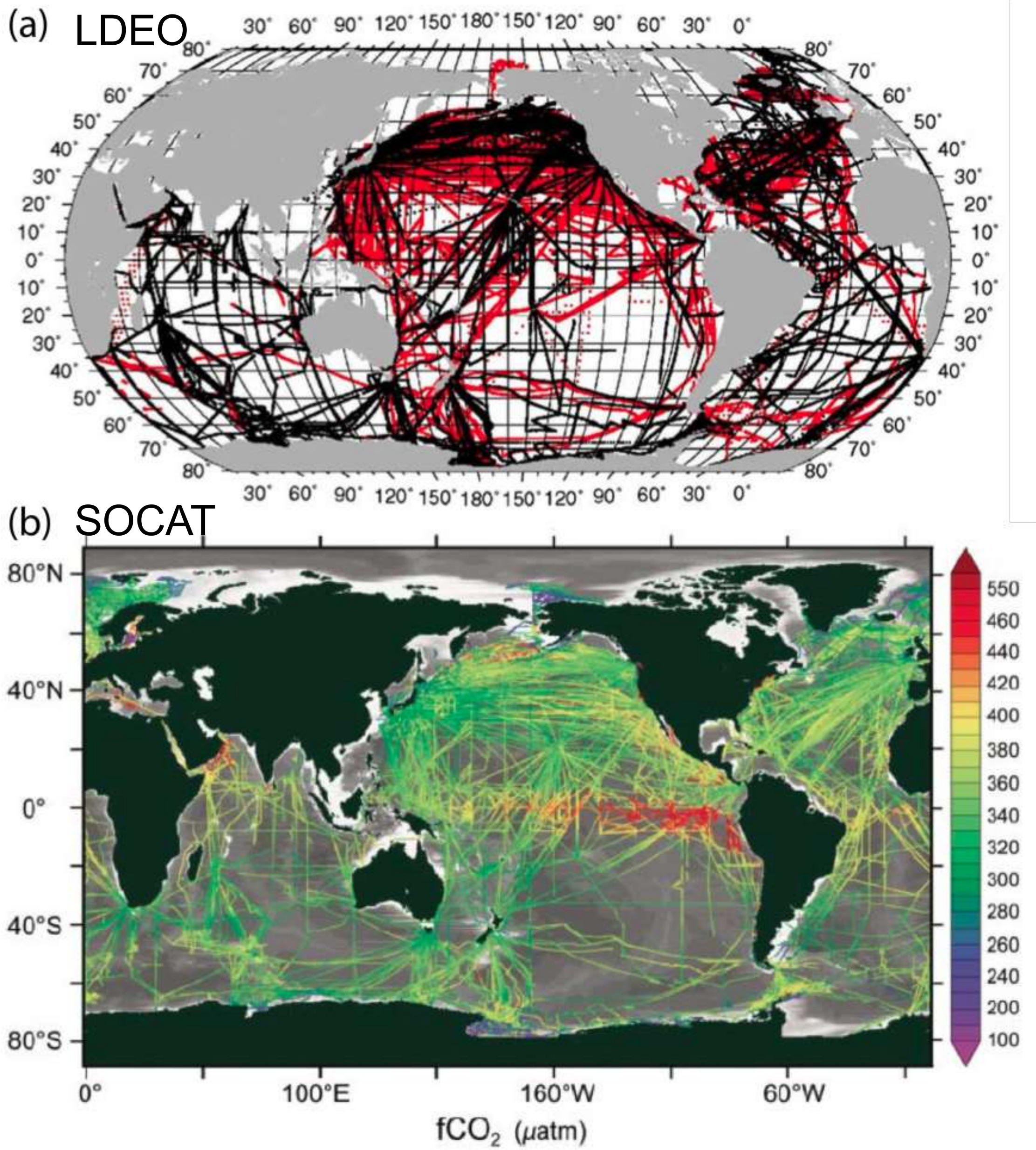
Why ?

Ocean Carbon sink is:

⇒ Better understood that land carbon sink

⇒ Better constrained by land carbon sink = 7 different methods to compute ocean C sink

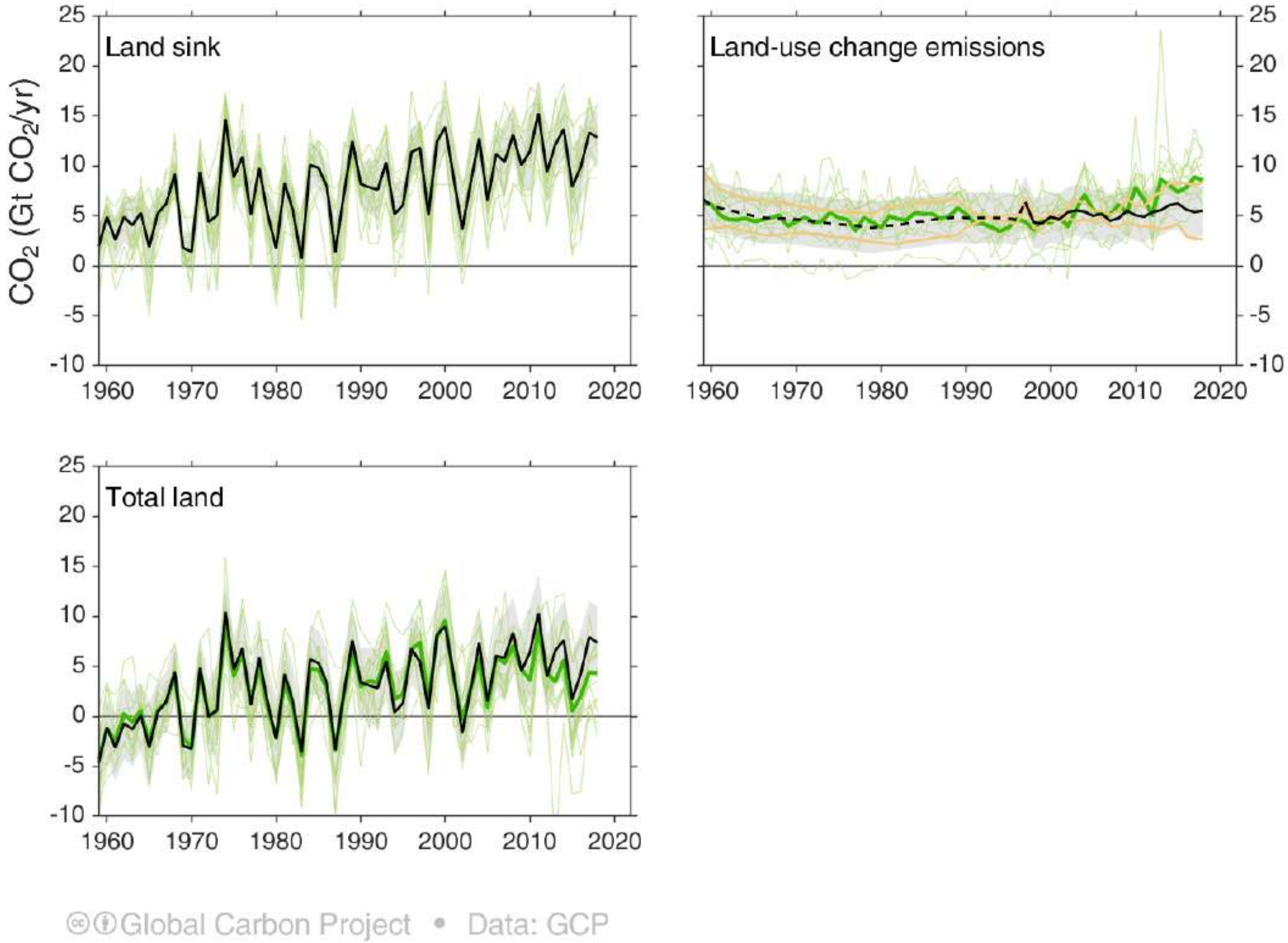




Land Carbon Sink

The land sink was 11.5±2.2 $GtCO_2$/yr during 2009–2018 and 12.7±2.5 $GtCO_2$/yr in 2018

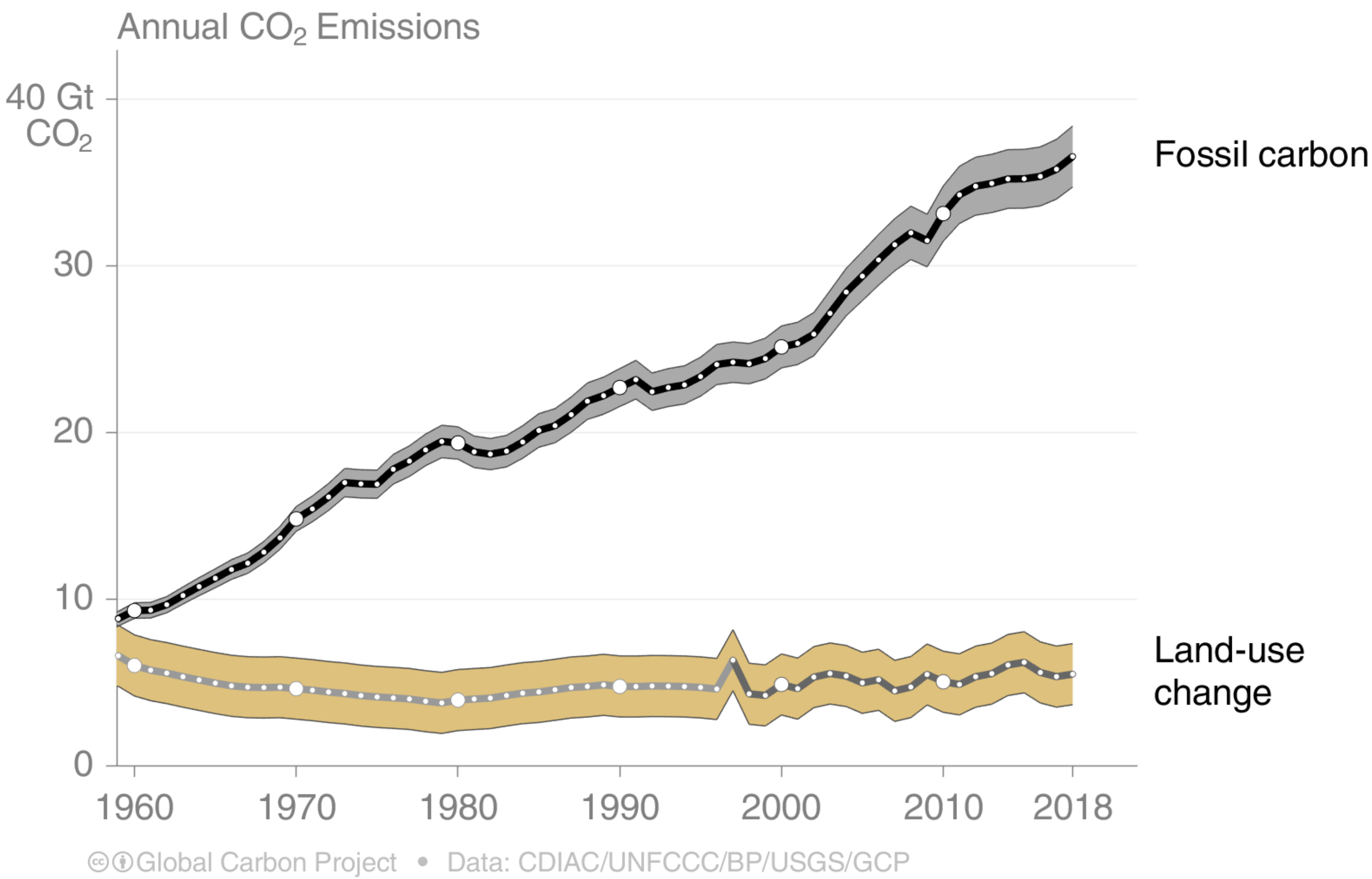
Total CO_2 fluxes on land (including land-use change) are constrained by atmospheric inversions



Source: [Friedlingstein et al 2019]

Human CO_2 emissions

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

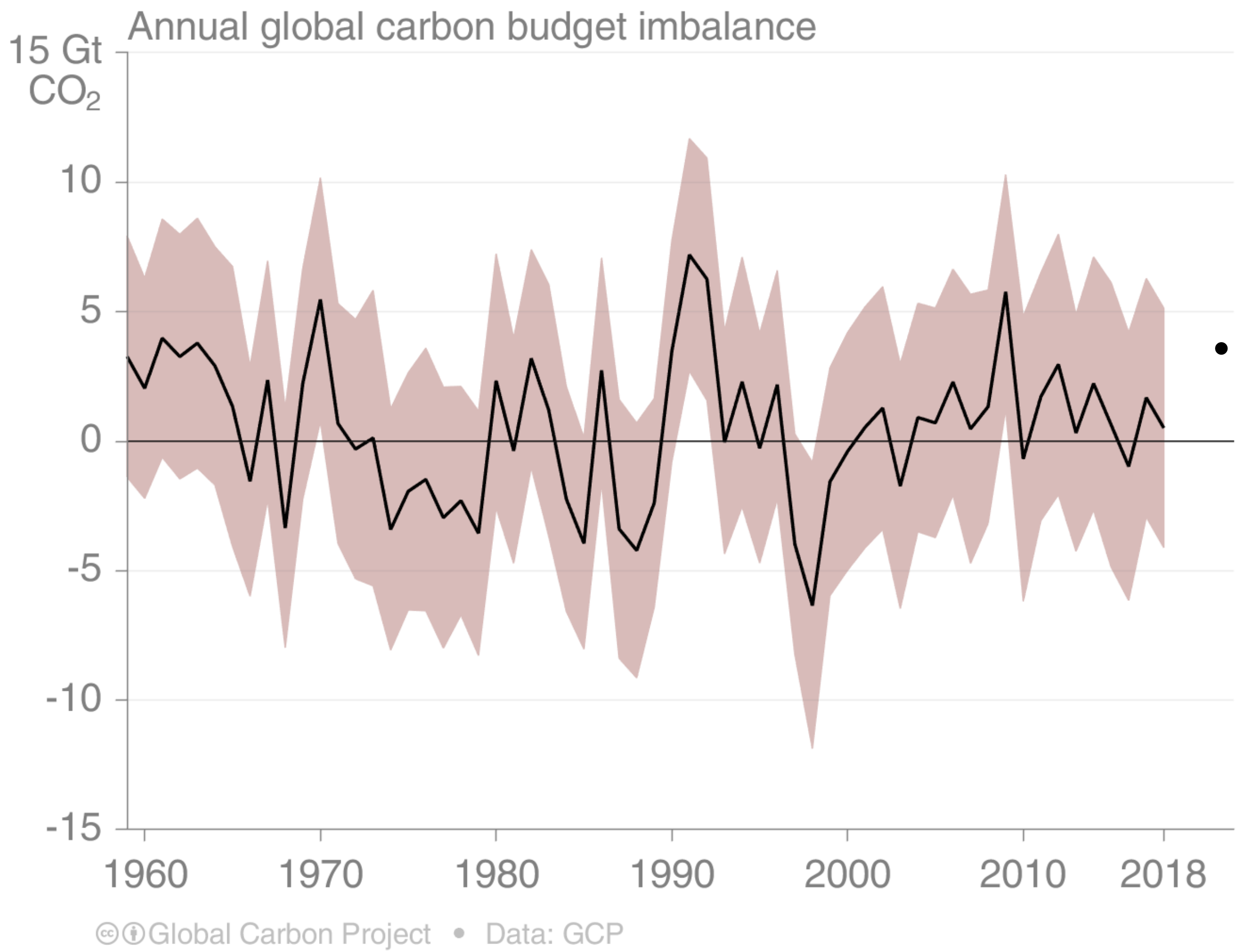


Land-use change estimates from two bookkeeping models, using fire-based variability from 1997
Source: CDIAC; Houghton and Nassikas 2017; Hansis et al 2015; van der Werf et al. 2017; Friedlingstein et al 2019; Global Carbon Budget 2019

Budget Imbalance

Residuals in our understanding

BIM=EFOS+ELUC-Socean-Sland-Gatm



- 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

Source: Friedlingstein et al 2019; Global Carbon Budget 2019

Data Access and Additional Resources

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

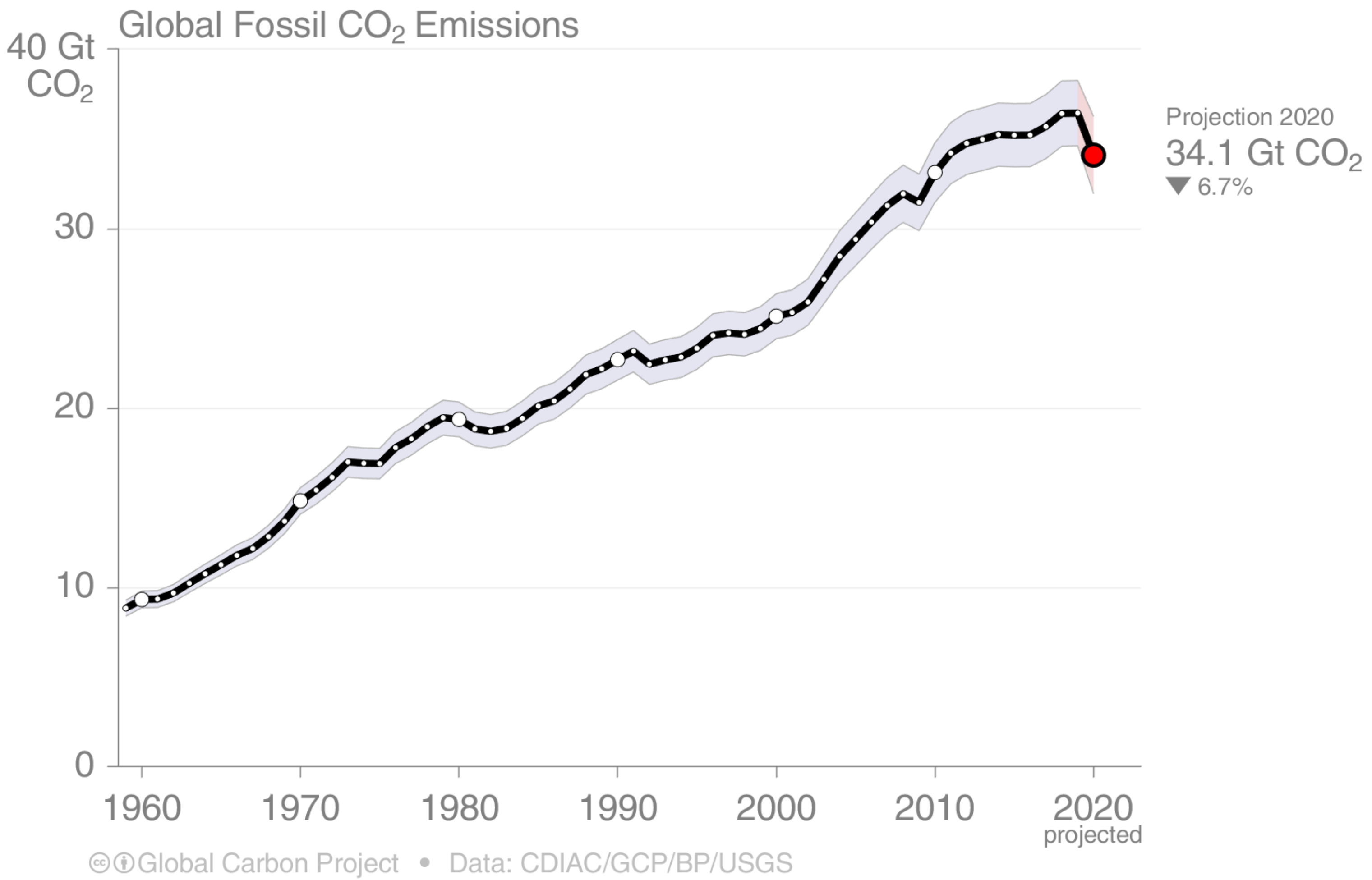
More information, data sources and data files: www.globalcarbonatlas.org (co-funded in part by BNP Paribas Foundation)

Contact: philippe.ciais@lsce.ipsl.fr

Scrutinize anthropogenic CO_2 emissions

Global Fossil CO_2 Emissions

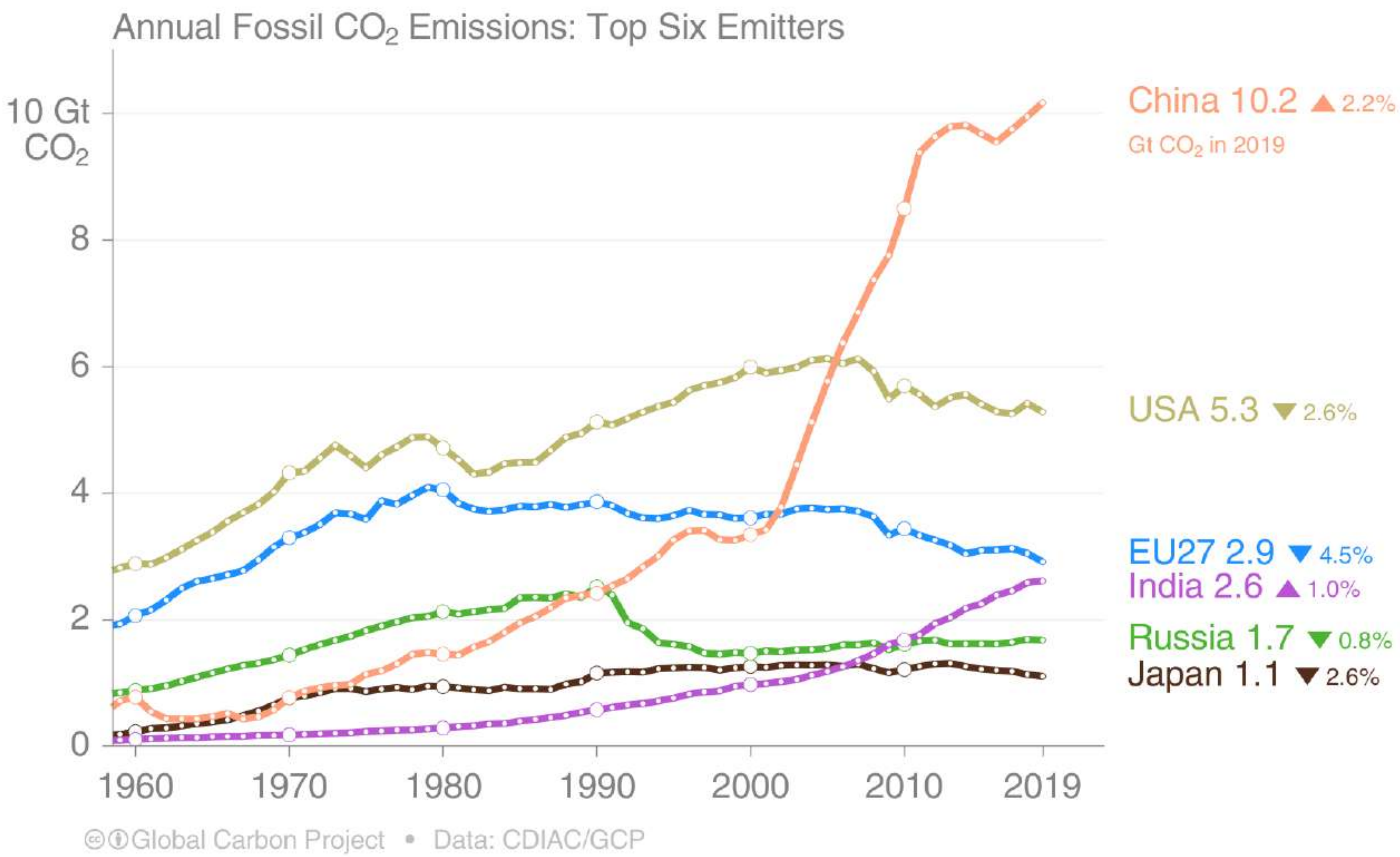
Global fossil CO_2 emissions have risen steadily over the last decades
While 2020 has witnessed an unprecedented drop, emissions will likely rebound in 2021



The 2020 projection is based on preliminary data and modelling.
Source: CDIAC; Friedlingstein et al 2020; Global Carbon Budget 2020

Top emitters: Fossil CO_2 Emissions to 2019

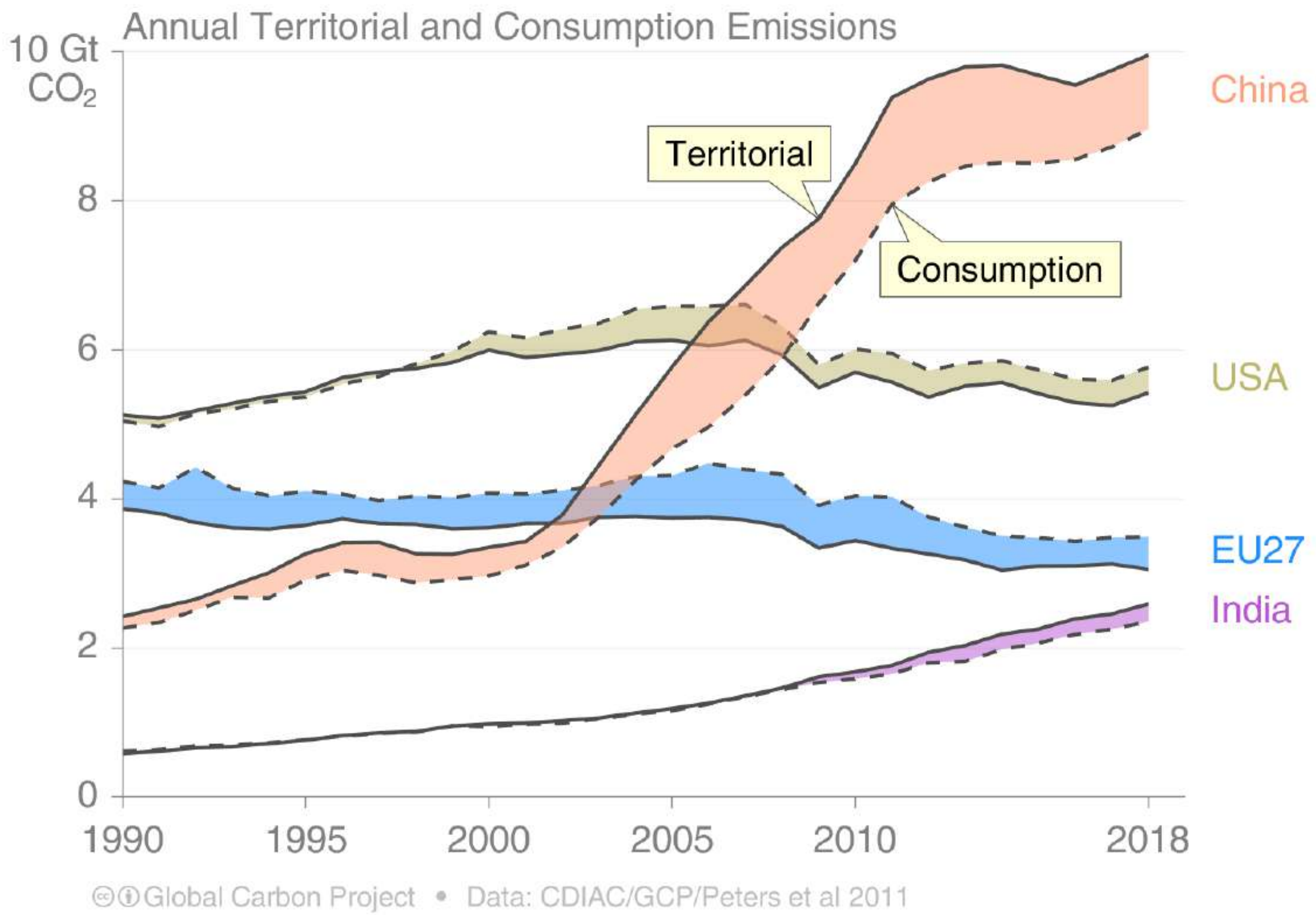
The top six emitters in 2019 covered 65% of global emissions
China 28%, United States 15%, EU27 8%, India 7%, Russia 5%, and Japan 3%



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

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.

