emiliano.merlin@inaf.it

The impact of animal agriculture on climate change

Emiliano Merlin, Ph.D.
INAF
23.10.2025

emiliano.merlin@inaf.it

1. Is climate changing? Is it caused by human activities? Is this debated by experts?
2. Can we foresee the consequences of climate change?
3. Which are its physical causes?
4. Which human activities are more impactful?
5. What can/should we do?

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NEWS

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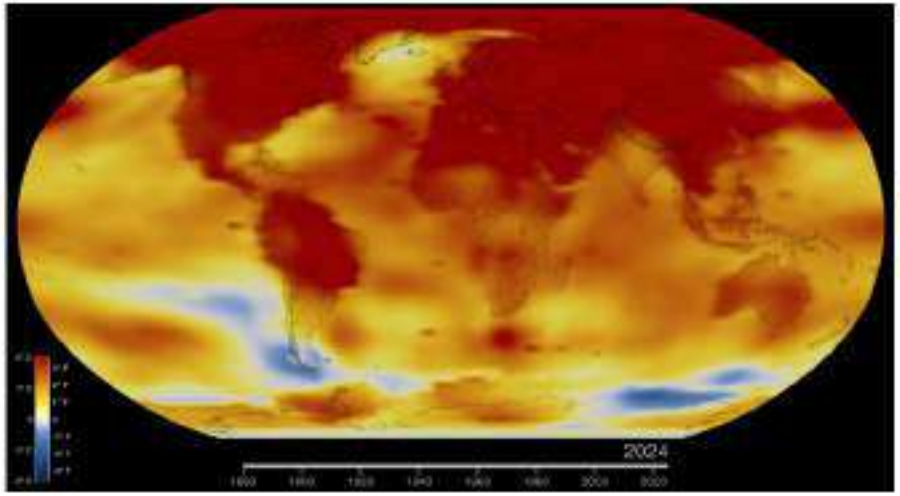
Science

2023 confirmed as world's hottest year on record

9 January 1 Comments

Climate

Temperatures Rising: NASA Confirms 2024 Warmest Year on Record



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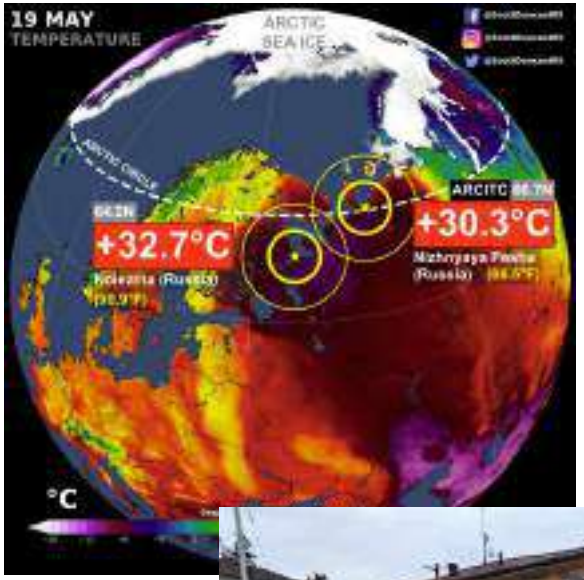
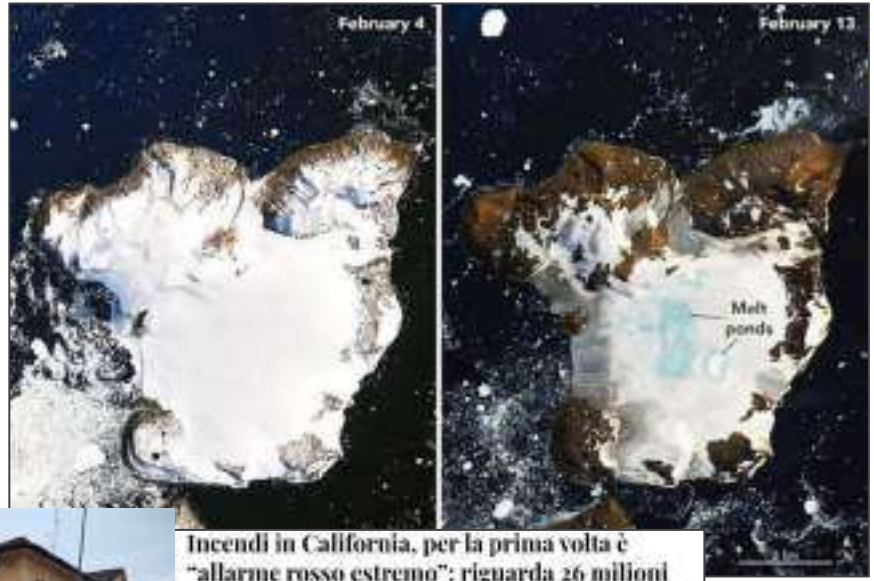
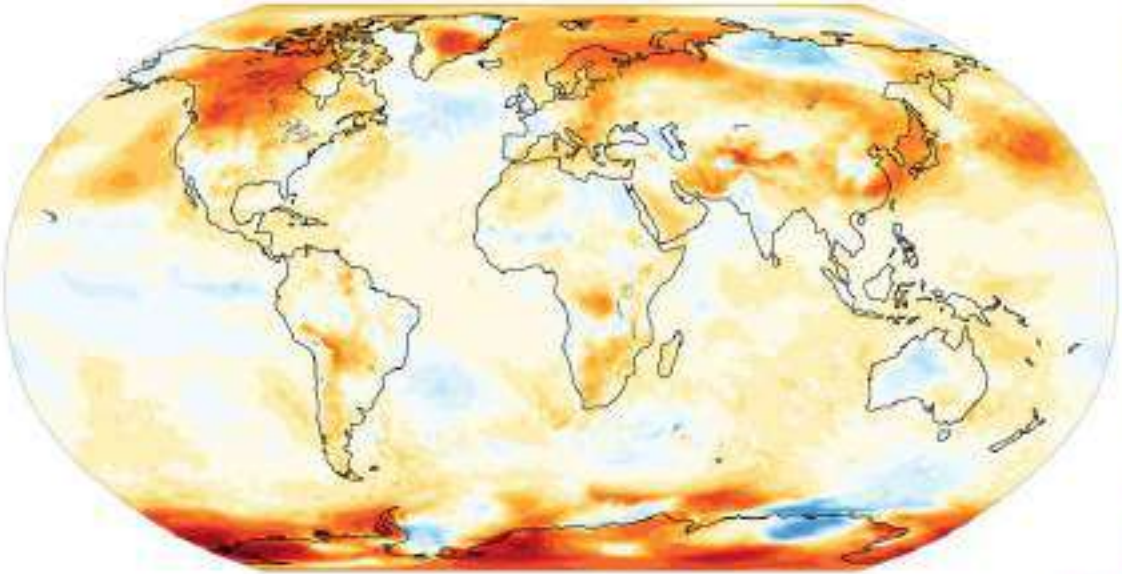


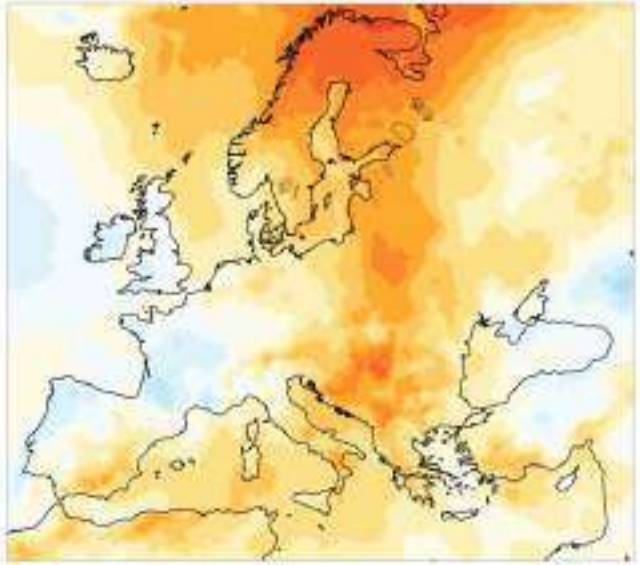


Incendi in California, per la prima volta è "allarme rosso estremo": riguarda 26 milioni di persone. Solo il 15% dei roghi è stato domato

Surface air temperature anomaly • September 2025

Data: ERA5 • Reference period: 1991–2020 • Credit: C3S/ECMWF



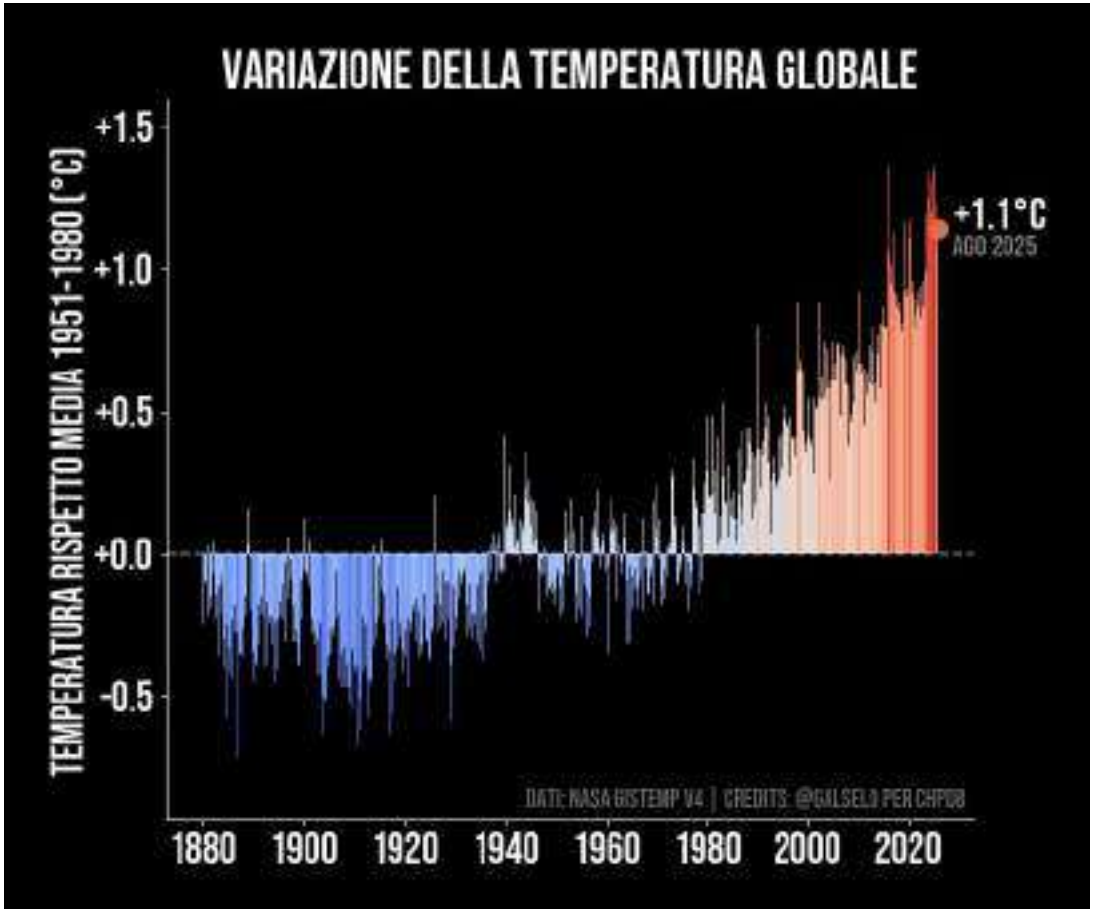


PROGRAMME OF THE EUROPEAN UNION

opernicus

ECMWF

emiliano.merlin@inaf.it



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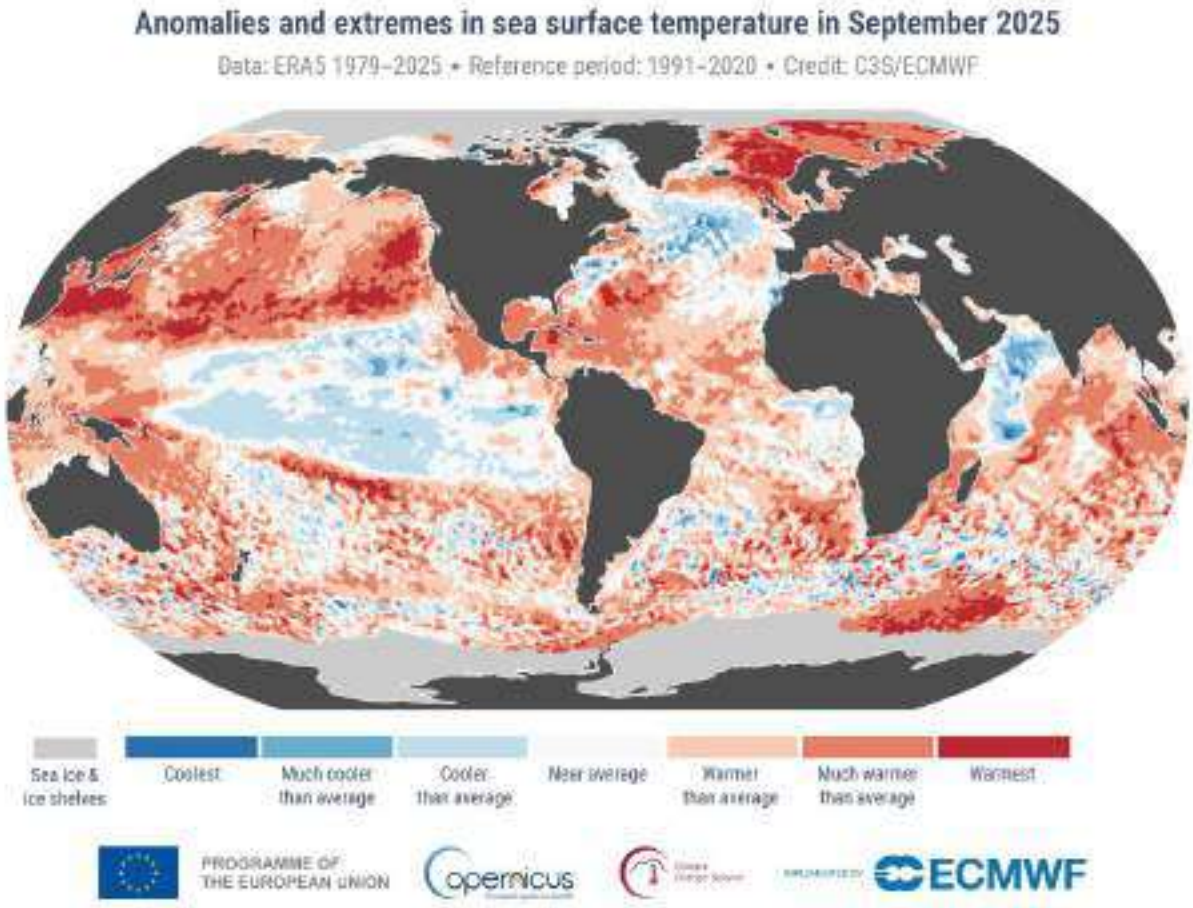

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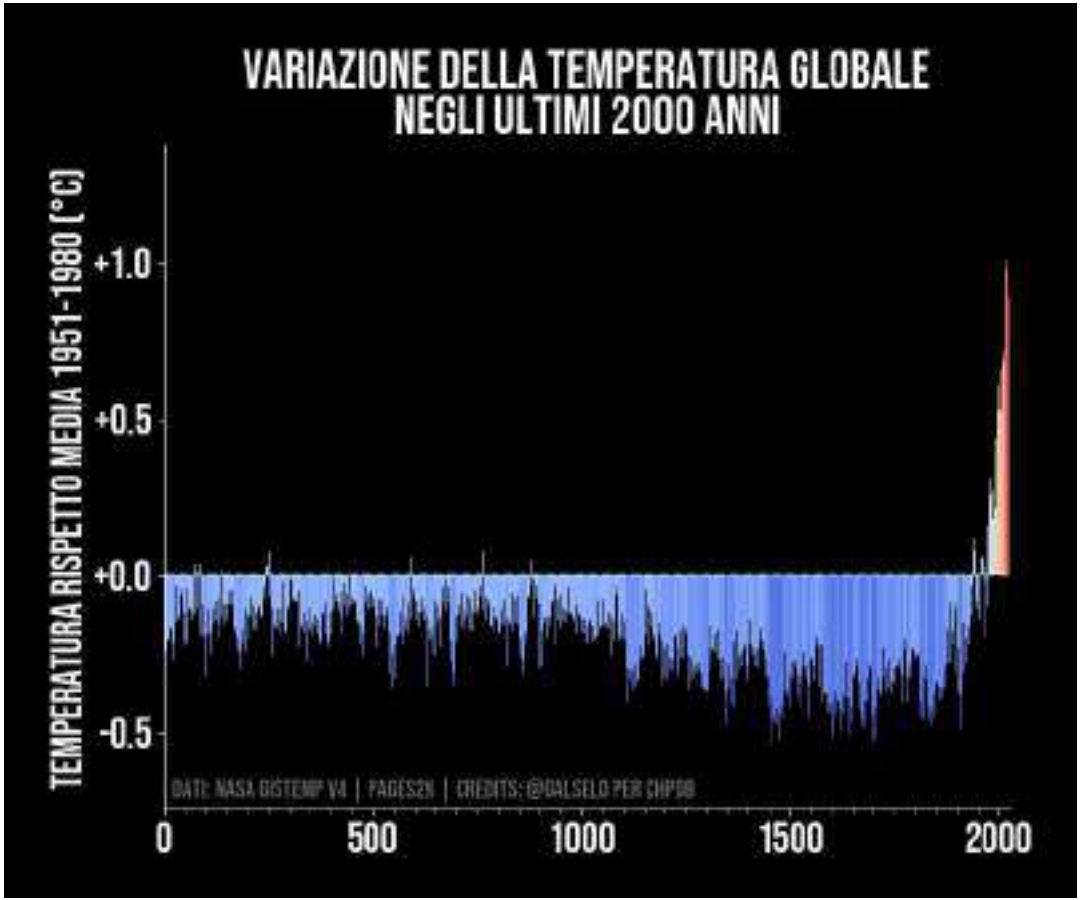

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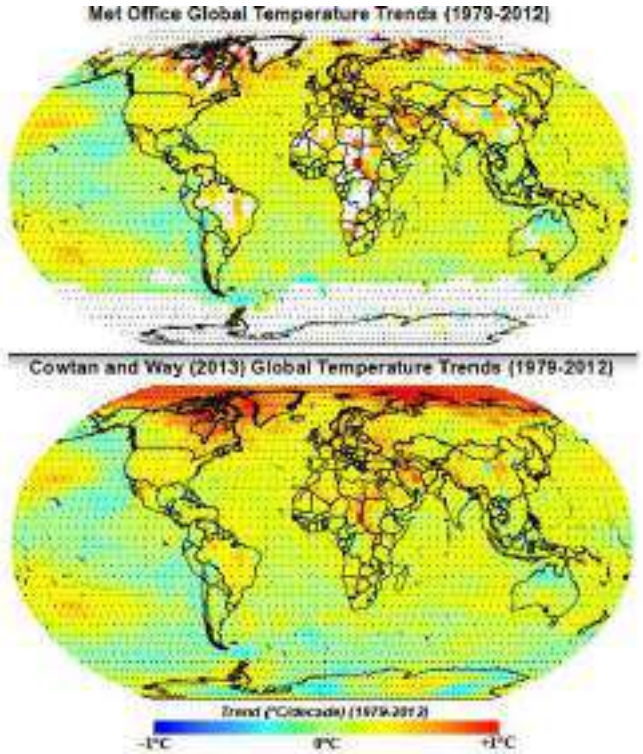
How do we measure the temperature of the planet?



- Direct measurements on the surface of Earth with stations, boats, balloons, satellites
- Monthly averages vs. 30-years average, assessing local anomalies
- Grid of global data, global average, comparison vs models
- 4 main datasets:
  - **HadCRUT** (UK Met, since 1850, 5° box)
  - **GISTEMP** (USA, NASA, since 1880, 99% cop., 2° box)
  - **MLOST** (USA, NOAA, since 1880, 5° box)
  - **JMA** (Japan, since 1891, 85% cop., 5° box)

https://www.carbonbrief.org/explainer-how-do-scientists-measure-global-temperature

emiliano.merlin@inaf.it

IPCC 2021-2022 REPORTS

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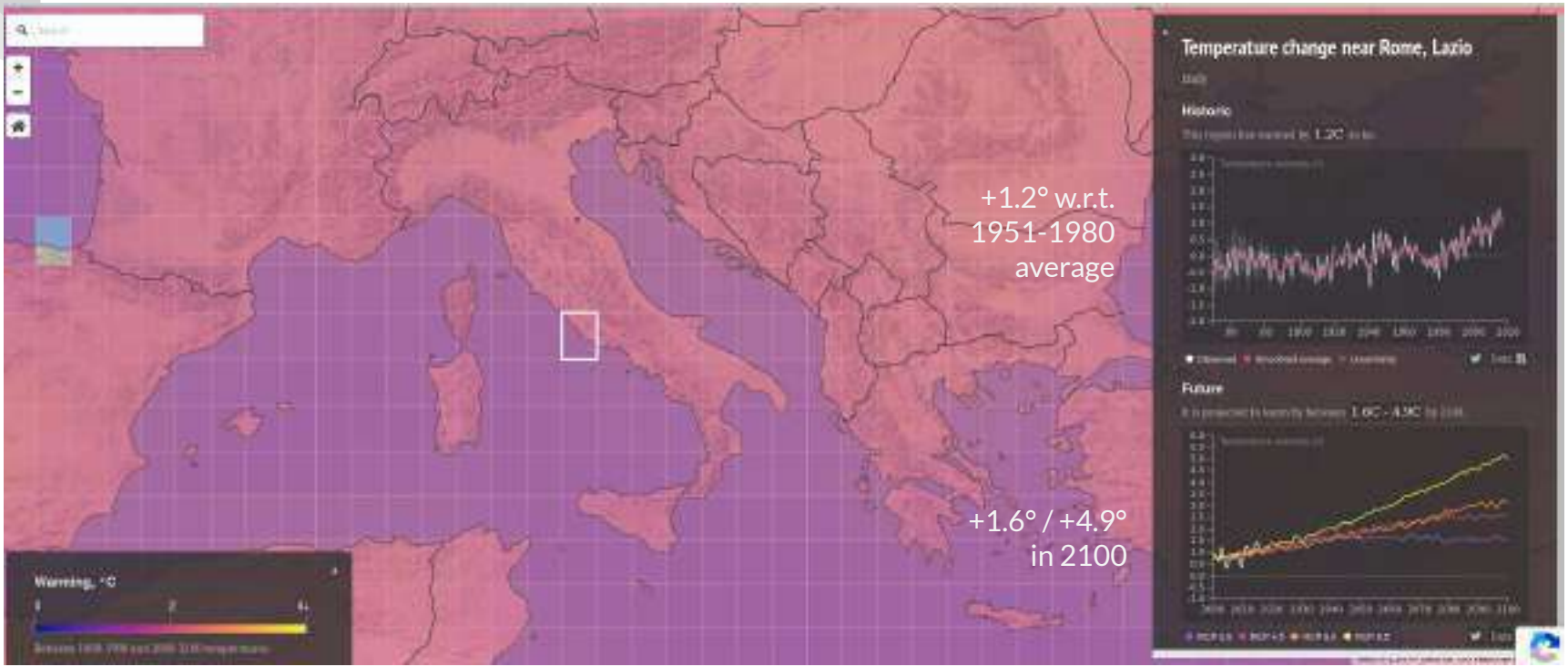

RCPs
(Representative
Concentration
Pathways)

https://www.carbonbrief.org/mapped-how-every-part-of-the-world-has-warmed-and-could-continue-to-warm

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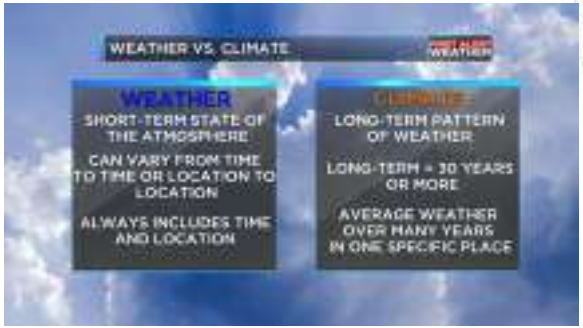