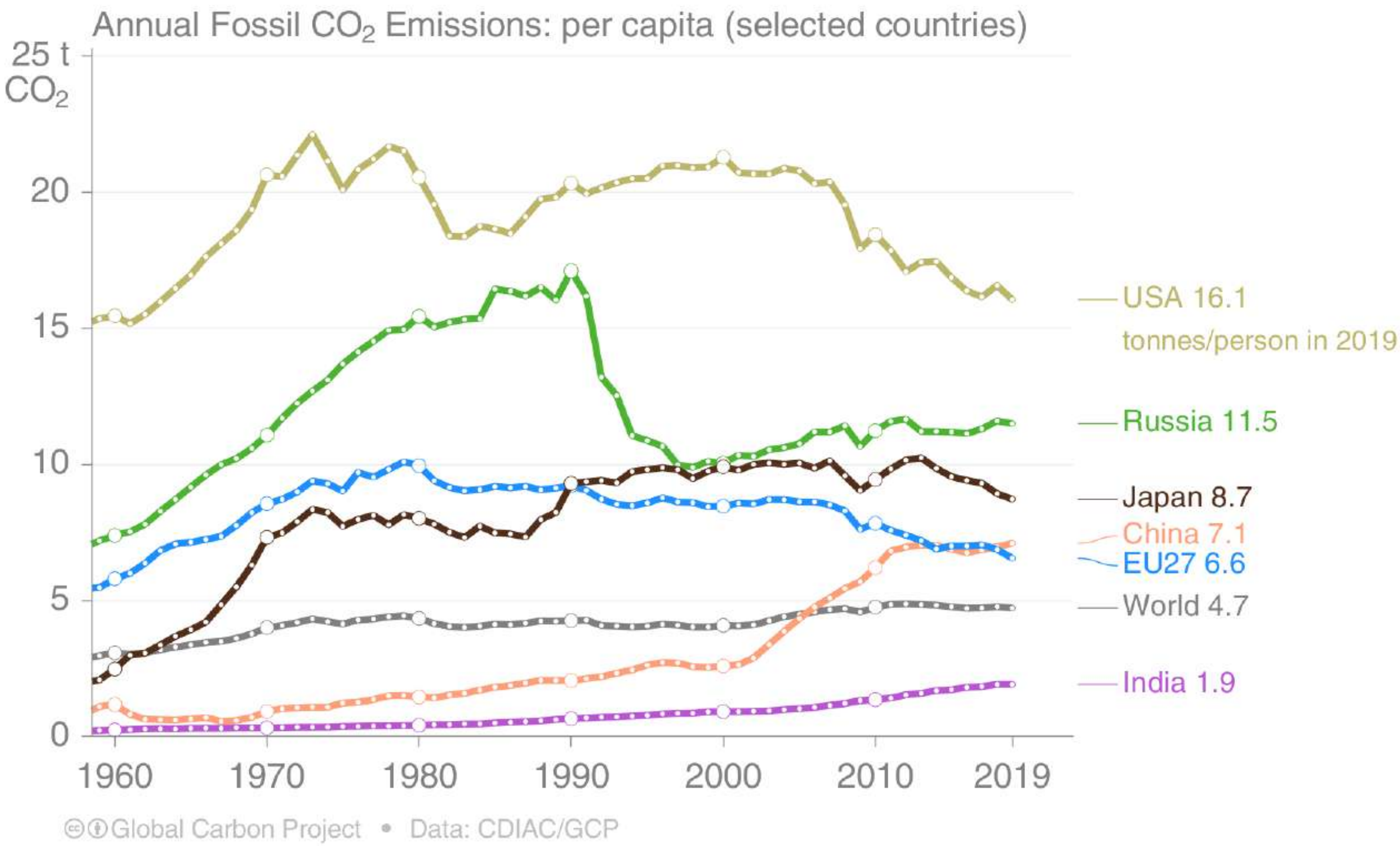


Consumption-based emissions are calculated by adjusting the standard production-based emissions to account for international trade

Source: Peters et al 2011; Friedlingstein et al 2020; Global Carbon Project 2019

Top emitters: Fossil CO_2 Emissions per capita to 2019

Countries have a broad range of per capita emissions reflecting their national circumstances (see previous chapter, link with revised NDCs)



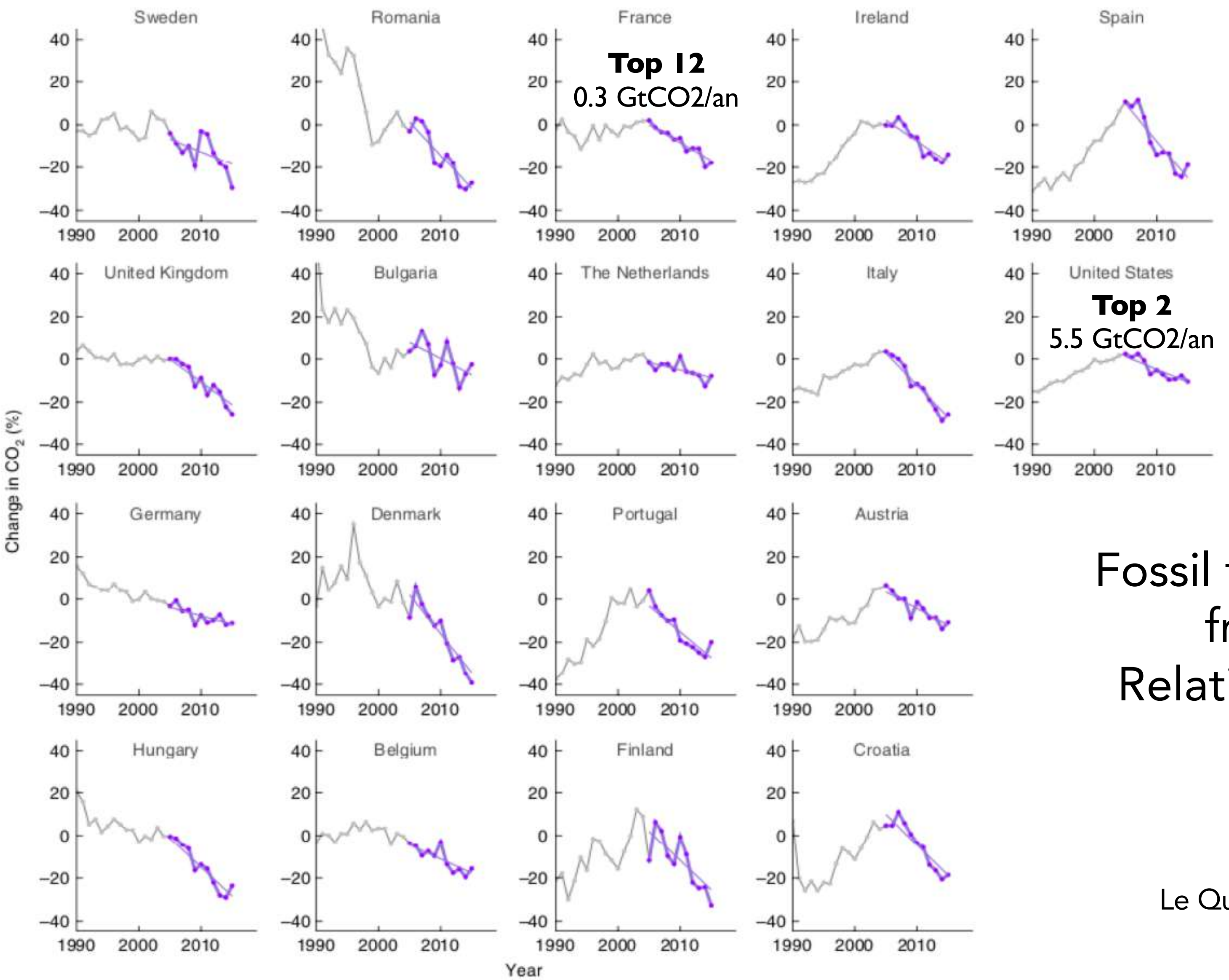
Source: CDIAC; Friedlingstein et al 2020; Global Carbon Budget 2020

Key statistics for emisions in 2019

Region/Country	Emissions 2019: Per capita tCO₂ per person	Total GtCO₂	Total %	Growth 2018–19 GtCO₂	Growth 2018–19 %
Global (including bunkers)	4.7	36.44	100	0.022	0.1
OECD Countries					
OECD	9.4	12.23	33.6	-0.378	-3.0
USA	16.1	5.28	14.5	-0.140	-2.6
OECD Europe	6.5	3.21	8.8	-0.145	-4.3
Japan	8.7	1.11	3.0	-0.029	-2.6
South Korea	11.9	0.61	1.7	-0.024	-3.7
Canada	15.4	0.58	1.6	-0.010	-1.7
Non-OECD Countries					
Non-OECD	3.6	22.94	63.0	0.400	1.8
China	7.1	10.17	27.9	0.218	2.2
India	1.9	2.62	7.2	0.025	1.0
Russia	11.5	1.68	4.6	-0.013	-0.8
Iran	9.4	0.78	2.1	0.024	3.2
Indonesia	2.3	0.62	1.7	0.041	7.1
International Bunkers					
Bunkers	-	1.27	3.5	0.000	0.0

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

Reminder from the previous chapter



Fossil fuel emission from IAE Relative to 2000-2005

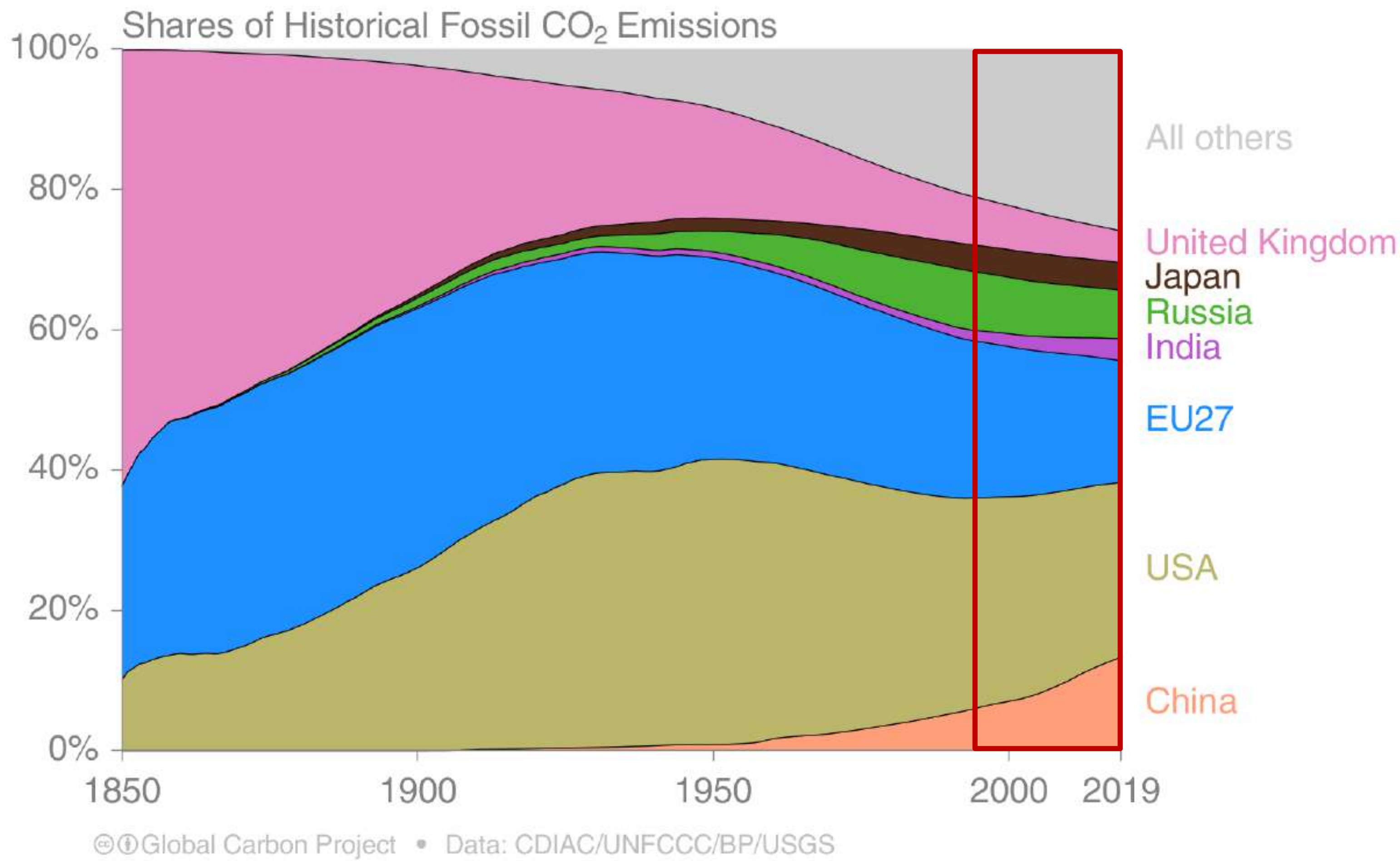
Le Quéré et al. (2019)

⇒ Reduction is CO2 emission in several countries

⇒ Emission cut-off is largely driven by an increase of the energy-to-carbon intensity

Responsability in past emissions

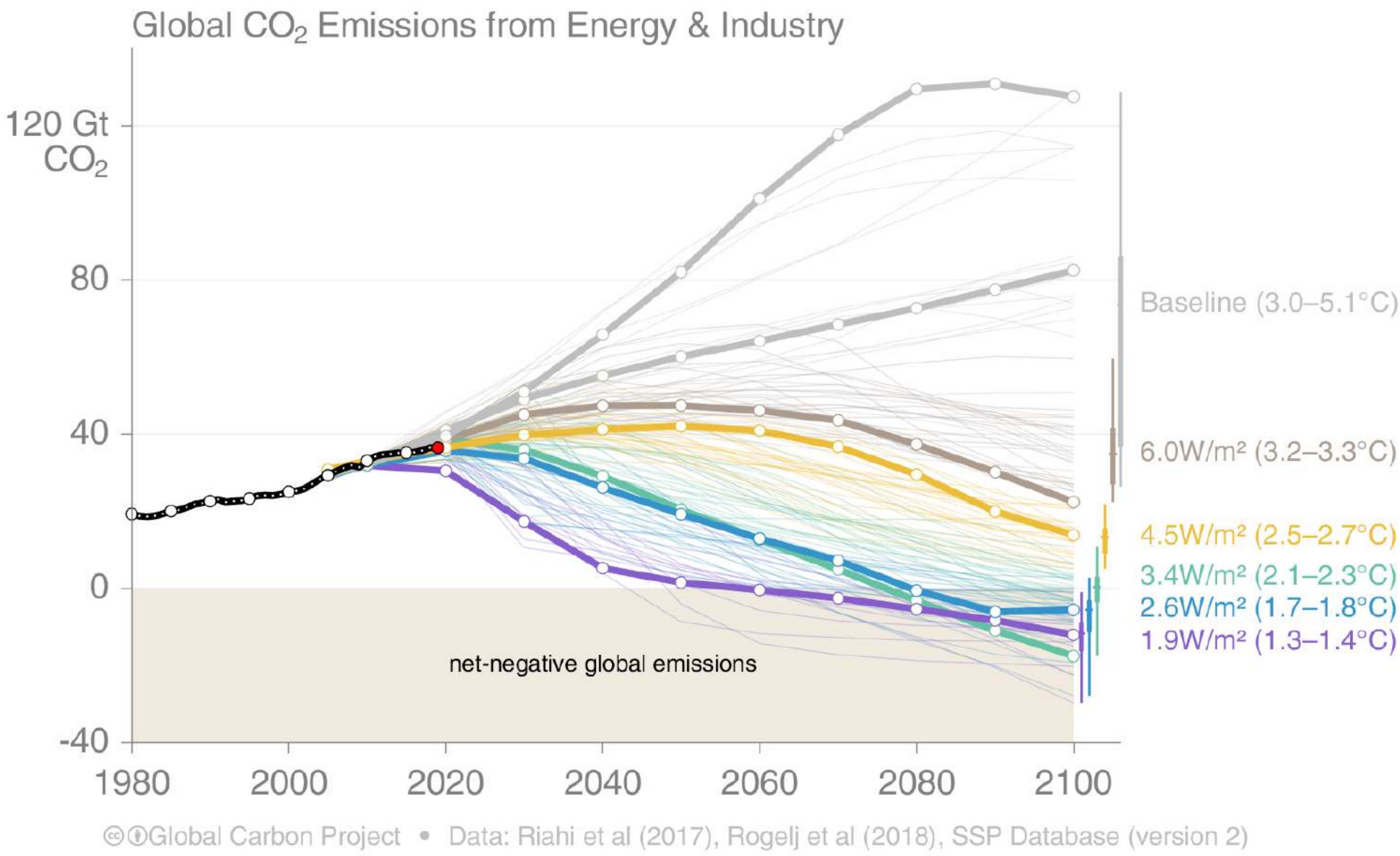
- Cumulative fossil CO_2 emissions were distributed (1850–2019): USA 25%, EU27 17%, China 13%, Russia 7%, UK 5%, Japan 4% and India 3%
- Cumulative emissions (1990–2019) were distributed China 21%, USA 19%, EU27 12%, Russia 6%, India 5%, Japan 4%, UK 2%



'All others' includes all other countries along with international bunker fuels

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

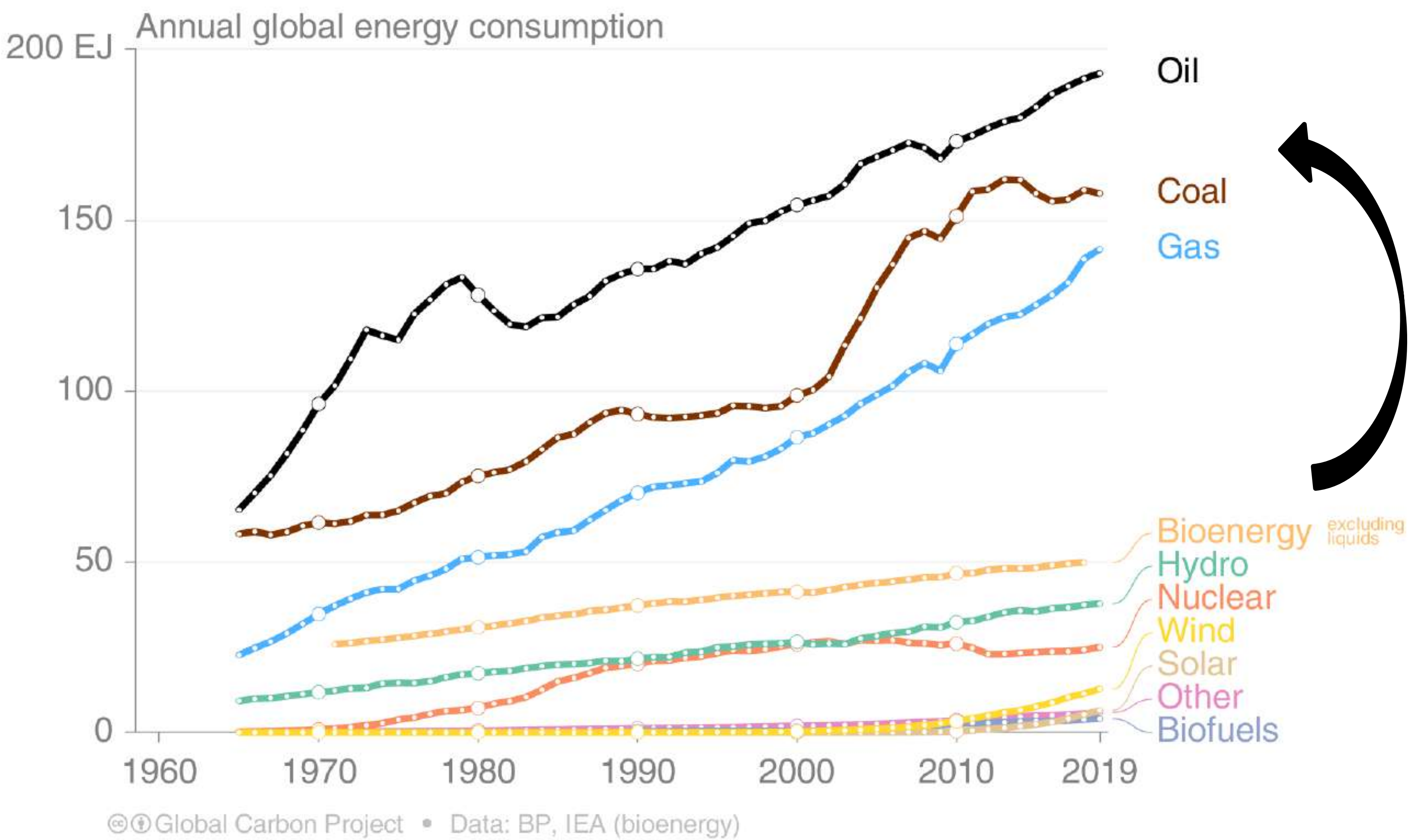
Current emissions vs emission pathways



Anthropogenic CO_2 emissions and energy use

Split-up of Energy use

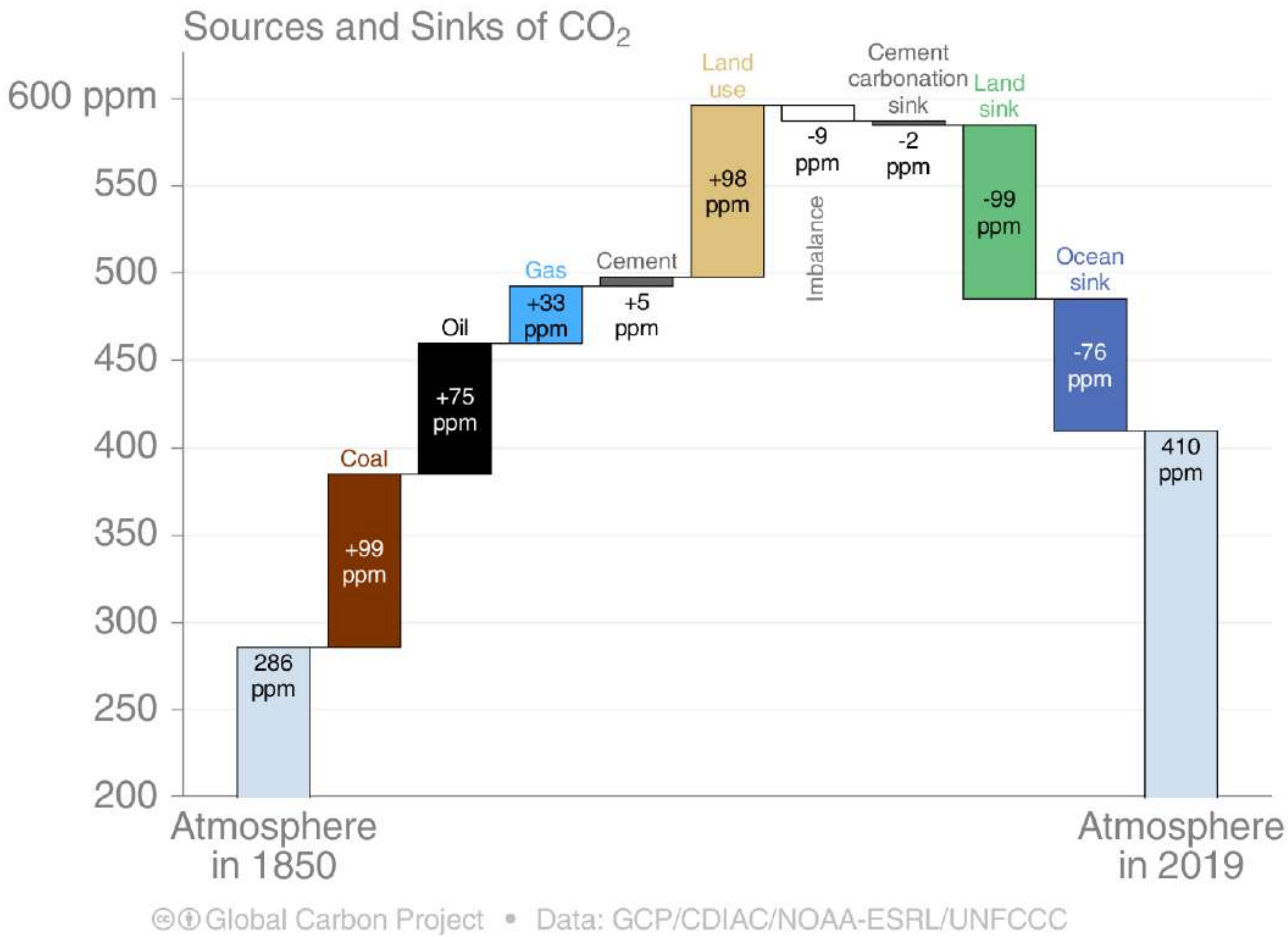
Renewable energy is growing exponentially, but this growth has so far been too low to offset the growth in fossil energy consumption.