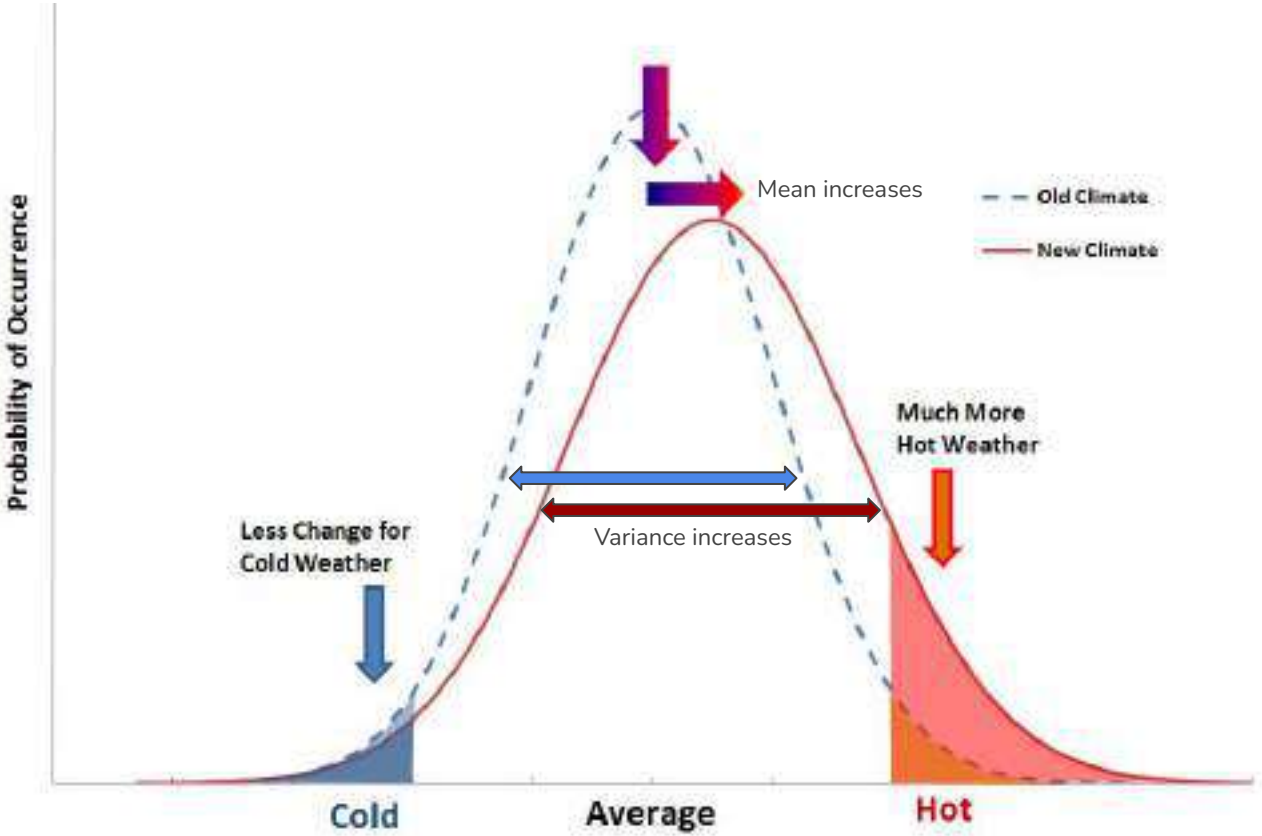

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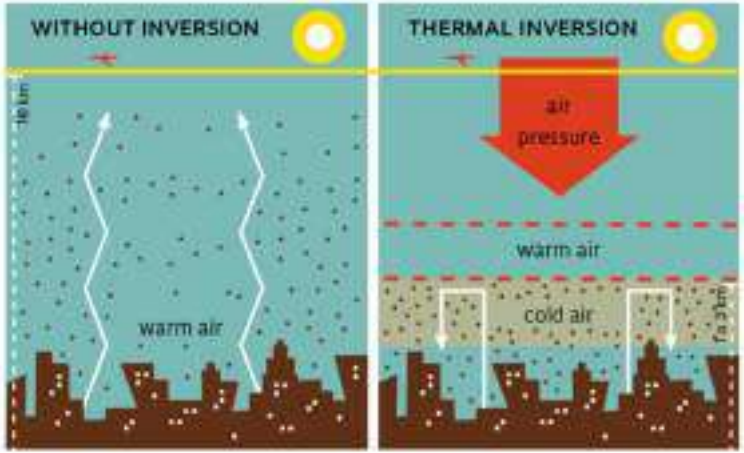
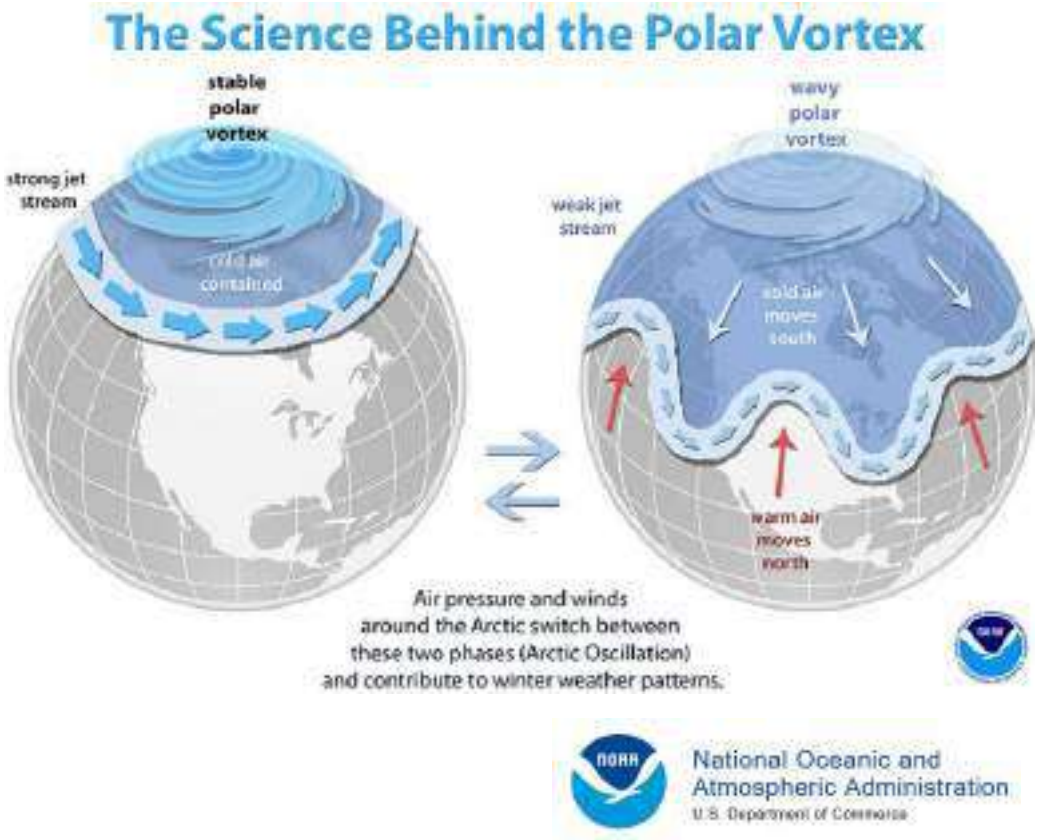
But it’s freezing outside!





https://www.noaa.gov/multimedia/infographic/science-behind-polar-vortex

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In the middle ages it was hotter than now!
(a.k.a. “the warm medieval period”)

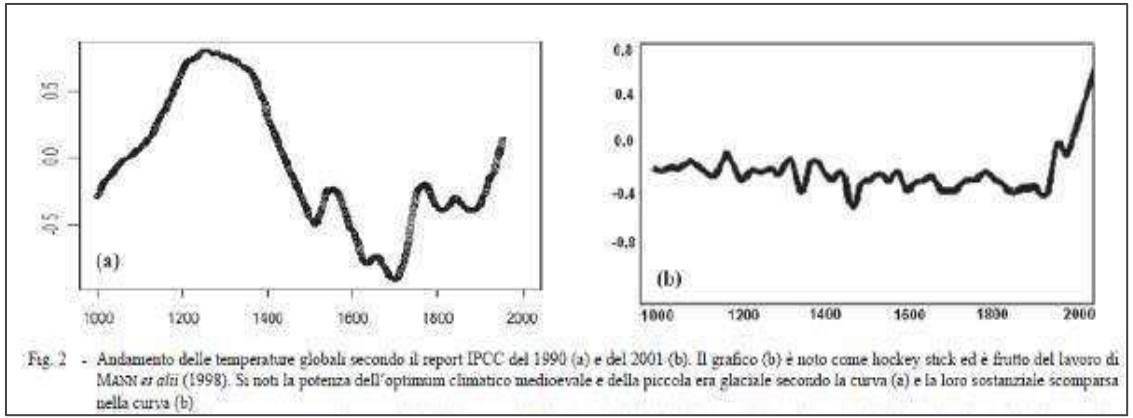
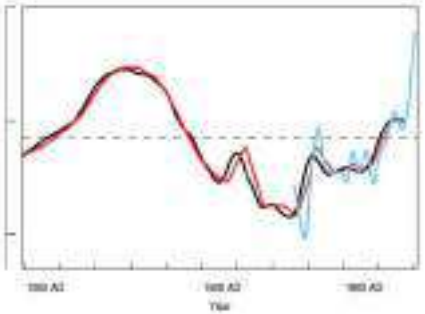


Fig. 2 - Andamento delle temperature globali secondo il report IPCC del 1990 (a) e del 2001 (b). Il grafico (b) è noto come hockey stick ed è frutto del lavoro di MANN *et alii* (1998). Si noti la potenza dell'optimum climatico medioevale e della piccola era glaciale secondo la curva (a) e la loro sostanziale scomparsa nella curva (b)

Crescenti+2010

High-resolution palaeoclimatology of the last millennium: a review of current status and future prospects

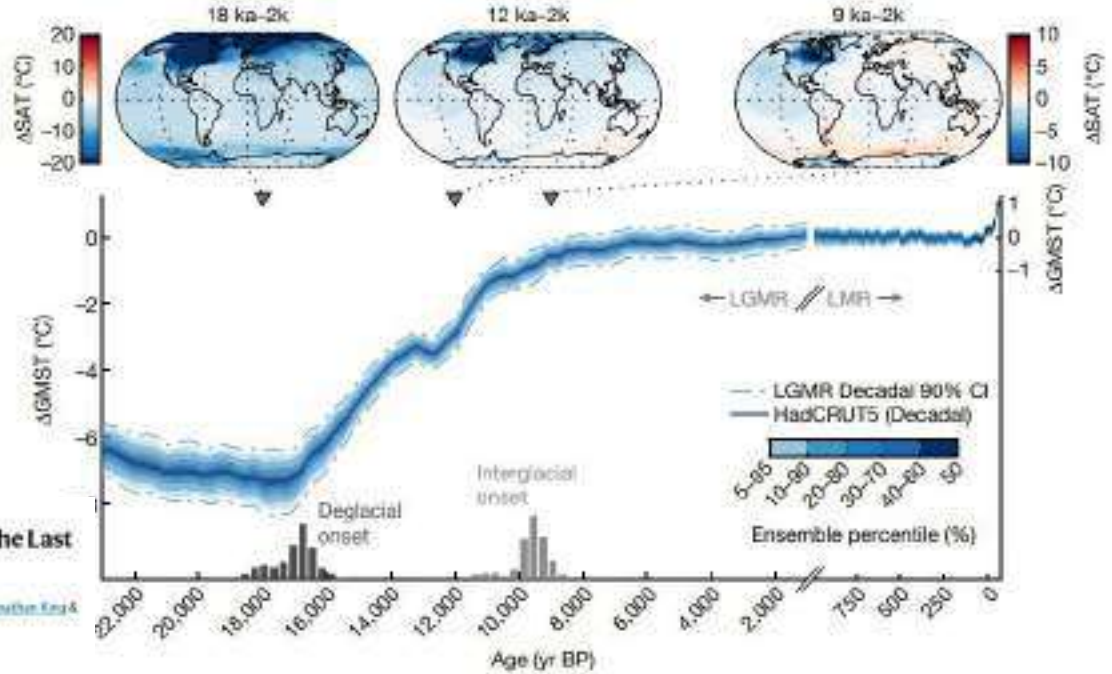
P.D. Jones,[1]* K.R. Briffa,[2] T.J. Osborn,[2] J.M. Lough,[2] T.D. van Ommen,[3] B.M. Vinther,[4] J. Luterbacher,[5] E.R. Wahl,[6] F.W. Zwiers,[7] M.E. Mann,[8] G.A. Schmidt,[9] C.M. Ammann,[10] B.M. Buckley,[11] K.M. Cobb,[12] J. Esper,[13] H. Goosse,[14] N. Graham,[15] E. Jansen,[16] T. Kiefer,[17] C. Kull,[18] M. Küttel,[5] E. Mosley-Thompson,[19] J.T. Overpeck,[20] N. Riedwyl,[5] M. Schulz,[21] A.W. Tudhope,[22] R. Villalba,[23] H. Wanner,[5] E. Wolff[24] and E. Xoplaki[5]



In summary, we show that the curve used by IPCC (1990) was locally representative (essentially of Central England) and not global, and was referred to at the time with the word 'schematic'.

emiliano.merlin@inaf.it

Climate has been changing since forever!



Article | Published: 10 November 2021

Globally resolved surface temperatures since the Last Glacial Maximum

Matthew B. Osman, Jessica E. Tierney, Jiang Zhu, Robert Tardif, Gregory J. Hakim, Jonathan King & Christopher J. Poulsen

Nature 599, 239–244 (2021) | Cite this article

Fig. 2 | Global mean surface temperature change over the past 24 kyr. Ensemble distribution ($n = 500$ posterior means) of LGMR GMST for the past 24 kyr (blue colours), with a decadal 90th-percentile range (dotted-dashed lines) estimated using decadal-to-centennial variance ratios from iCESM (Methods). Shown at the top are spatial surface air temperature (SAT) anomalies relative to the past two millennia ('2k', 0–2 ka) for intervals discussed in the main text. The estimated last deglacial and interglacial onset timings are shown as dark and light histograms at the bottom (Supplementary Information). Reconstructed decadal GMST from the last millennium reanalysis v2.1 (ref. [37]) and HadCRUT5 observational product[11] are plotted to the right of the LGMR. ΔGMST is computed relative to the preindustrial last millennium average (1000–1850 CE).

https://www.nature.com/articles/s41586-021-03984-4

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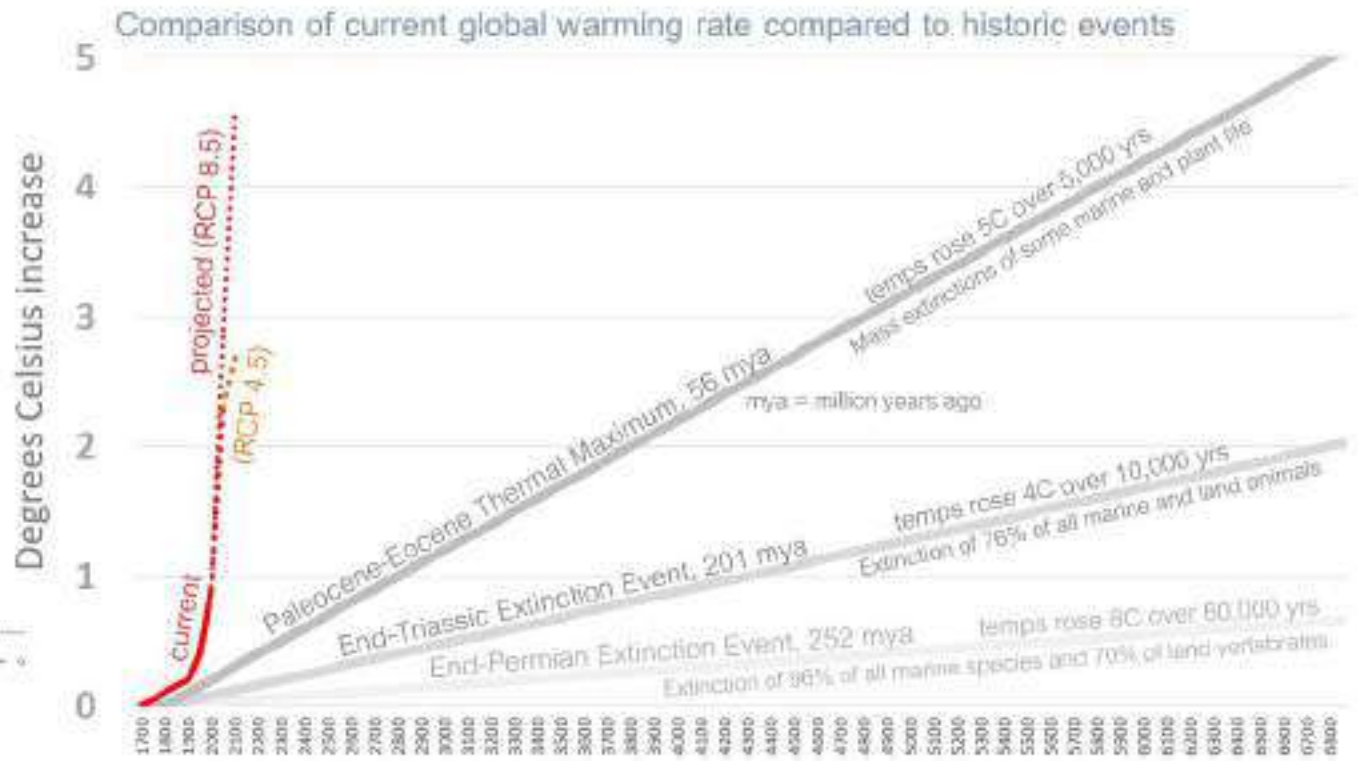

Mass Extinctions Tied to Past Climate Changes

https://thecottonwoodpost.net/2019/12/10/modern-climate-change-is-10x-faster-than-historic-global-warming-mass-extinction-events/

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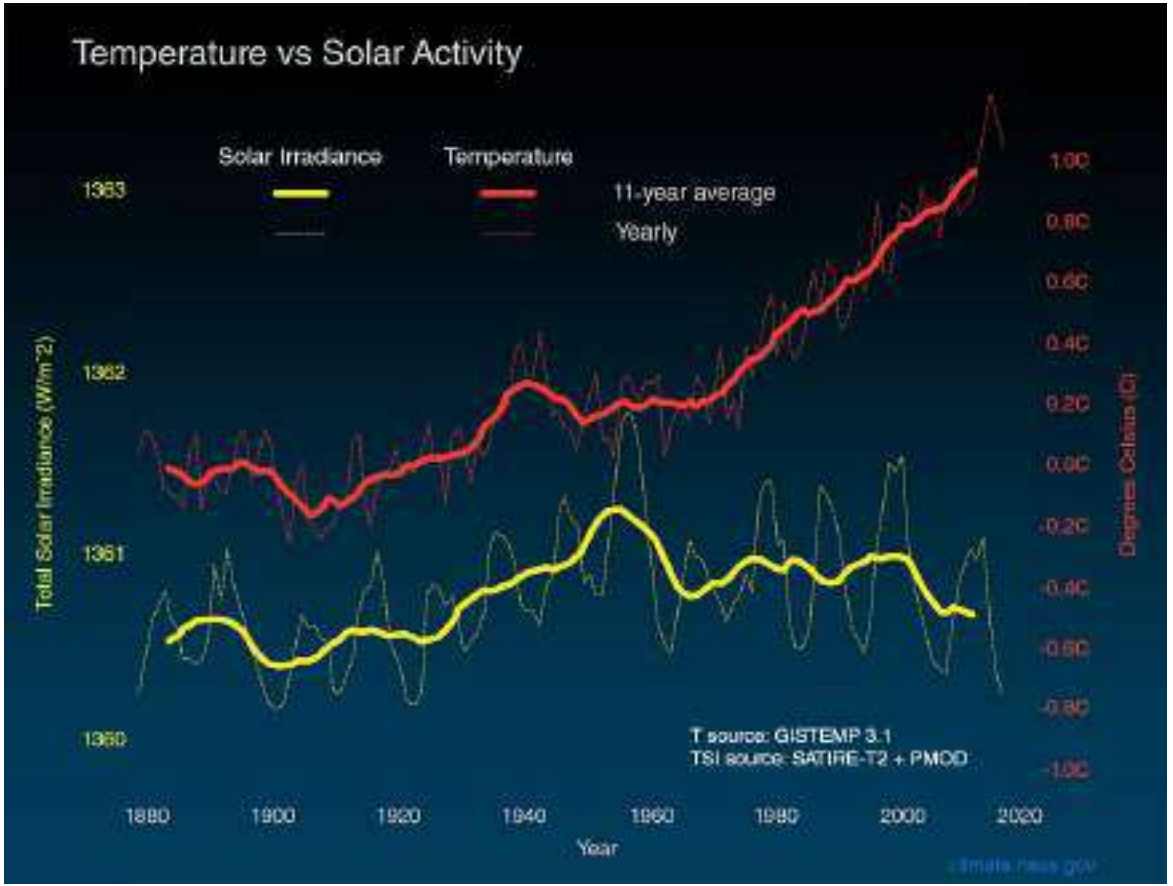
Ok it’s getting hotter, but it’s just solar activity!



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Climate models

$$\frac{\partial \mathbf{u}}{\partial t} = -(\mathbf{u}\cdot\nabla)\mathbf{u} + \nabla\cdot(\mu\nabla\mathbf{u}) - \frac{1}{\rho}\nabla p + \mathbf{f}$$

kinematic viscosity (constant)

density (constant)

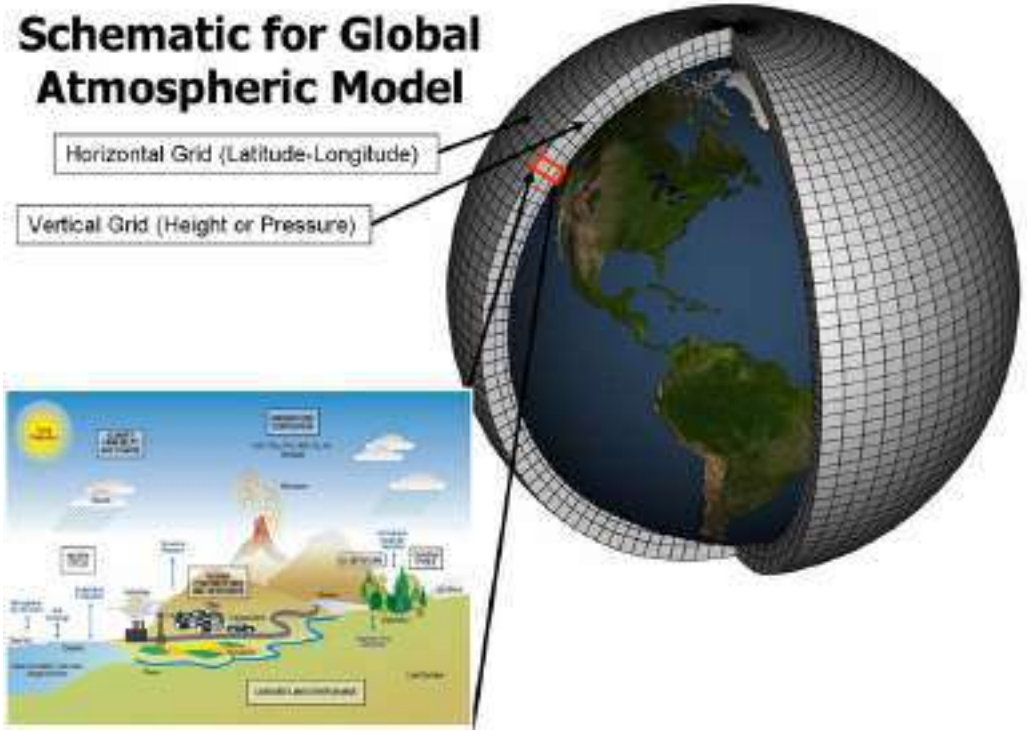
pressure

external force (such as gravity)

Navier-Stokes
Clausius-Clapeyron
Stefan-Boltzmann

$$P = \varepsilon\sigma A T^4$$

$$\ln\frac{P_1}{P_2} = \frac{\Delta H_{vap}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$



https://www.carbonbrief.org/qa-how-do-climate-models-work

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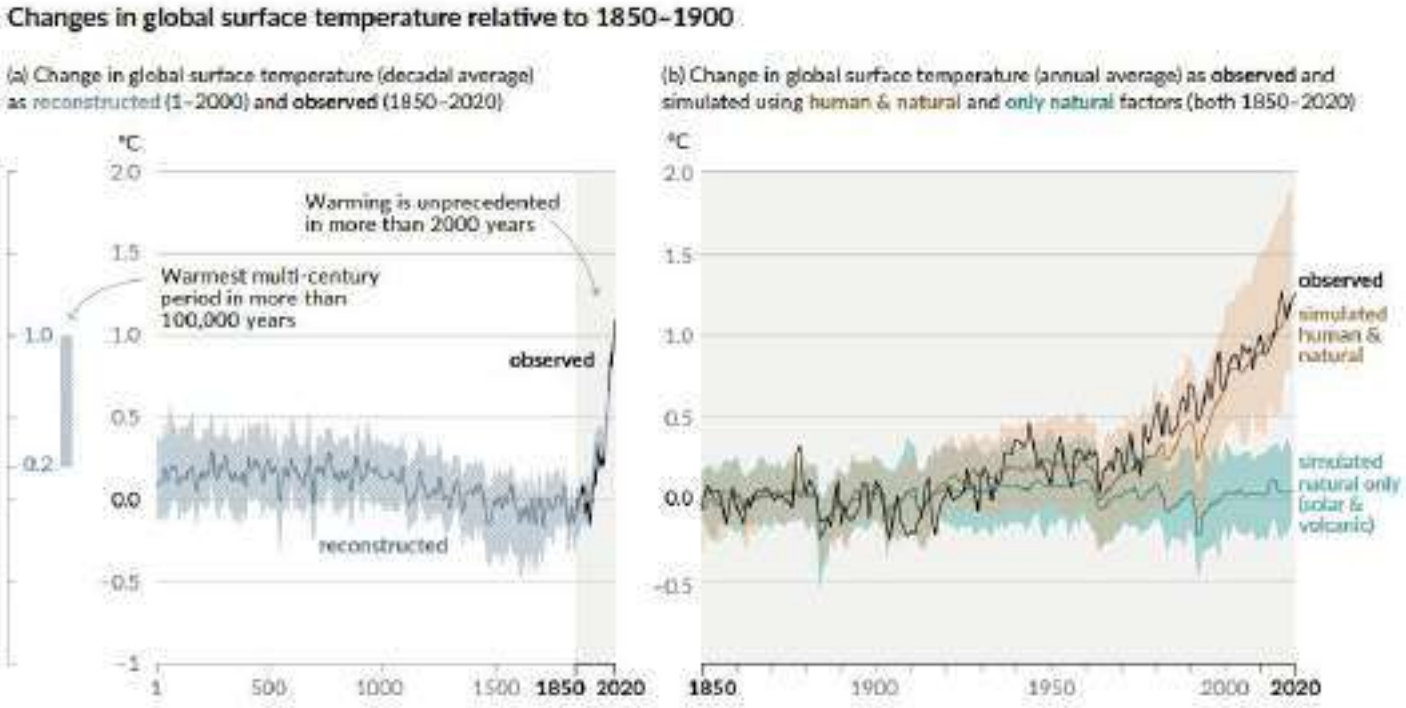
Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years



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Climate Change 2021
The Physical Science Basis
Summary for Policymakers

https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf

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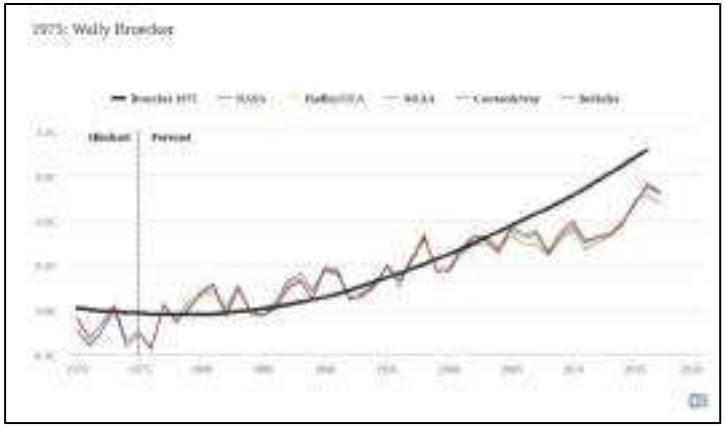

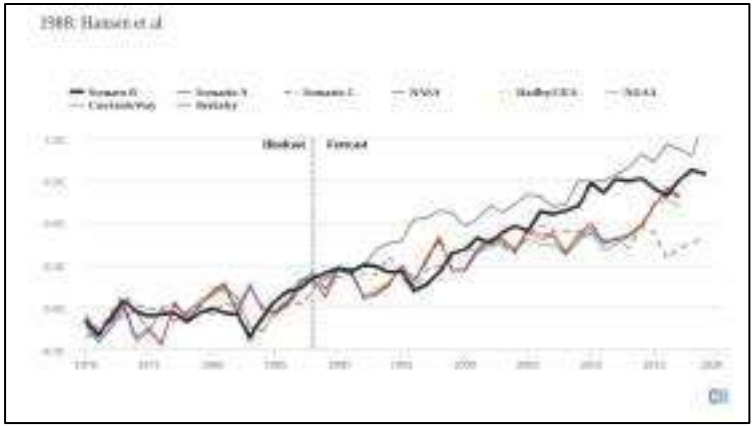

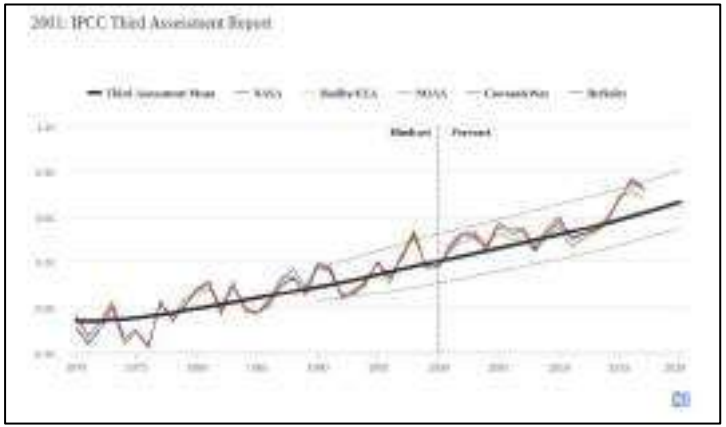

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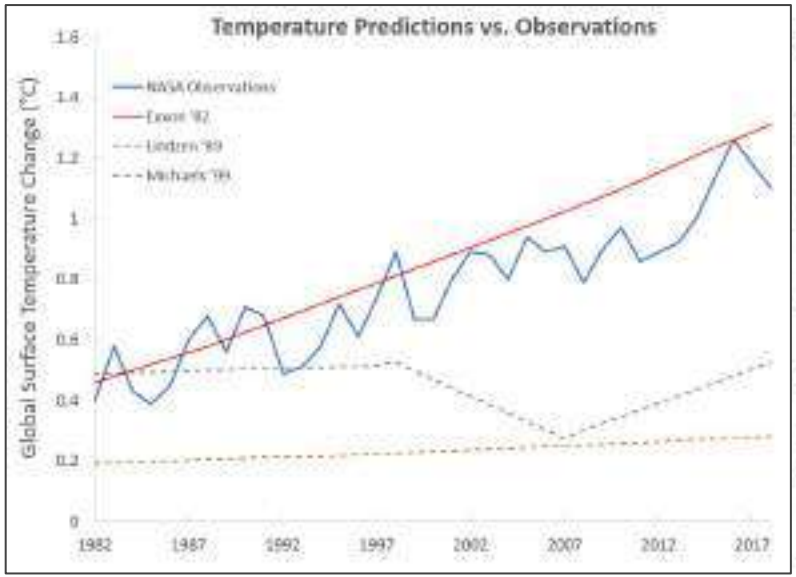