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 2020; Global Carbon Budget 2020

Global carbon budget with energy split-up

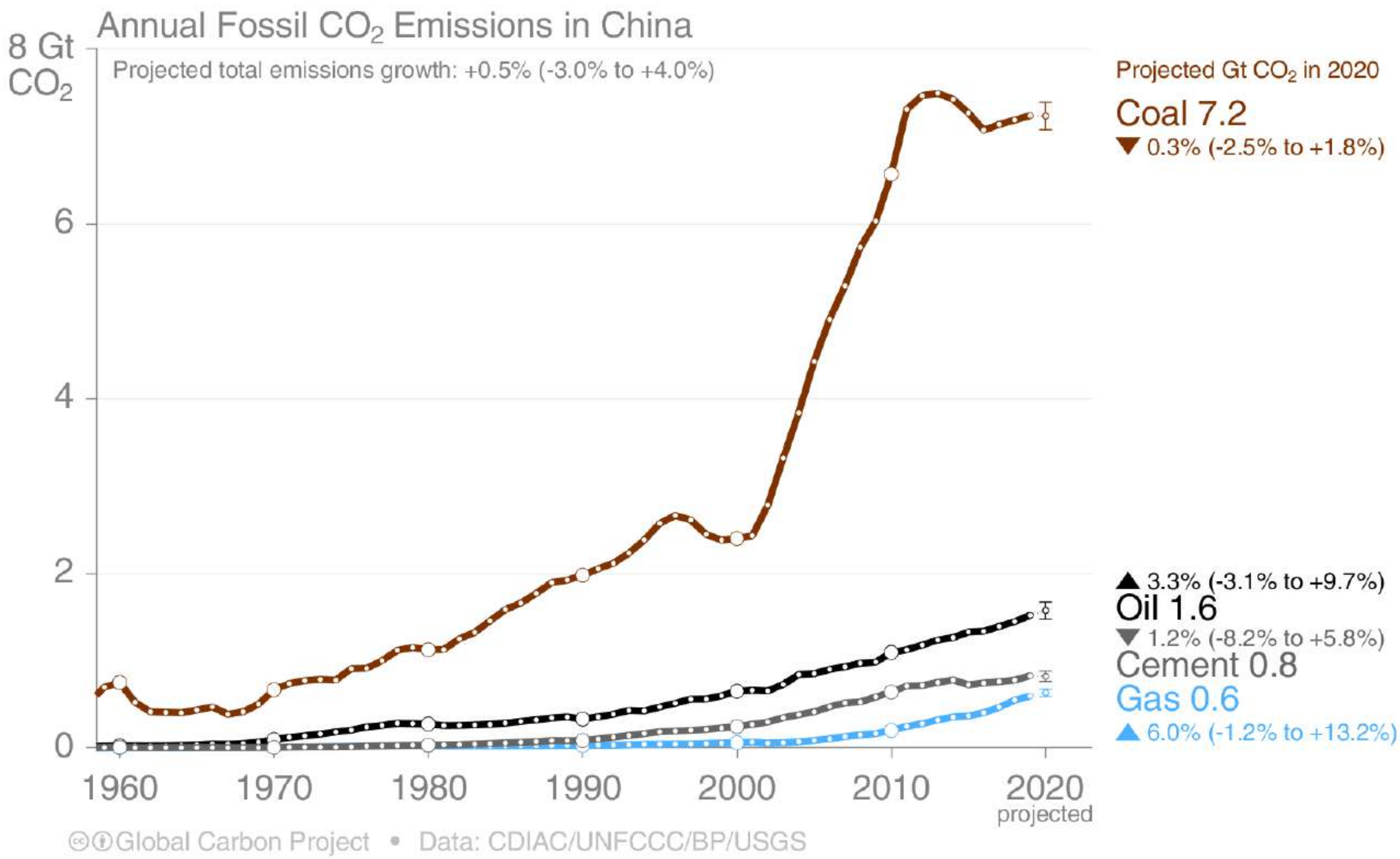
The cumulative contributions to the global carbon budget from 1850
The carbon imbalance represents the gap in our current understanding of sources & sinks



Source: Friedlingstein et al 2020; Global Carbon Budget 2020

Fossil CO_2 Emissions in China

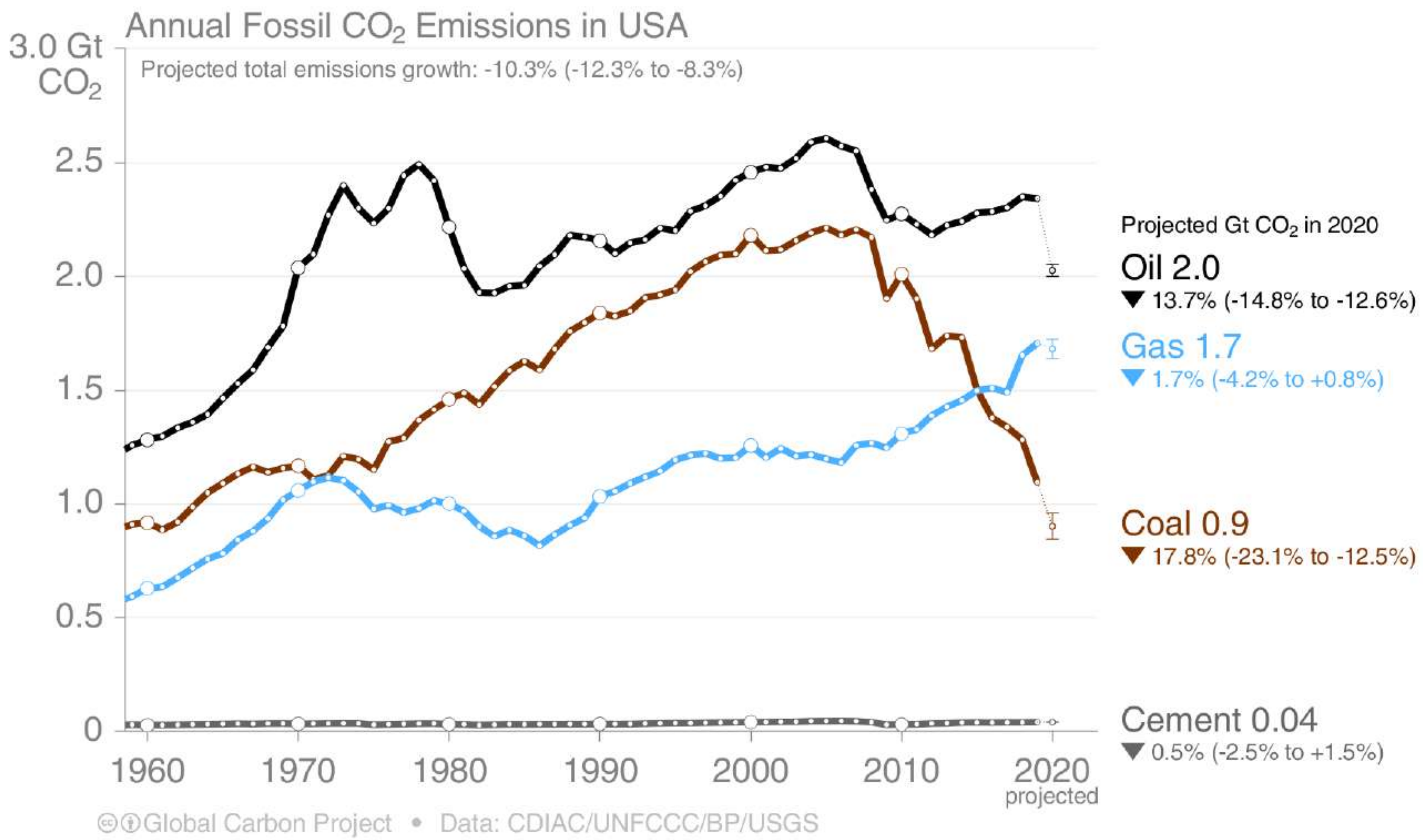
Annual emissions for China hide the story of 2020, suggesting no impact from the global pandemic
Emissions from oil and natural gas continue to grow strongly



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

Fossil CO_2 Emissions in USA

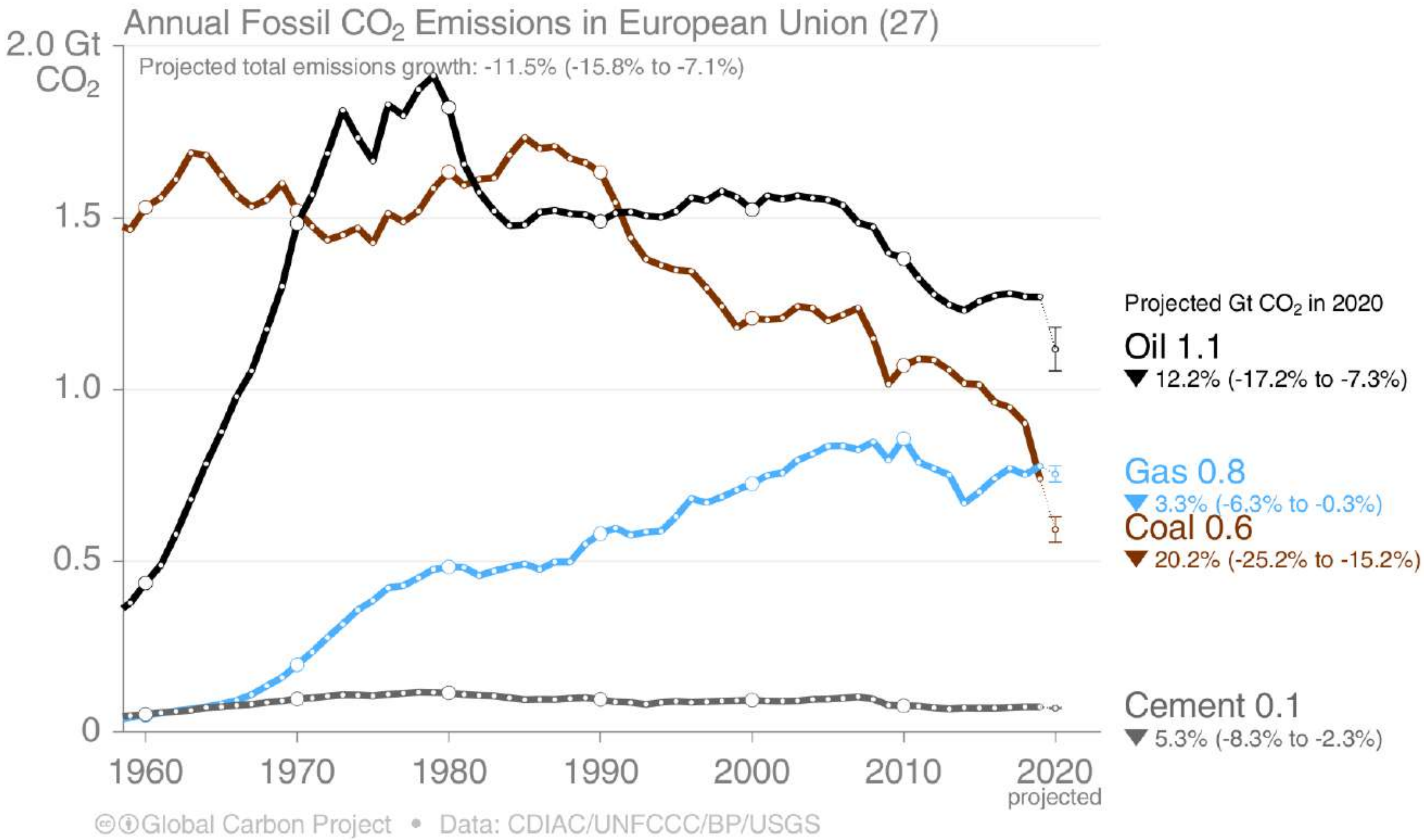
The USA's emissions from oil are expected to decline sharply in 2020 as a result of restrictions on transportation
Coal emissions also decline, while the recent strong growth in natural gas falters.



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

Fossil CO_2 Emissions in the European Union (EU27)

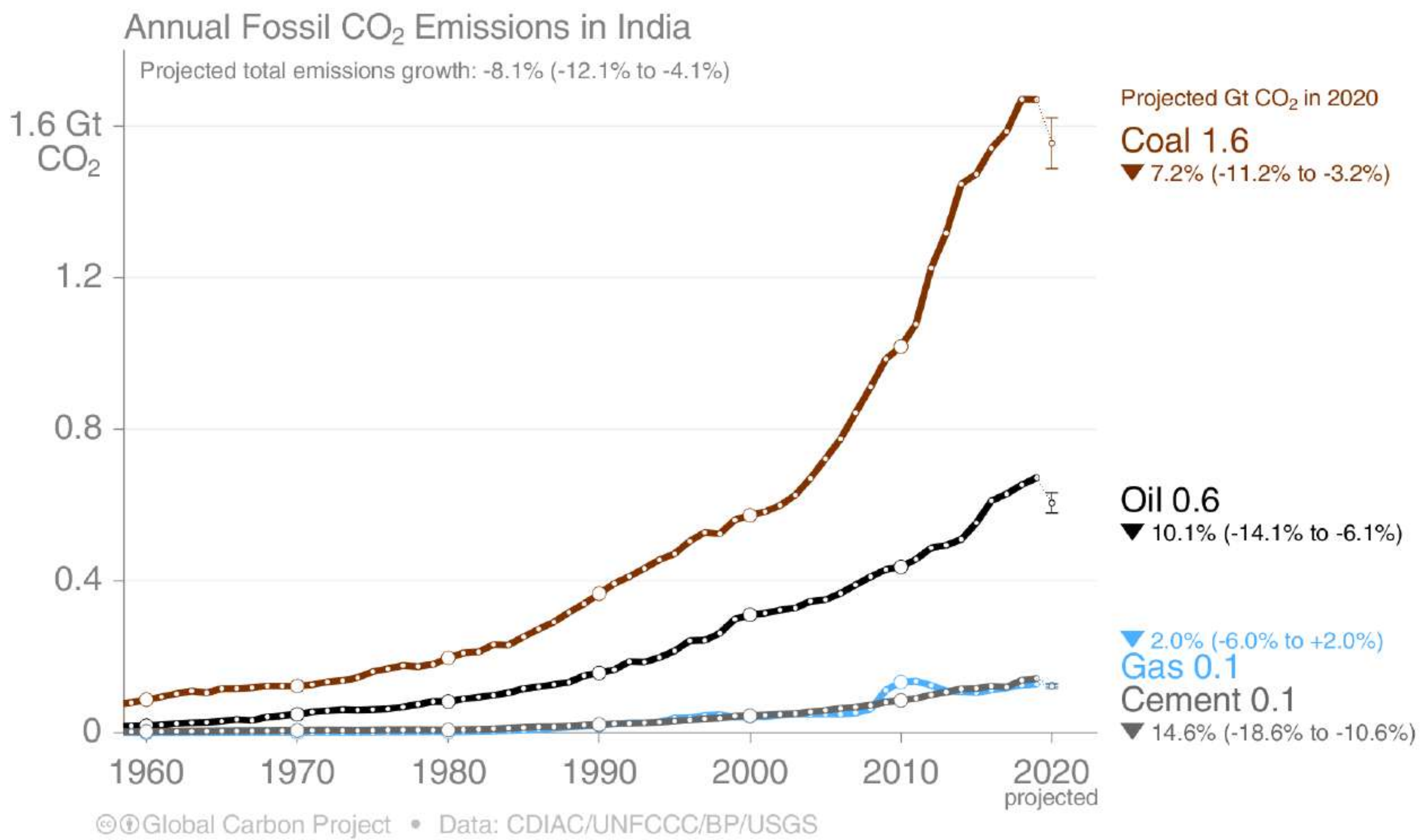
Emissions in the EU see sharp declines in both oil and coal due to the pandemic, with less effect seen for natural gas



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

Fossil CO_2 Emissions in India

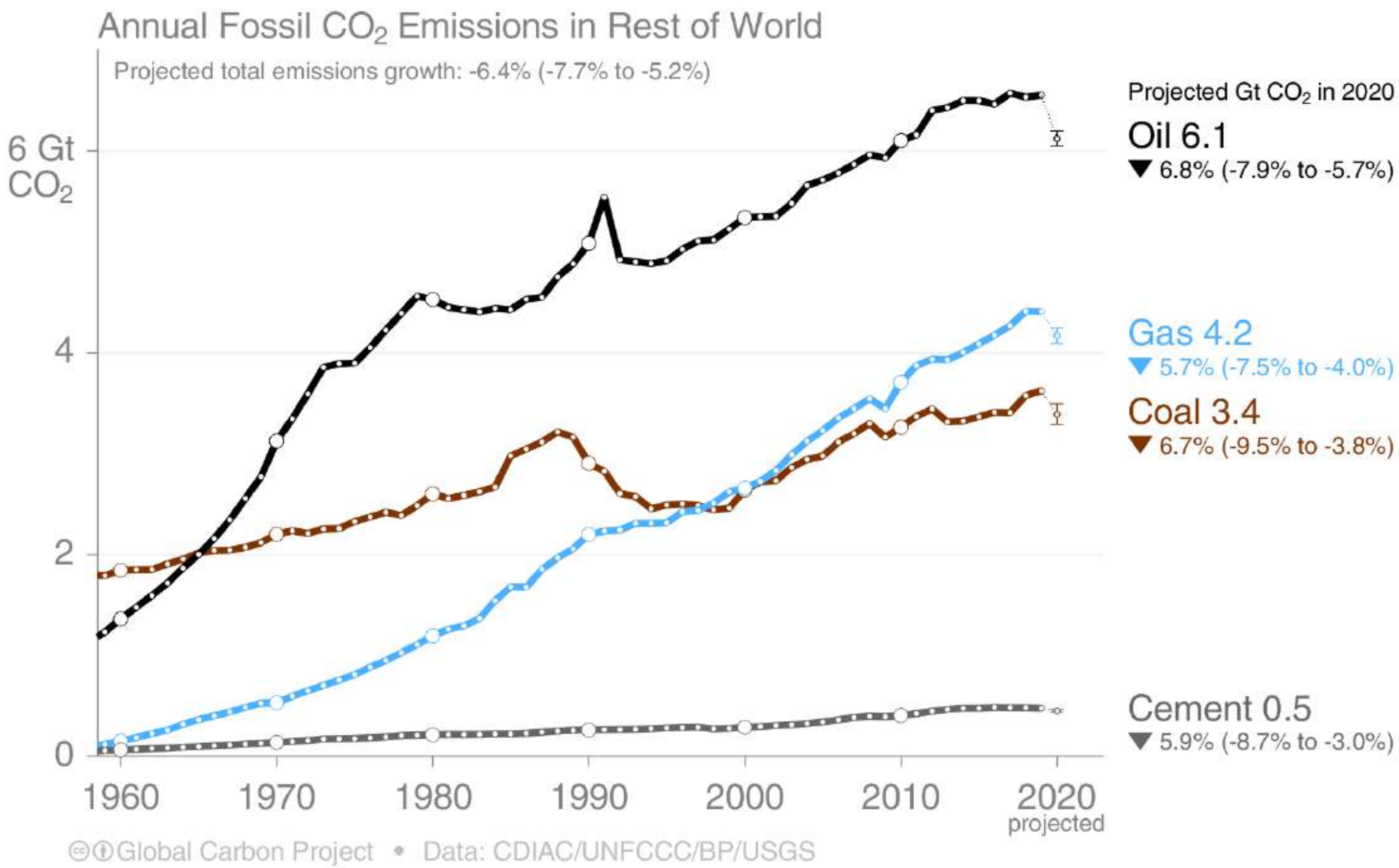
India’s emissions are likely to drop about 8% in 2020, following substantial contractions in
economic activity because of strict lockdowns in response to the pandemic



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

Fossil CO_2 Emissions in Rest of World

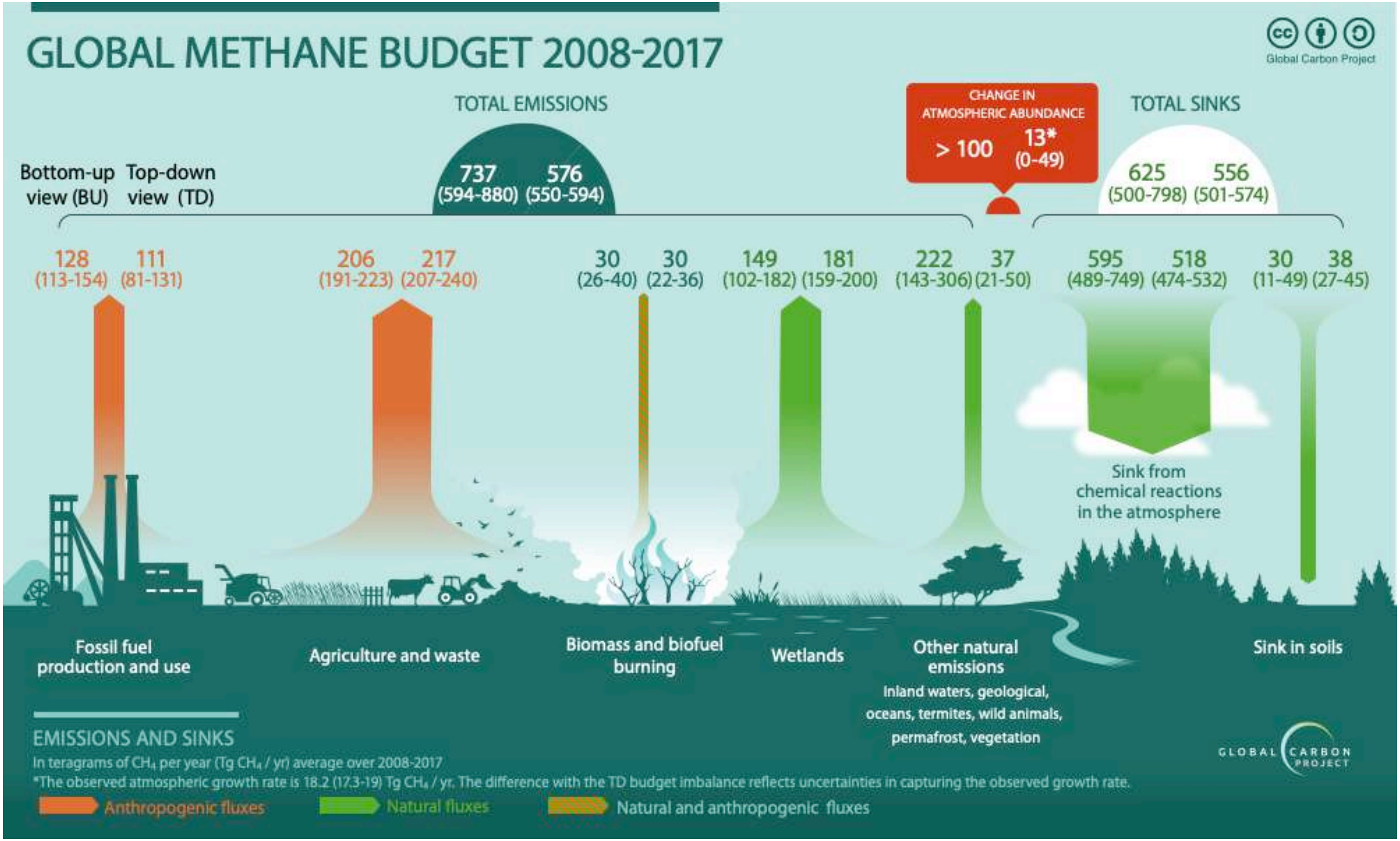
Emissions in the Rest of the World are expected to drop sharply in 2020, on the back of weaker economic activity.
Growth is estimated based on efficiency improvements of the last 10 years combined with projected economic growth.



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

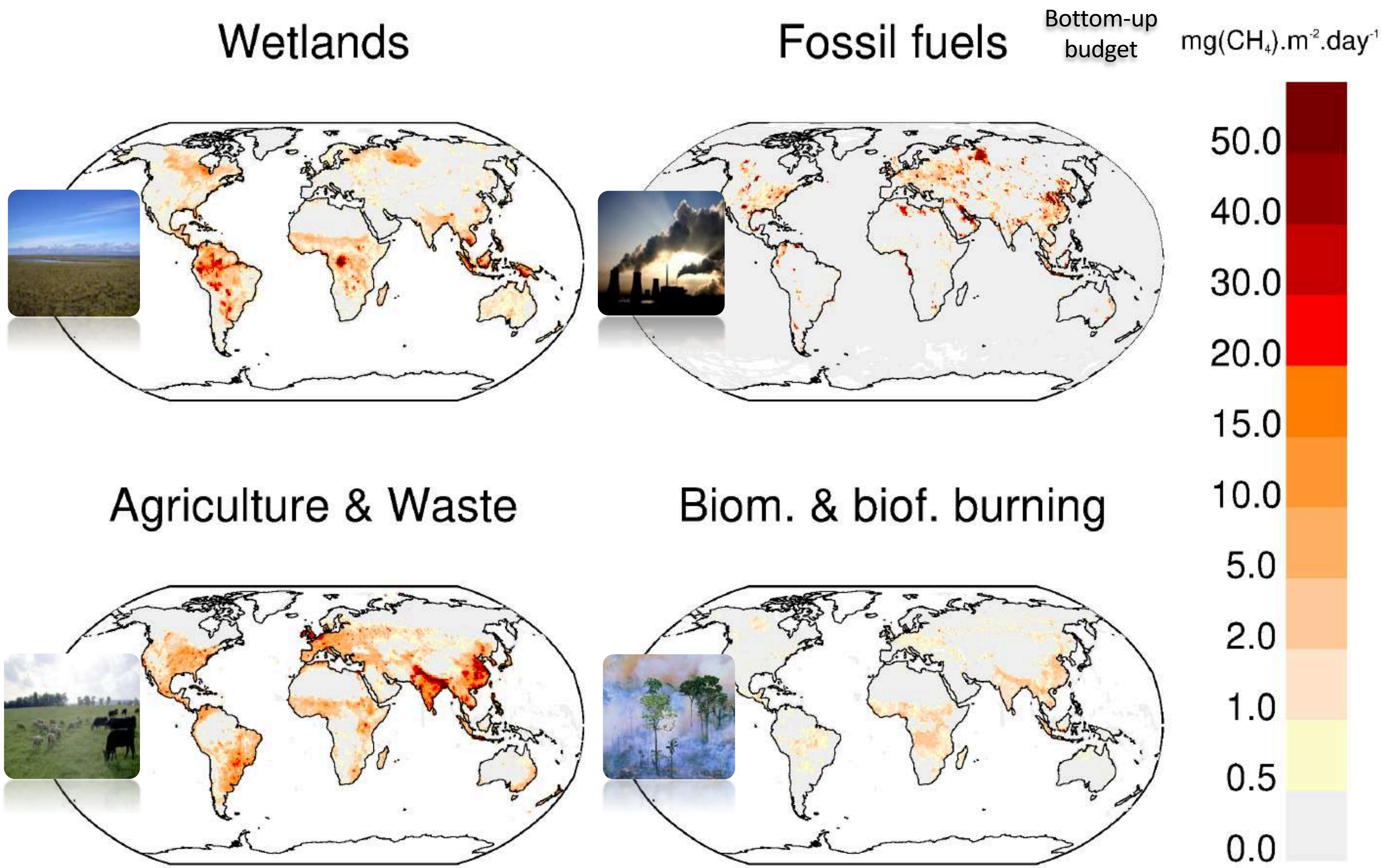
Global CH_4 emissions

Fate of CH_4 emissions (2008–2017)



Source: Saunois et al. 2020, ESSD (Fig. 6)

Mapping the largest source of methane emissions

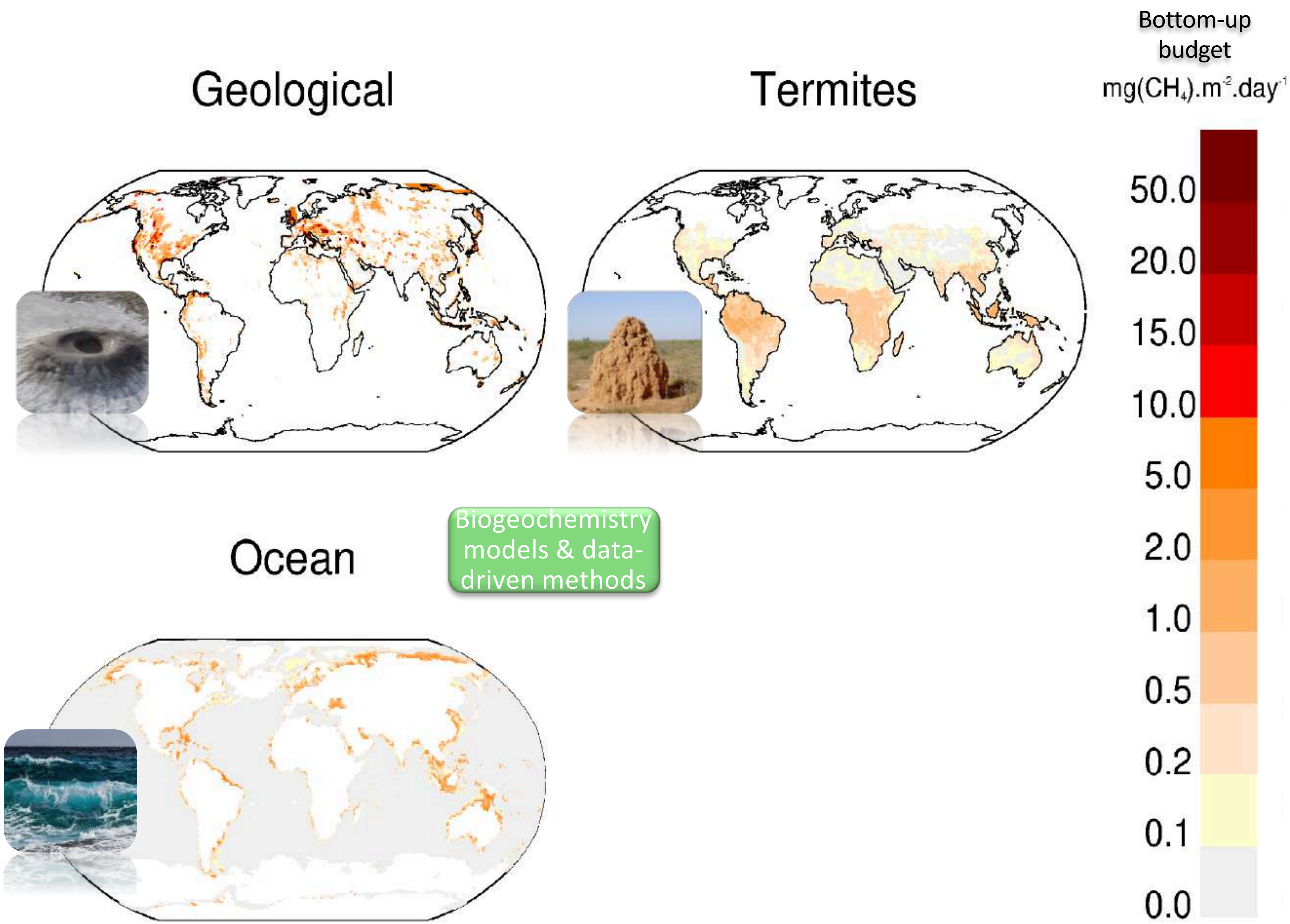


Emission inventories

Biogeochemistry models & data-driven methods

Source: Saunois et al. 2020, ESSD (Fig 3);

Mapping the largest source of methane emissions

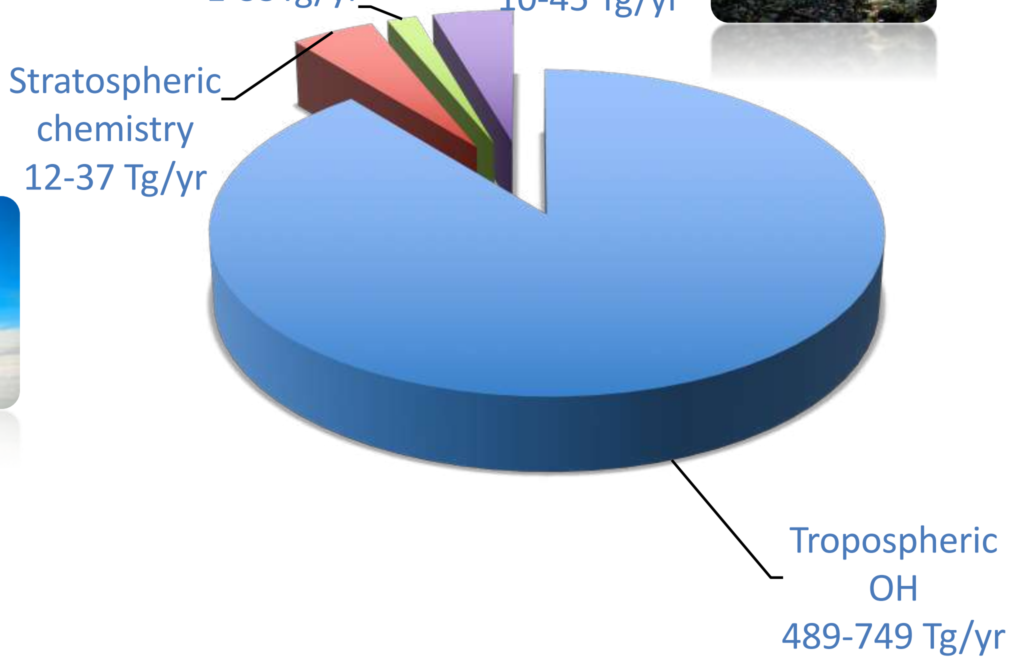


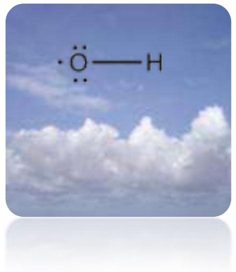
Other natural sources not mapped here are inland water emissions, permafrost and hydrates

Source: Saunois et al. 2020 (Fig 4)

Methane sink

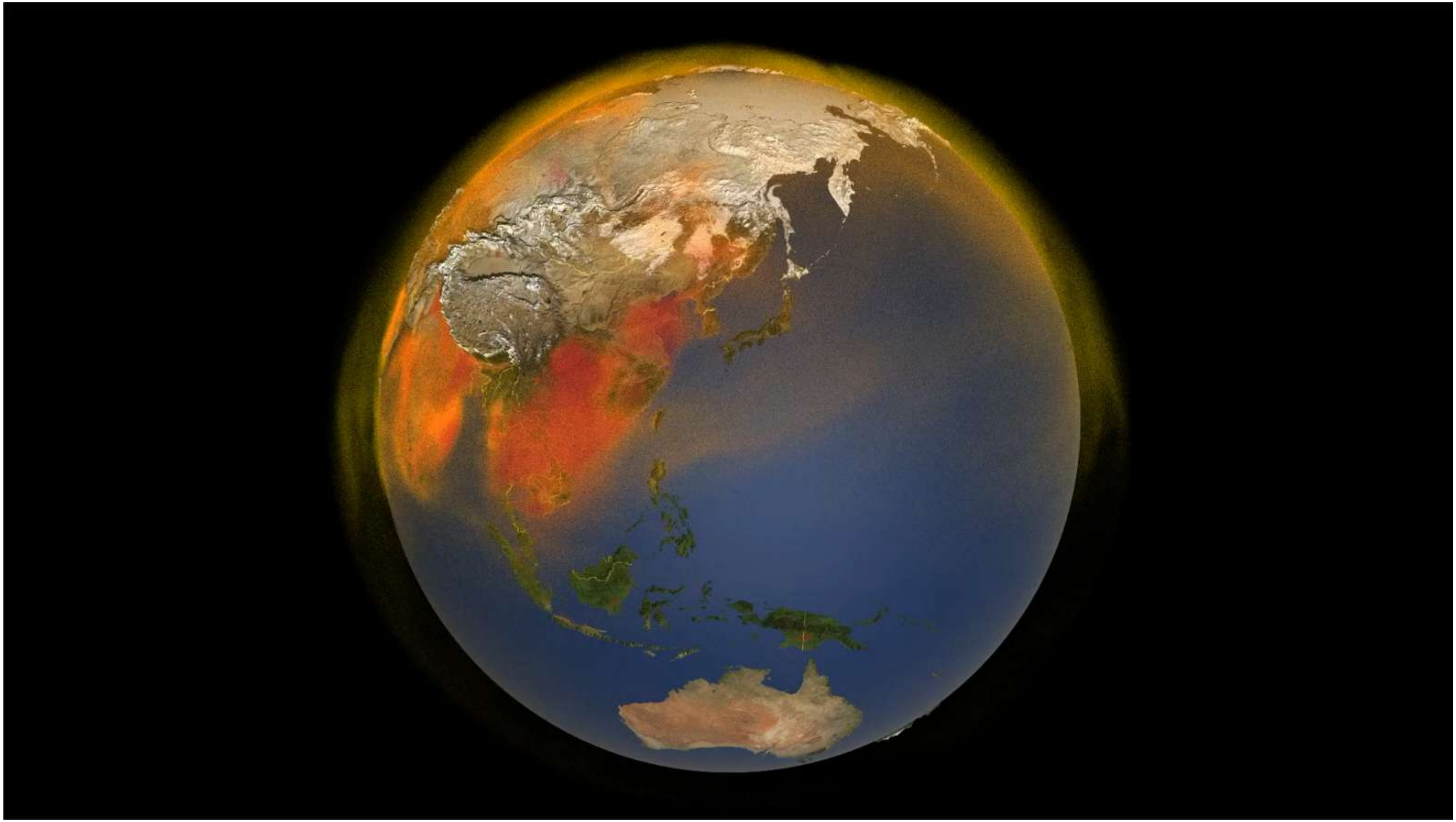
Bottom-up
budget





Source : Saunois et al., 2020

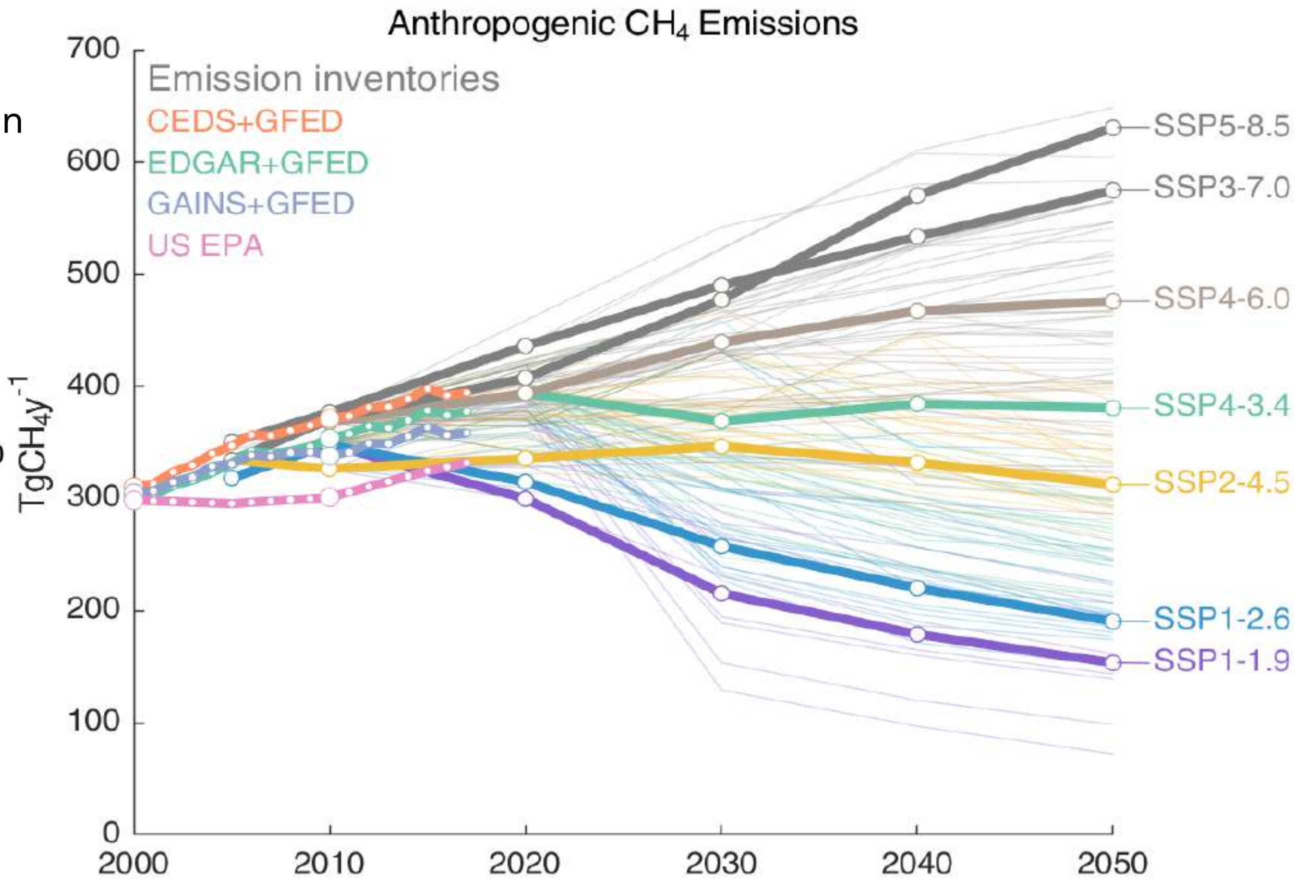
Methane emission in motion



Anthropogenic Methane Emissions & Socioeconomic Pathways (SSPs)

The projections represented here correspond to SSPs defined for IPCC 6th Assessment Report

Anthropogenic emissions:
All inventories, except EPA, infers an increase in emissions as fast as the warmest scenarios between 2005 and 2017.



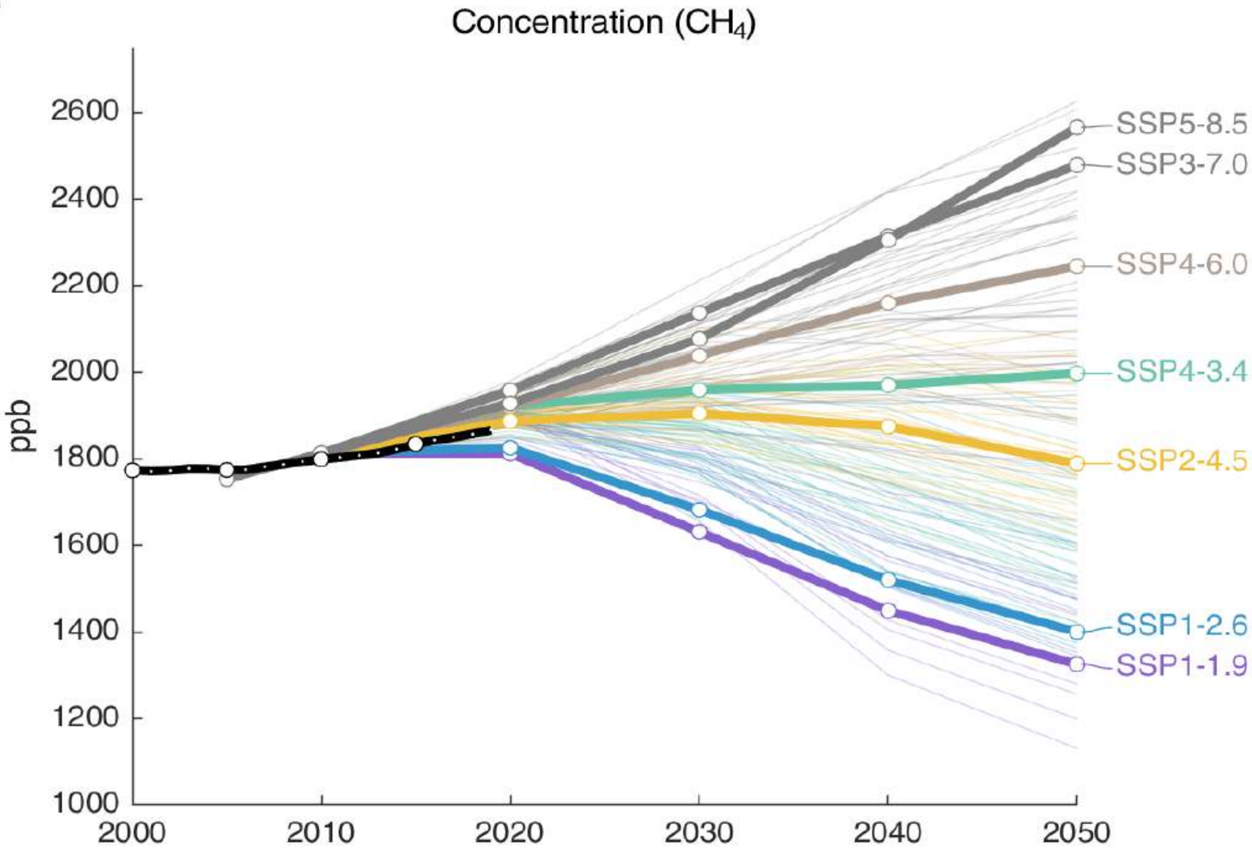
Source: Saunois et al. 2020, ESSD (Fig. 2)

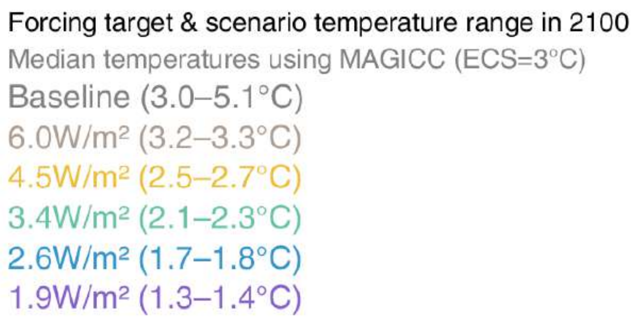
Methane Concetration
& Socioeconomic Pathways (SSPs)

The projections represented here correspond to SSPs defined for IPCC 6th Assessment Report

Atmospheric concentrations:
Atmospheric observations (black line) fall between the estimates of the different scenarios

=> Monitoring of future years trends in emissions and concentration is critical to assess mitigation policy efficiency

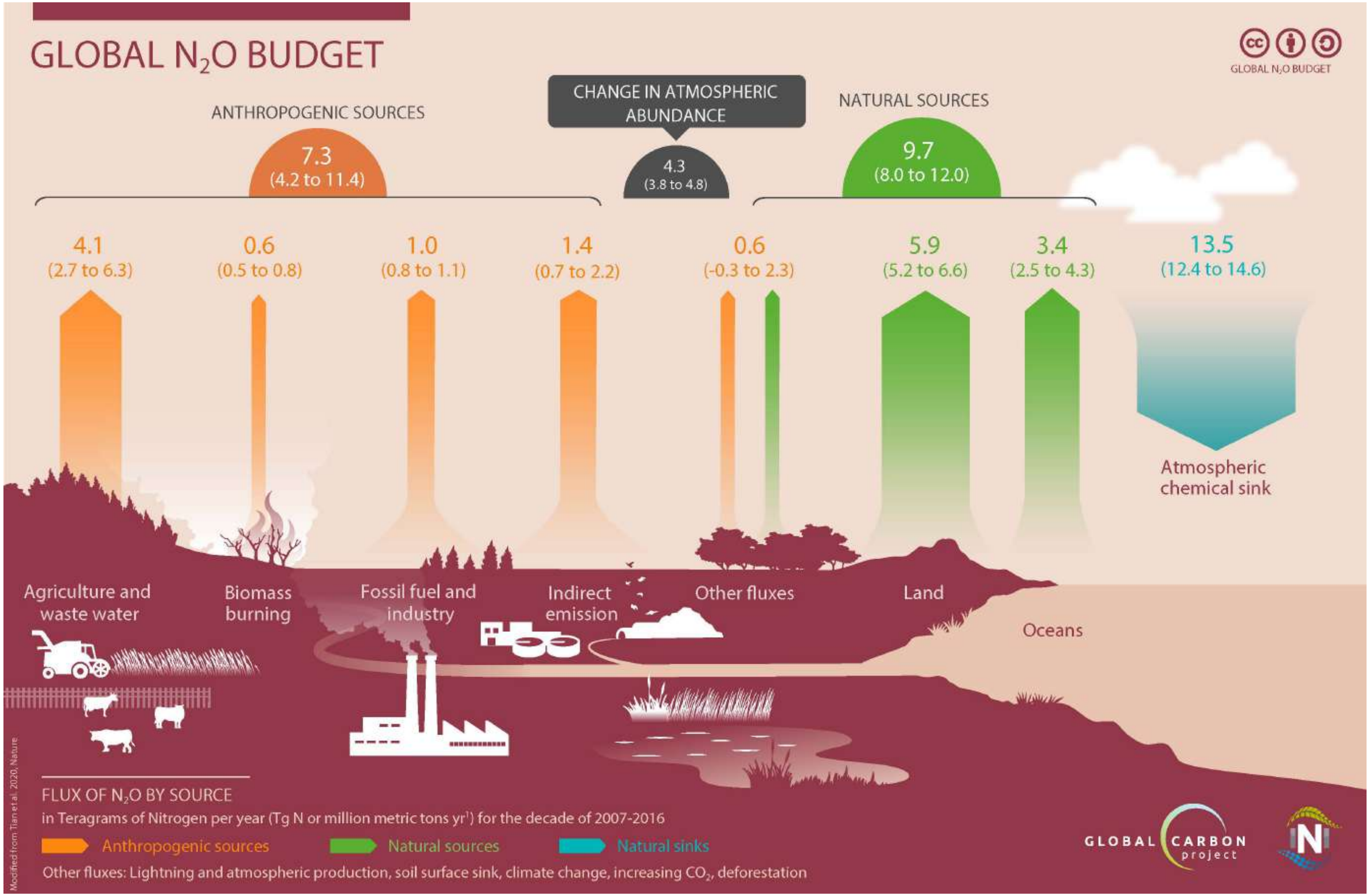




Global N_2O emissions

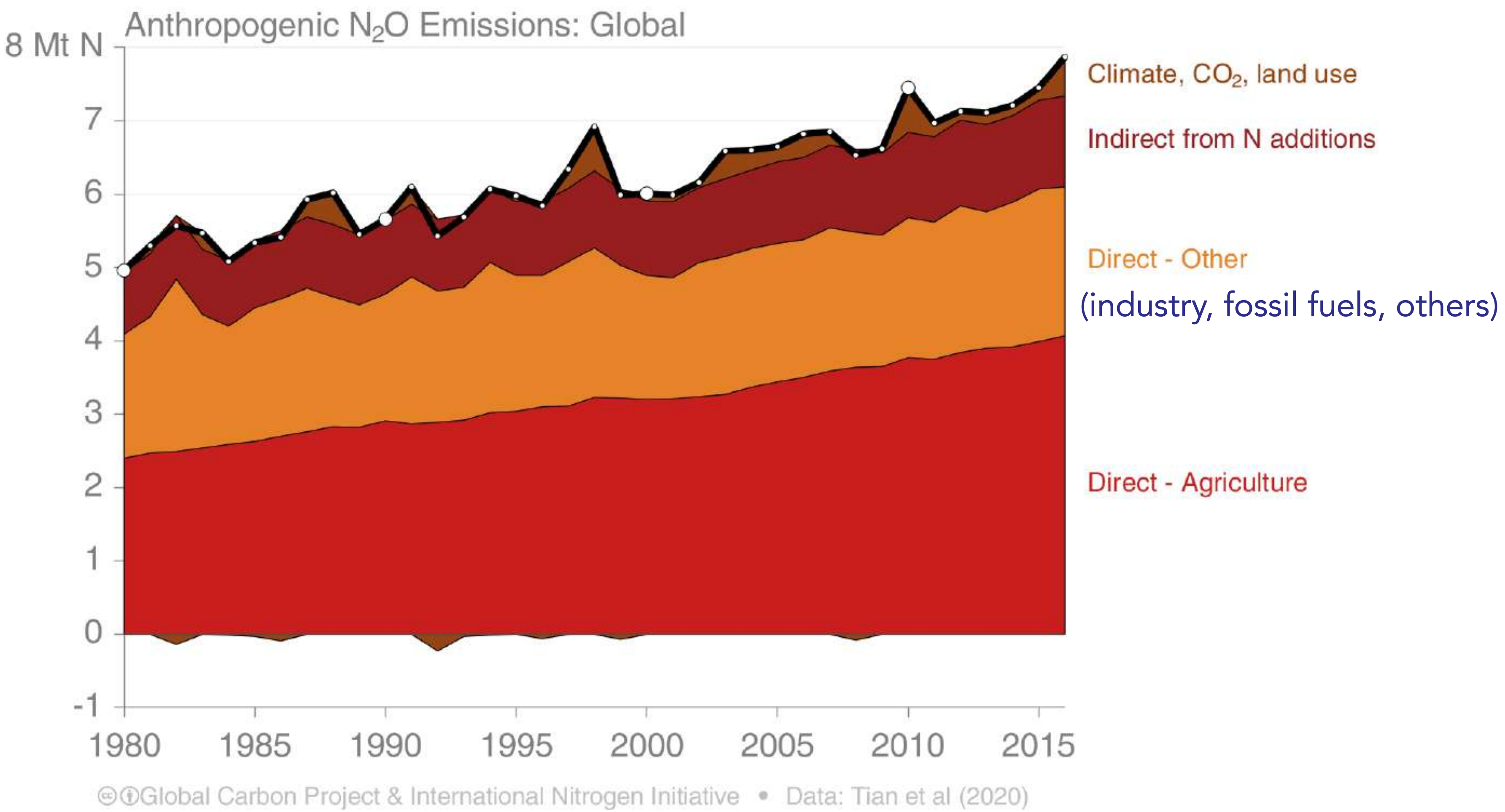
Fate of N_2O emissions (2007–2016)

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



Split-up of 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.