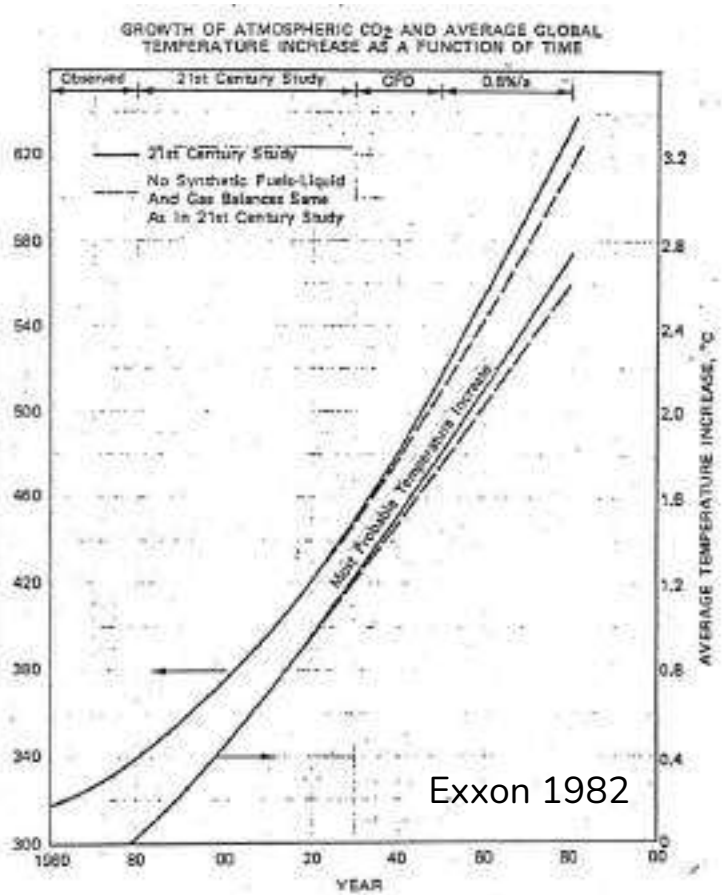

https://insideclimatenews.org/sites/default/files/documents/1982%20Exxon%20Primer%20on%20CO2%20Greenhouse%20Effect.pdf

emiliano.merlin@inaf.it

Scientific consensus is ~100%

Article

Scientists Reach 100% Consensus on Anthropogenic Global Warming

Bulletin of Science, Technology & Society
2017, Vol. 37(4) 183–184
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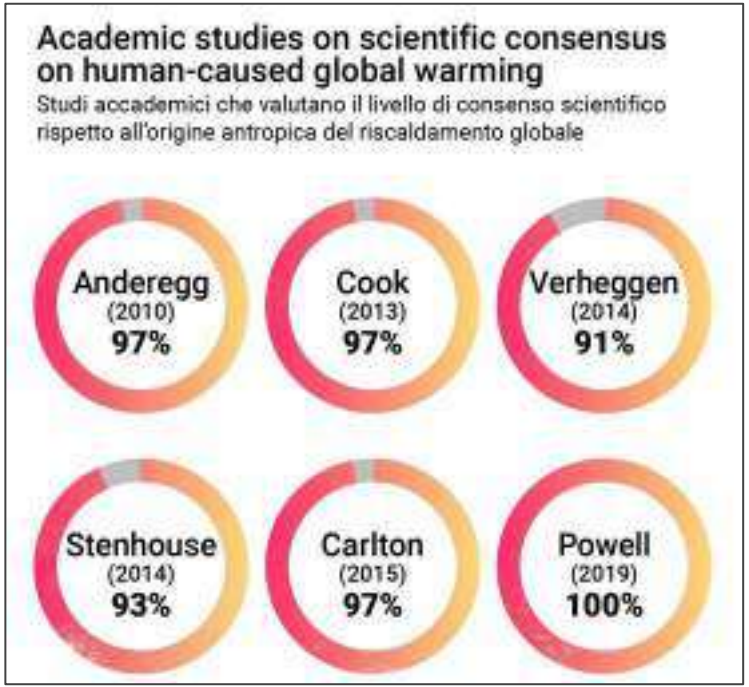
DOI: 10.1177/0270467619886266
journals.sagepub.com/home/bst
SAGE

James Powell[1]

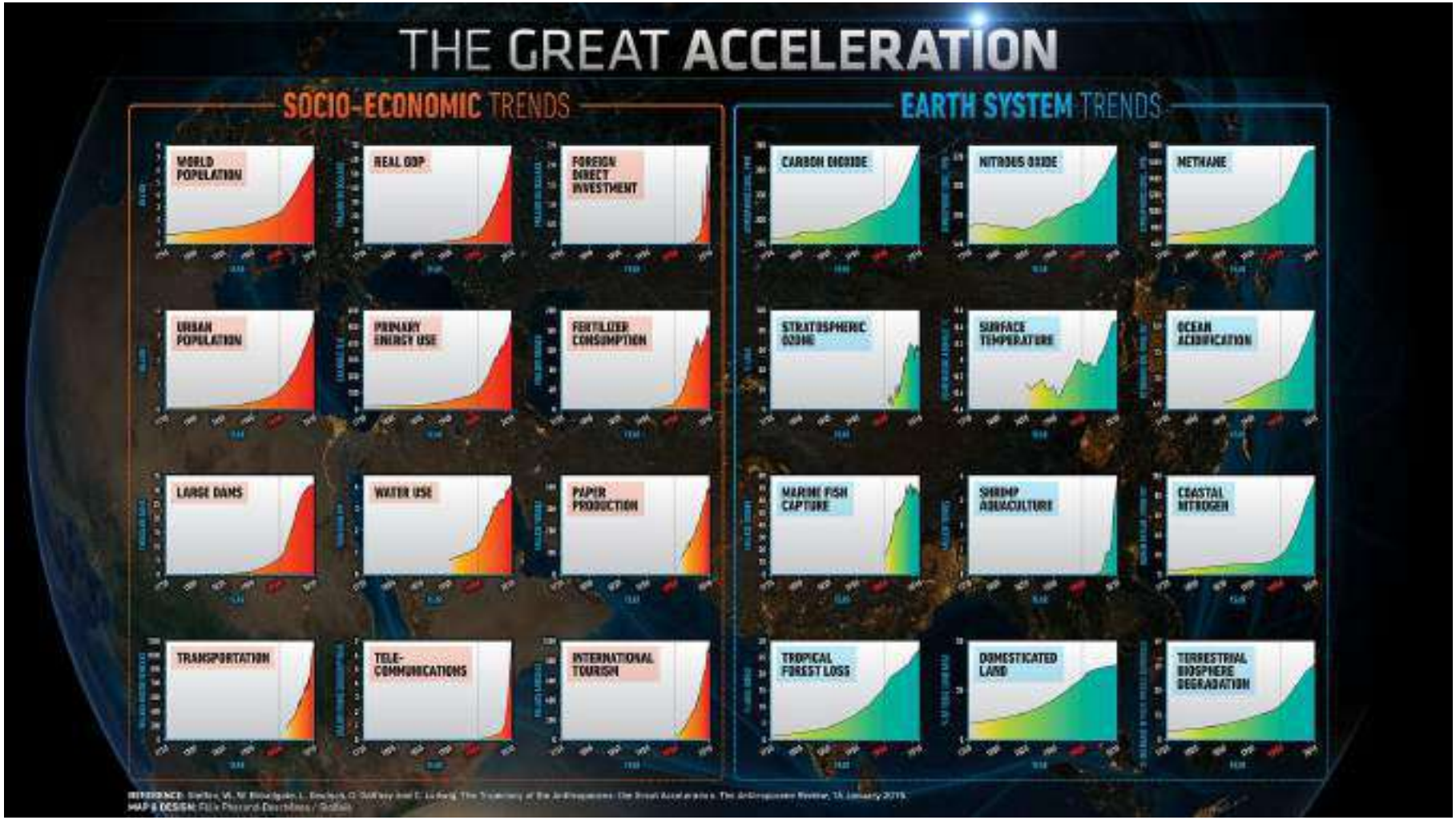
2019

Abstract
The consensus among research scientists on anthropogenic global warming has grown to 100%, based on a review of 11,602 peer-reviewed articles on "climate change" and "global warming" published in the first 7 months of 2019.

Keywords
global warming, climate change, anthropogenic global warming, consensus, climate



https://weather.com/science/environment/news/americans-climate-change-scientific-consensus


THE GREAT ACCELERATION
SOCIO-ECONOMIC TRENDS
WORLD POPULATION
REAL GDP
FOREIGN DIRECT INVESTMENT
URBAN POPULATION
PRIMARY ENERGY USE
FERTILIZER CONSUMPTION
LARGE DAMS
WATER USE
PAPER PRODUCTION
TRANSPORTATION
TELE-COMMUNICATIONS
INTERNATIONAL TOURISM
EARTH SYSTEM TRENDS
CARBON DIOXIDE
NITROUS OXIDE
METHANE
STRATOSPHERIC OZONE
SURFACE TEMPERATURE
OCEAN ACIDIFICATION
MARINE FISH CAPTURE
SHRIMP AQUACULTURE
COASTAL NITROGEN
TROPICAL FOREST LOSS
DOMESTICATED LAND
TERRESTRIAL BIOSPHERE DEGRADATION

emiliano.merlin@inaf.it

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2. Can we foresee the consequences of climate change?
3. Which are its physical causes?
4. Which human activities are more impactful?
5. What can/should we do?

Yes, yes, no.

emiliano.merlin@inaf.it

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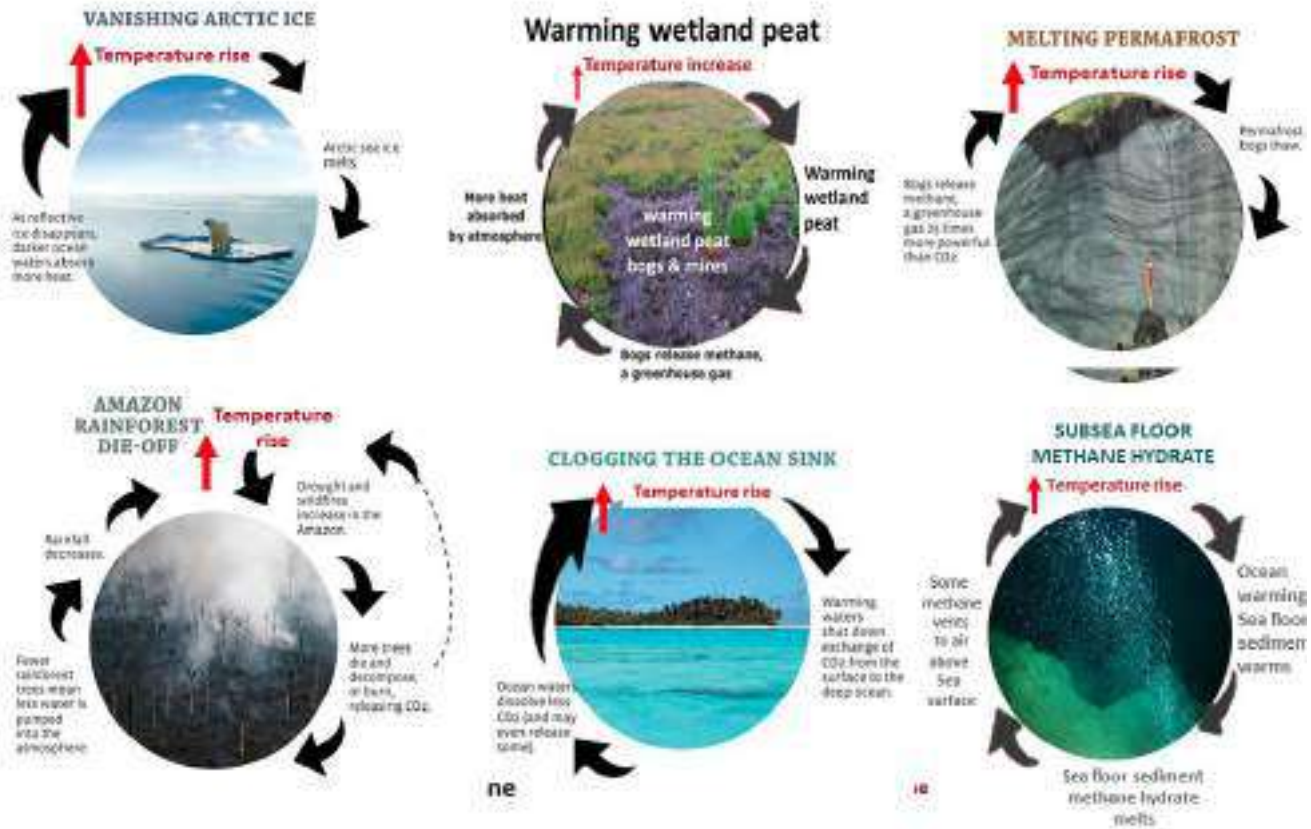
Feedback effects



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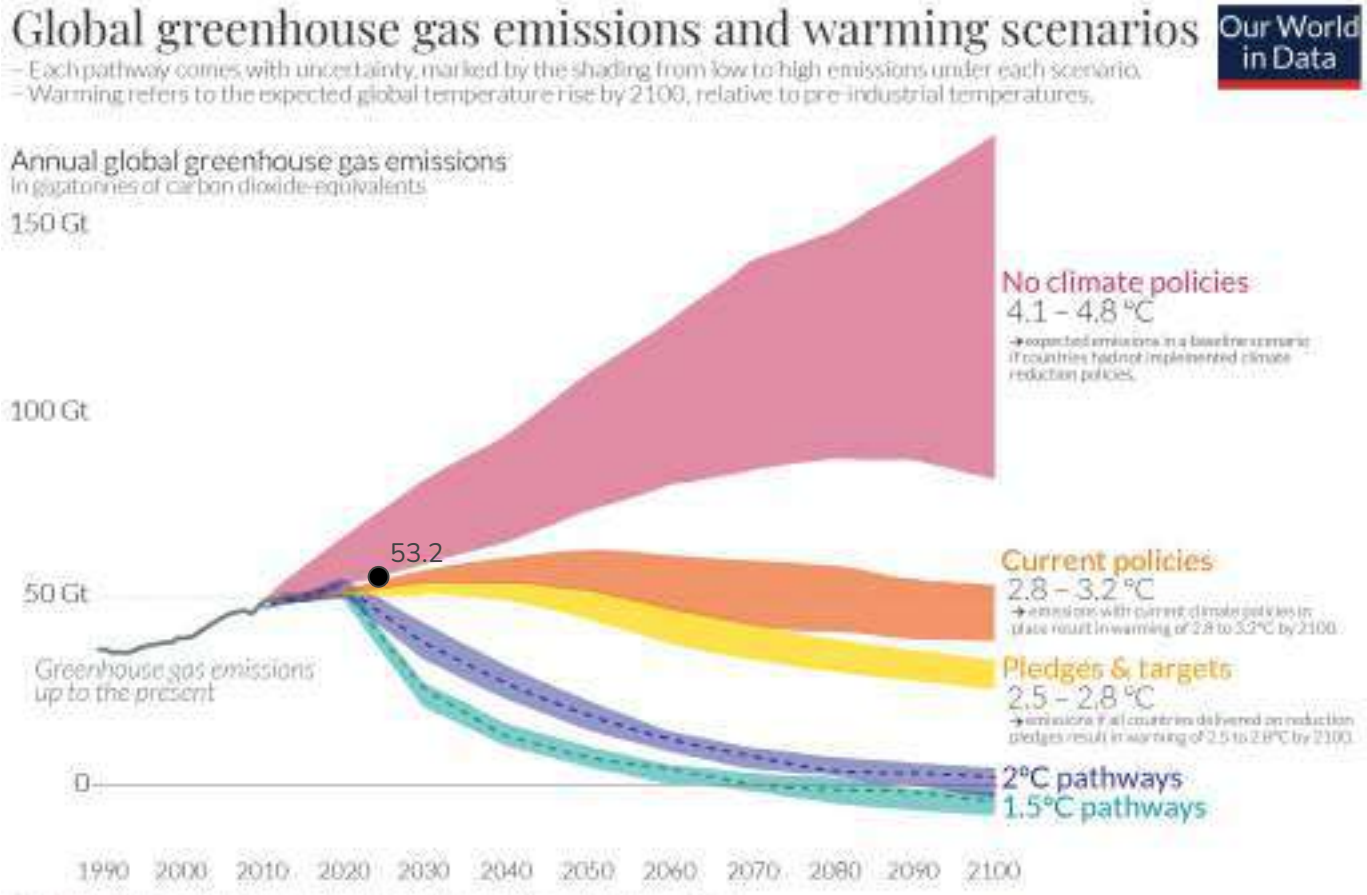

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INDEPENDENT

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BP and Shell planning for catastrophic 5°C global warming despite publicly backing Paris climate agreement

Companies are trying to 'have their oil and drink it' by committing to 2°C in public while planning for much higher temperature rises, says shareholder campaign group, ShareAction

Ben Chapman | @b_r_chapman | Friday 27 October 2017 08:07 |
35 comments

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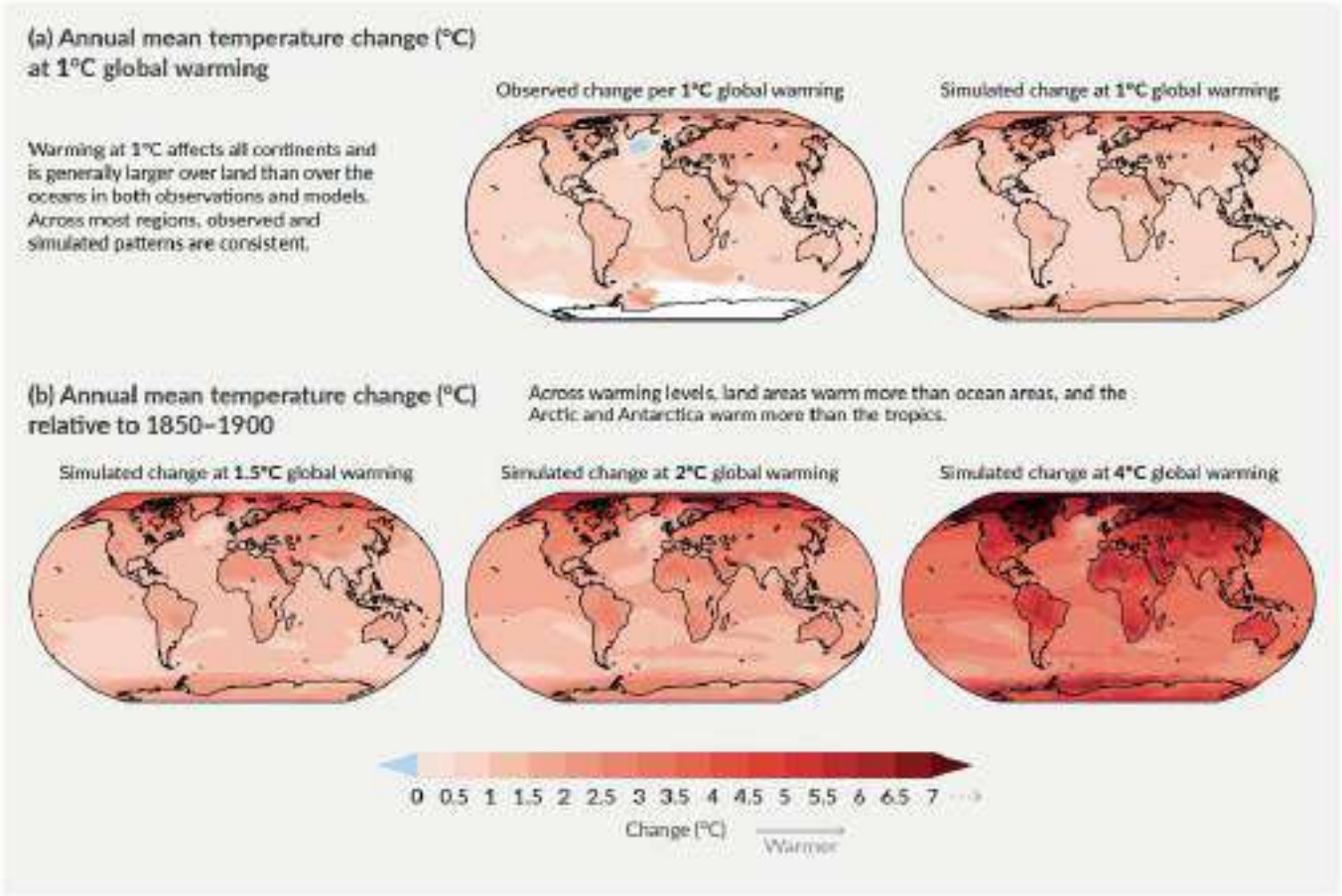

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Summary for Policymakers

https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf

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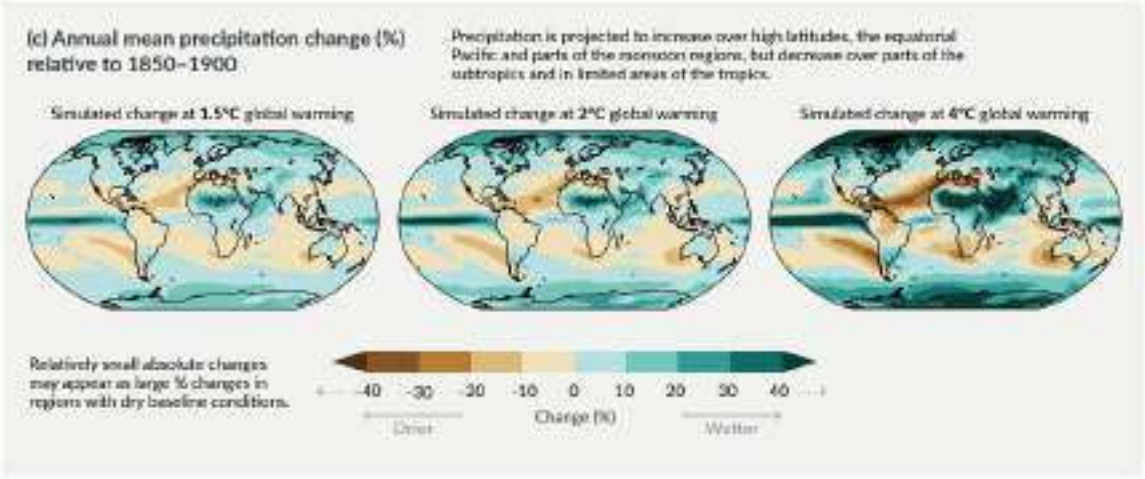
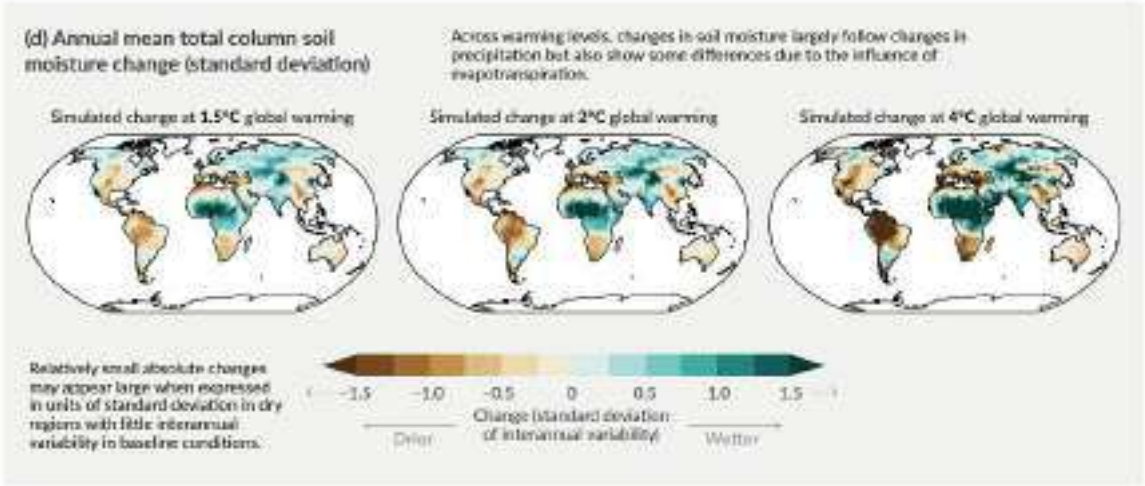
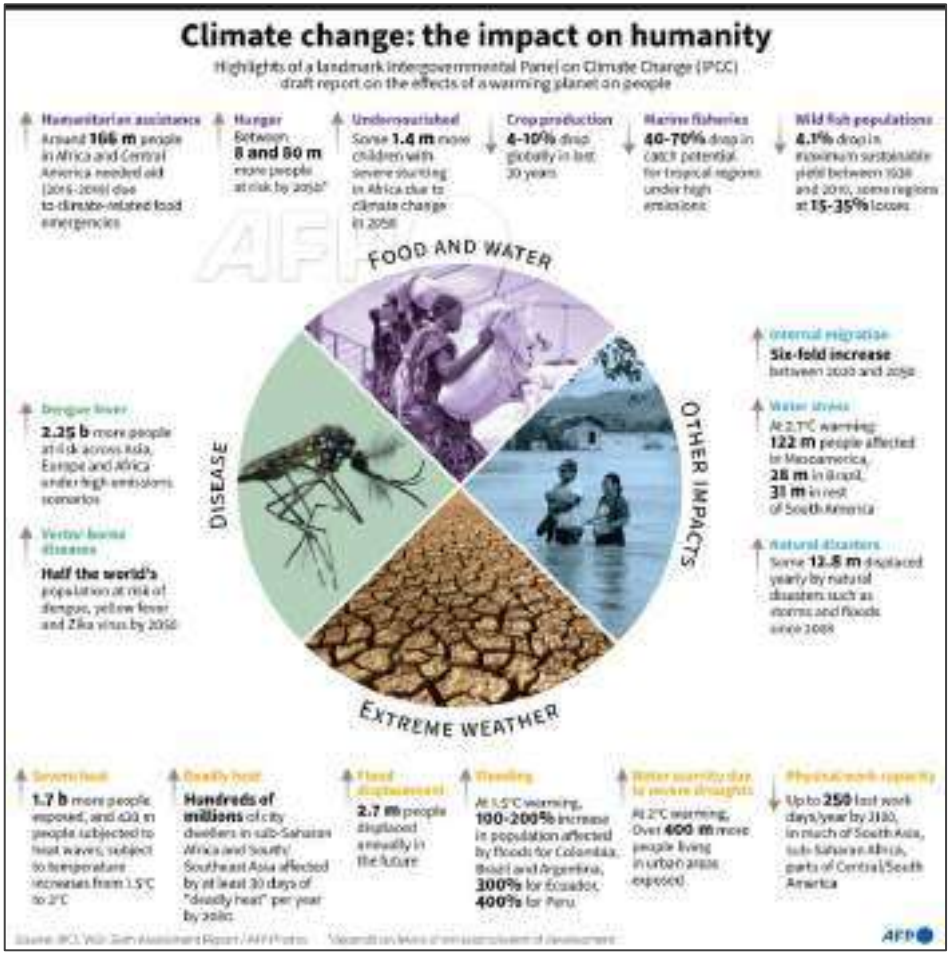
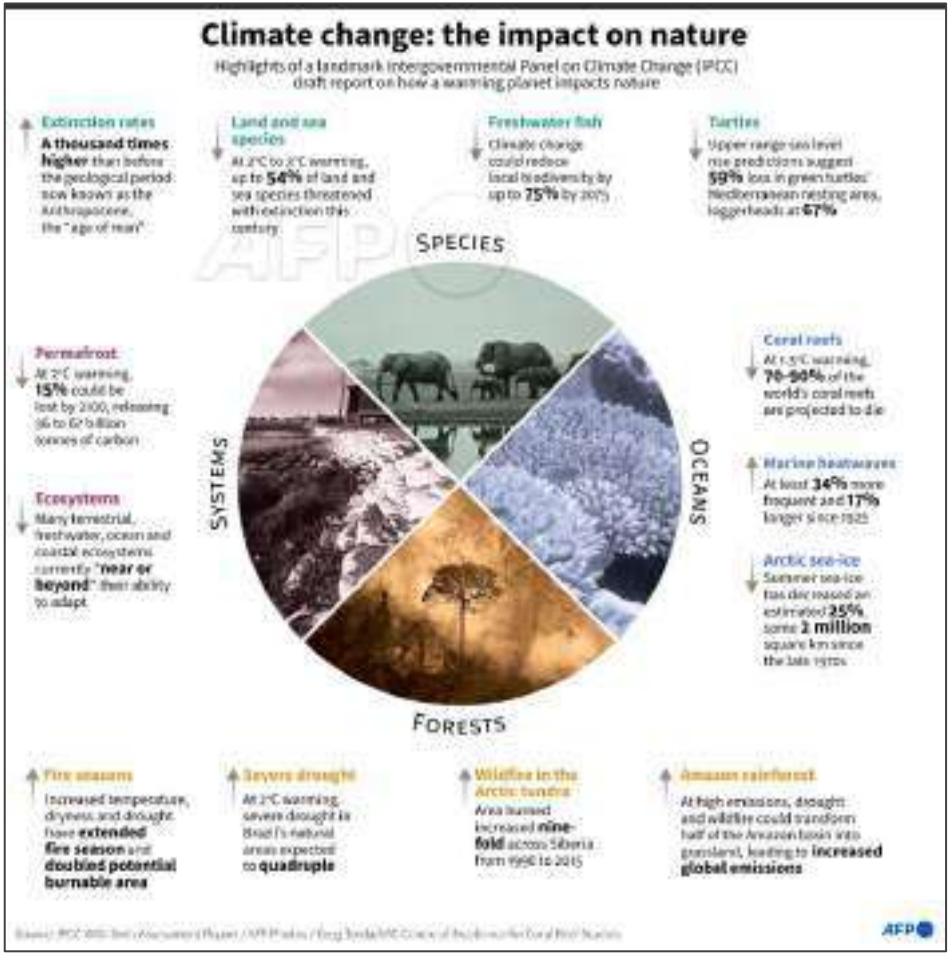