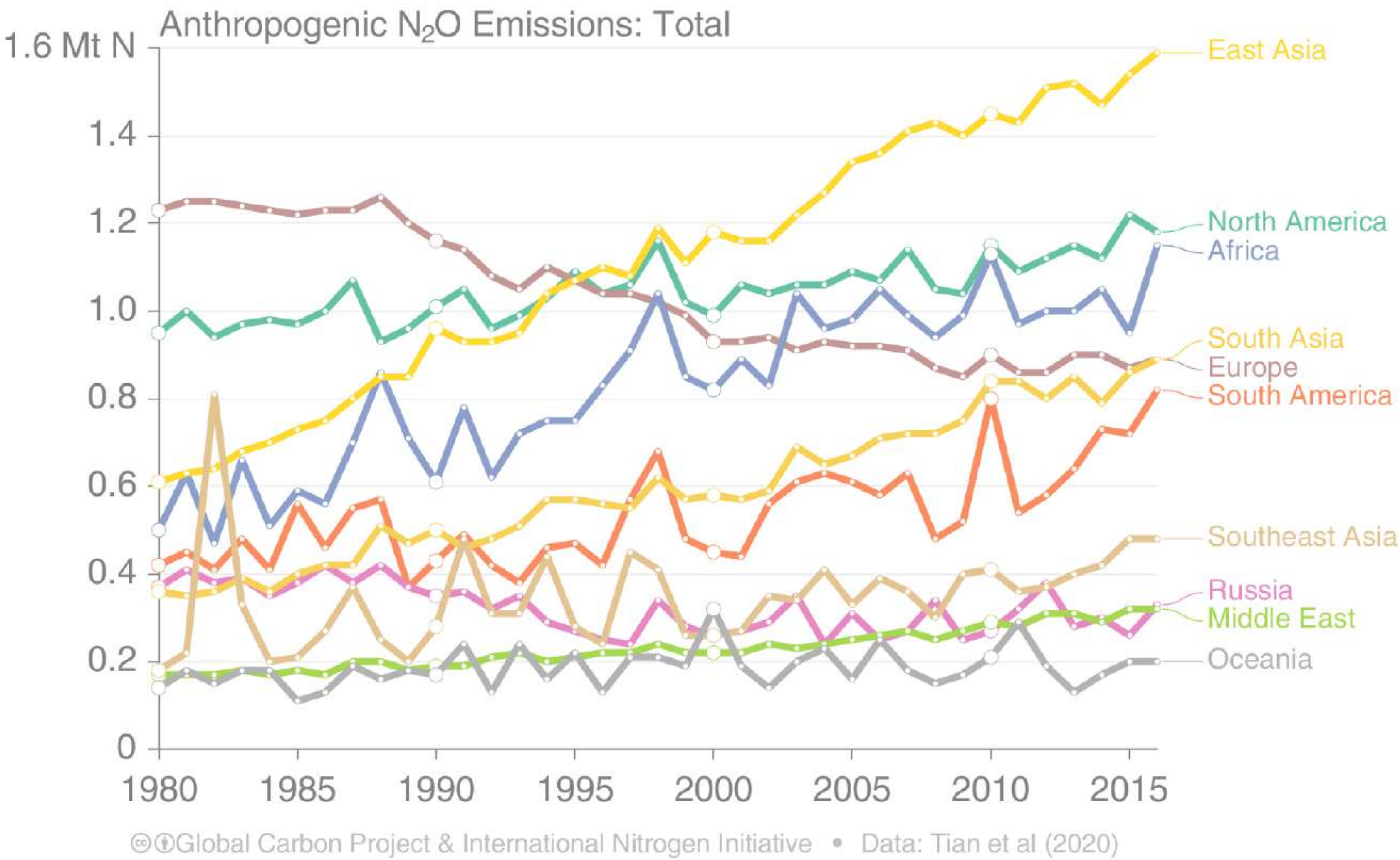


Direct sources are those occurring where nitrogen additions are made, while indirect sources are those occurring down-stream or downwind

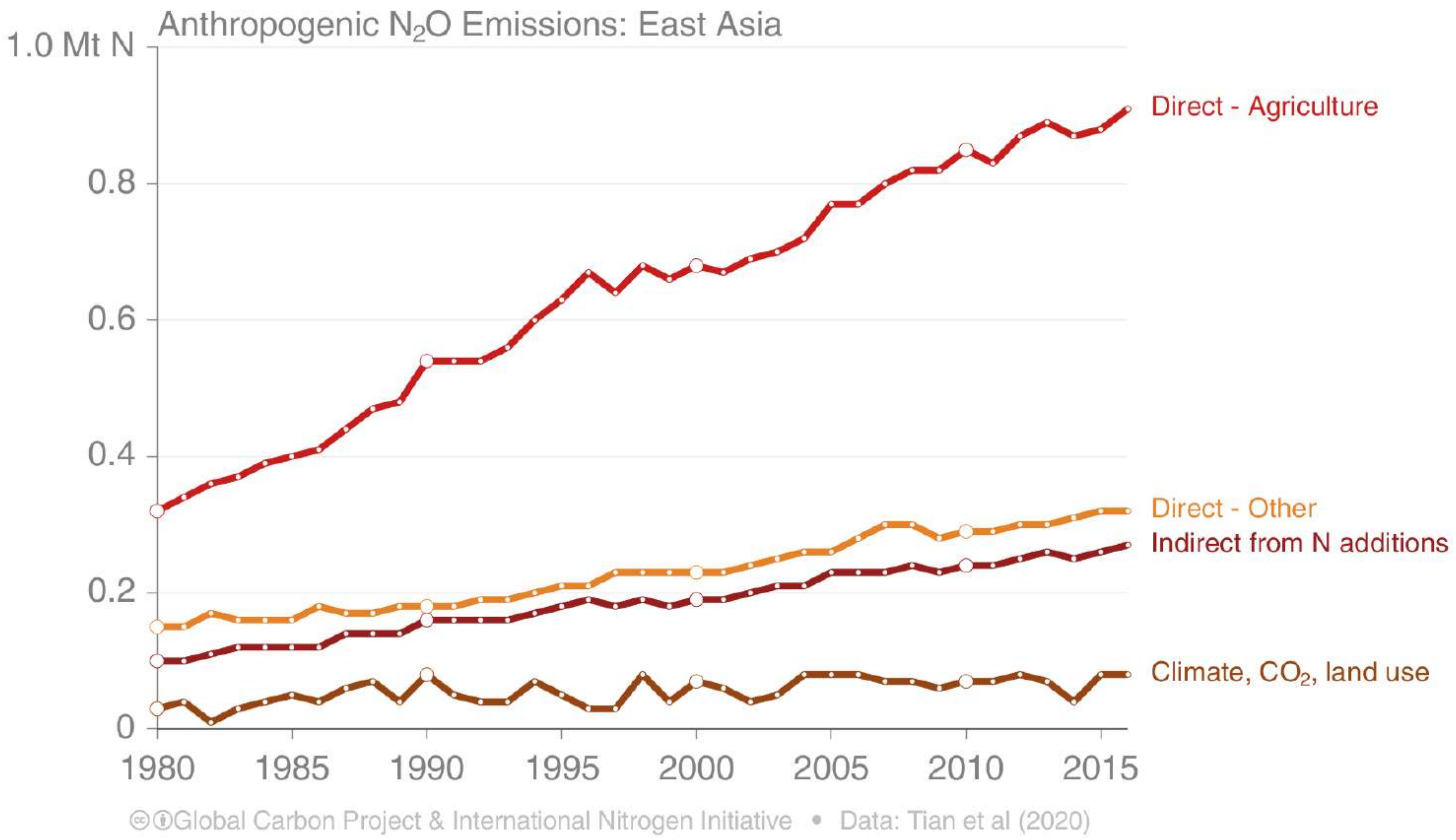
Source: Tian et al. (2020)

N_2O top emitters

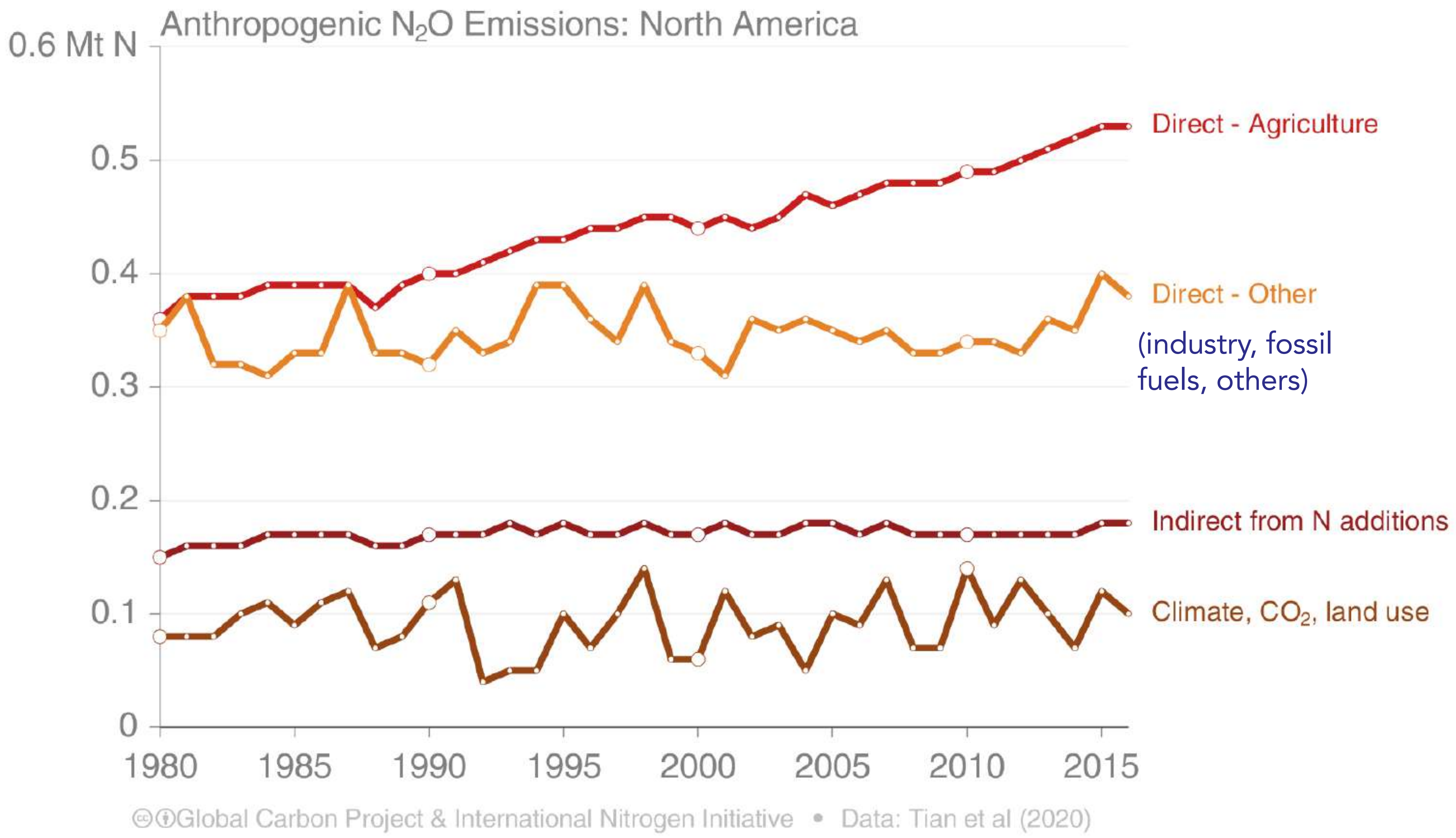
The recent global increase in N_2O emissions is driven by Asia, followed by South America and Africa, while emissions in Europe have decreased since 1990



N_2O top emitters: East Asia

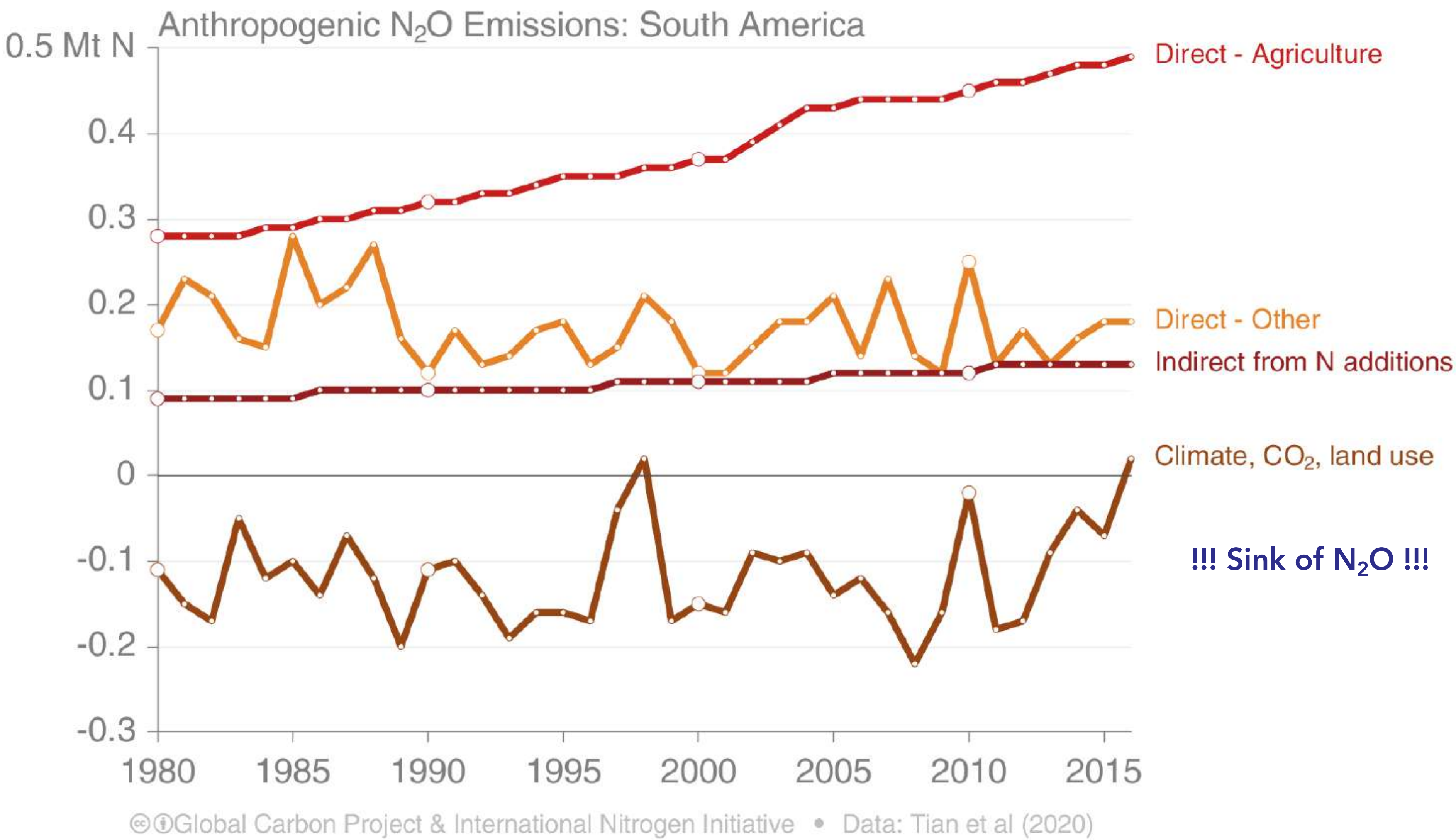


N_2O top emitters: North America



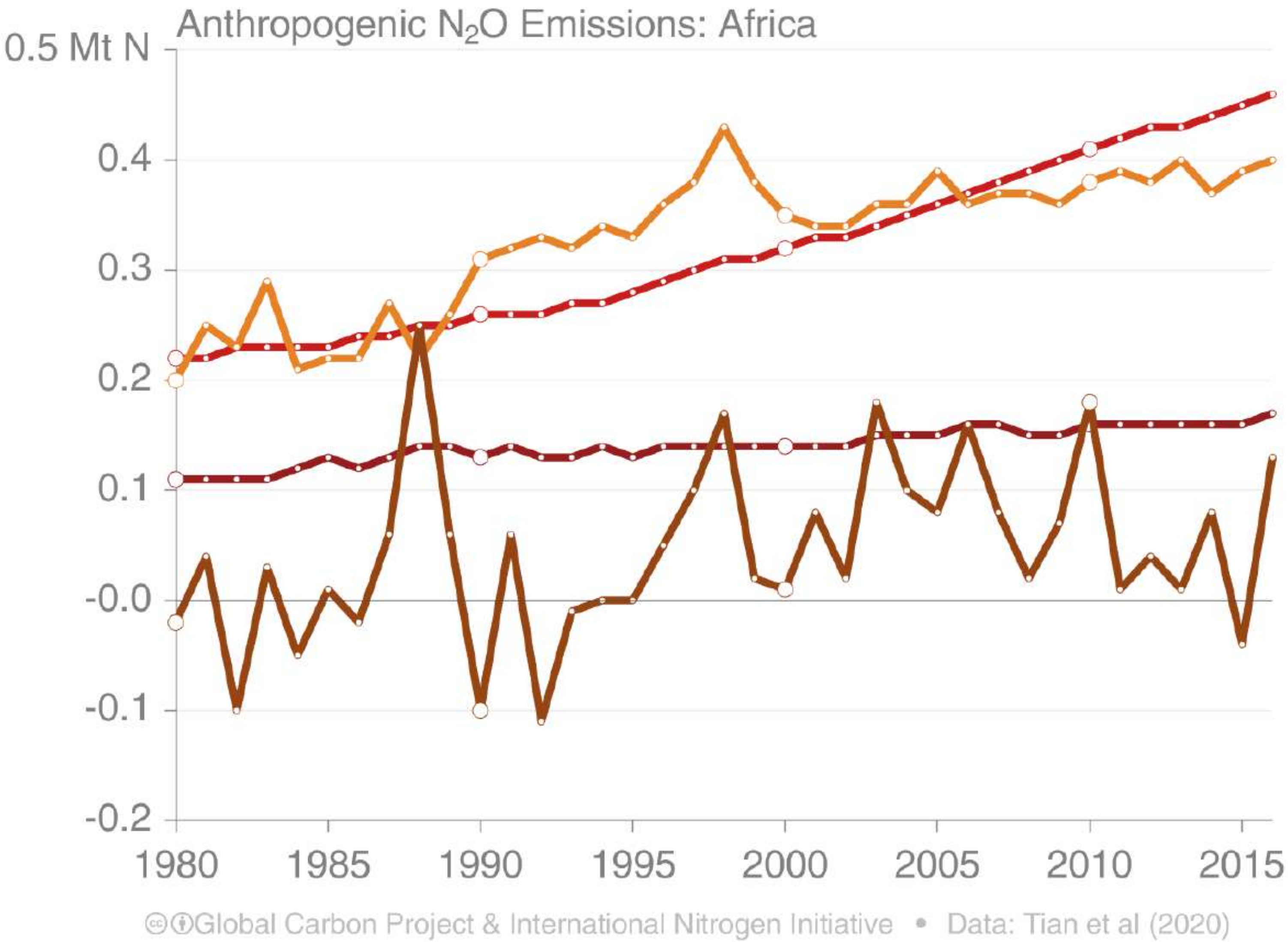
(industry, fossil fuels, others)

N_2O top emitters: South America



!!! Sink of N_2O !!!

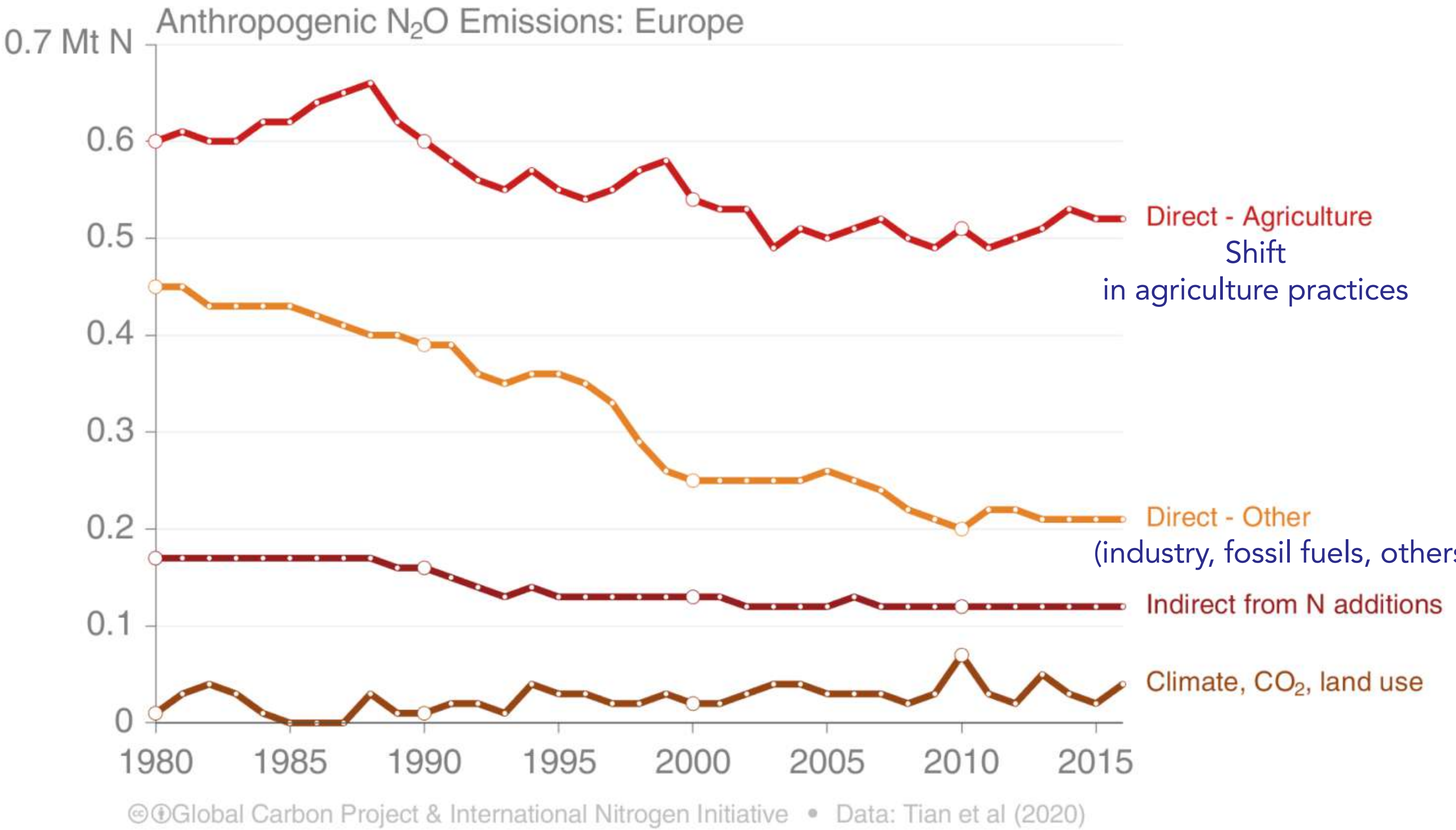
N_2O top emitters: South America



(industry, fossil fuels, others)

!!! Source & Sink of N_2O !!!

European N_2O emission (to compare)

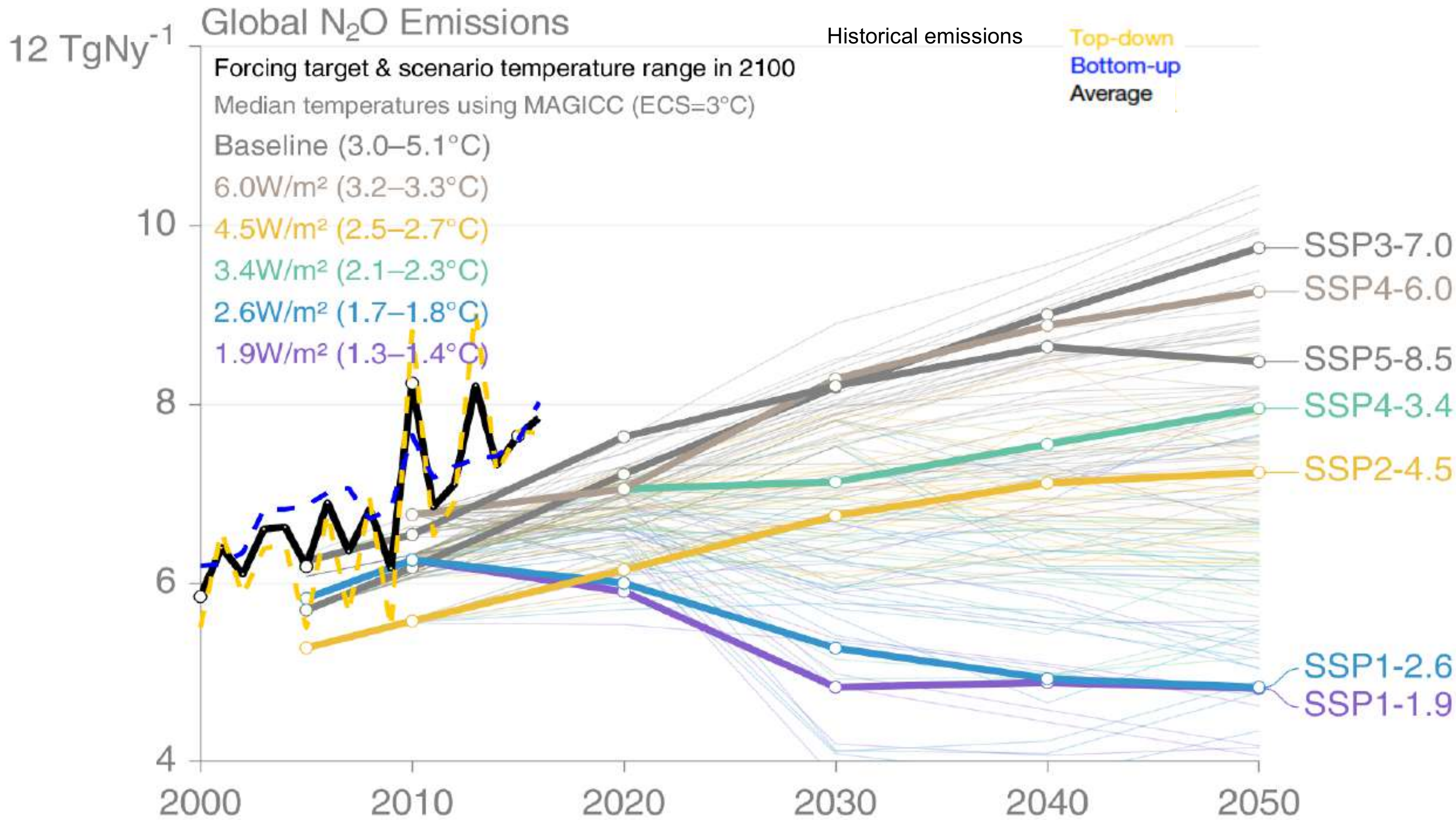


Shift
in agriculture practices

(industry, fossil fuels, others)

Anthropogenic Methane Emissions & Socioeconomic Pathways (SSPs)

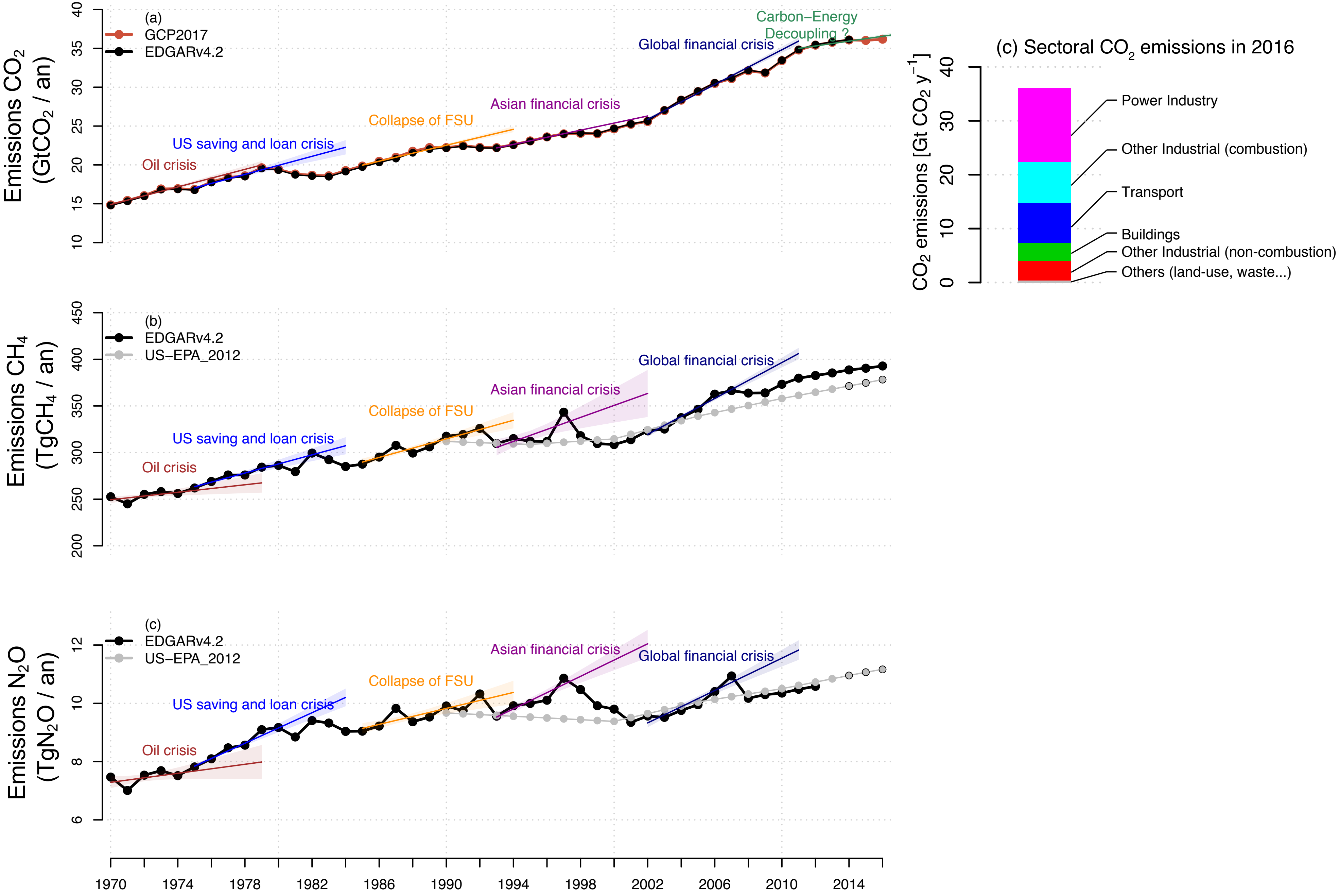
- The SSPs lead to a broad range in baselines (grey), with more aggressive mitigation leading to lower temperature outcomes.
  The bold lines are scenarios that will be analysed in CMIP6 and the results assessed in the IPCC AR6 process.
- The bold black and dashed blue and yellow lines are the estimated actual emissions



Source: Tian et al. 2020

Overview

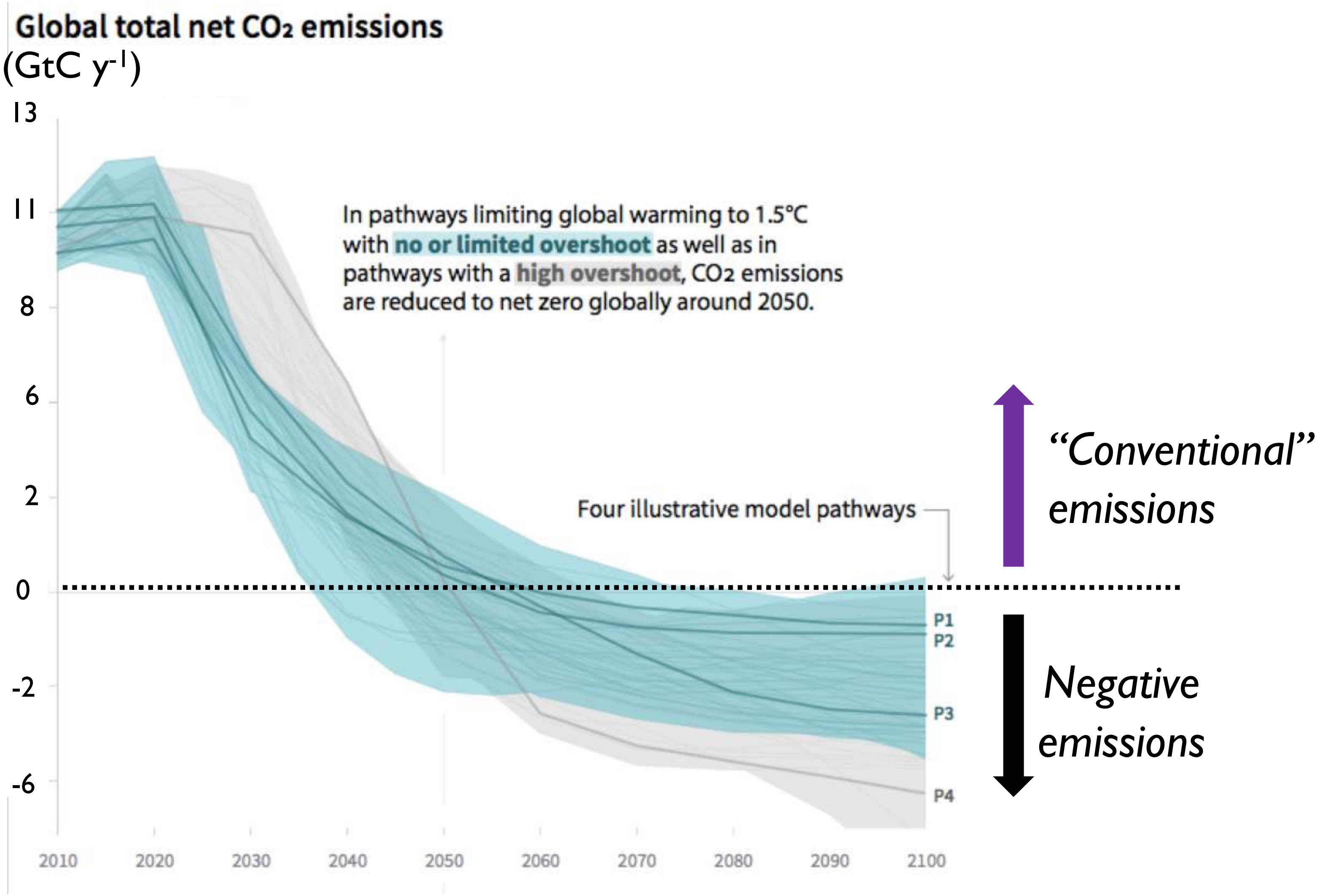
Anthropogenic GHG emissions are connected to global economics



How mitigation options are represented in mitigation pathways

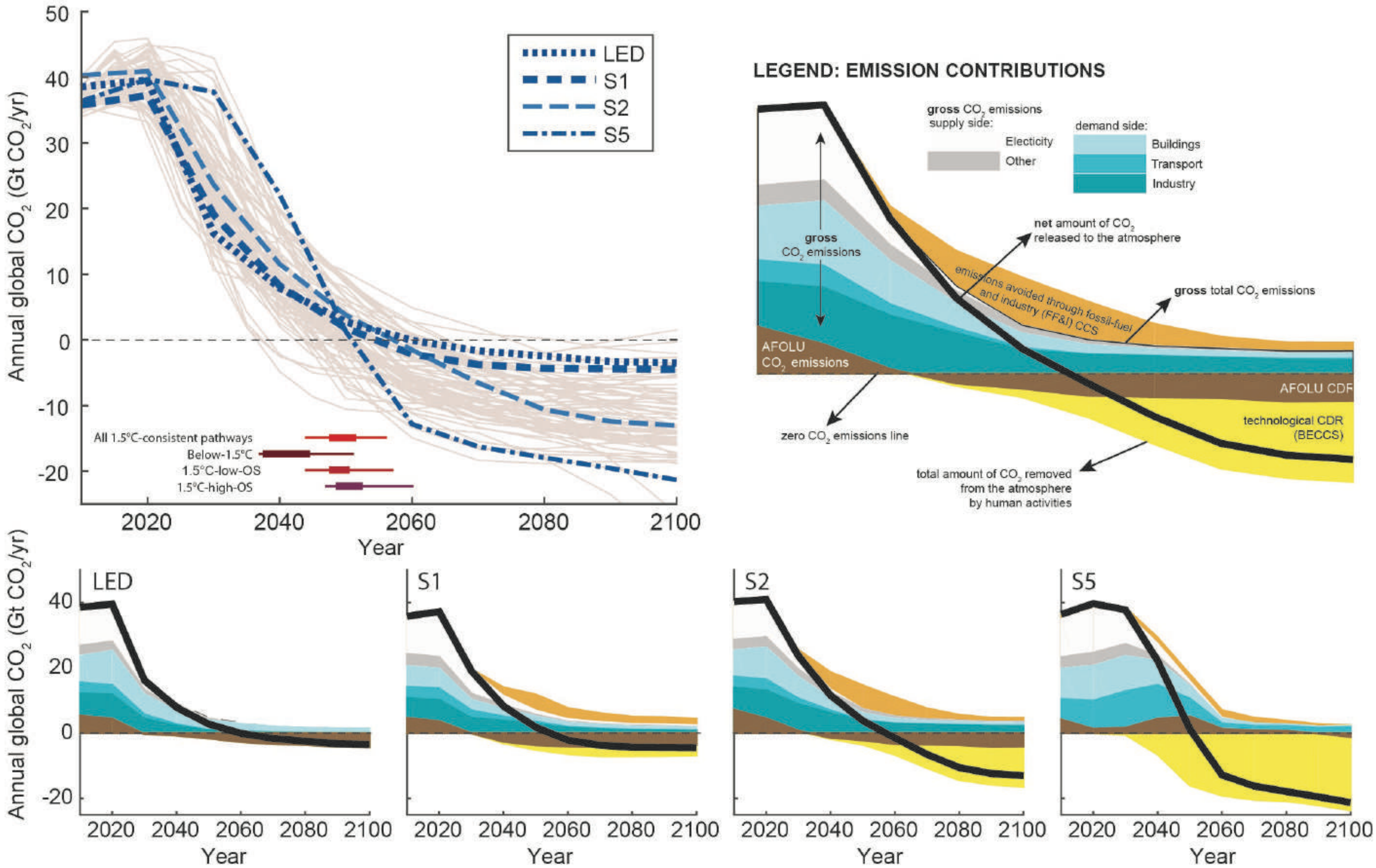
Mitigation pathways modelled by Integrated assessment models (IAMs)

Mitigation pathways holding global warming below 1.5 ºC



IPCC SR15 (2018)

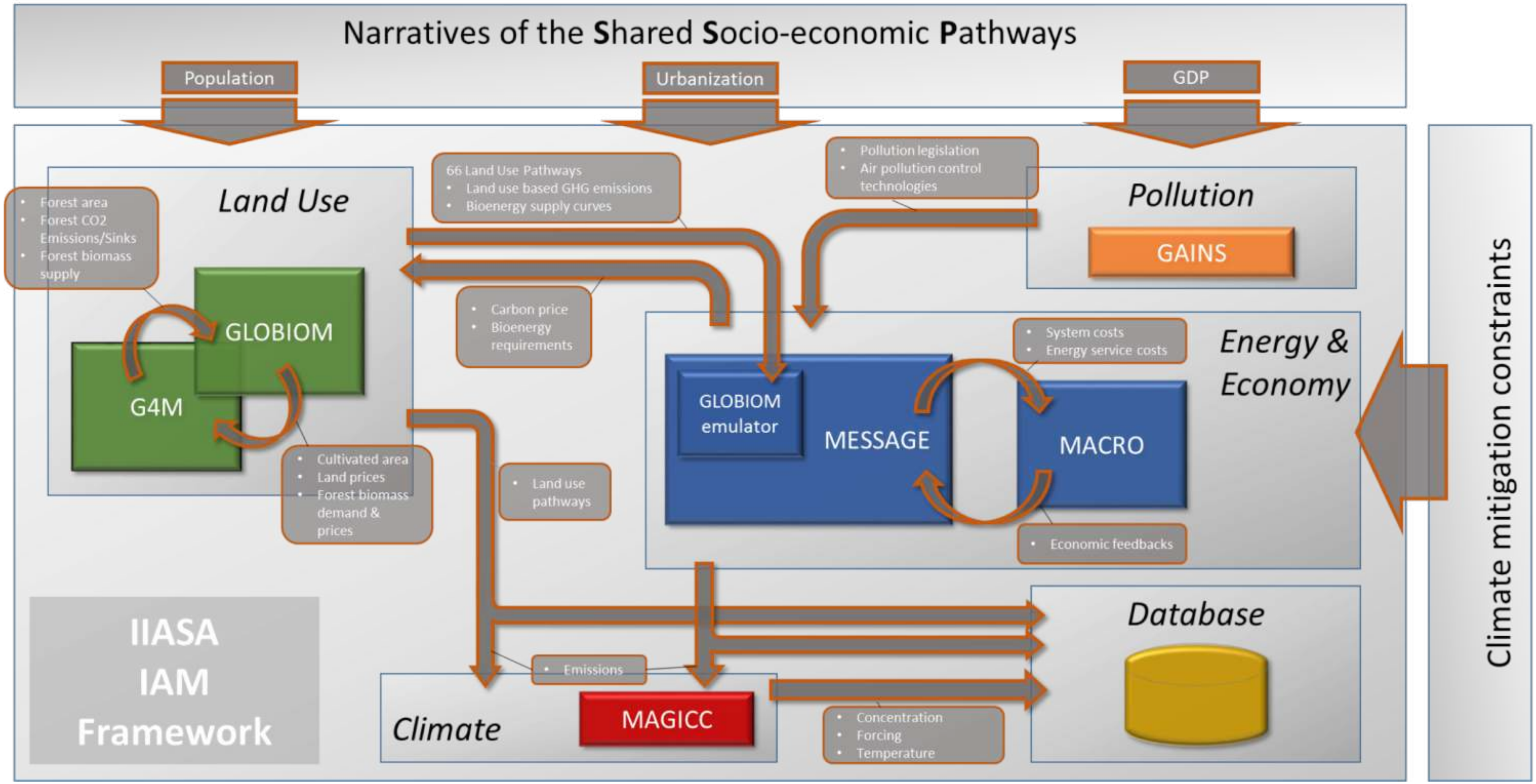
Mitigation pathways
split-up by contributions/mitigation options



IPCC SR15 (2018)

What are Integrated Assessment Models? (IAMs)

IPCC SR15 Glossary:
Integrated assessment model (IAM) Integrated assessment models (IAMs) integrate knowledge from two or more domains into a single framework.



Friko et al. (2016)

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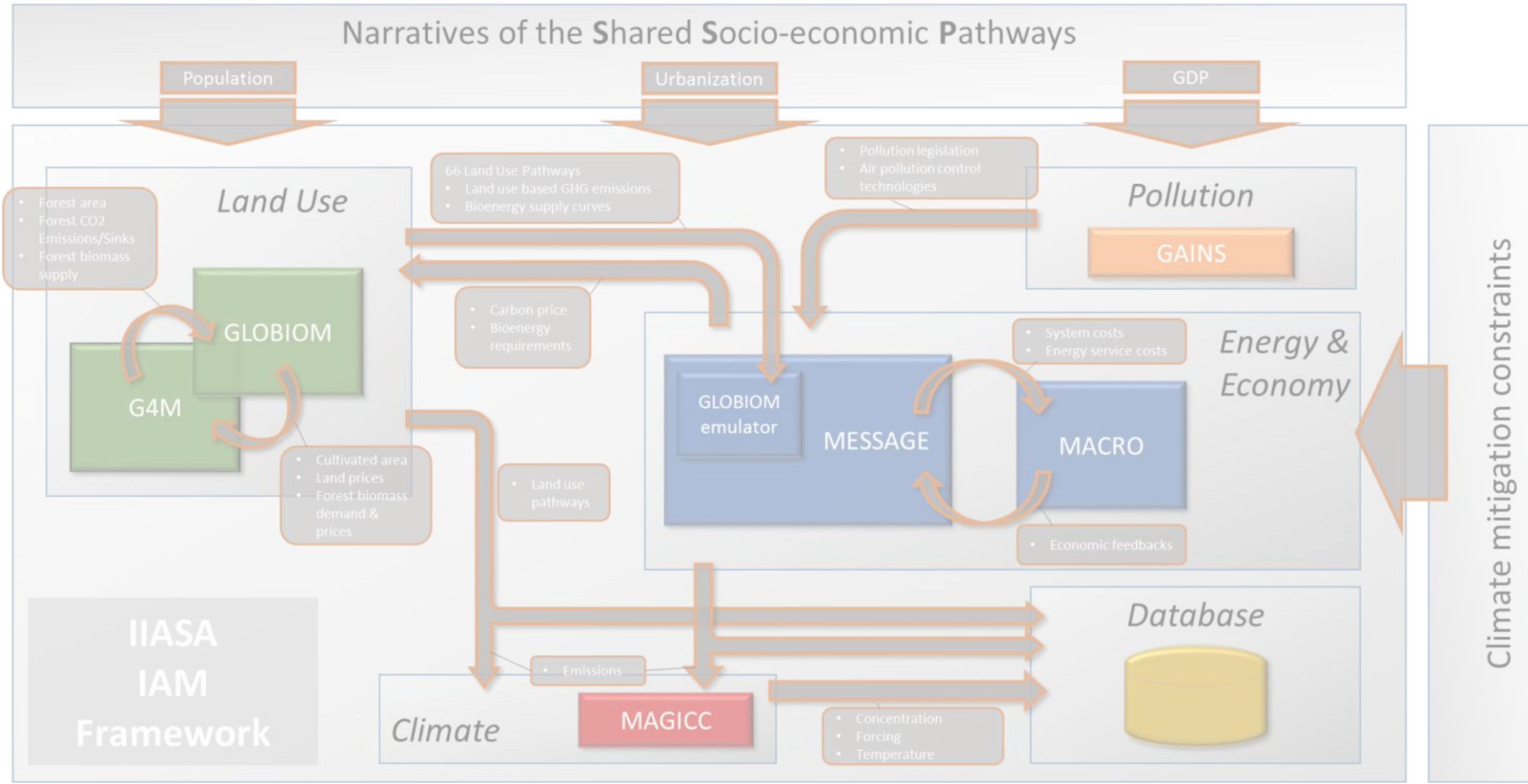

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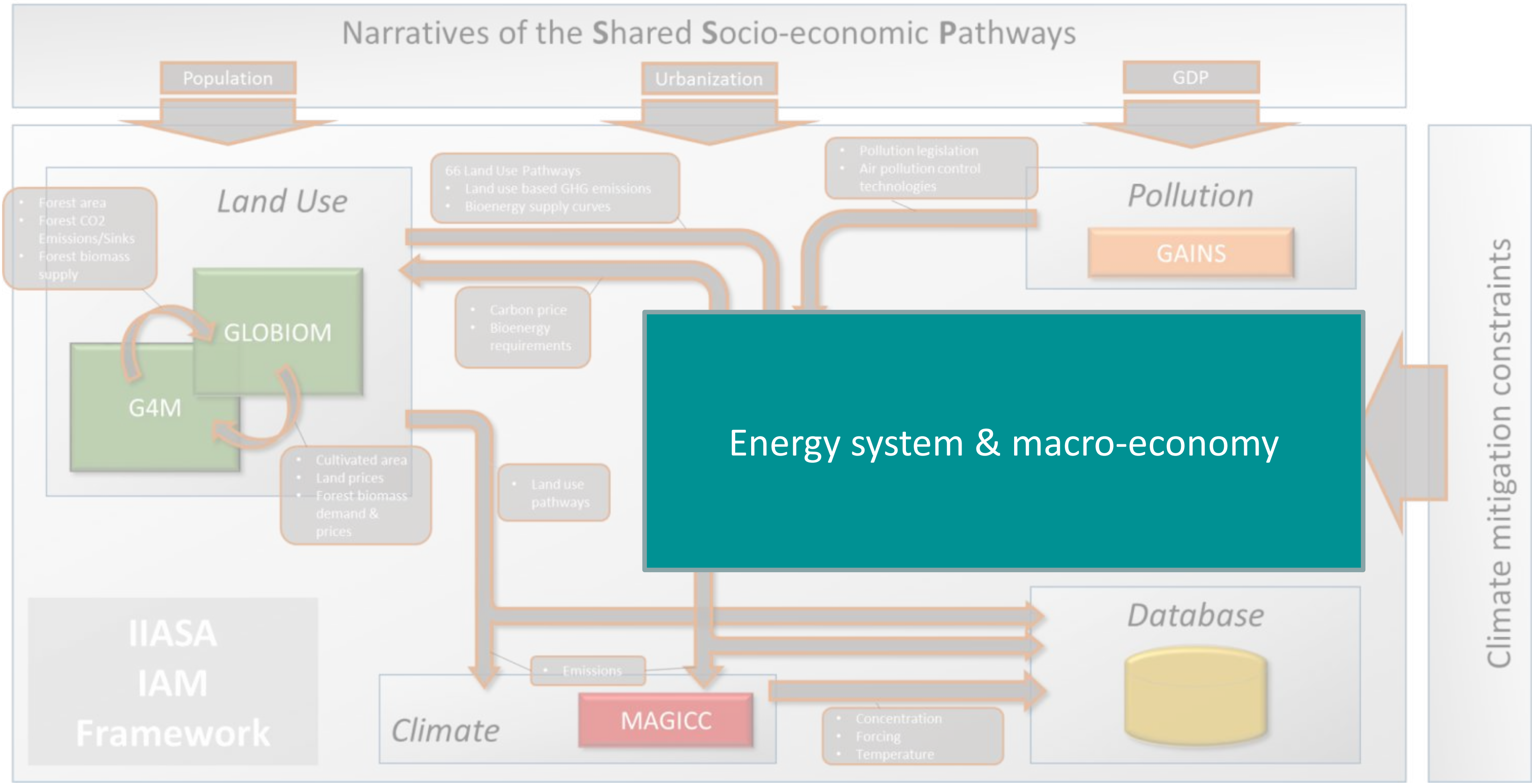

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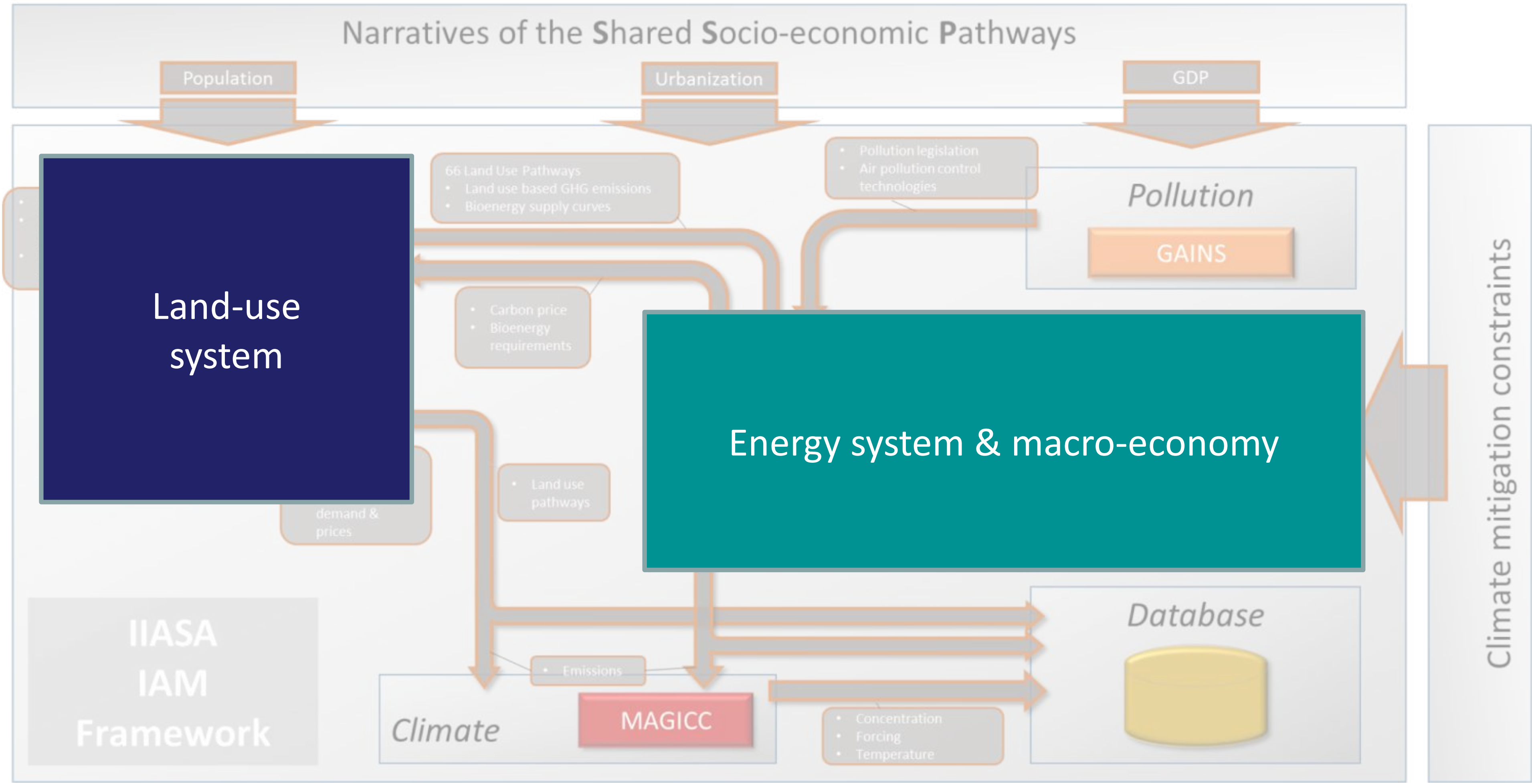