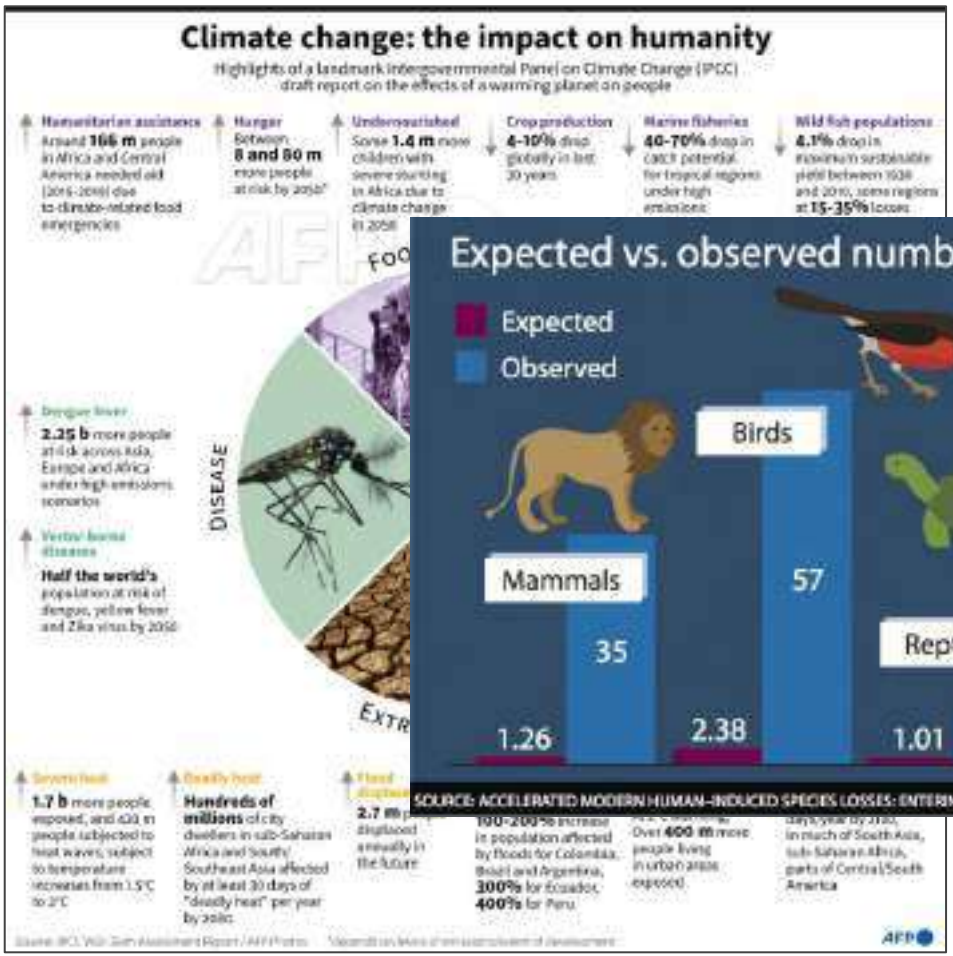
https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf





Report IPCC 2022

https://twitter.com/afp/status/1407514775882330112



Report IPCC 2022

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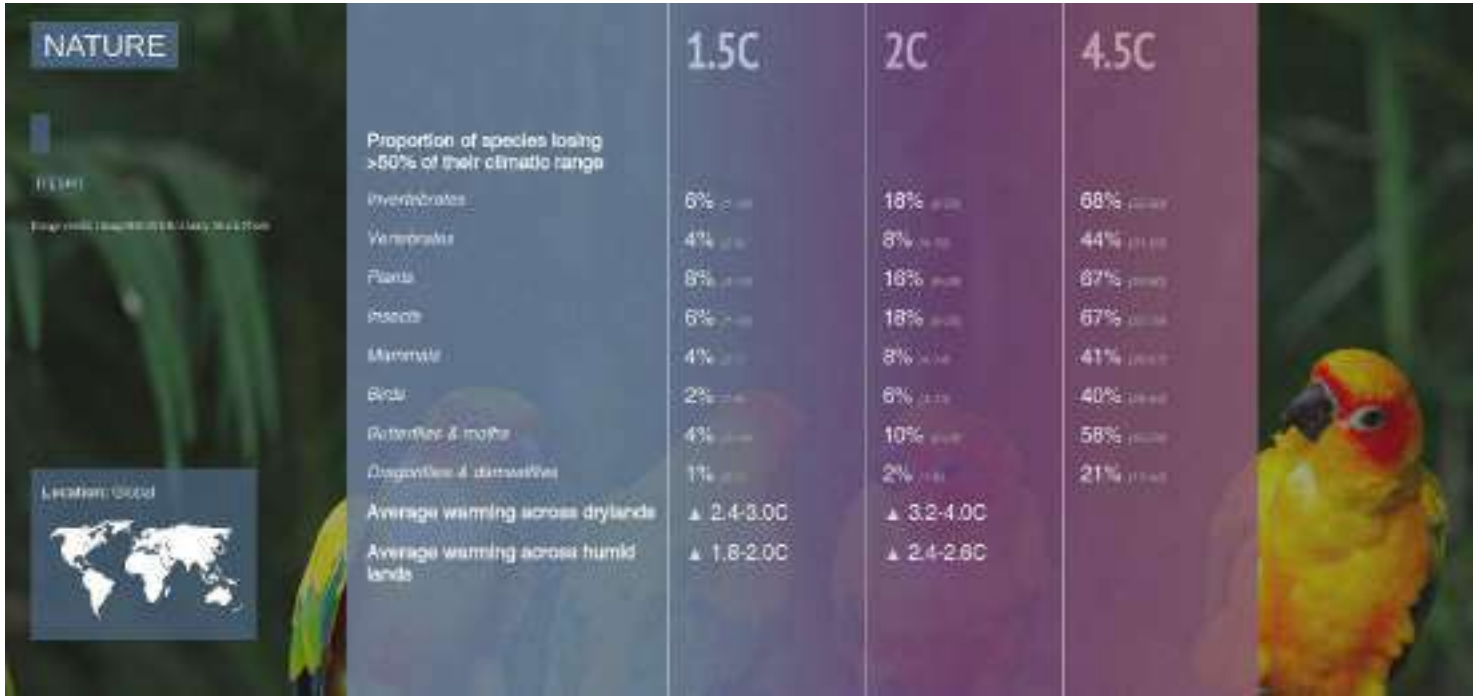
Consequences for the biosphere



https://interactive.carbonbrief.org/impacts-climate-change-one-point-five-degrees-two-degrees

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2. Can we foresee the consequences of climate change?
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4. Which human activities are more impactful?
5. What can/should we do?

Yes, within (large) uncertainties; it's *probably* going to be worse than we expect

emiliano.merlin@inaf.it

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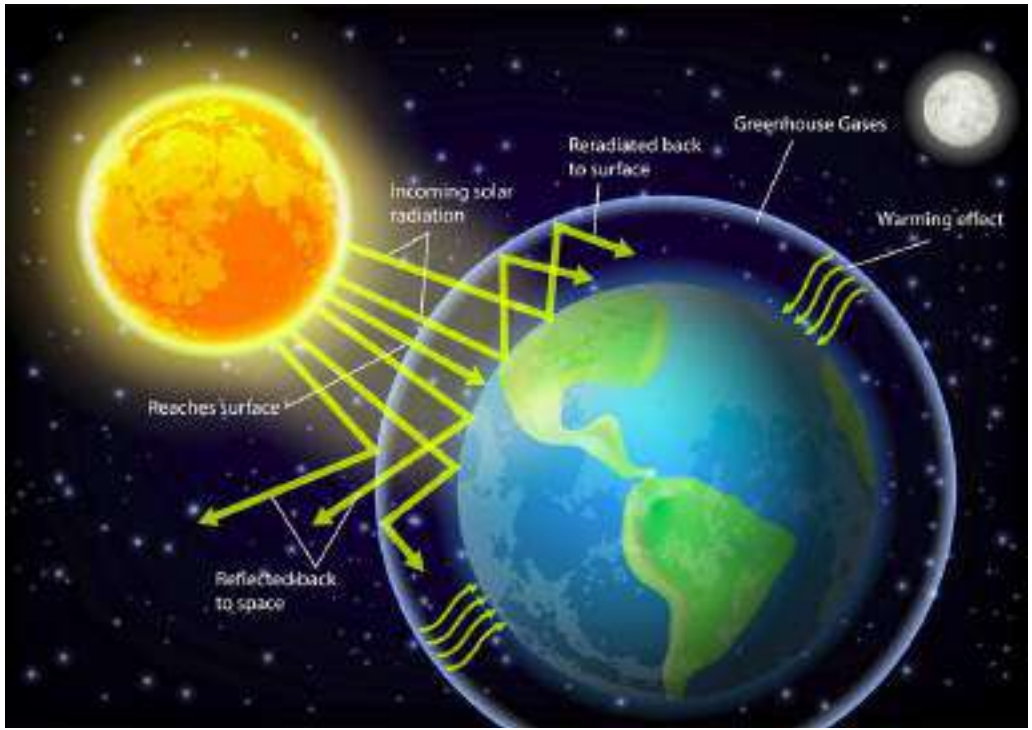
emiliano.merlin@inaf.it

Greenhouse effect



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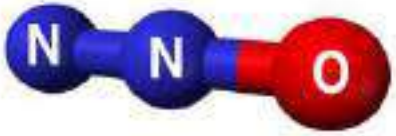
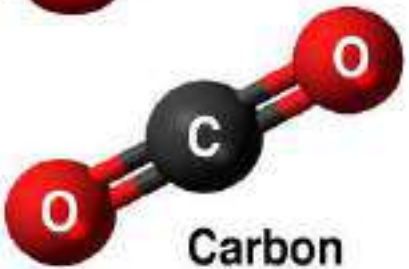
Greenhouse gases

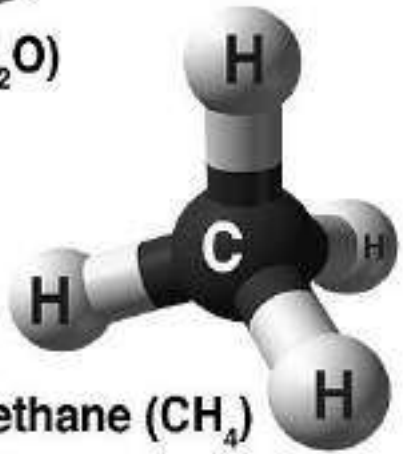
Water vapor (H_2O)



Nitrous oxide (N_2O)



Carbon dioxide (CO_2)

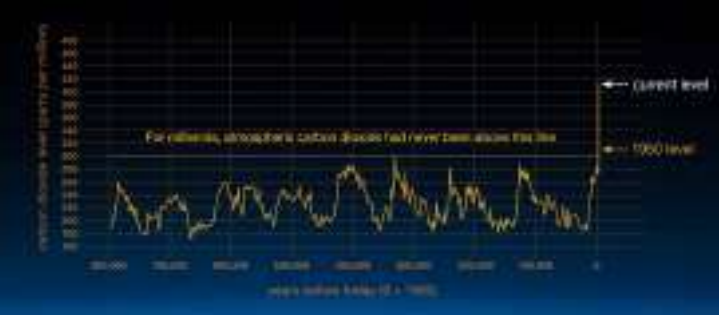


Methane (CH_4)

Water vapor is responsible for most of the "good" greenhouse effect, and would be in equilibrium if it were not perturbed by the other greenhouse gases released by human activities

https://climate.mit.edu/ask-mit/why-do-we-blame-climate-change-carbon-dioxide-when-water-vapor-much-more-common-greenhouse

https://climate.nasa.gov/causes/

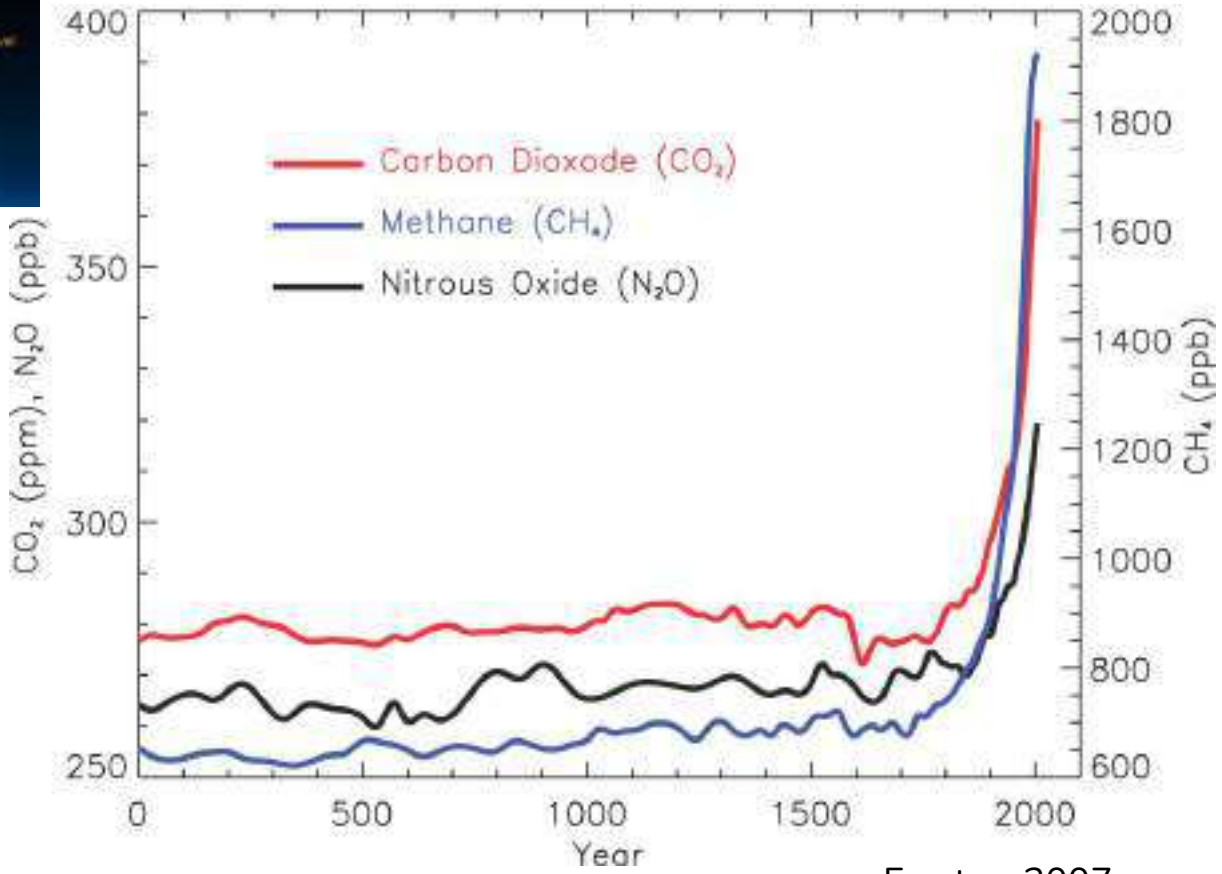


W.r.t. pre-industrial values:

CO2: (425) +50%

CH4: (1934)+300%

N2O: (337) +30%



Forster+2007

https://nca2009.globalchange.gov/2000-years-greenhouse-gas-concentrations/index.html

emiliano.merlin@inaf.it

Table SPM1. Net anthropogenic emissions due to Agriculture, Forestry, and other Land Use (AFOLU) and non-AFOLU (Panel 1) and global food systems (average for 2007-2016)[1] (Panel 2). Positive value represents emissions; negative value represents removals.

		Direct Anthropogenic							
		Net anthropogenic emissions due to Agriculture, Forestry, and Other Land Use (AFOLU)			Non-AFOLU anthropogenic GHG emissions[6]	Total net anthropogenic emissions (AFOLU + non-AFOLU) by gas	AFOLU as a % of total net anthropogenic emissions, by gas	Natural response of land to human-induced environmental change[7]	Net land – atmosphere flux from all lands
Panel 1: Contribution of AFOLU									
		FOLU	Agriculture	Total					
		A	B	C = B + A	D	E = C + D	F = (C/E)*100	G	A + G
CO_2[2]	Gt CO_2 y^{-1}	5.2 ± 2.6	–[11]	5.2 ± 2.6	33.9 ± 1.8	**39.1 ± 3.2**	~13%	-11.2 ± 2.6	-6.0 ± 2.0
CH_4[3,8]	Mt CH_4 y^{-1}	19 ± 6	142 ± 43	162 ± 48.6	201 ± 100	**363 ± 111**			
	Gt CO_2e y^{-1}	0.5 ± 0.2	4.0 ± 1.2	4.5 ± 1.4	5.6 ± 2.8	**10.1 ± 3.1**	~44%		
N_2O[3,8]	Mt N_2O y^{-1}	0.3 ± 0.1	8 ±2	8.3 ± 2.5	2.0 ± 1.0	**10.4 ± 2.7**			
	Gt CO_2e y^{-1}	0.09 ± 0.03	2.2 ± 0.7	2.3 ± 0.7	0.5 ± 0.3	**2.8 ± 0.7**	~82%		
Total (GHG)	**Gt CO_2e y^{-1}**	**5.8 ± 2.6**	**6.2 ± 1.4**	**12.0 ± 3.0**	**40.0 ± 3.4**	**52.0 ± 4.5**	**~23%**		

ipcc
INTERGOVERNMENTAL PANEL ON climate change

CO2 → 39.1 Gt/yr
CH4 → 0.363 Gt/yr

https://www.ipcc.ch/site/assets/uploads/2019/08/Fullreport-1.pdf

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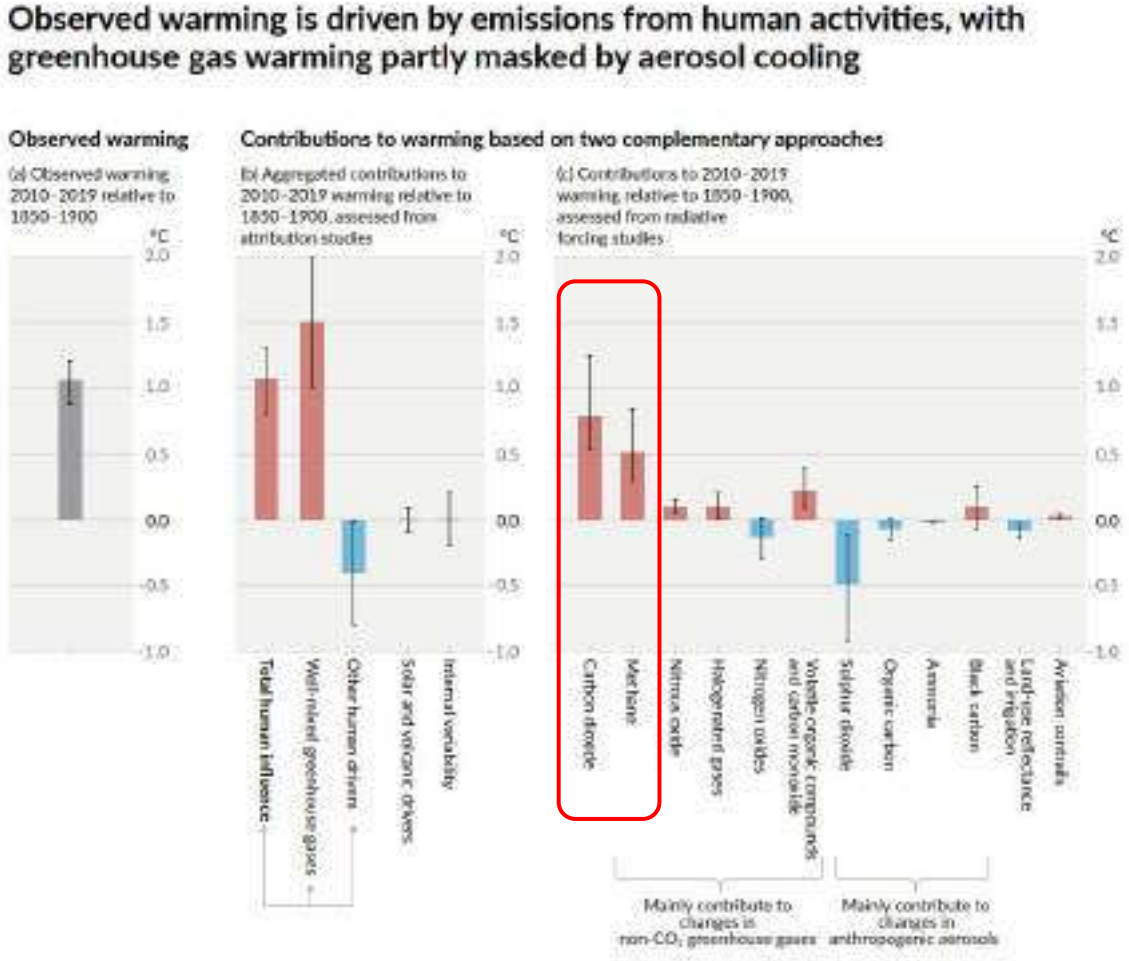
Methane

CO2 → 39.1 Gt/yr
CH4 → 0.363 Gt/yr



https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf

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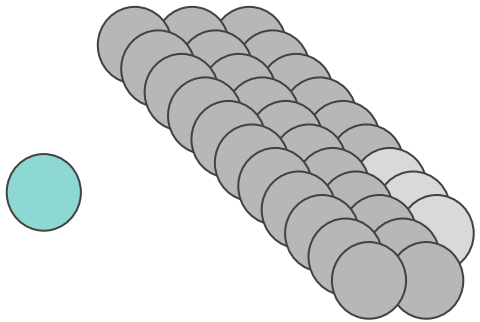
Global Warming Potential

Substance	AR1 (1990)	AR2 (1995)	AR3 (2001)	AR4 (2007)	AR5 (2013)
Carbon dioxide, fossil (CO_2)	1	1	1	1	1
Methane, fossil (CH_4)	21	21	23	25	28
Methane, biogenic (CH_4)	18.25	18.25	20.25	22.25	25.25
Dinitrogen monoxide (N_2O)	290	310	296	298	265
HCFC-141b	440	-	700	725	782
HFC-134a	1200	1300	1300	1430	1300
HCFC-22	1500	-	1700	1810	1760
HCFC-142b	1600	-	2400	2310	1980
CFC-11	3500	-	4600	4750	4660
CFC-12	7300	-	10600	10900	10200
Sulfur hexafluoride	-	23900	22200	22800	23500