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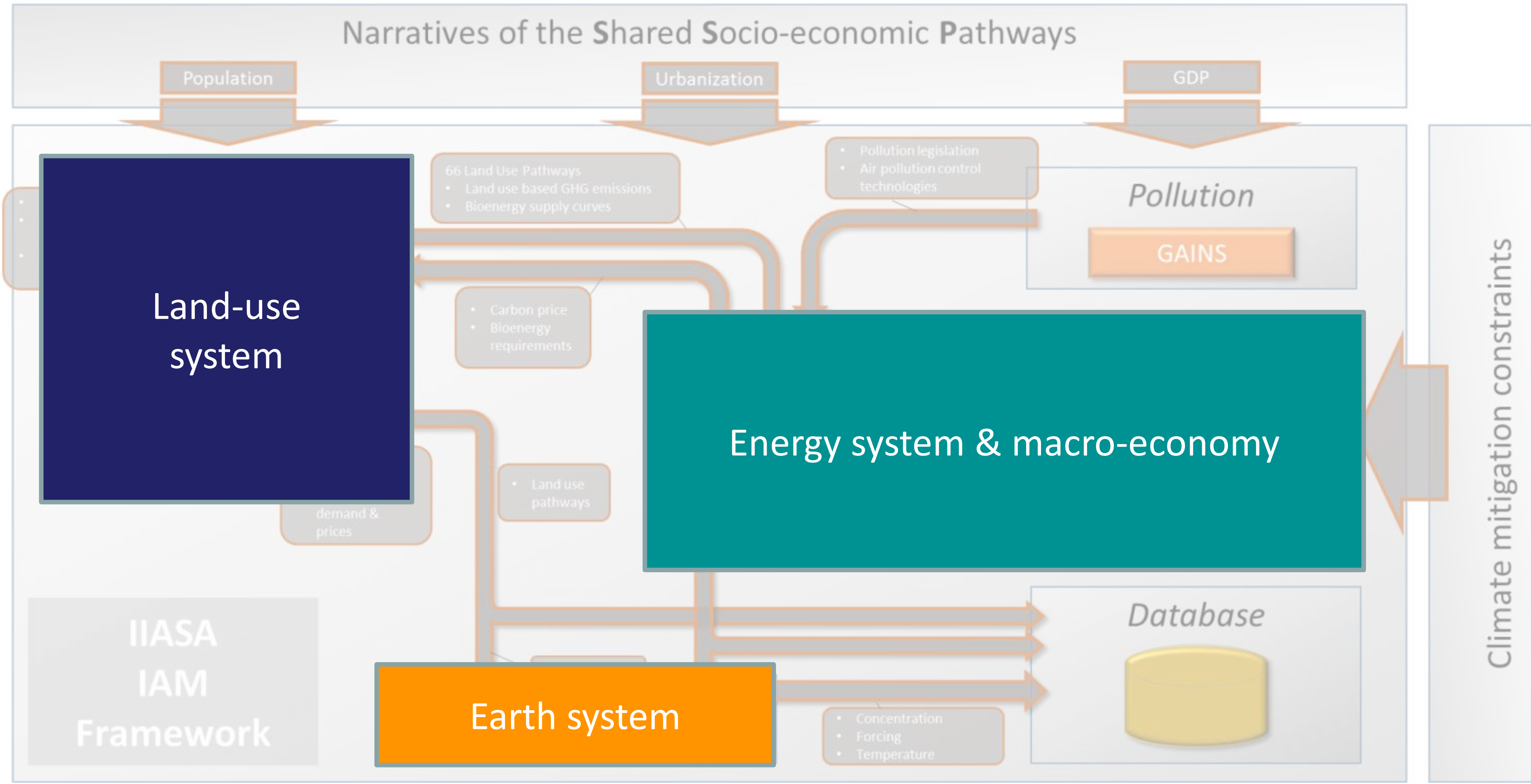

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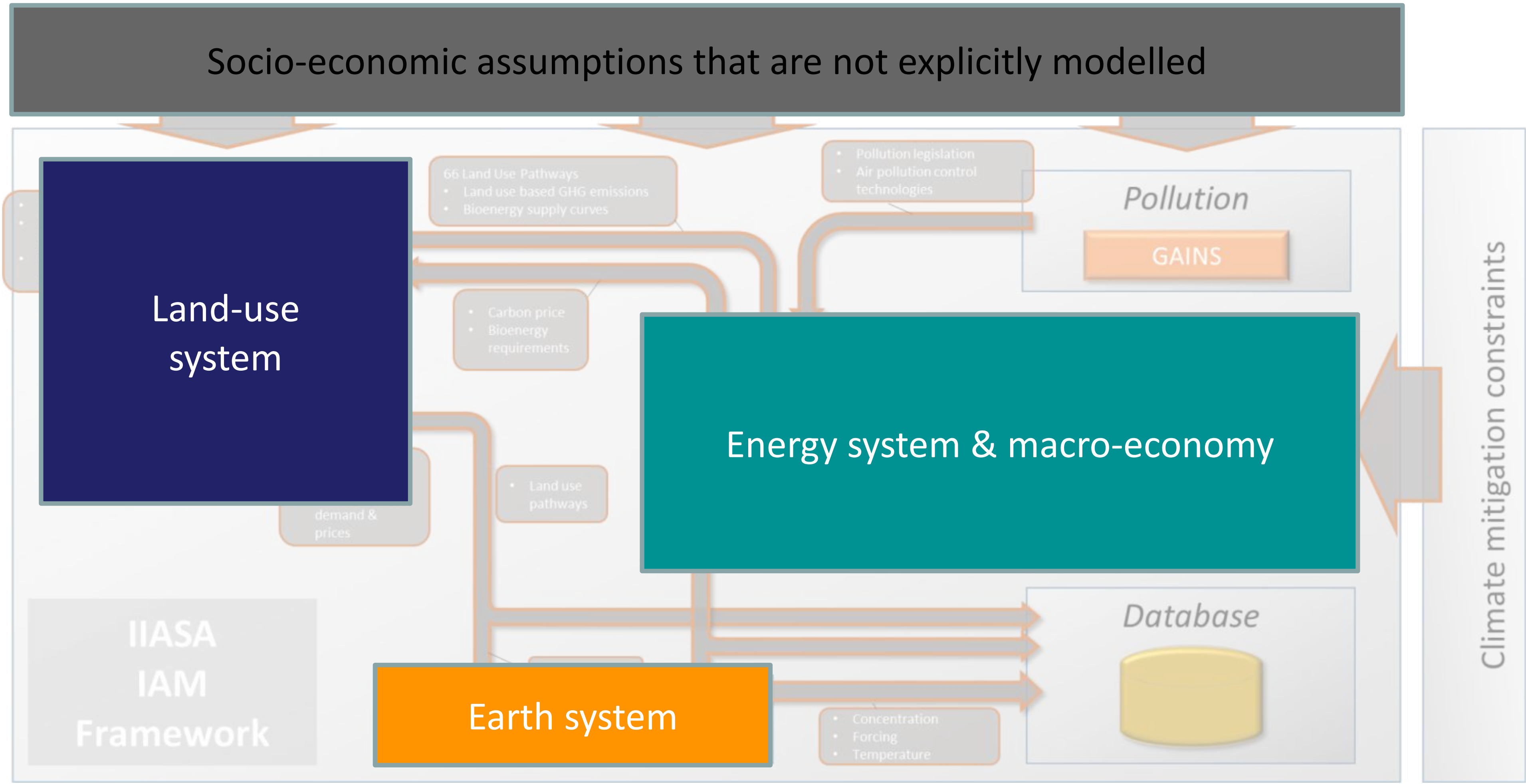

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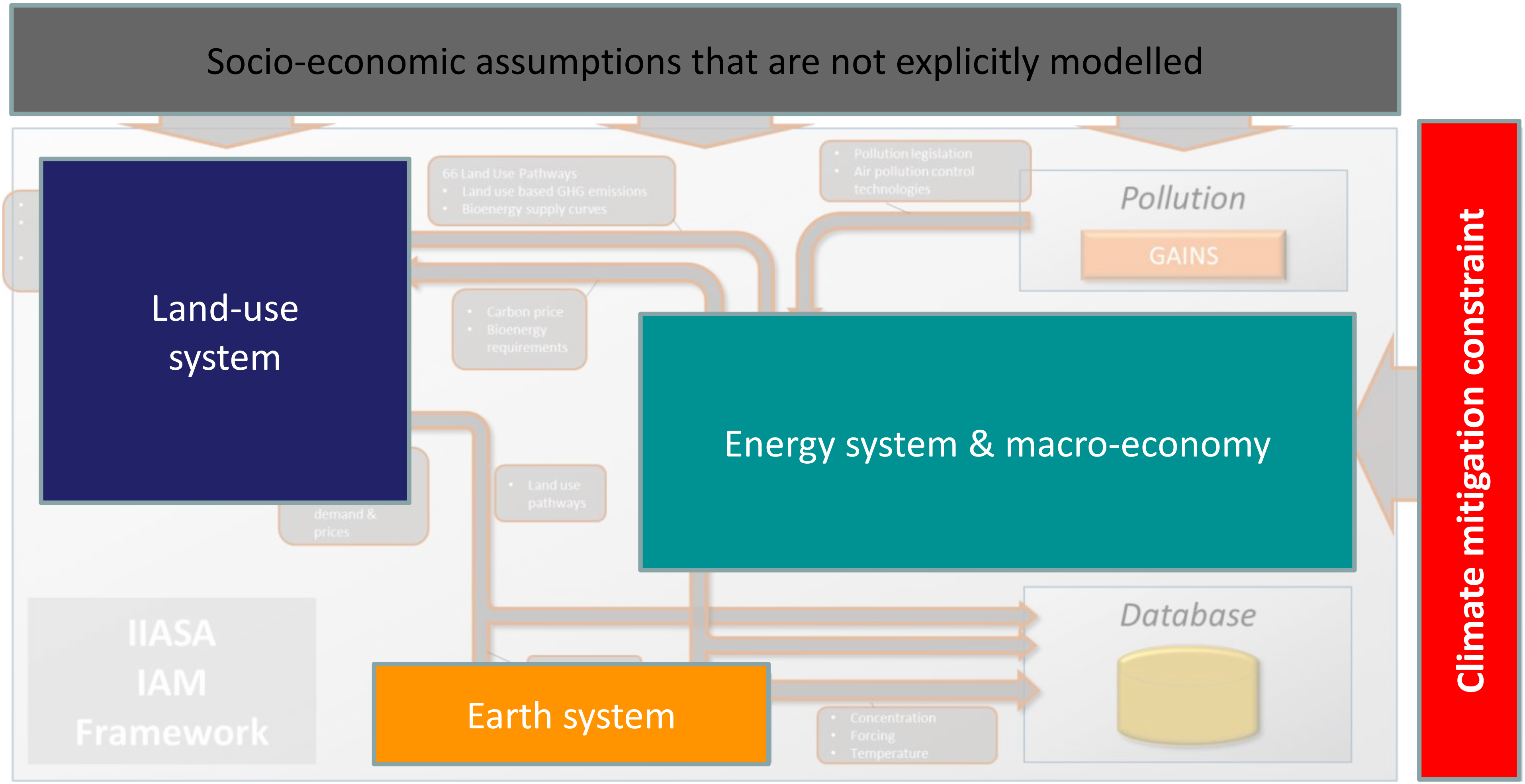
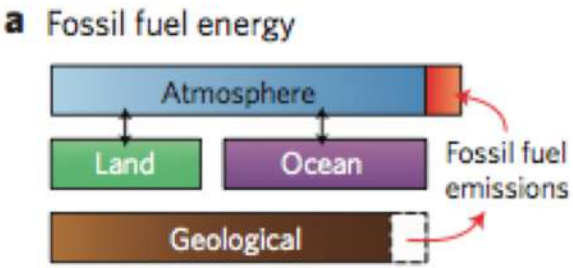


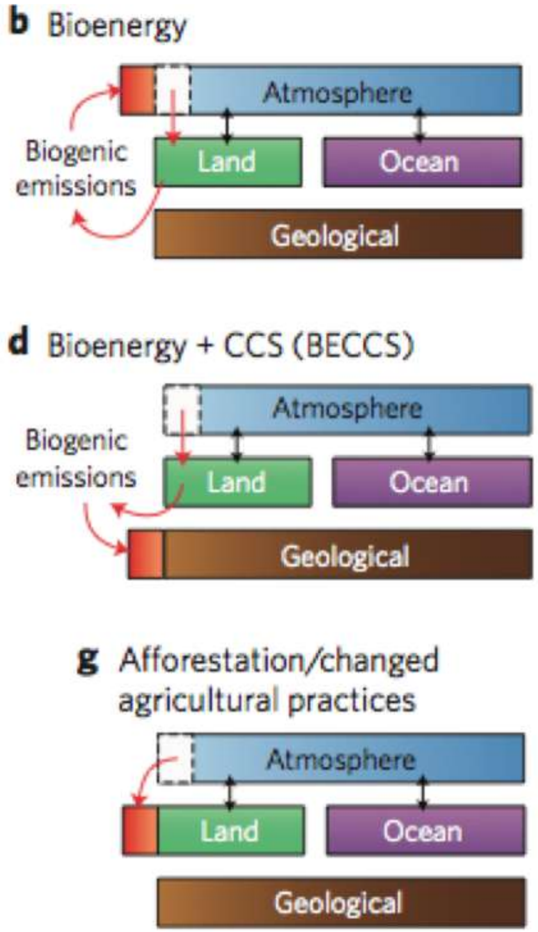
Friko et al. (2016)

Negative emissions technologies used in IAMs

“Conventional” emissions
Problem



Negative Emissions technologies
Solutions (?)

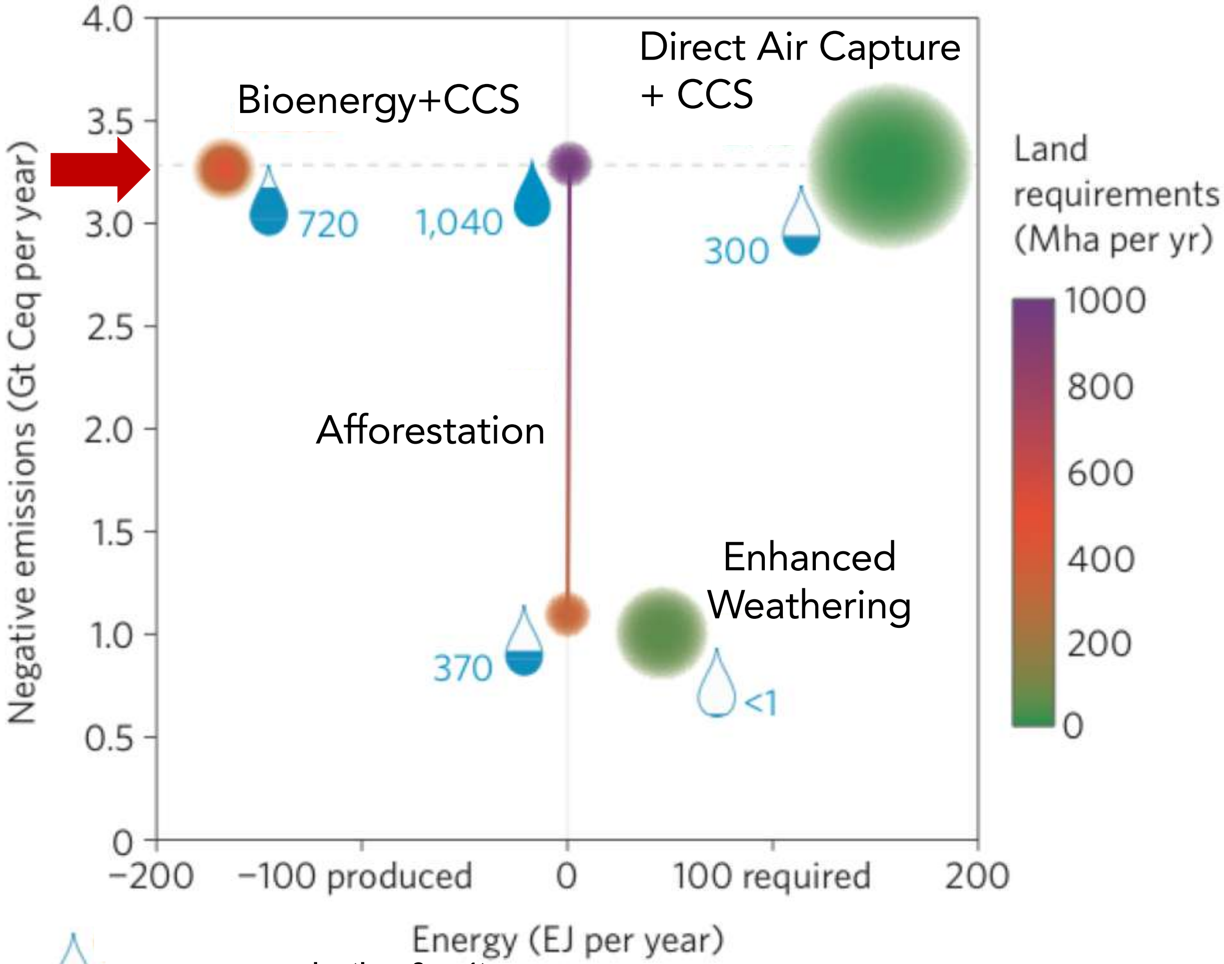


Smith et al. (2016)

Geophysical footprint of Negative emissions technologies

Level of carbon dioxide removal to hold warming below 1.5 °C warming in 2100

720 km³ y⁻¹ = annual freshwater withdrawals of Japan



Water needs ($km^3\ y^{-1}$)

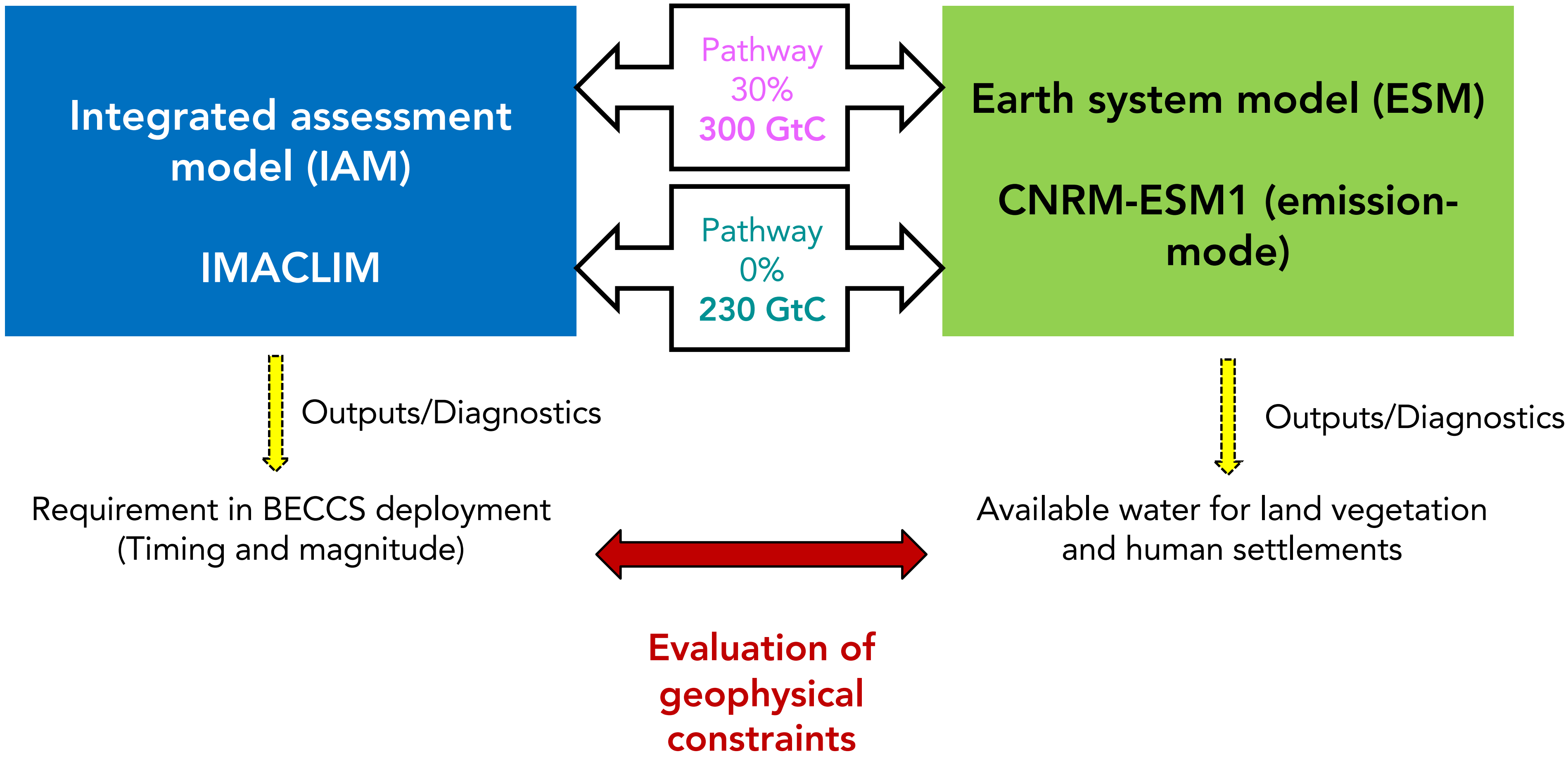
Investment cost relative to Bioenergy+CCS

Smith et al. (2016), IPCC SRLCC (2019)

A modelling framework to assess BECCS deployment

Stylized mitigation pathways
Compatible with 2 °C

Remaining Carbon budgets from 1 Jan 2016 onwards



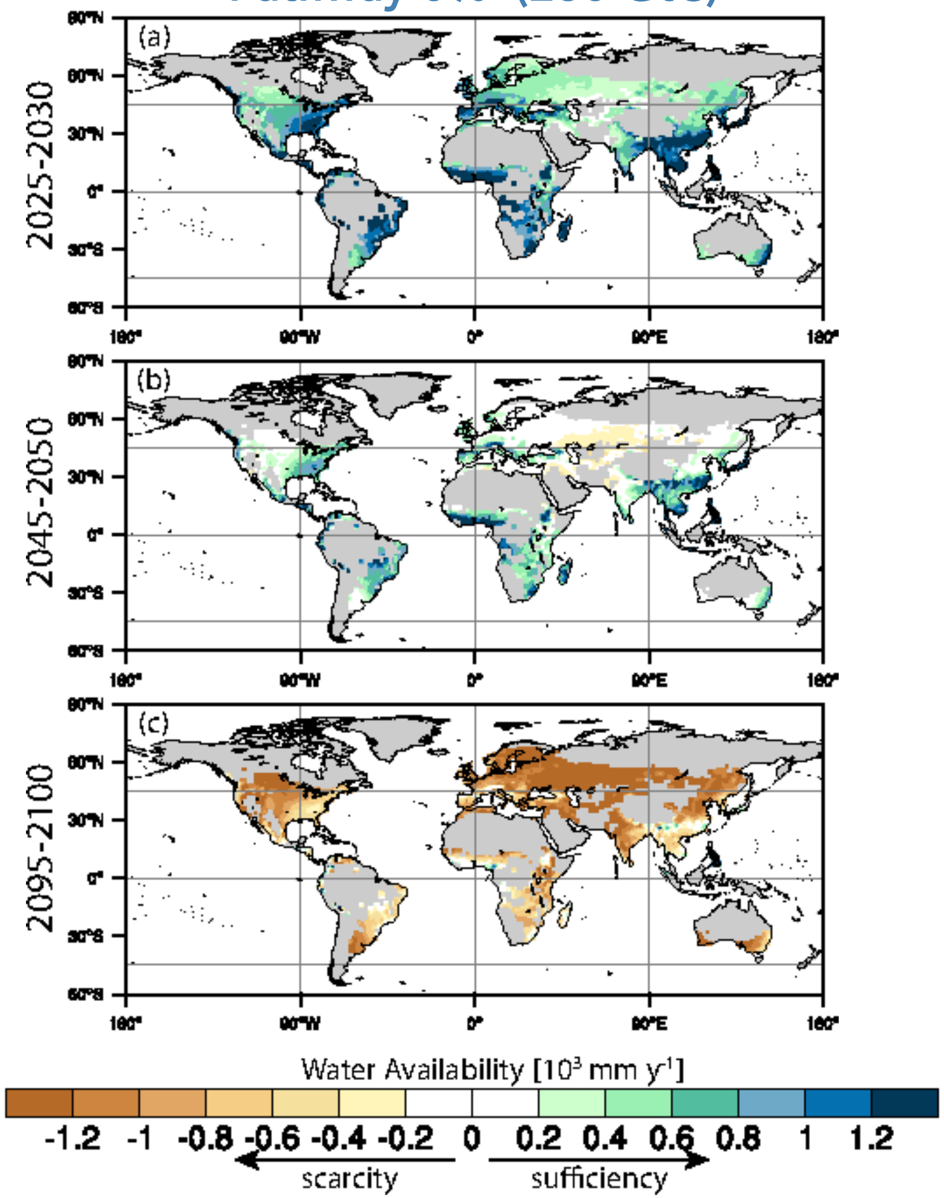
Séférian, Rocher, Guivarch and Colin, 2018

A modelling framework to assess BECCS deployment

Water Availability = (precipitation – runoff) – BECCS water needs

CNRM-ESM1 results **IMACLIM results**

Pathway 0% (230 GtC)



For the scenario with carbon budget compatible with 2ºC (1000 GtC), we find:

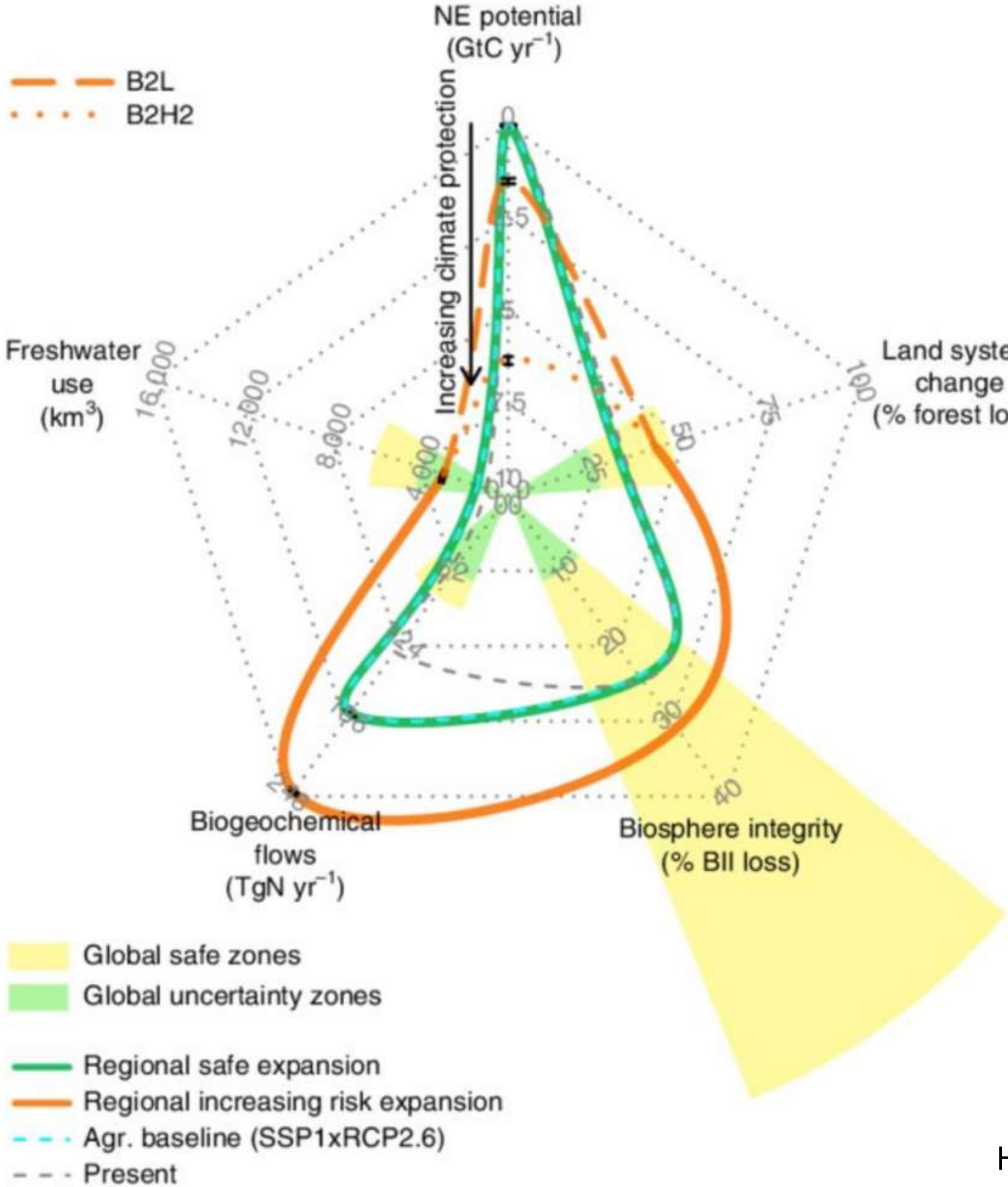
⇒ Large water scarcity is the mid-latitude

⇒ Less prominent in the tropics

Séférian, Rocher, Guivarch and Colin, 2018

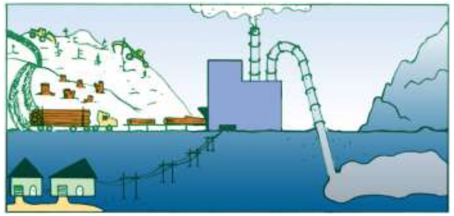
Sustainable development goals (ODD)

Compressive footprints of Negative emissions technologies



Heck et al. (2018)

Trade-off/synergies mitigation options/behaviour

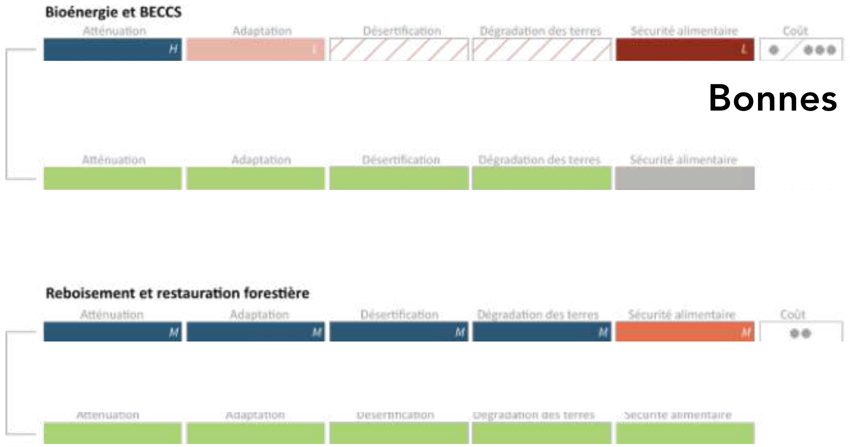


Bioénergie avec capture et stockage géologique du CO_2

Boisement ou Reboisement

Plusieurs millions de km²

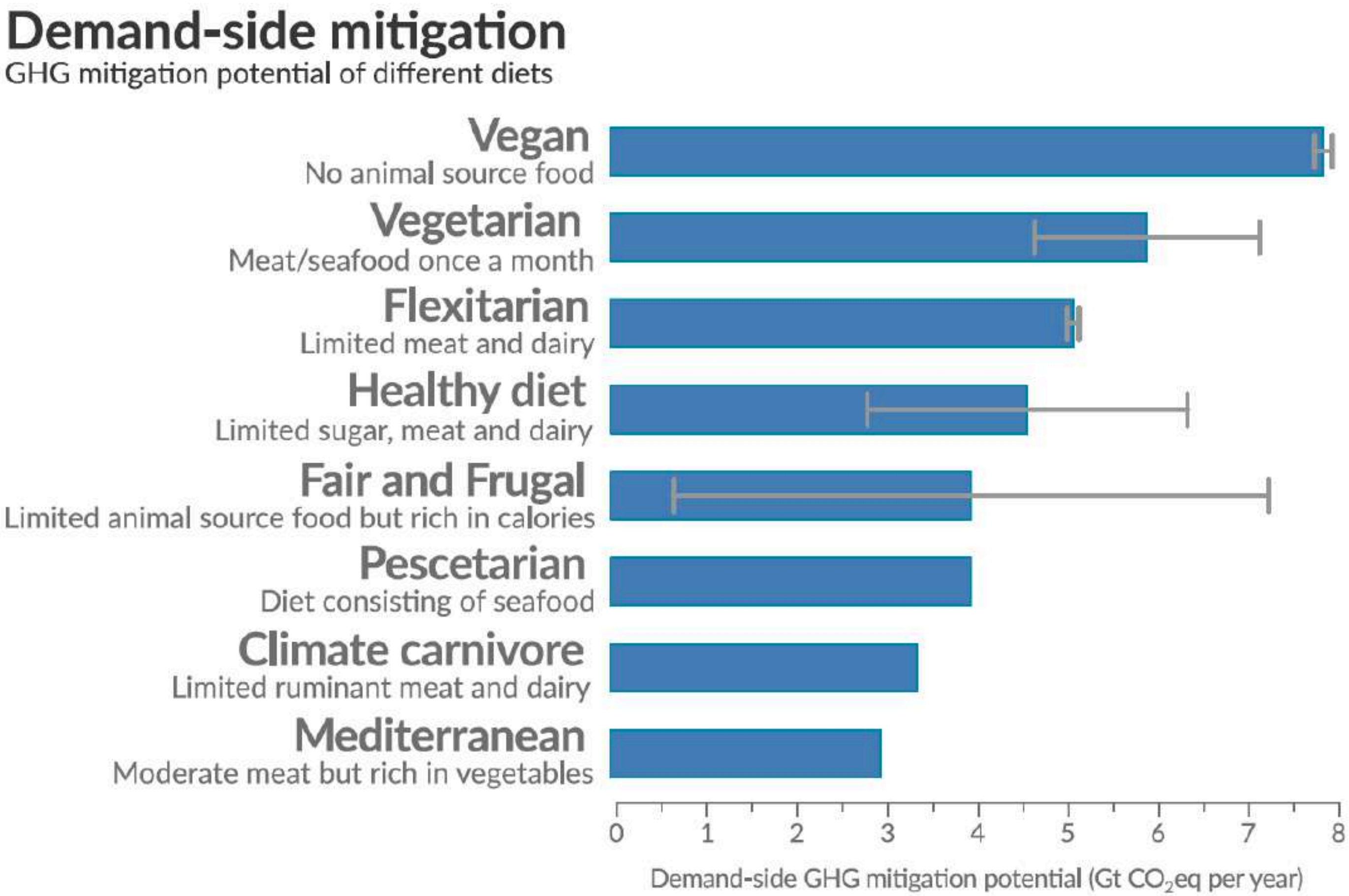
Bonnes pratiques



IPCC SRLCC (2019)

Quatre options liées au secteur de l'énergie consomment des terres : leurs impacts dépendent de l'échelle de déploiement et des pratiques

Trade-off/synergies mitigation options/behaviour



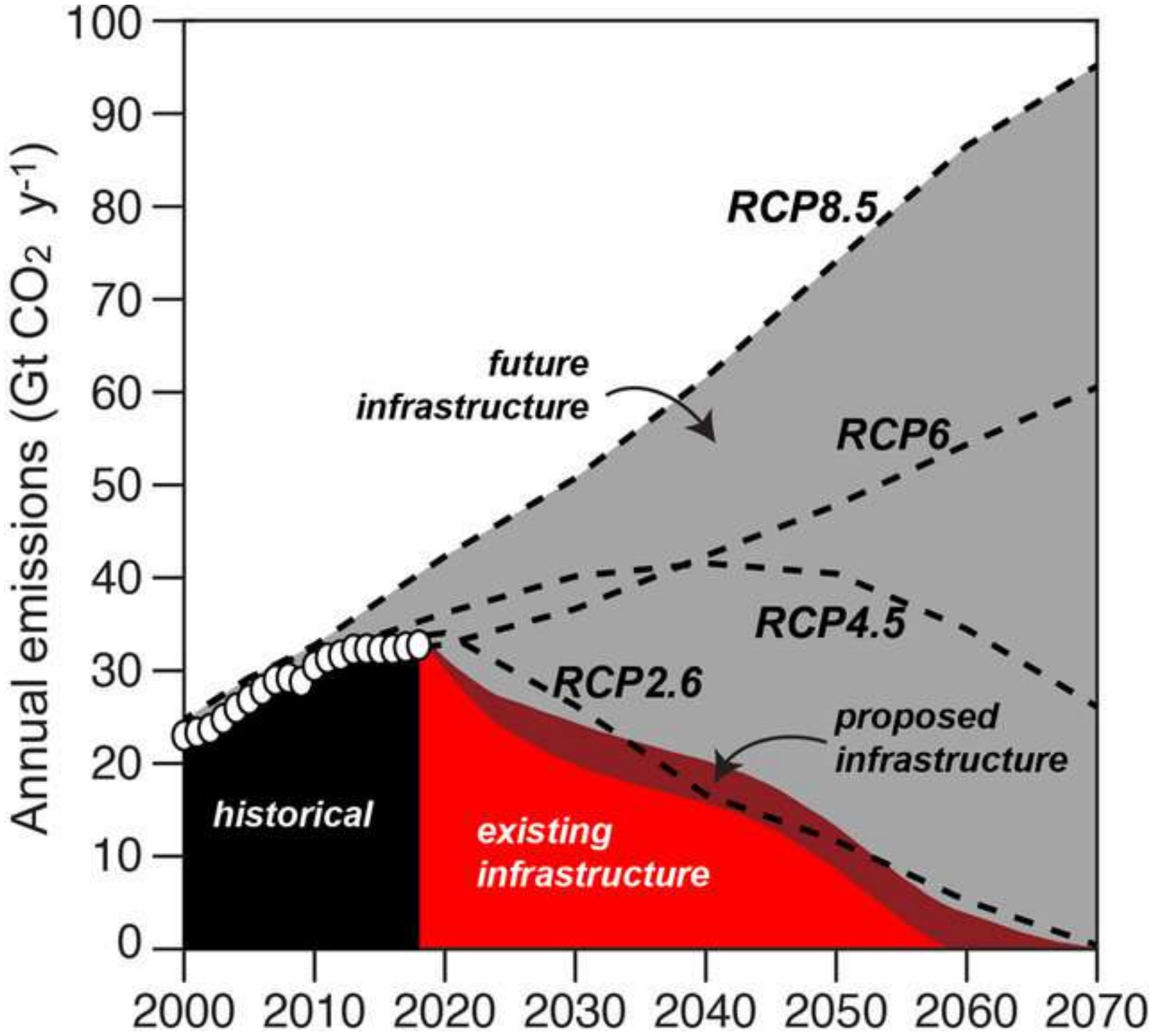
D'ici à 2050, les transitions alimentaires pourraient libérer des millions de km^2 de terres avec des co-bénéfices pour l'environnement et la santé et apporter une atténuation des émissions comprise entre 0,7 et 8,0 Gt CO_2eq

IPCC SRLCC (2019)

Other players in global mitigation

Infrastructure emission committment

Engagement de nos infrastructures dans les émissions:



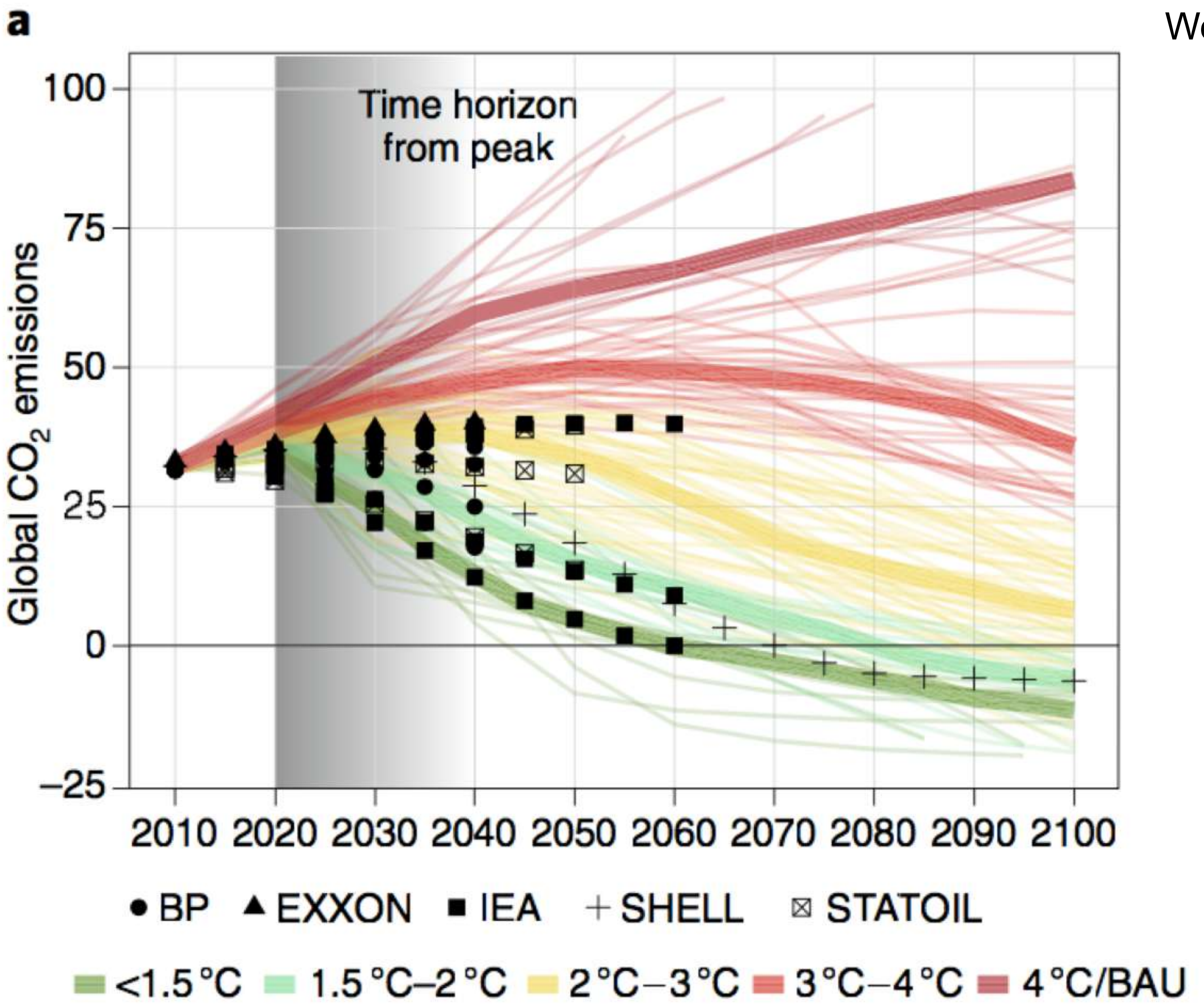
Infrastructures=
Centrale d'énergie, transport etc…

=> Arrêter la construction de nouvelles centrales à charbon dès aujourd'hui quelque soit le pays

Tong et al. (2019)

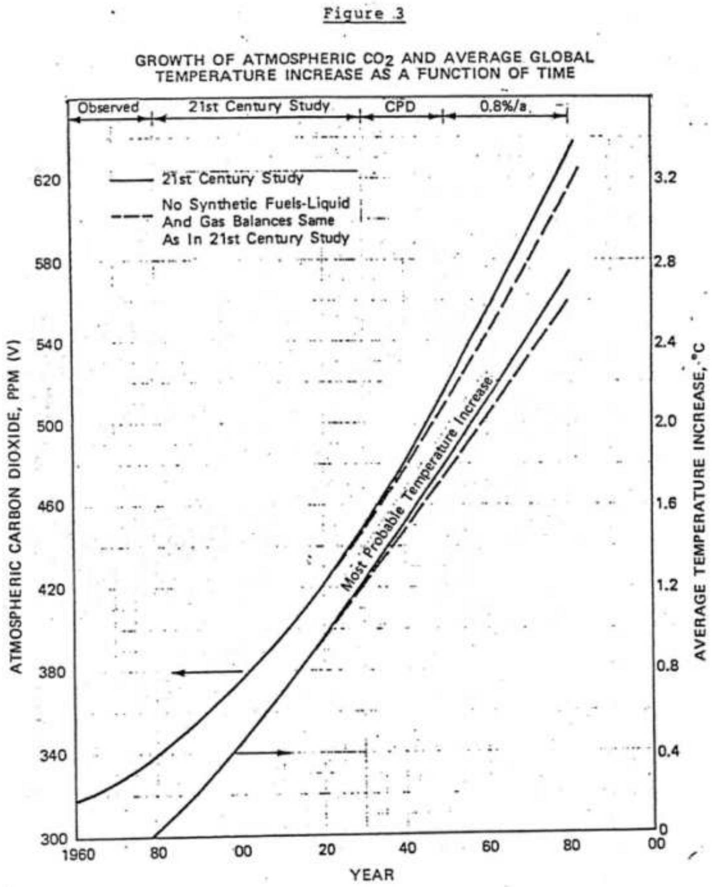
Emission projection for Oil Companies

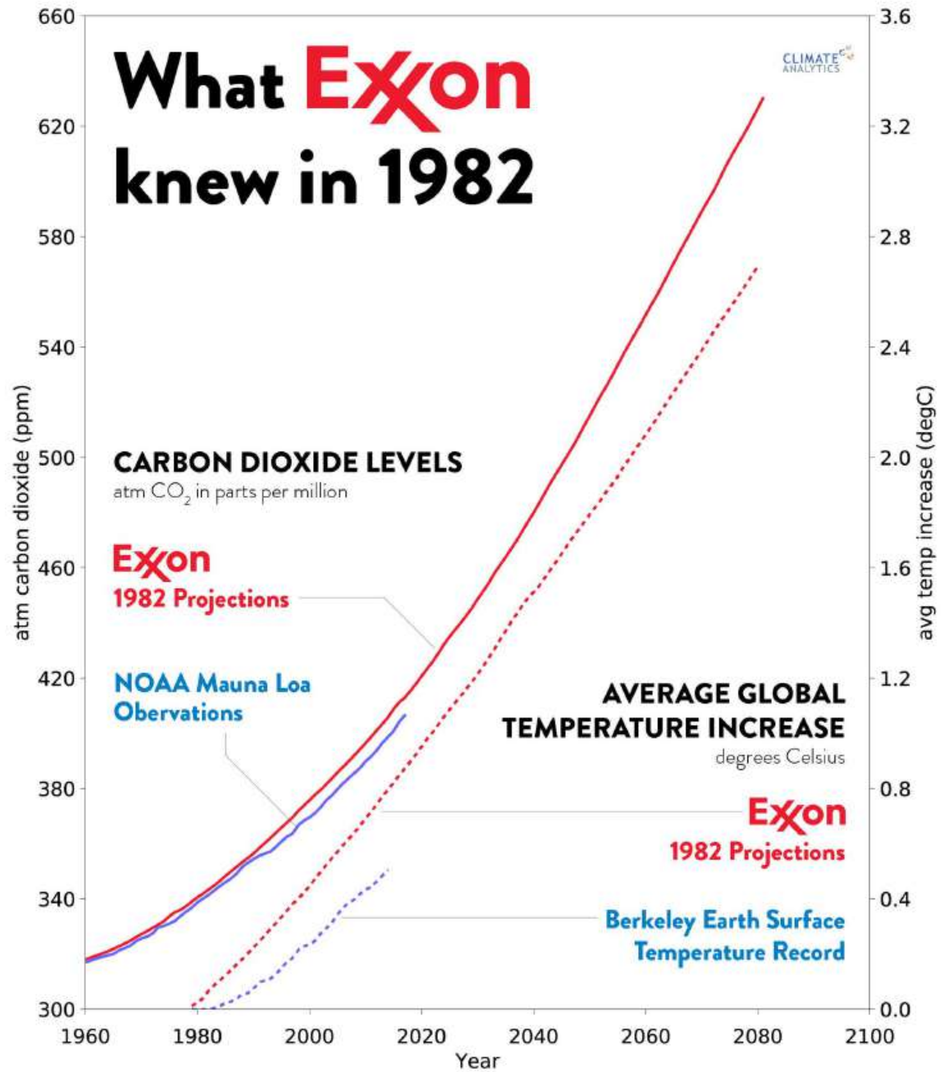
Weber et al. (2018)



Emission projection for Oil Companies

Scientists were not the only ones who knew…





Source: Exxon 1982

What mitigation pathways tell us on the energy supply ?

Global indicators	P1	P2	P3	P4	Interquartile range
Pathway classification	No or low overshoot	No or low overshoot	No or low overshoot	High overshoot	No or low overshoot
CO_2 emission change in 2030 (% rel to 2010)	-58	-47	-41	4	(-59,-40)
└ in 2050 (% rel to 2010)	-93	-95	-91	-97	(-104,-91)
Kyoto-GHG emissions in 2030 (% rel to 2010)*	-50	-49	-35	-2	(-55,-38)
└ in 2050 (% rel to 2010)	-82	-89	-78	-80	(-93,-81)
*Final energy demand** in 2030 (% rel to 2010)*	-15	-5	17	39	(-12, 7)
└ in 2050 (% rel to 2010)	-32	2	21	44	(-11, 22)
Renewable share in electricity in 2030 (%)	60	58	48	25	(47, 65)
└ in 2050 (%)	77	81	63	70	(69, 87)
Primary energy from coal in 2030 (% rel to 2010)	-78	-61	-75	-59	(-78, -59)
└ in 2050 (% rel to 2010)	-97	-77	-73	-97	(-95, -74)
from oil in 2030 (% rel to 2010)	-37	-13	-3	86	(-34,3)
└ in 2050 (% rel to 2010)	-87	-50	-81	-32	(-78,-31)
from gas in 2030 (% rel to 2010)	-25	-20	33	37	(-26,21)
└ in 2050 (% rel to 2010)	-74	-53	21	-48	(-56,6)
from nuclear in 2030 (% rel to 2010)	59	83	98	106	(44,102)
└ in 2050 (% rel to 2010)	150	98	501	468	(91,190)
from biomass in 2030 (% rel to 2010)	-11	0	36	-1	(29,80)
└ in 2050 (% rel to 2010)	-16	49	121	418	(123,261)
from non-biomass renewables in 2030 (% rel to 2010)	430	470	315	110	(243,438)
└ in 2050 (% rel to 2010)	832	1327	878	1137	(575,1300)
Cumulative CCS until 2100 ($GtCO_2$)	0	348	687	1218	(550, 1017)
└ of which BECCS ($GtCO_2$)	0	151	414	1191	(364, 662)
Land area of bioenergy crops in 2050 (million hectare)	22	93	283	724	(151, 320)
Agricultural CH_4 emissions in 2030 (% rel to 2010)	-24	-48	1	14	(-30,-11)
in 2050 (% rel to 2010)	-33	-69	-23	2	(-46,-23)
Agricultural N_2O emissions in 2030 (% rel to 2010)	5	-26	15	3	(-21,4)
in 2050 (% rel to 2010)	6	-26	0	39	(-26,1)

NOTE: Indicators have been selected to show global trends identified by the Chapter 2 assessment. National and sectoral characteristics can differ substantially from the global trends shown above.

** Kyoto-gas emissions are based on SAR GWP-100*
*** Changes in energy demand are associated with improvements in energy efficiency and behaviour change*

Température et émissions

Systèmes énergétiques

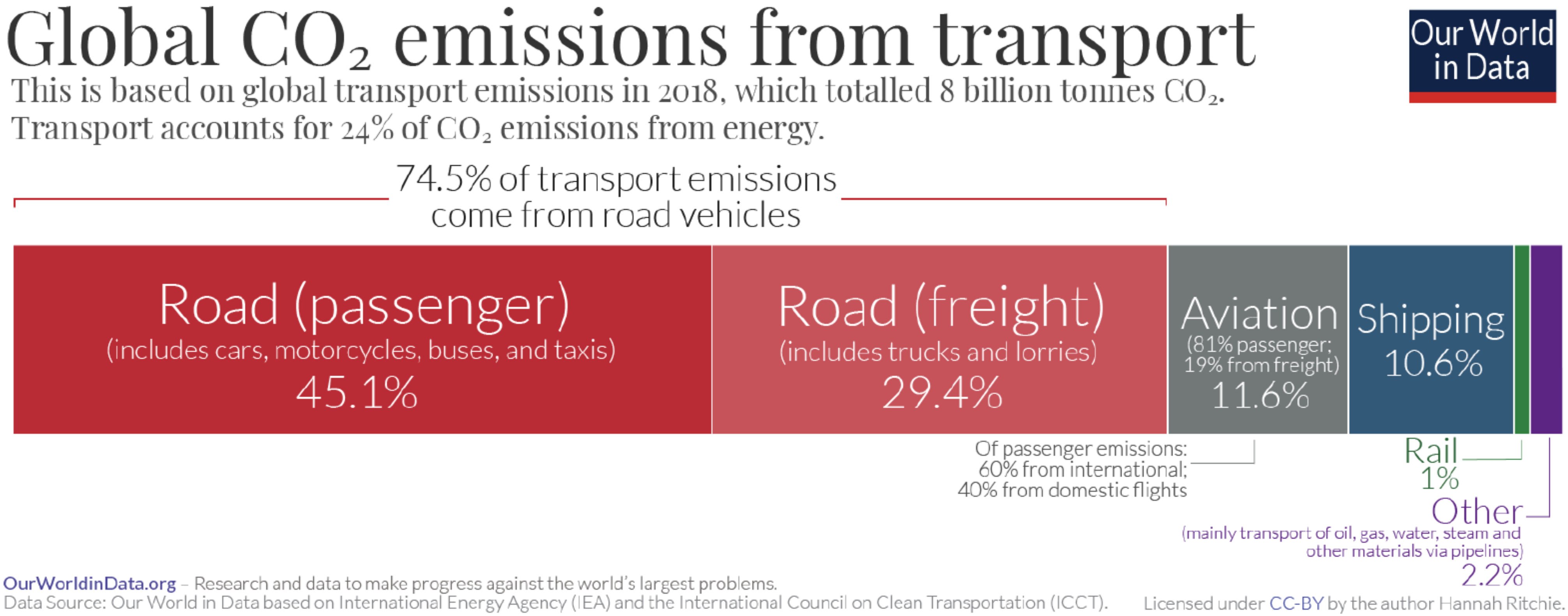
Énergie Météo-dépendante

Extraction du CO_2

Agriculture

Let's talk about tranport's emissions

a major issue in a globalized world ?



Last word ?