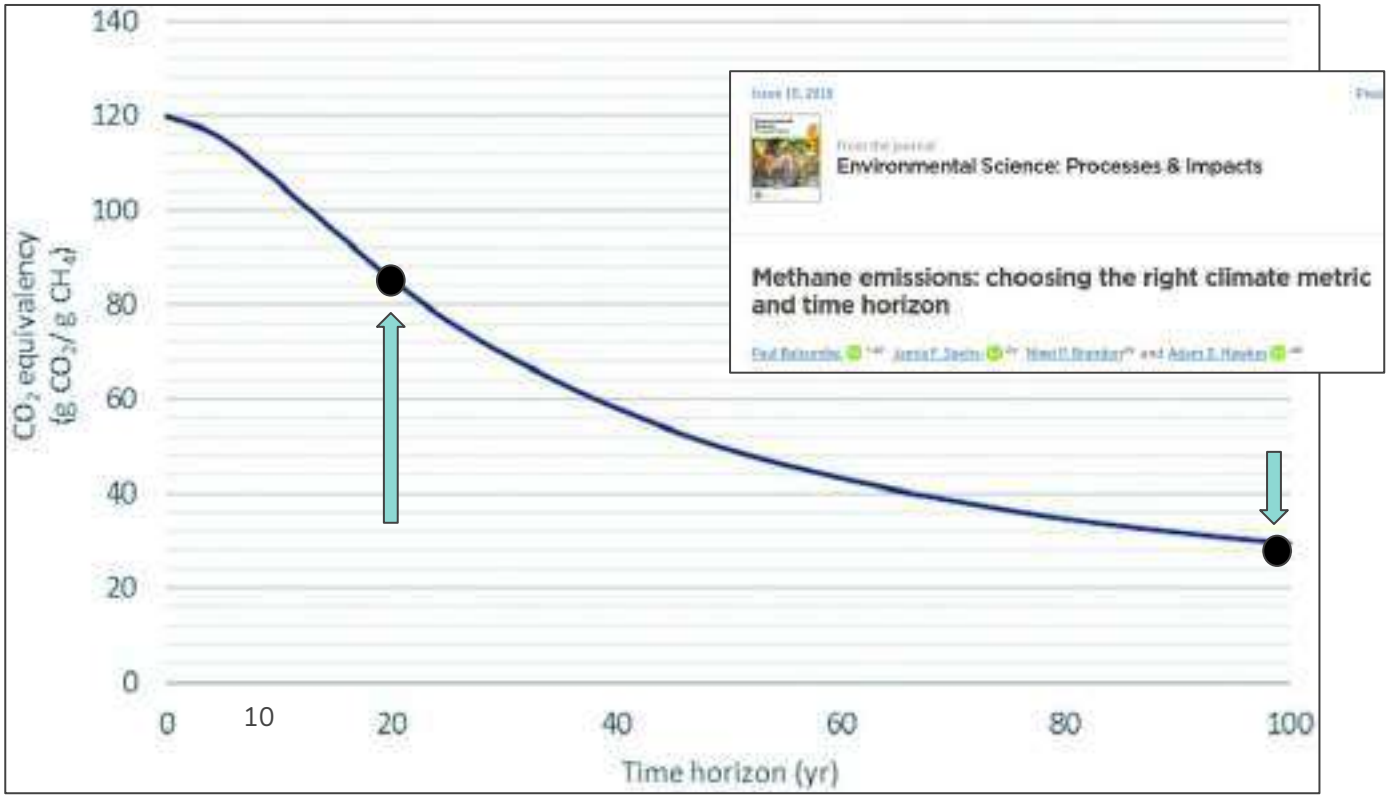
1 ton CH4 ≈25-28 ton CO2
IPCC 2019 report

https://www.ipcc.ch/assessment-report/ar5/

CH4 → 28 x 0.363 = 10.16 GtCO2eq/yr

emiliano.merlin@inaf.it

Methane GWP as a function of time horizon



https://pubs.rsc.org/en/content/articlelanding/2018/em/c8em00414e#!divAbstract

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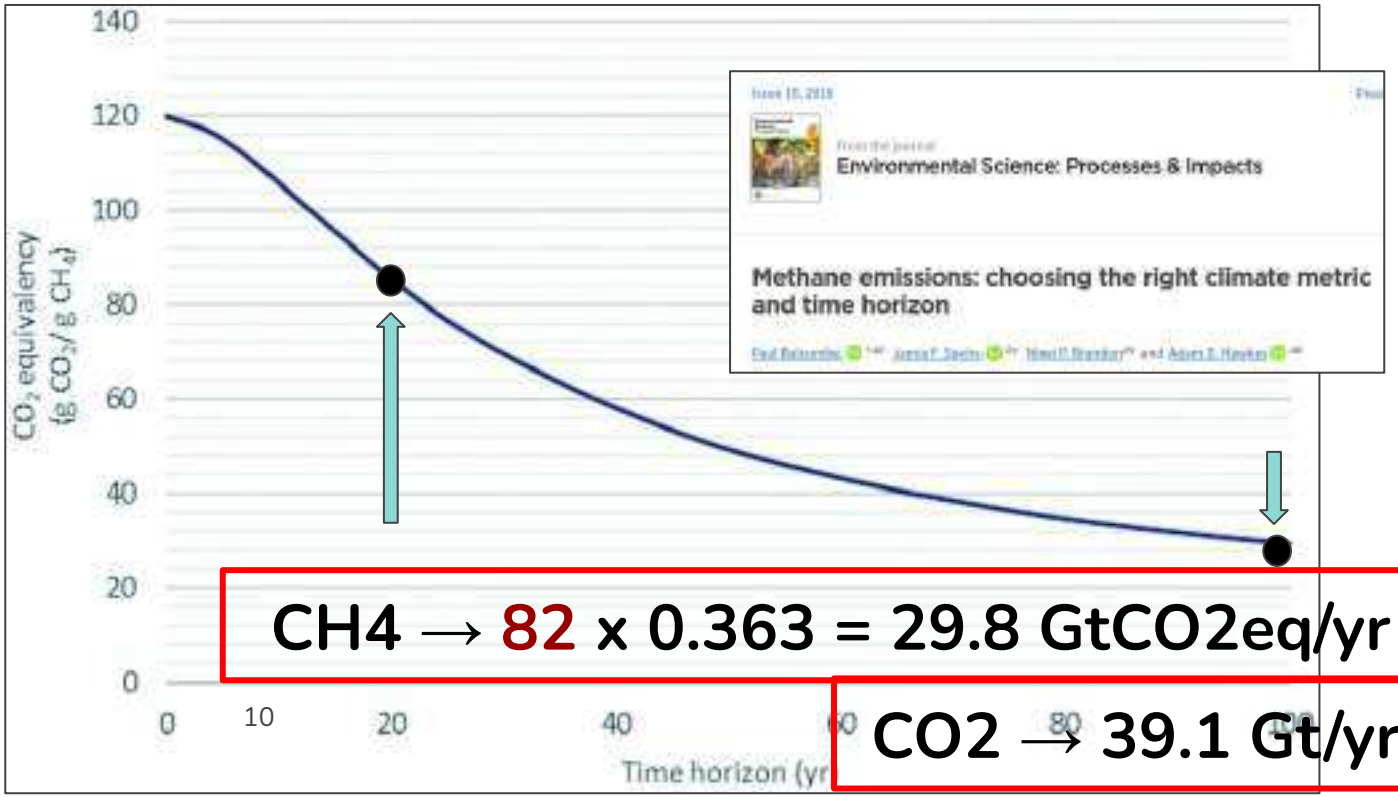
Methane GWP as a function of time horizon



https://pubs.rsc.org/en/content/articlelanding/2018/em/c8em00414e#!divAbstract

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Climate Change 2014
Mitigation of Climate Change

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INTERGOVERNMENTAL PANEL ON climate change

Table 1.1 | Implications of the choice of Global Warming Potential (GWP) for mitigation strategy. Table shows the main geophysical properties of the major Kyoto gases and the implications of the choice of values for GWPs with different time horizons (20, 100, or 500 years) on the share of weighted total emissions for 2010; other IPCC chapters report detail on alternative indexes such as Global Temperature change Potential (GTP) (Chapter 3; WGI Chapter 8). At present, the 100-year GWPs are used most widely, and we show those values as reported in the IPCC Second Assessment Report (SAR) in 1995 and subsequently used in the Kyoto Protocol. Note that CO_2 is removed by multiple processes and thus has no single lifetime (see WGI Box 6.1). We show CF_4 as one example of the class of perfluorocarbons (PFCs) and HFC-134a and HFC-23 as examples of hydrofluorocarbons (HFCs). All other industrial fluorinated gases listed in the Kyoto Protocol ('F-gases') are summed. We do not show warming agents that are not included in the Kyoto Protocol, such as black carbon. Emissions reported in JRC/PBL (2013) using GWPs reported in IPCC's Second, Fourth and Fifth Assessment Reports (IPCC, 1995, 2007c, 2013a). The AR4 was used for GWP-500 data; interpretation of long time horizon GWPs is particularly difficult due to uncertainties in carbon uptake and climate response—differences that are apparent in how different models respond to different pulses and scenarios for CO_2 and the many nonlinearities in the climate system (see WGI, Supplemental Material 8.SM.11.4 and Joos et al., 2013) and thus IPCC no longer reports 500 year GWPs. Due to changes in the GWP values from AR4 to AR5 the 500-year shares are not precisely comparable with the other GWPs reported here. Geophysical properties of the gases drawn from WGI, Appendix 8.A, Table 8.A.1—final draft data).

Kyoto gases	Geophysical properties		GWP-weighted share of global GHG emissions in 2010			
	Atmospheric lifetime (year)	Instantaneous forcing (W/m²/ppb)	SAR (Kyoto)	WGI (20 and 100 year from AR5 & 500 year from AR4)		
			100 years	20 years	100 years	500 years
CO_2	various	1.37×10^{-5}	76%	52%	73%	88%
CH_4	12.4	3.63×10^{-4}	16%	40%	20%	7%
N_2O	121	3.00×10^{-3}	6.2%	3.6%	5.0%	3.5%
F-gases:			2.0%	2.3%	2.2%	1.8%
HFC-134a	13.4	0.16	0.5%	0.9%	0.4%	0.2%
HFC-23	222	0.18	0.4%	0.3%	0.4%	0.5%
CF_4	50,000	0.09	0.1%	0.1%	0.1%	0.2%
SF_6	3,200	0.57	0.3%	0.2%	0.3%	0.5%
NF_3 *	500	0.20	not applicable	0.0%	0.0%	0.0%
Other F-gases **	various	various	0.1%	0.9%	0.8%	0.4%

* NF_3 was added for the second commitment period of the Kyoto period. NF_3 is included here but contributes much less than 0.1%.
** Other HFCs, PFCs and SF_6 included in the Kyoto Protocol's first commitment period. For more details see the Glossary (Annex I).

https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_full.pdf

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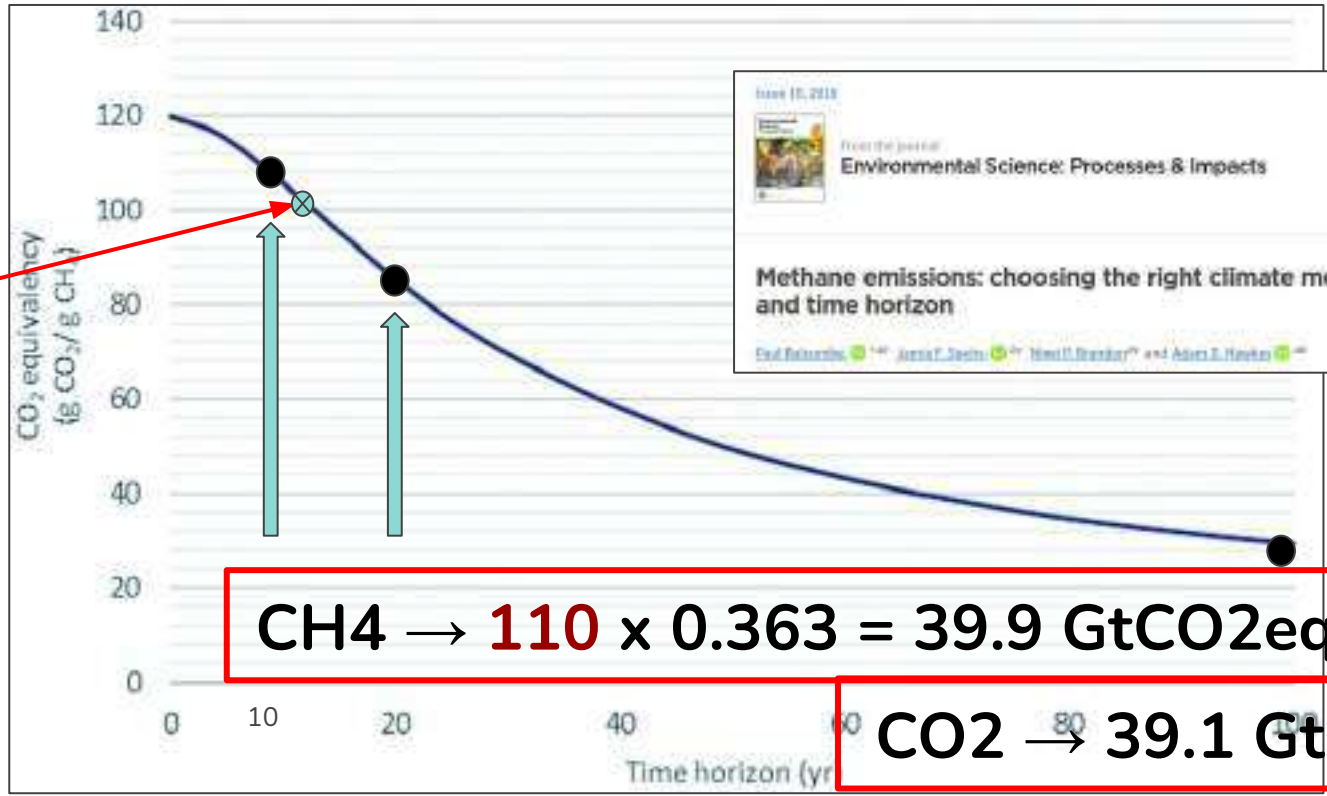
Methane GWP as a function of time horizon

Methane average lifetime in atmosphere: ~12 years



CH4 → 110 x 0.363 = 39.9 GtCO2eq/yr

CO2 → 39.1 Gt/yr

https://pubs.rsc.org/en/content/articlelanding/2018/em/c8em00414e#!divAbstract

Fate of anthropogenic CO_2 emissions (2013–2022)

Sources = **Sinks**

35.3 $GtCO_2/yr$

88%

12%

4.7 $GtCO_2/yr$

18.9 $GtCO_2/yr$

47%

31%

12.3 $GtCO_2/yr$

26%

10.4 $GtCO_2/yr$

Trees and other plants absorb carbon dioxide from the atmosphere as they grow. This is converted into carbon and stored in the plant's branches, leaves, trunks, roots and in the soil.

When forests are cleared or burnt, stored carbon is released into the atmosphere, mainly as carbon dioxide.

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

4%
-1.6 $GtCO_2/yr$

Source: Friedlingstein et al 2023; Global Carbon Project 2023

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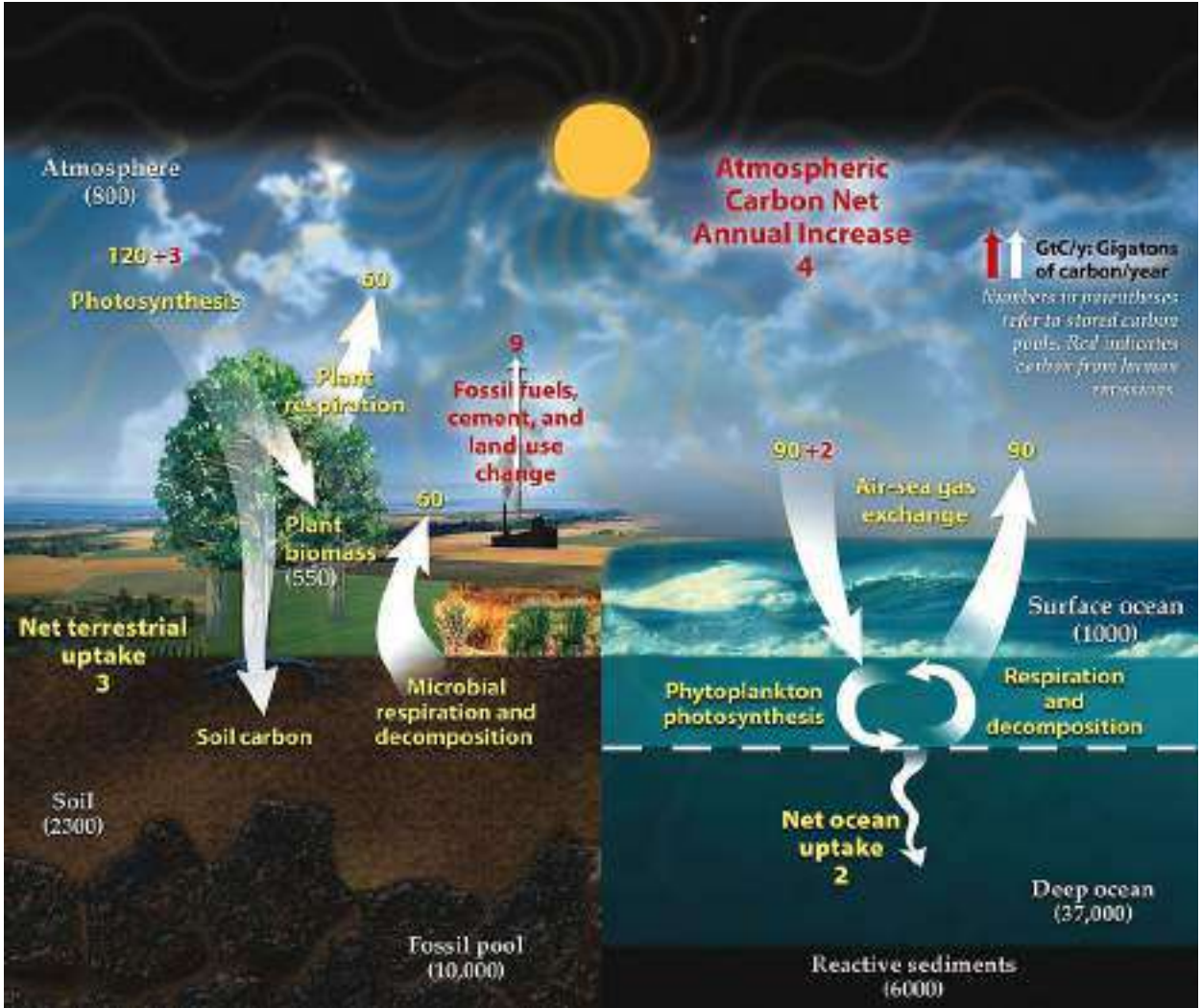
Carbon cycle



https://earthobservatory.nasa.gov/features/CarbonCycle

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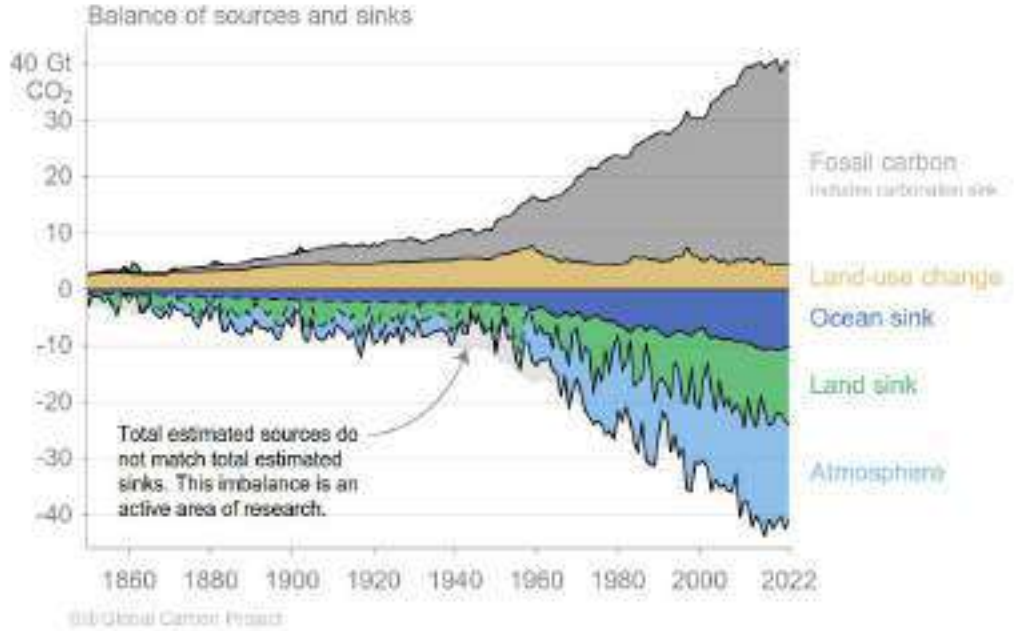
Carbon emissions are partitioned among the atmosphere and carbon sinks on land and in the ocean
The "imbalance" between total emissions and total sinks is an active area of research



https://www.globalcarbonproject.org/index.htm

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Table SPM.1. Net anthropogenic emissions due to Agriculture, Forestry, and other Land Use (AFOLU) and non-AFOLU (Panel 1) and global land systems (average for 2007–2016)[1] (Panel 2). Positive value represents emissions, negative value represents removals.

		Direct Anthropogenic						
		Net anthropogenic emissions due to Agriculture, Forestry, and Other Land Use (AFOLU)			Non-AFOLU anthropogenic GHG emissions[2]	Total net anthropogenic emissions (AFOLU + non-AFOLU) by gas	AFOLU as a % of total net anthropogenic emissions, by gas	Natural response of land or human-induced environmental change[3]
Panel 1: Contribution of AFOLU								
		FOLU	Agriculture	Total				
		A	B	C = B + A	D	E = C + D	F = (C/E)*100	G
CO_2	($GtCO_2 y^{-1}$)	5.2 ± 2.6	[4]	5.2 ± 2.6	33.8 ± 1.8	39.1 ± 3.2	~13%	-11.2 ± 2.6
CH_4[5]	($MtCH_4 y^{-1}$)	19 ± 6	342 ± 43	362 ± 46.6	204 ± 109	363 ± 131		
	($GtCO_2eq y^{-1}$)	0.5 ± 0.2	4.8 ± 1.2	4.5 ± 1.4	5.6 ± 2.8	10.1 ± 3.1	~44%	
N_2O[5]	($MtN_2O y^{-1}$)	0.3 ± 0.1	8 ± 2	8.3 ± 2.5	2.0 ± 1.0	10.4 ± 2.7		
	($GtCO_2eq y^{-1}$)	0.09 ± 0.03	2.2 ± 0.7	2.3 ± 0.7	0.5 ± 0.3	2.8 ± 0.7	~82%	
Total (GHG)	$GtCO_2eq y^{-1}$	5.8 ± 2.6	6.2 ± 1.4	12.0 ± 3.8	40.8 ± 3.4	52.8 ± 4.5	~23%	

$CO_2 \rightarrow 39.1$ Gt/yr

$CH_4 \rightarrow 0.363$ Gt/yr

$CO_2 \rightarrow 0.5 \times 39.1 = 19.55$ Gt/yr

$CH_4 \rightarrow 110 \times 0.363 = 39.93$ GtCO2eq/yr

emiliano.merlin@inaf.it

1. Is climate changing? Is it caused by human activities? Is this debated by experts?
2. Can we foresee the consequences of climate change?
3. Which are its physical causes?
4. Which human activities are more impactful?
5. What can/should we do?

Anthropogenic greenhouse gases. CO_2 on long time scales; currently, CH_4 causes most (up to 2:1) of warming rate

emiliano.merlin@inaf.it

1. Is climate changing? Is it caused by human activities? Is this debated by experts?
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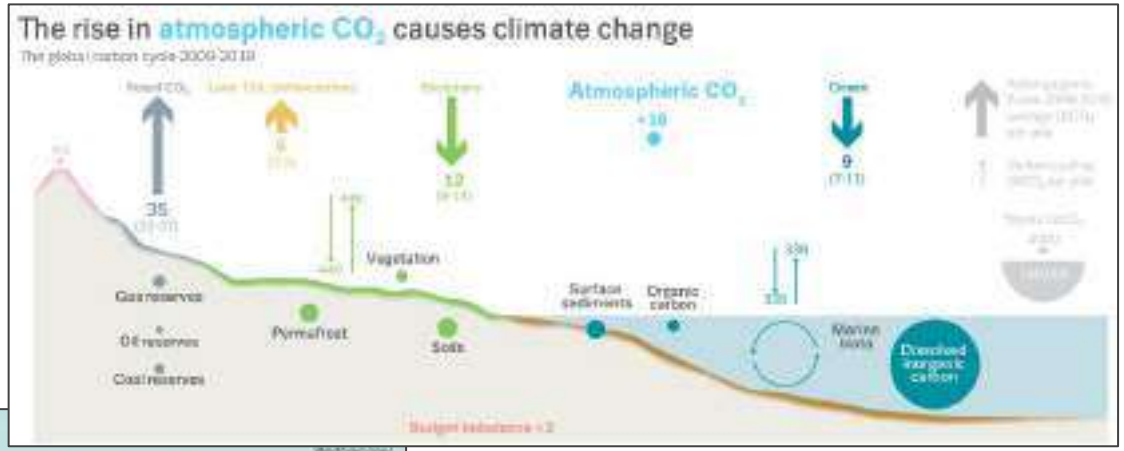
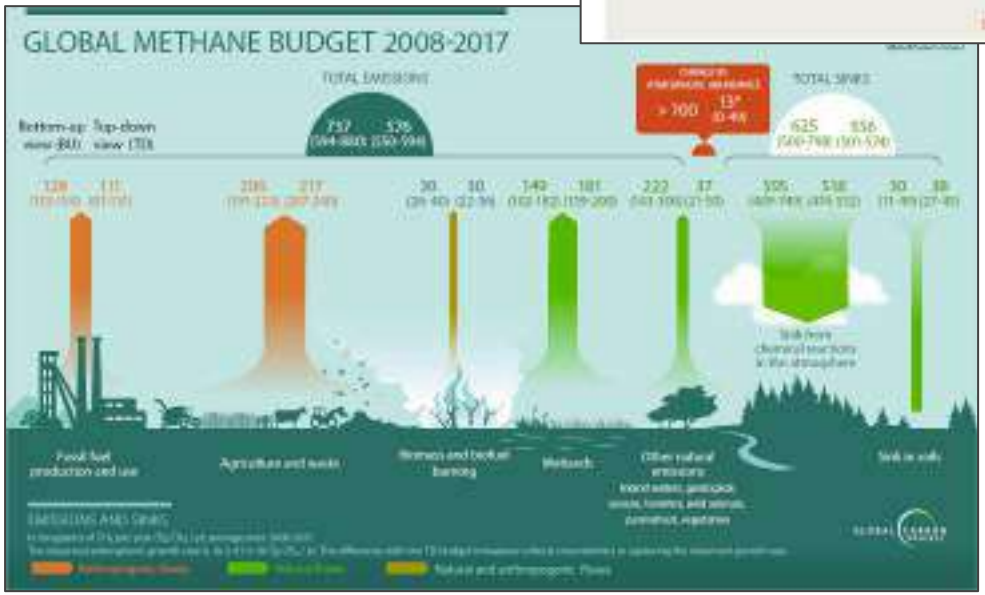
emiliano.merlin@inaf.it

Anthropogenic sources of greenhouse gases

https://www.globalcarbonproject.org/





Anthropogenic emissions

CO2 41 Gt/yr
Fossil fuels 35 Gt/yr = 85%
Land use 6 Gt/yr = 15%

CH4 358 Mt/yr (62% of total)
[+ Natural 218 Mt/yr (38% of total)]
Fossil fuels 128 Mt/yr = 35%
Animal farming 111 Mt/yr = 31%
Waste management 65+5 Mt/yr = 20%
Rice cultivation 30 Mt/yr = 7%
Biomass/biofuel 30 Mt/yr = 7%

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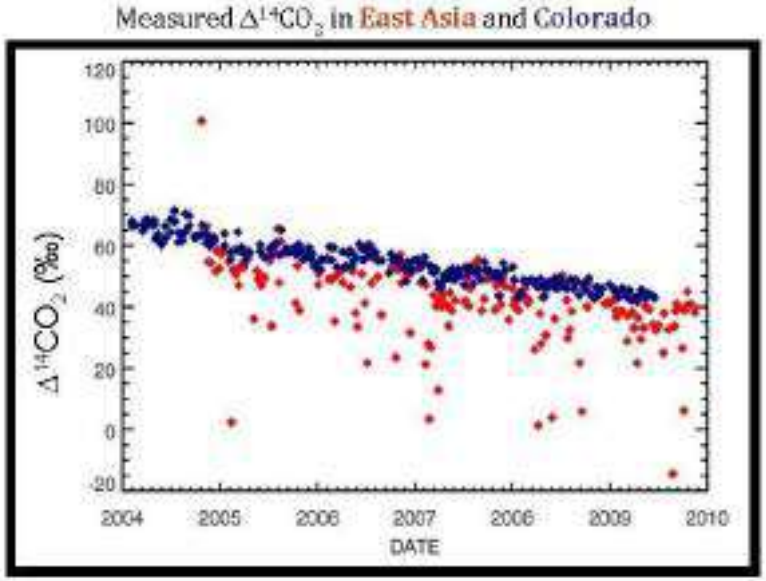
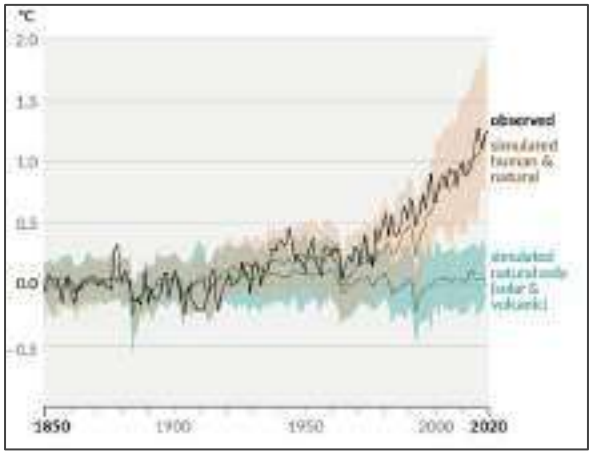
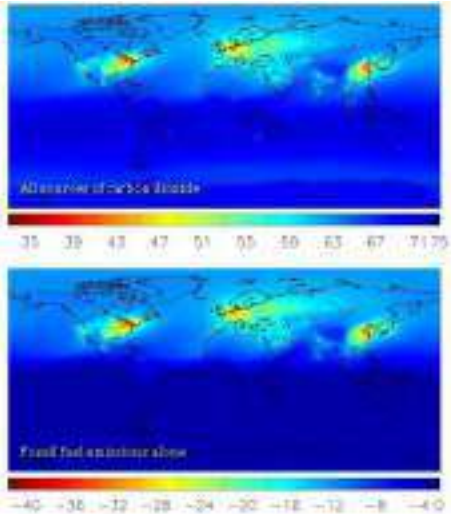
Carbon dioxide
How do we know it's anthropogenic?







https://www.esrl.noaa.gov/gmd/education/isotopes/c14tellsus.html

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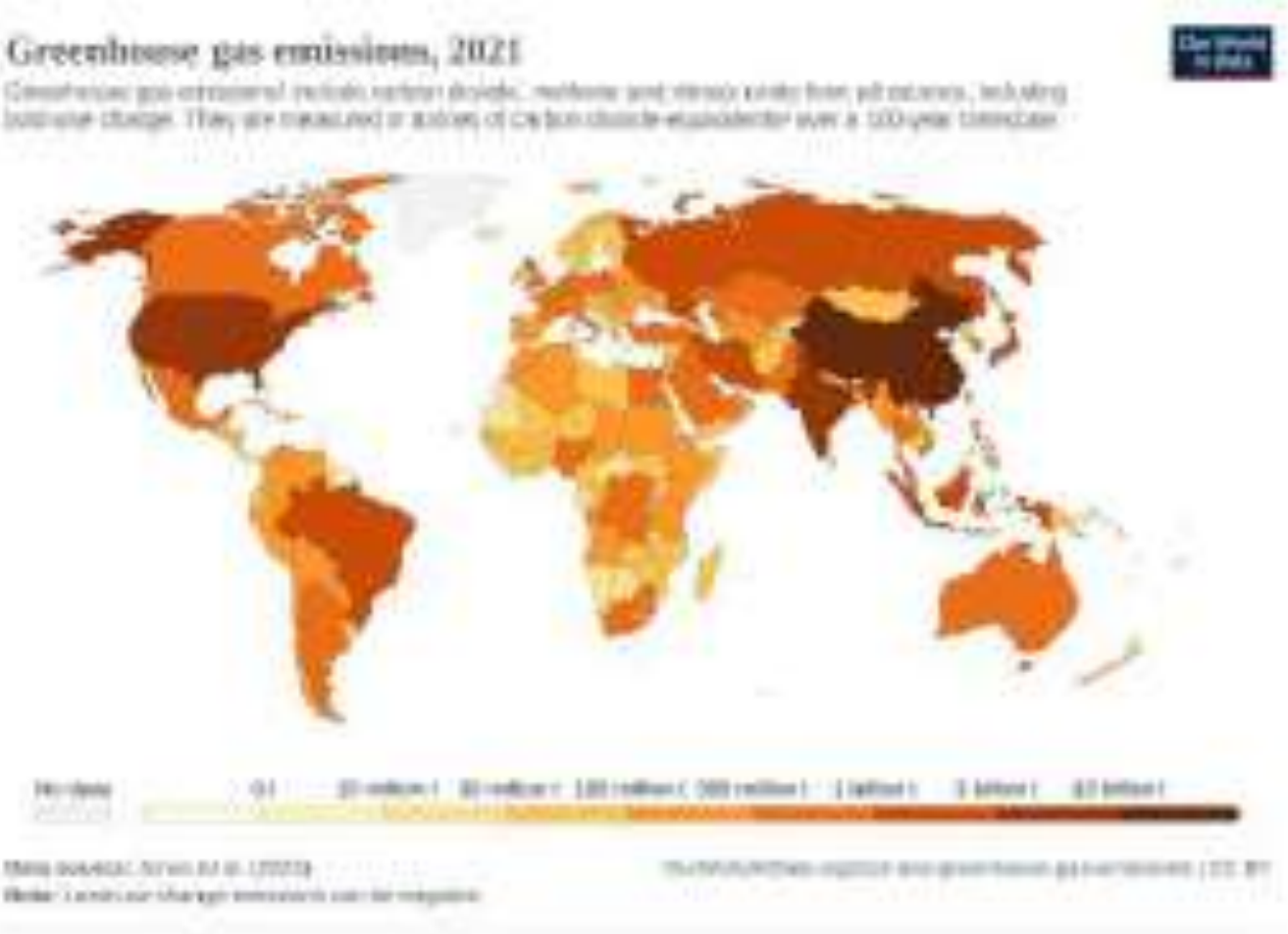

https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

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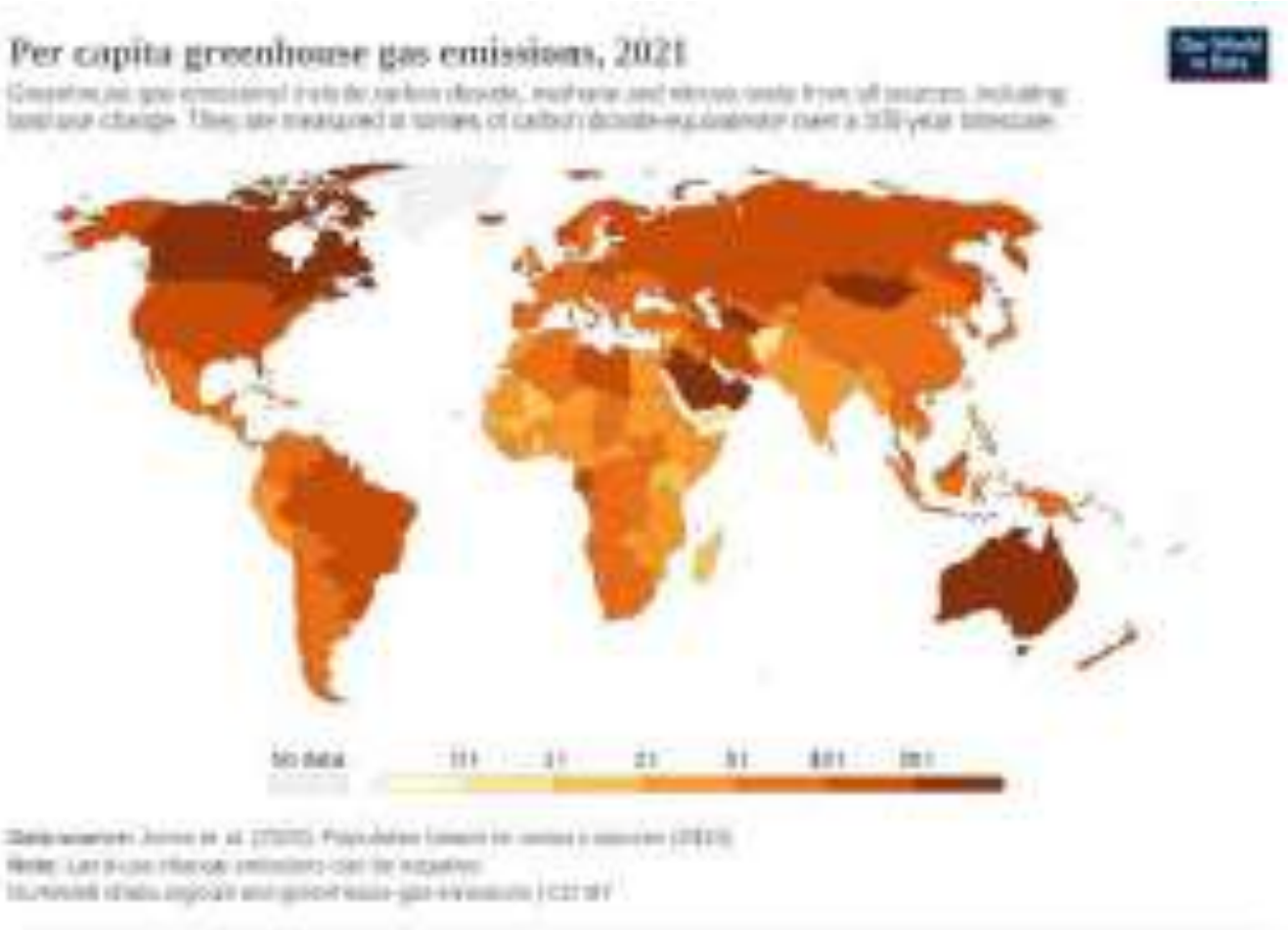

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https://ourworldindata.org/grapher/co-emissions-embedded-in-global-trade

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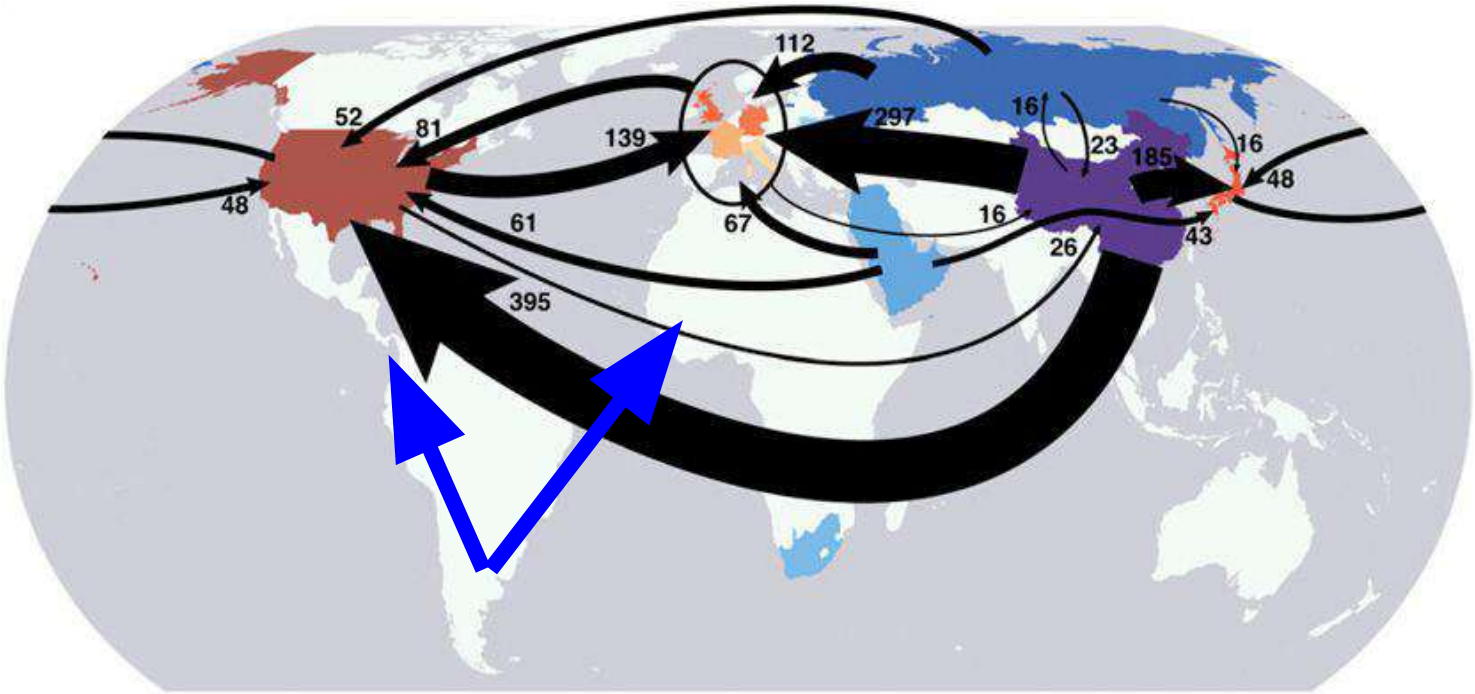
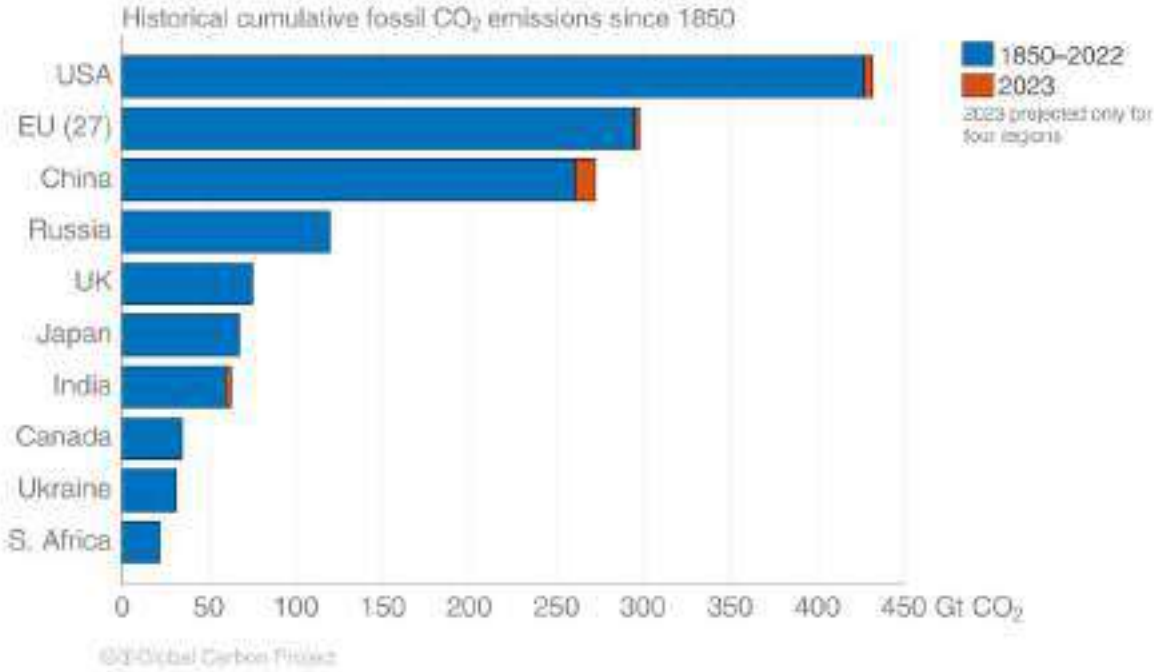


Global emission transfers between countries in 2004 in millions of tonnes of CO2 (MtCO2), taken from Figure 1 in Davis and Caldeira 2010.

GLOBAL CARBON project

Historical cumulative fossil CO_2 emissions

The USA and EU have the highest accumulated fossil CO_2 emissions since 1850, but China is a close third.



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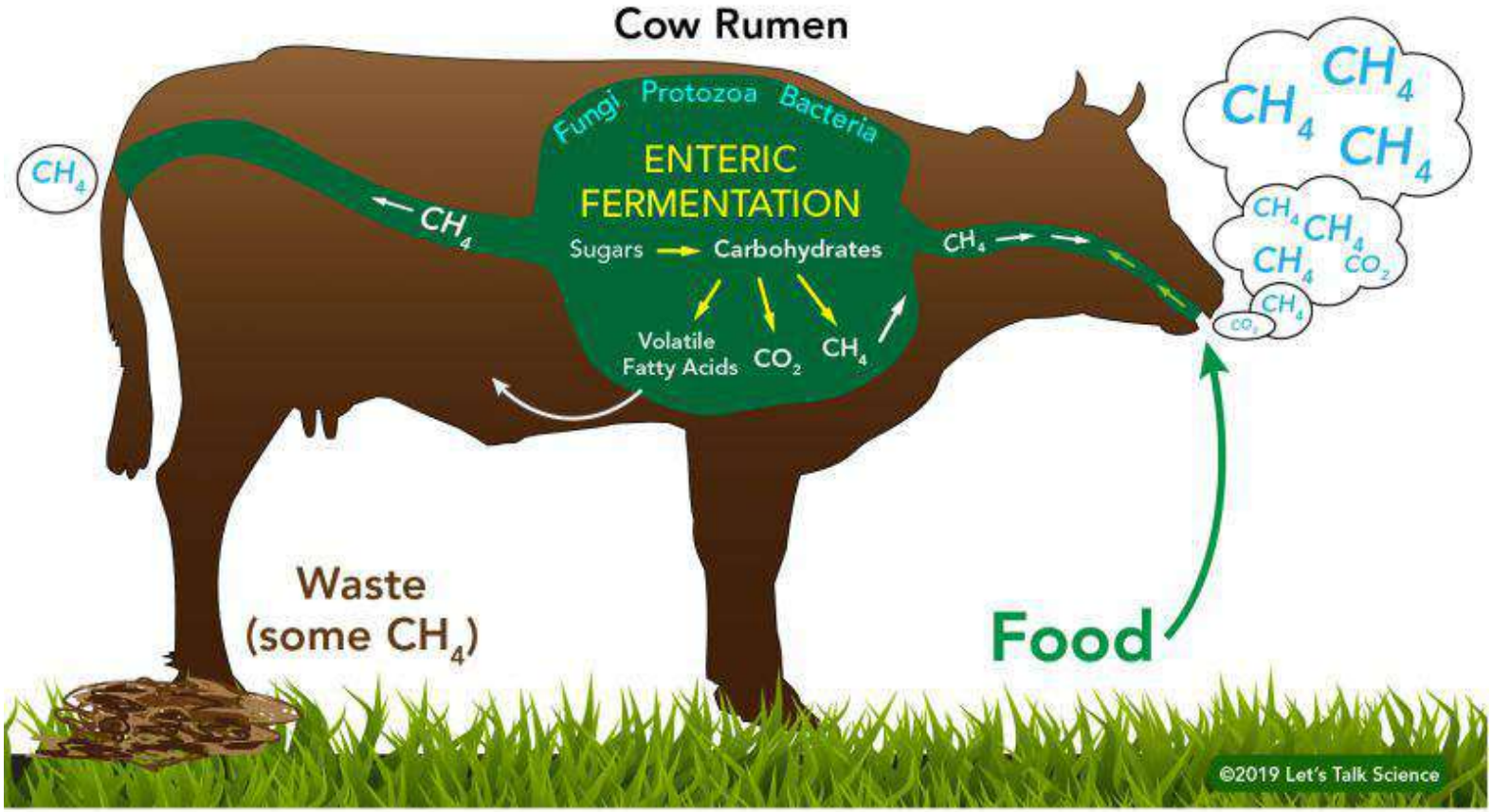

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APPROXIMATE NUMBER OF LIVING SPECIMENS

(quick Wiki search)

hainan gibbon 20

mediterranean monk seal 700

tiger 4000

black rhino 5000

red panda 10 thousand

blue whale 15 thousand

Leo 20 thousand

polar bear 30 thousand

leopard 75 thousand

long-eared owl 120 thousand

gorillas 150 thousand

golden eagle 170 thousand

chimpanzees 250 thousand

american bison 500 thousand

emperor penguin 600 thousand

african buffalo, american black bear 900 thousand

eagle owl 1 million

peregrine falcon 1.2 million

kestrel 5 million

mule 10 million

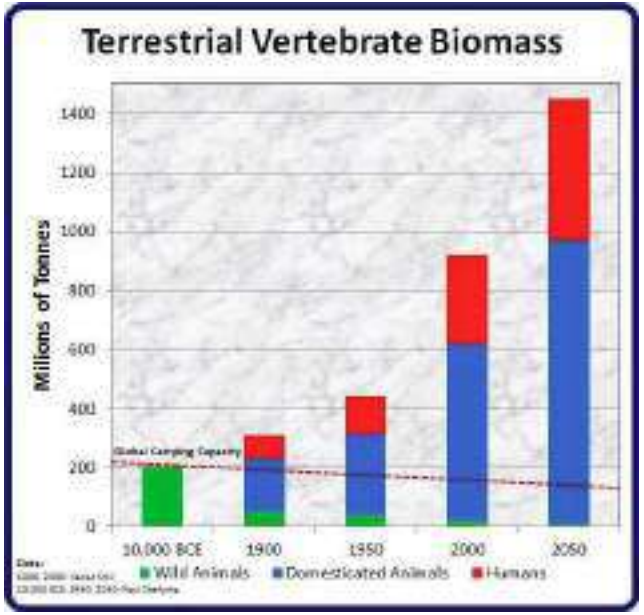
common cuckoo 50 million

horse 60 million

swift 100 million

pheasant 150 million

dove 475 million



domestic cat 600 million

domestic goat 850 million

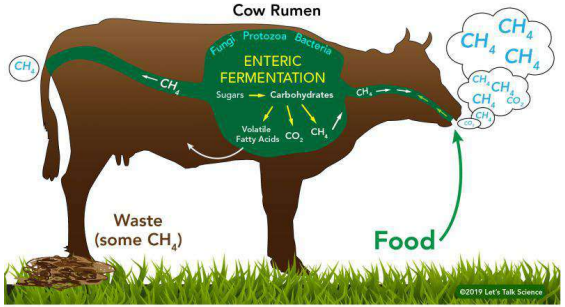
dog 900 million

ox (cow), pig (sow), sheep 1 billion

rat 7 billion

man 8 billion

rooster (hens) 24 billion



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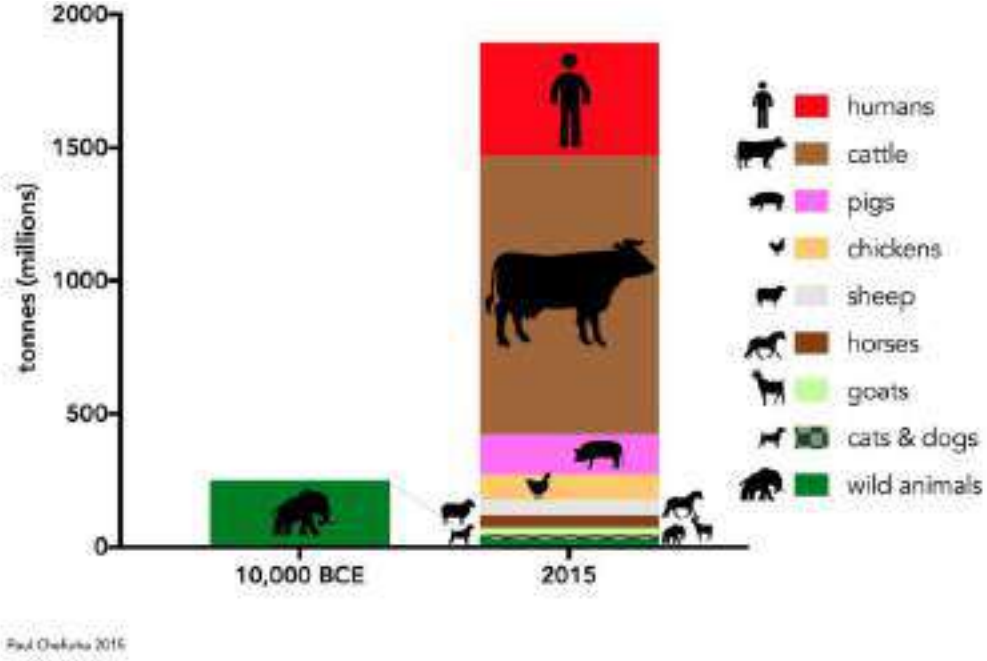
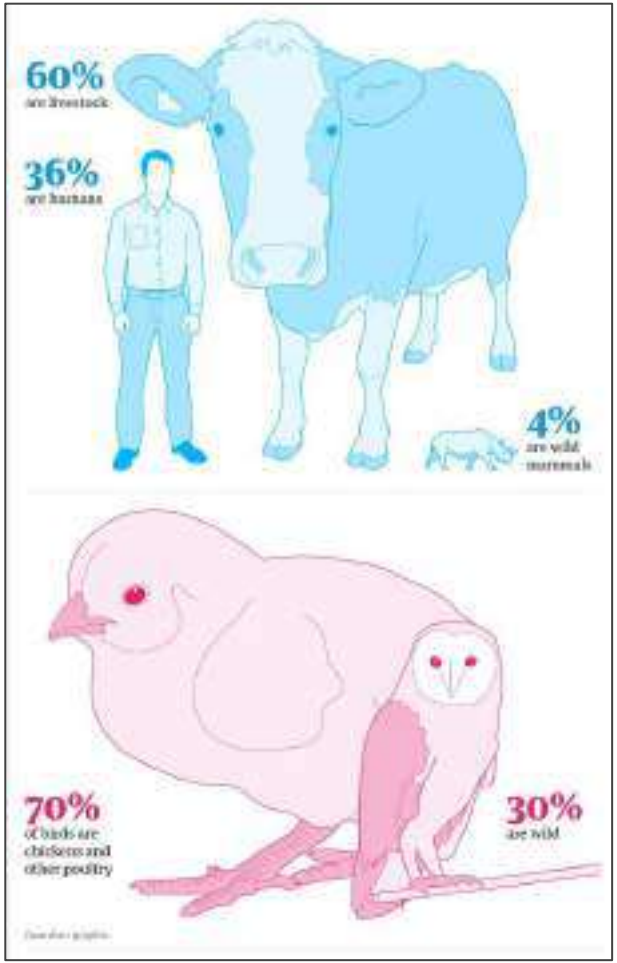
Biomass of earth mammals & birds

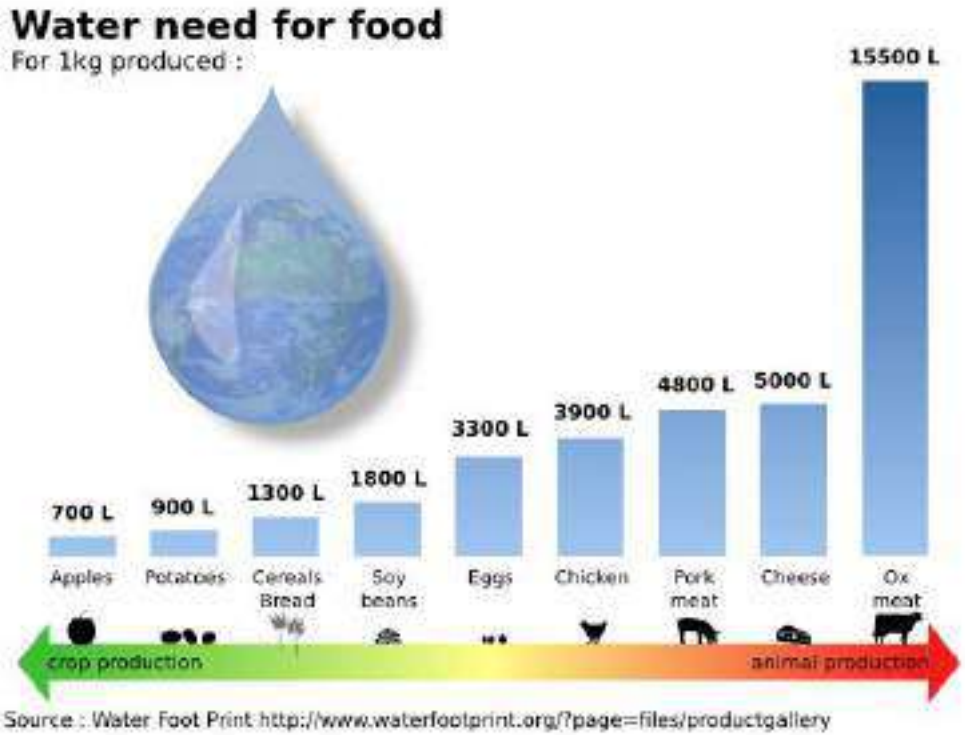




https://www.pnas.org/content/115/25/6506

emiliano.merlin@inaf.it

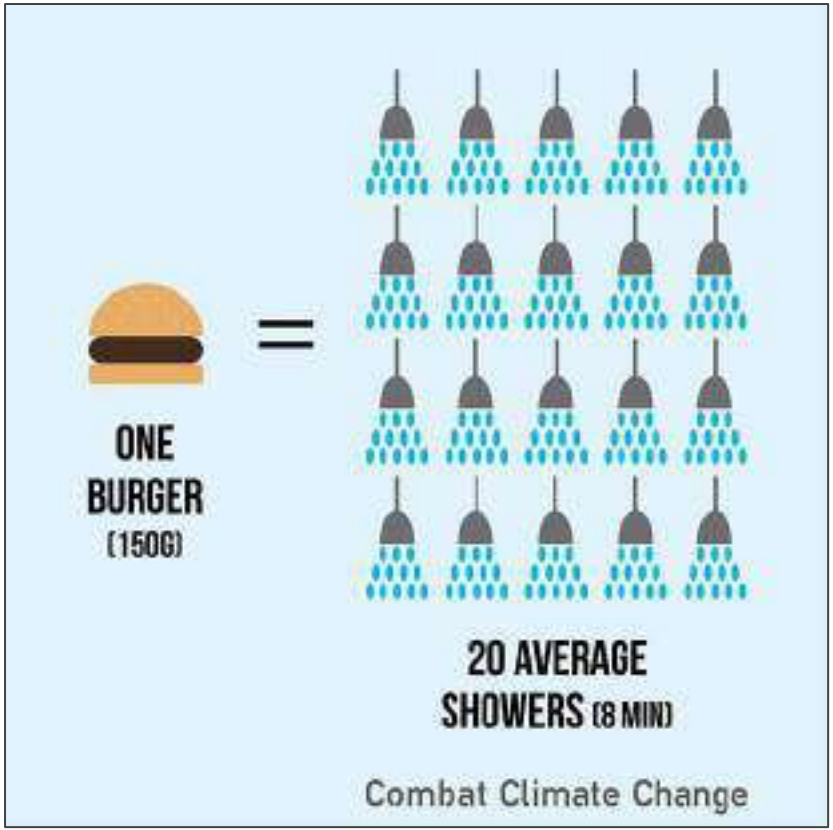
It’s not just direct emissions



“Agriculture accounts for 92% of the freshwater footprint of humanity; almost one third relates to animal products”
https://www.sciencedirect.com/science/article/pii/S2212371713000024

https://ec.europa.eu/jrc/en/news/water-footprint-eu-different-diets-9674

emiliano.merlin@inaf.it



https://mercyforanimals.org/animal-agriculture-wastes-one-third-of-drinkable/

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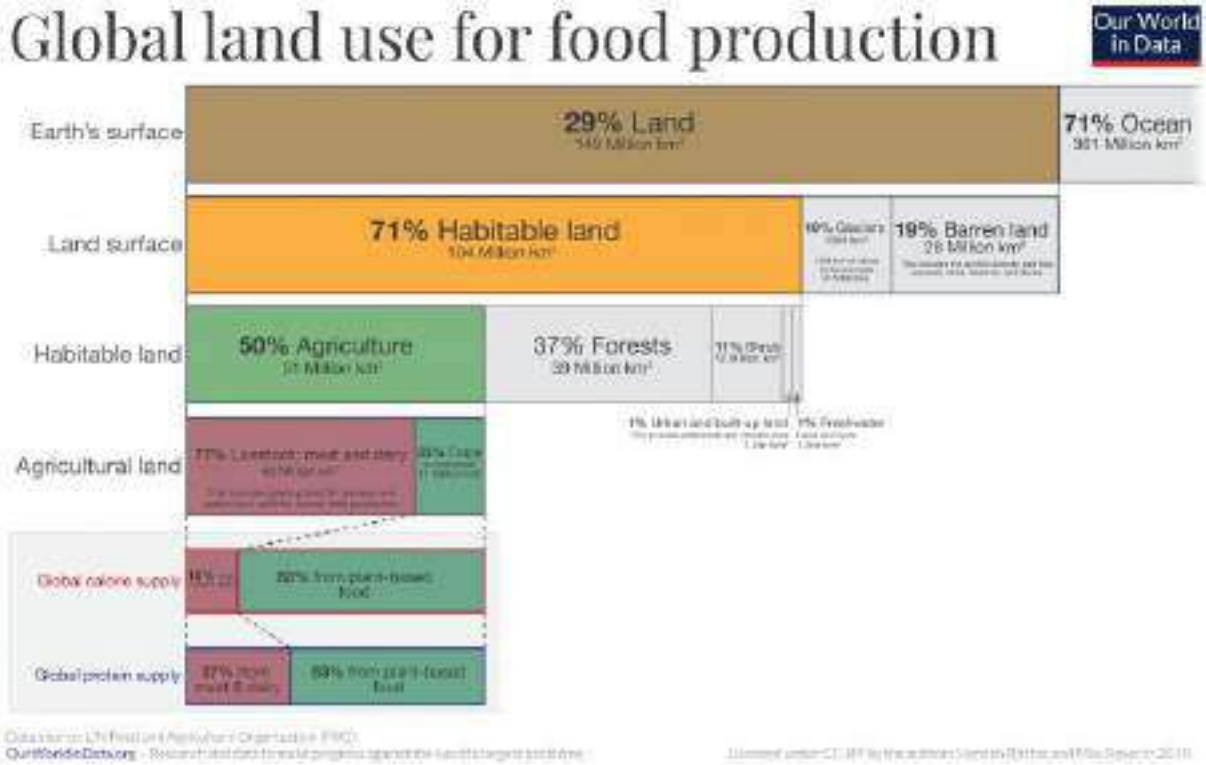

https://ourworldindata.org/global-land-for-agriculture

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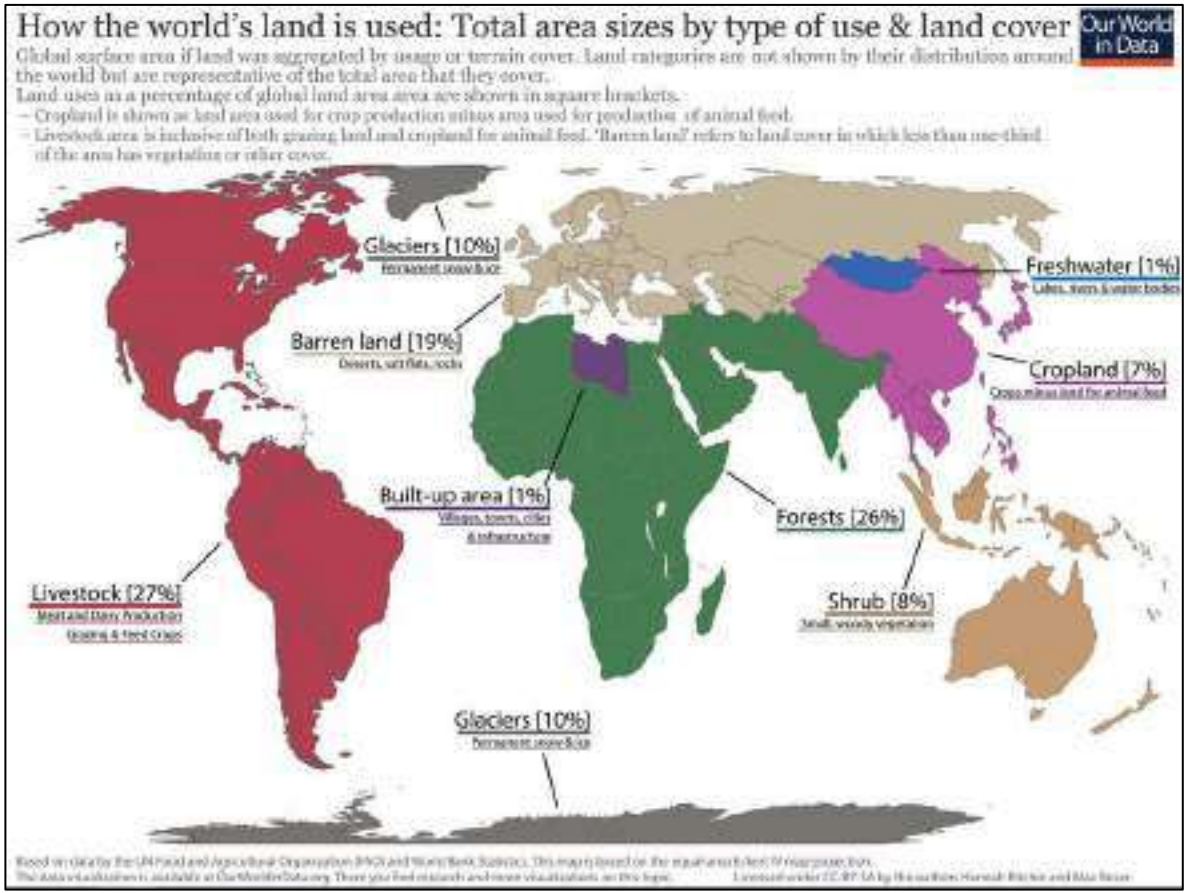

https://ourworldindata.org/uploads/2013/10/World-Map-by-Land-Use-01.png

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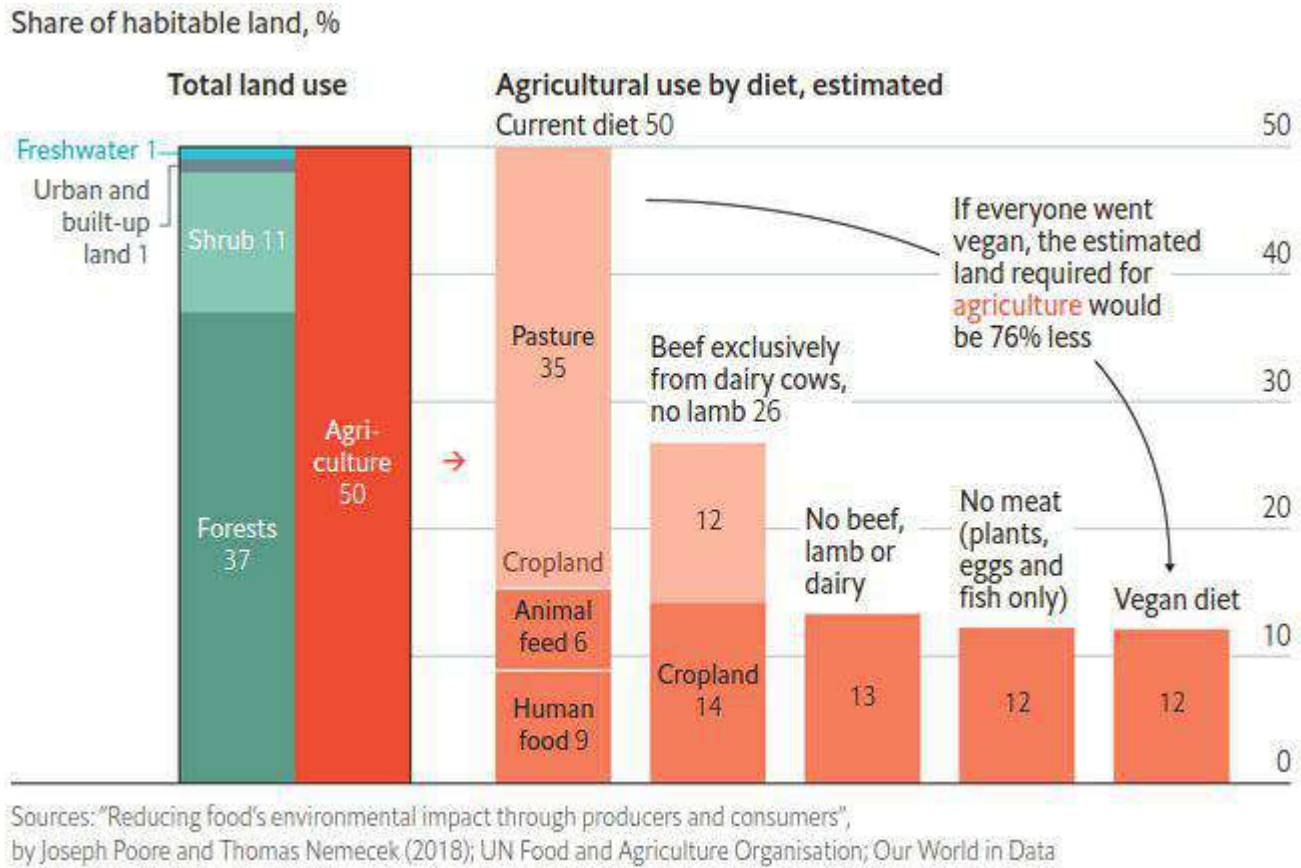


https://www.economist.com/graphic-detail/2022/01/28/if-everyone-were-vegan-only-a-quarter-of-current-farmland-would-be-needed

Poore & Nemecek 2018

emiliano.merlin@inaf.it

nature sustainability

BRIEF COMMUNICATION

The carbon opportunity cost of animal-sourced food production on land

Matthew N. Hayek[1]✉, Helen Harwatt[2], William J. Ripple[3] and Nathaniel D. Mueller[4,5]

Extensive land uses to meet dietary preferences incur a 'carbon opportunity cost' given the potential for carbon sequestration through ecosystem restoration. Here we map the magnitude of this opportunity, finding that shifts in global food production to plant-based diets by 2050 could lead to sequestration of 332–547 $GtCO_2$, equivalent to 99–163% of the CO_2 emissions budget consistent with a 66% chance of limiting warming to 1.5 °C.

to the past decade of global fossil fuel emissions. The largest potential for negative emissions—74 GtC or 48% of the global total—lies in upper-middle-income countries (Fig. 2), which will further increase as meat and dairy production expand. This is approximately equal to the past 19 years of fossil fuel emissions in these countries. In high-income countries, in which animal-sourced food demand is high but plateauing[7], the total carbon opportunity cost of animal-sourced food production is 32 GtC, approximately equal to the past 9 years of their domestic fossil fuel emissions.

Restoration of native ecosystems, including forests (relative to

To understand the potential future consequences of animal-sourced food consumption on global CO_2 budgets, we modelled land use of three global dietary scenarios in the year 2050 relative to the present day (base year 2015). The net CO_2 balance was calculated for a business-as-usual (BAU) diet following economic trends[7], a healthier diet with approximately 70% meat reduction globally relative to BAU[7] (the EAT-Lancet Commission or ELC diet) and a vegan (VGN) diet with no animal-sourced foods[7].

Vegan diet:
547 GtCO2 / 30yr = 18.23 GtCO2/yr

NATURE SUSTAINABILITY

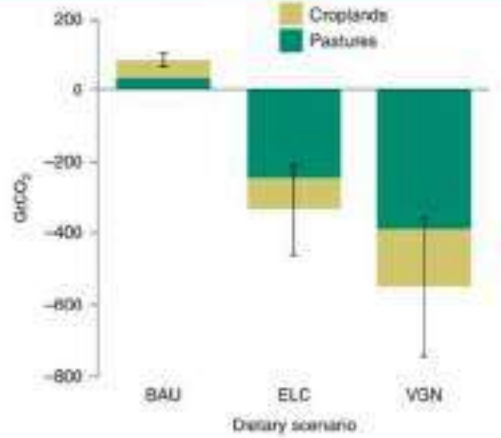


Fig. 3 | Cumulative changes in terrestrial carbon from three dietary scenarios in 2050: BAU, ELC and VGN. Scenarios do not include abated emissions associated with agricultural production (for example, ref.). Positive CO_2 indicates a loss of ecosystem vegetation carbon and emissions to the atmosphere; negative indicates CO_2 removal via vegetation growth. Error bars are 95% confidence intervals, reflecting various estimates of potential vegetation and distributions of cropland removal from low- and high-carbon biomes.

https://www.nature.com/articles/s41893-020-00603-4.epdf (2020); https://scientistswarning.forestry.oregonstate.edu/sites/default/files/Hayek2020.pdf

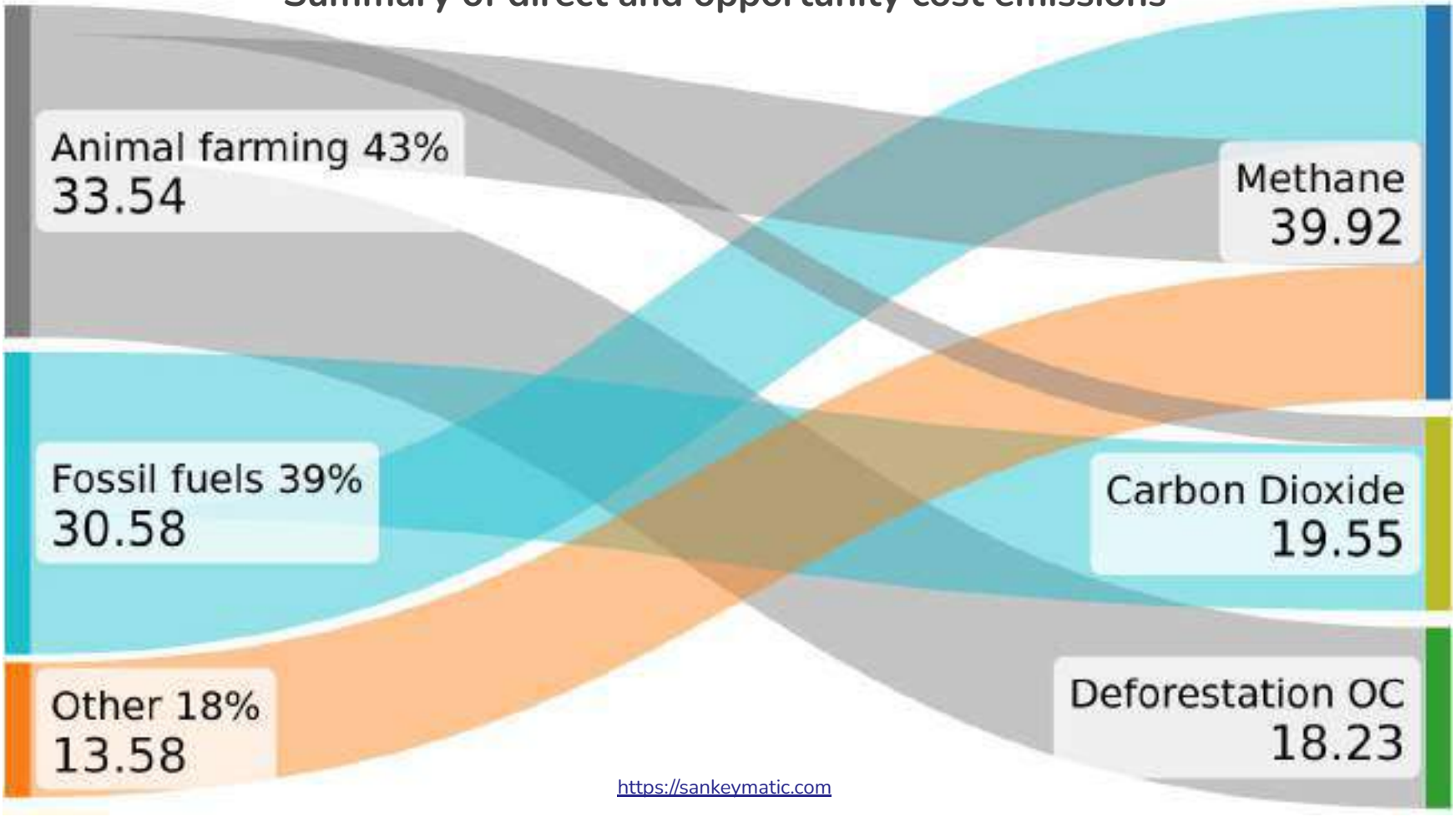
emiliano.merlin@inaf.it

Including direct and indirect sources:

CO_2 fossil fuels → 0.85 x 0.5 x 39.1 = 16.62 Gt/yr
CO_2 animal farming → 0.15 x 0.5 x 39.1 = 2.93 Gt/yr
CO_2 opportunity cost animal farming → 18.23 Gt/yr
CH_4 fossil fuels → 0.35 x 39.93 = 13.96 $GtCO_2eq$/yr
CH_4 animal farming → 0.31 x 39.93 = 12.38 $GtCO_2eq$/yr
CH_4 other sources → 0.34 x 39.93 = 13.58 $GtCO_2eq$/yr

Fossil fuels: 39% | Animal farming: 43% | Other: 18%

Summary of direct and opportunity cost emissions



https://sankeymatic.com

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A word about fishing

nature

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Article | Published: 17 March 2021

Protecting the global ocean for biodiversity, food and climate

Enric Sala, Juan Mayorga, [illegible] Lubchenco

Nature 592, 397–402 (2021) | Cite this article

22k Accesses | 6 Citations | 1783 Altmetric | Metrics

An Author Correction to this article was published on 08 April 2021

Bottom trawling releases as much carbon as air travel, landmark study finds

Dragging heavy nets across seabed disturbs marine sediments, world's largest carbon sink, scientists report

▲ An area of seabed damaged by trawling. Bottom trawling by fishing boats pumps out 1 gigaton of carbon every year. Photograph: Howard Wood/CEFAS

Fishing boats that travel the ocean floor release as much carbon dioxide as the entire aviation industry, according to a groundbreaking study.

Bottom trawling, a widespread practice in which heavy nets are dragged along the seabed, pumps out 1 gigaton of carbon every year, says the study written by 26 marine biologists, climate experts and economists and published in Nature on Wednesday.

The carbon is released from the seabed sediment into the water, and can increase ocean acidification, as well as adversely affecting productivity and biodiversity, the study said. Marine sediments are the largest pool of carbon storage in the world.

https://www.nature.com/articles/s41586-021-03371-z

emiliano.merlin@inaf.it

1. Is climate changing? Is it caused by human activities? Is this debated by experts?
2. Can we foresee the consequences of climate change?
3. Which are its physical causes?
4. Which human activities are more impactful?
5. What can/should we do?

Considering the effects of emissions *and* the opportunity cost, it is caused by fossil fuels *and* by animal agriculture, in comparable amounts

emiliano.merlin@inaf.it

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emiliano.merlin@inaf.it

REDUCE emissions urgently, deeply and rapidly, while ensuring an orderly, just transition;

- Individually
- Systematically

REMOVE CO_2 from the atmosphere in vast quantities;

- Technology (?)
- Reforestation

REPAIR broken parts of the climate system, starting with the Arctic, to try and reverse local changes and stop the cascade effects of those changes through global climate systems.

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5. What can/should we do?

- Support/become activists
- Talk, spread information
- Change individual habits

PROJECT DRAWDOWN

https://drawdown.org/solutions/table-of-solutions

** Gigatons CO2 Equivalent Reduced / Sequestered (2020–2050)*

SOLUTION	SECTOR(S)	SCENARIO 1 *	SCENARIO 2 *
Reduced Food Waste	Food, Agriculture, and Land Use / Land Sinks	88.50	102.20
Plant-Rich Diets	Food, Agriculture, and Land Use / Land Sinks	78.33	103.11
Family Planning and Education	Health and Education	68.90	68.90
Refrigerant Management	Industry / Buildings	57.15	57.15
Tropical Forest Restoration	Land Sinks	54.45	85.14
Onshore Wind Turbines	Electricity	46.95	143.56
Alternative Refrigerants	Industry / Buildings	42.73	48.75
Utility-Scale Solar Photovoltaics	Electricity	40.83	111.59
Clean Cooking	Buildings	31.38	76.34
Distributed Solar Photovoltaics	Electricity	26.65	64.86
Electric Cars	Transportation	7.66	9.76
Smart Thermostats	Electricity / Buildings	6.91	7.25

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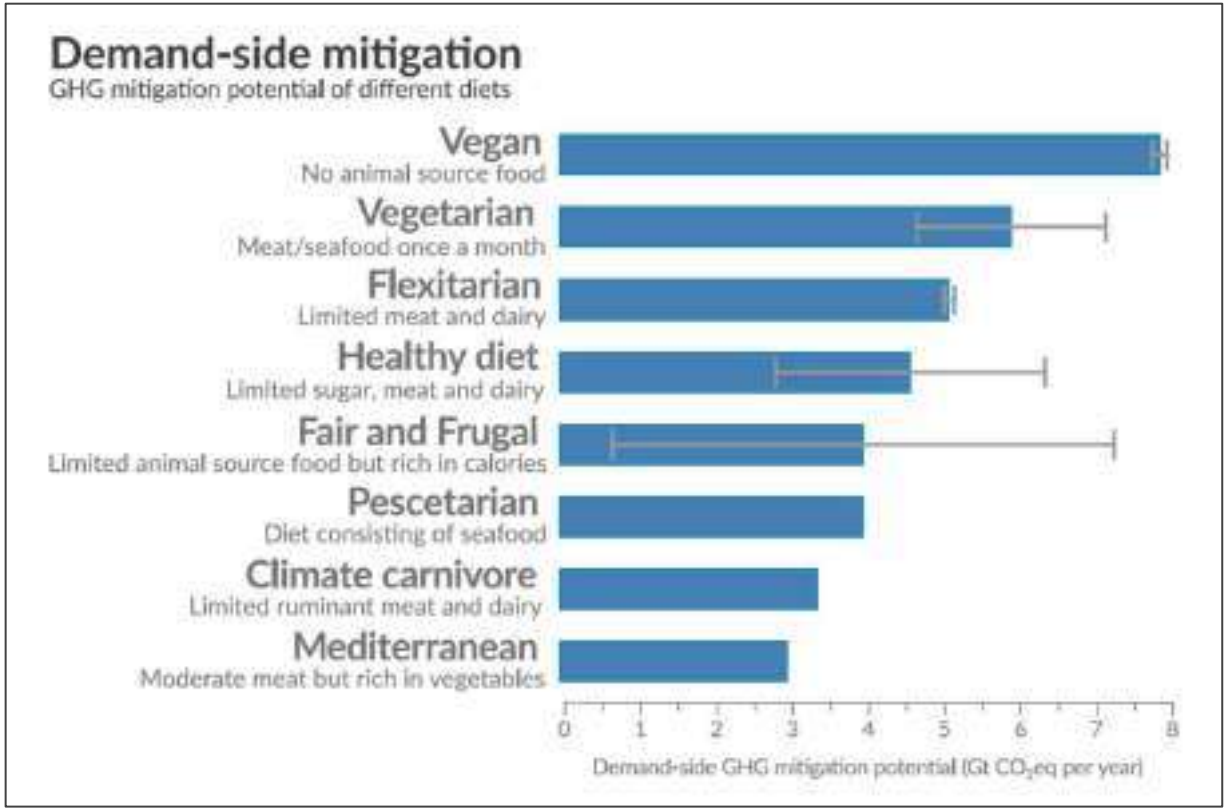
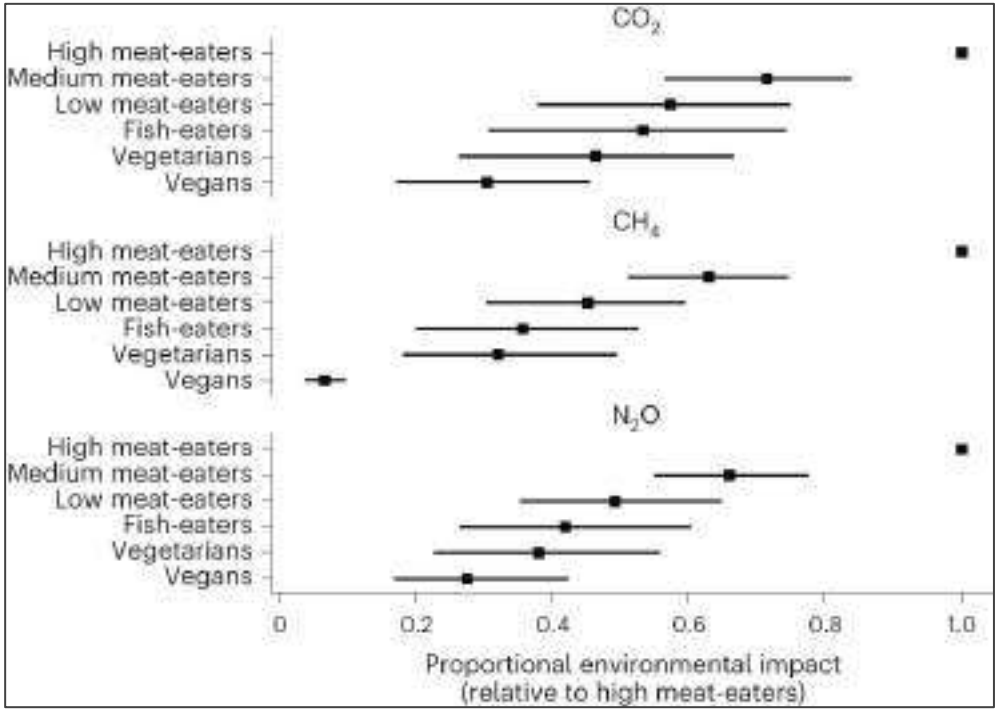
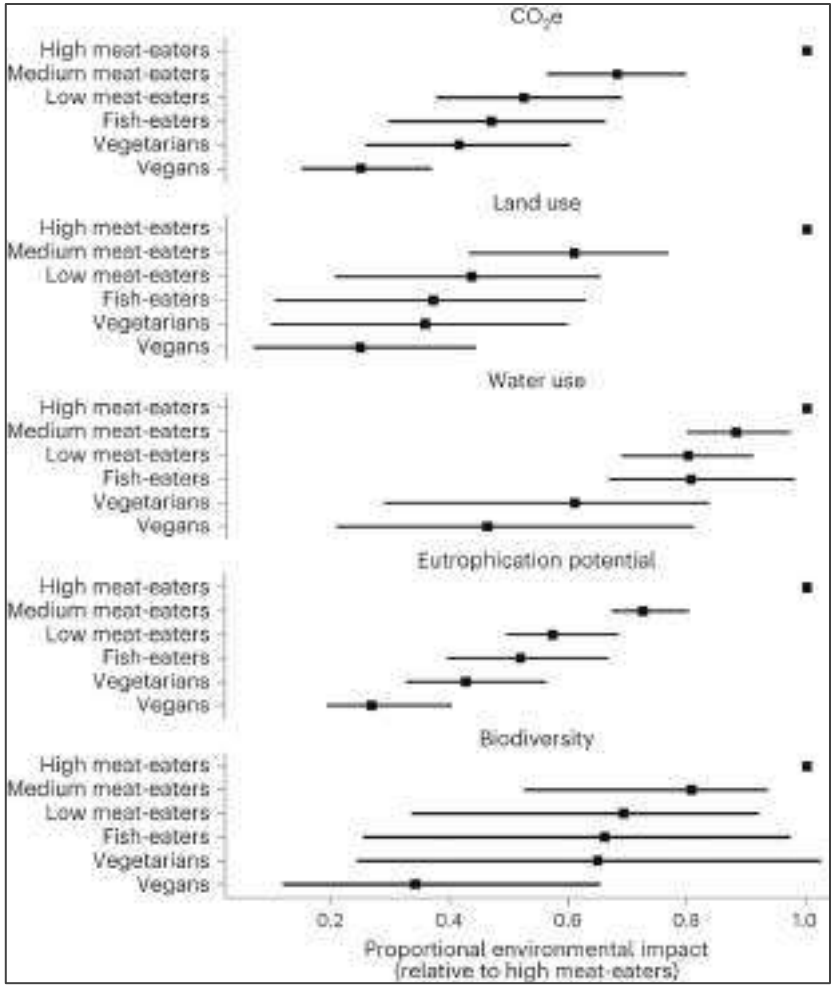


https://www.ipcc.ch/site/assets/uploads/2019/08/Fullreport-1.pdf

Vegan diet massively cuts environmental damage, study shows

Detailed analysis finds plant diets lead to 75% less climate-heating emissions, water pollution and land use than meat-rich ones





https://www.nature.com/articles/s43016-023-00795-w

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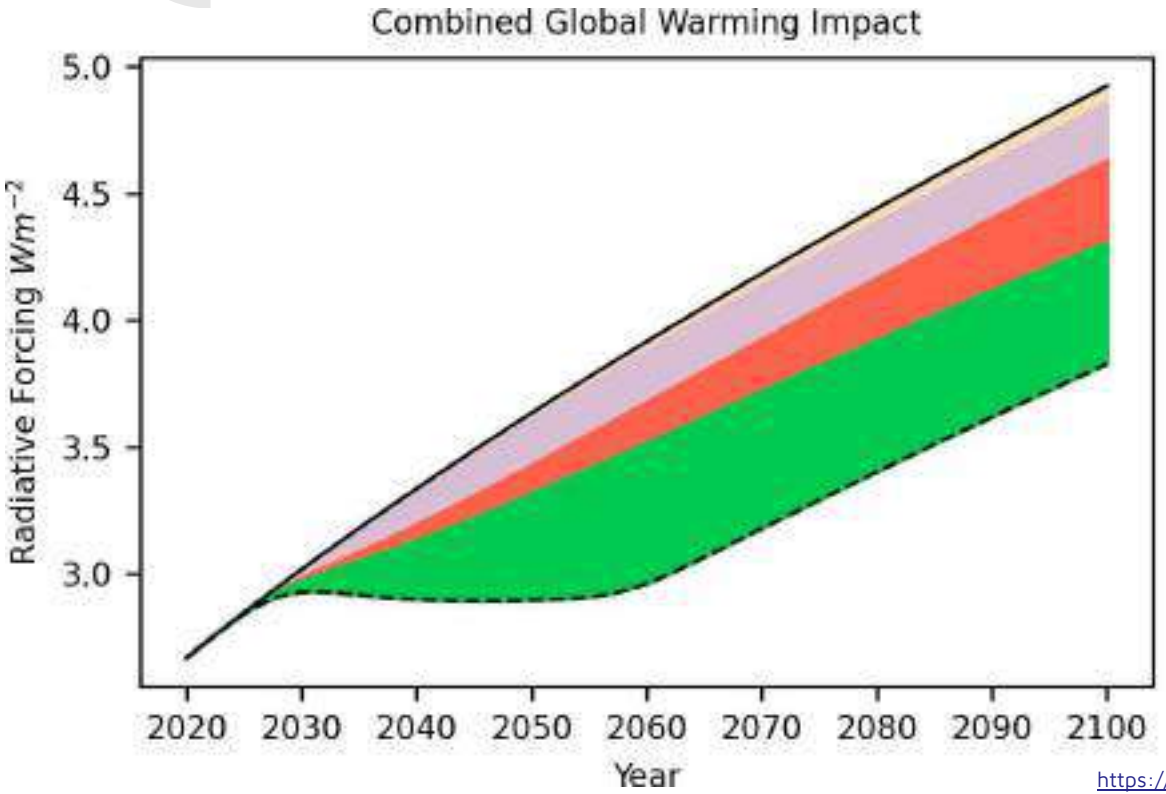
PLOS CLIMATE

OPEN ACCESS PEER-REVIEWED

Eisen & Brown 2022



Business As Usual

Eliminate Livestock CO_2 Emissions

Eliminate Livestock CH_4 Emissions

Eliminate Livestock N_2O Emissions

Biomass Recovery

Plant Only Diet (PHASE-POD)

15 yrs transition

We show that, even in the absence of any other emission reductions, persistent drops in atmospheric methane and nitrous oxide levels, and slower carbon dioxide accumulation, following a phaseout of livestock production would, through the end of the century, have the same cumulative effect on the warming potential of the atmosphere as a 25 gigaton per year reduction in anthropogenic CO_2 emissions, providing half of the net emission reductions necessary to limit warming to 2°C. The magnitude and rapidity of these potential effects should place the reduction or elimination of animal agriculture at the forefront of strategies for averting disastrous climate change.

https://journals.plos.org/climate/article?id=10.1371%2Fjournal.pclm.0000010

emiliano.merlin@inaf.it

How about free-range farming?
It's NOT the solution

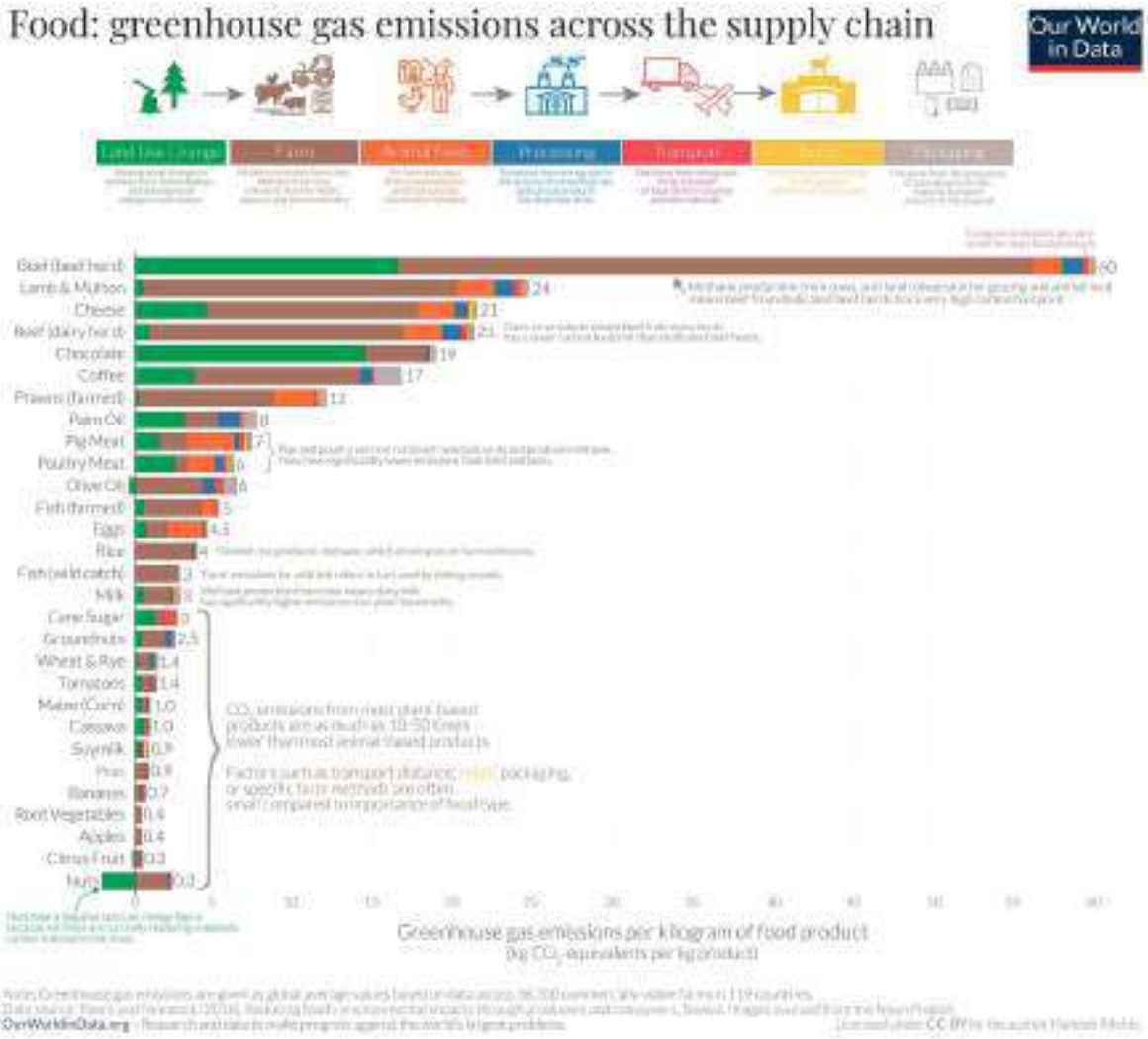
Reducing food's environmental impacts through producers and consumers

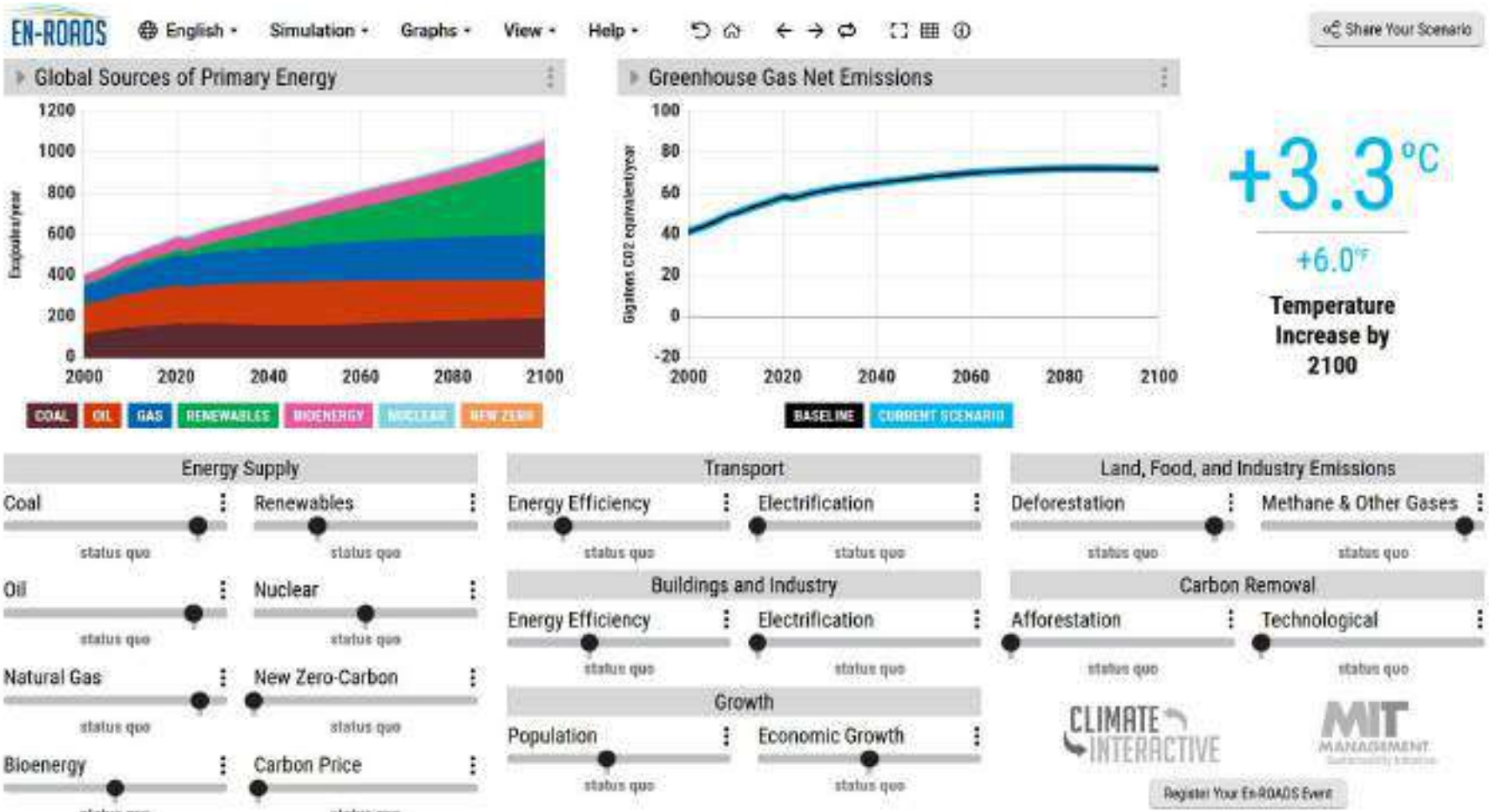
J. Poore[1,2]* and T. Nemecek[3]

Food's environmental impacts are created by millions of diverse producers. To identify solutions that are effective under this heterogeneity, we consolidated data covering five environmental indicators, 38,700 farms, and 1600 processors, packagers, transporters, retailers. Impact can vary 50-fold among producers of the same product, creating substantial mitigation opportunities. However, mitigation is complicated by trade-offs, multiple ways for producers to achieve low impacts, and interactions throughout the supply chain. Producers have limits on how far they can reduce impacts. Most strikingly, impacts of the lowest-impact animal products typically exceed those of vegetable substitutes, providing new evidence for the importance of dietary change. Cumulatively, our findings support an approach where producers monitor their own impacts, flexibly meet environmental targets by choosing from multiple practices, and communicate their impacts to consumers.

AAAS
Science

https://science.sciencemag.org/content/sci/360/6392/987.full.pdf

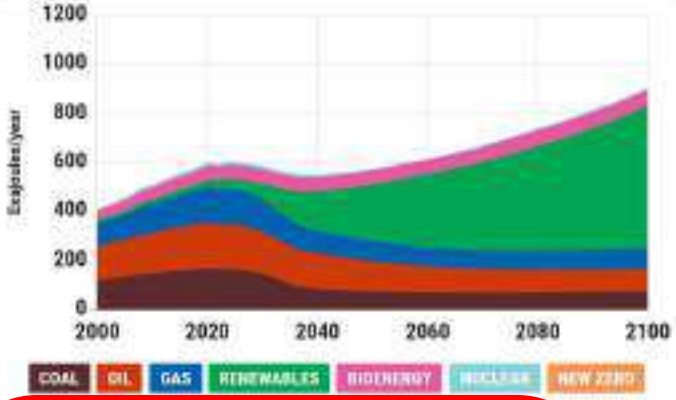




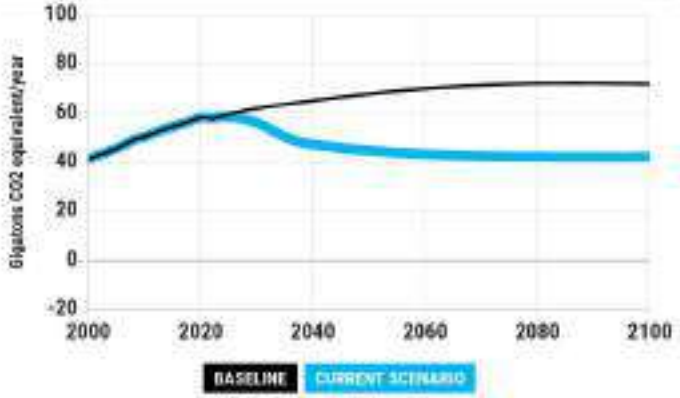
https://en-roads.climateinteractive.org/

EN-ROADS | English | Simulation | Graphs | View | Help | Share Your Scenario

Global Sources of Primary Energy



Greenhouse Gas Net Emissions



+2.6°C

+4.7°F

Temperature Increase by 2100

Energy Supply

- Coal: very highly taxed
- Renewables: highly subsidized
- Oil: very highly taxed
- Nuclear: status quo
- Natural Gas: very highly taxed
- New Zero-Carbon: status quo
- Bioenergy: highly taxed
- Carbon Price: status quo

Transport

- Energy Efficiency: status quo
- Electrification: status quo

Buildings and Industry

- Energy Efficiency: status quo
- Electrification: status quo

Growth

- Population: status quo
- Economic Growth: status quo

Land, Food, and Industry Emissions

- Deforestation: status quo
- Methane & Other Gases: status quo

Carbon Removal

- Afforestation: status quo
- Technological: status quo

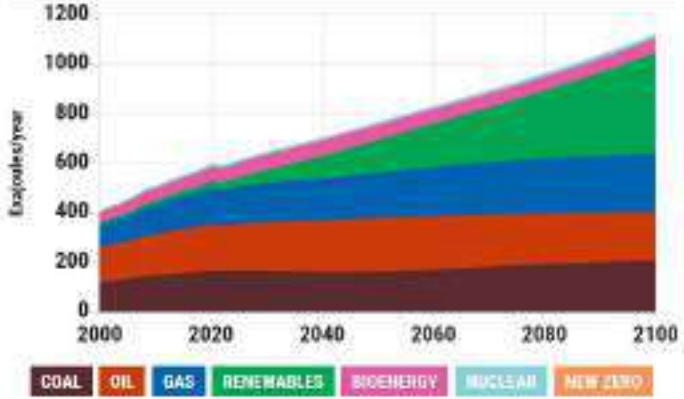
CLIMATE INTERACTIVE

MIT MANAGEMENT

Register Your En-ROADS Event

EN-ROADS English Simulation Graphs View Help Share Your Scenario

Global Sources of Primary Energy



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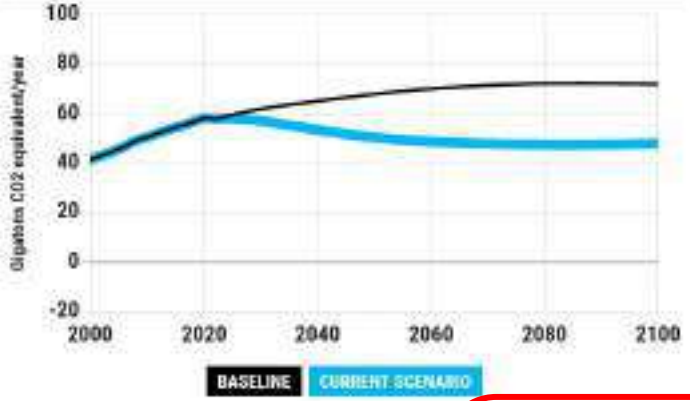

+2.6 °C

+4.7 °F

Temperature Increase by 2100

Energy Supply

Coal — status quo

Renewables — status quo

Oil — status quo

Nuclear — status quo

Natural Gas — status quo

New Zero-Carbon — status quo

Bioenergy — status quo

Carbon Price — status quo

Transport

Energy Efficiency — status quo

Electrification — status quo

Buildings and Industry

Energy Efficiency — status quo

Electrification — status quo

Growth

Population — status quo

Economic Growth — status quo

Land, Food, and Industry Emissions

Deforestation — highly reduced

Methane & Other Gases — highly reduced

Carbon Removal

Afforestation — high growth

Technological — status quo

CLIMATE INTERACTIVE

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emiliano.merlin@inaf.it

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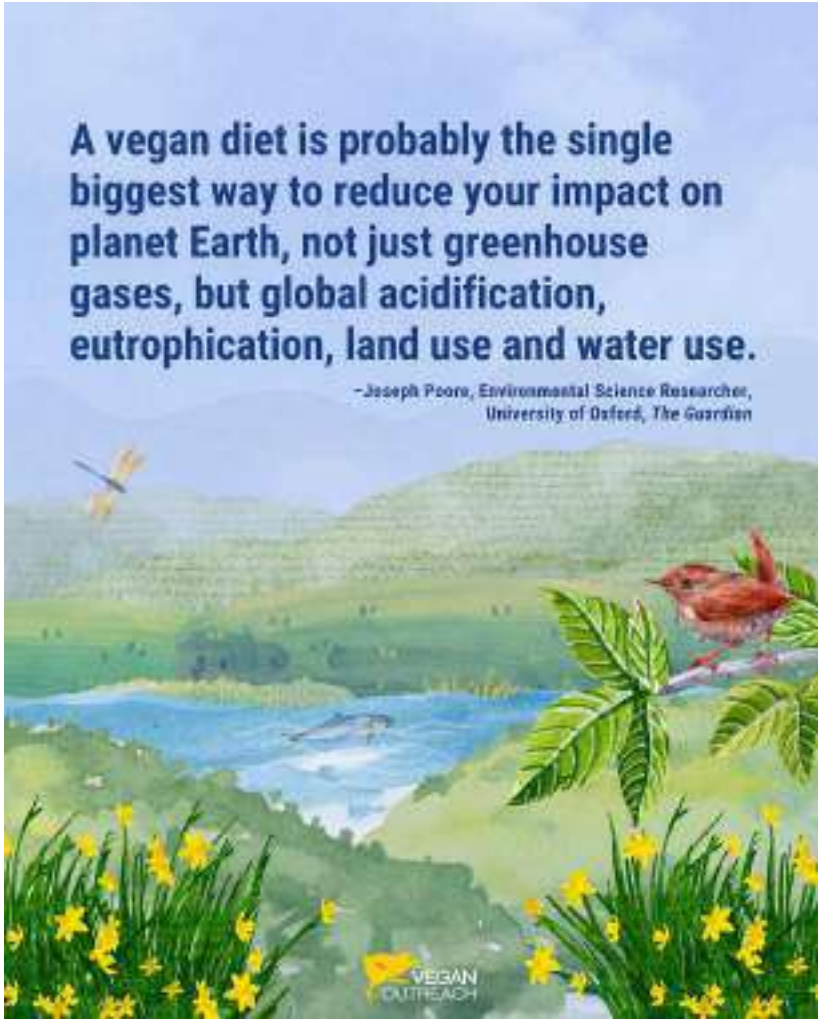
5. What can/should we do?
   - Support/become activists
   - Talk, spread information
   - Demand for real mitigation politics
   - Change own habits, starting from **food**

emiliano.merlin@inaf.it




BEYOND MEAT
BEYOND BEEF
PLANT-BASED
20G


NEXT LEVEL BURGER
20g


10
GOLOSISSIMI
DOLCI
VEGANI


ALMOND
RICE

emiliano.merlin@inaf.it

https://thevegancalculator.com/animal-slaughter/

emiliano.merlin@inaf.it

https://thevegancalculator.com/animal-slaughter/

emiliano.merlin@inaf.it

Conclusions

1. Climate is changing, because of human activities, and there is 100% consensus about this among experts
2. We can foresee the consequences of climate change within large uncertainties, but it’s probably going to be worse than expected for the ecosystem and the biosphere
3. Climate change is mostly caused by CO2 (historically) and CH4 (current rate of warming) emissions,
4. caused by fossil fuels production/consumption and animal farming, in comparable amounts if we include opportunity cost from deforestation
5. We (as scientists and human beings) should talk about this, spread awareness, and possibly change our habits

emiliano.merlin@inaf.it

Online resources

https://orsomerlin.wordpress.com/2020/04/06/perche-gli-allevamenti-sono-molto-piu-dannosi-per-il-clima-di-quanto-si-creda/

https://chpdb.it/_climate_dash/

https://www.ncdc.noaa.gov/sotc/global/

https://www.carbonbrief.org/mapped-how-every-part-of-the-world-has-warmed-and-could-continue-to-warm

https://www.carbonbrief.org/qa-how-do-climate-models-work

https://theveganscalculator.com/animal-slaughter/

https://www.carbonfootprint.com/calculator.aspx

https://en-roads.climateinteractive.org/scenario.html

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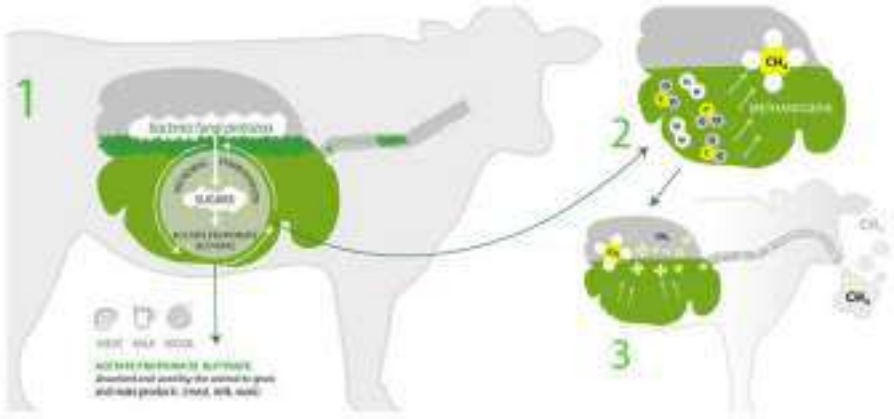
https://orsomerlin.wordpress.com/2020/04/06/perche-gli-allevamenti-sono-molto-piu-dannosi-per-il-clima-di-quanto-si-creda/

Perché gli allevamenti sono molto più dannosi per il clima di quanto si creda



6 APRILE 2020 – KAPPAZAPATA – MODIFICA

Secondo la FAO, **gli allevamenti di bestiame sono direttamente responsabili di poco meno del 40% del totale delle emissioni di metano di origine antropica.**
Ma perché dovremmo preoccuparci di quanto metano viene emesso nell'atmosfera?