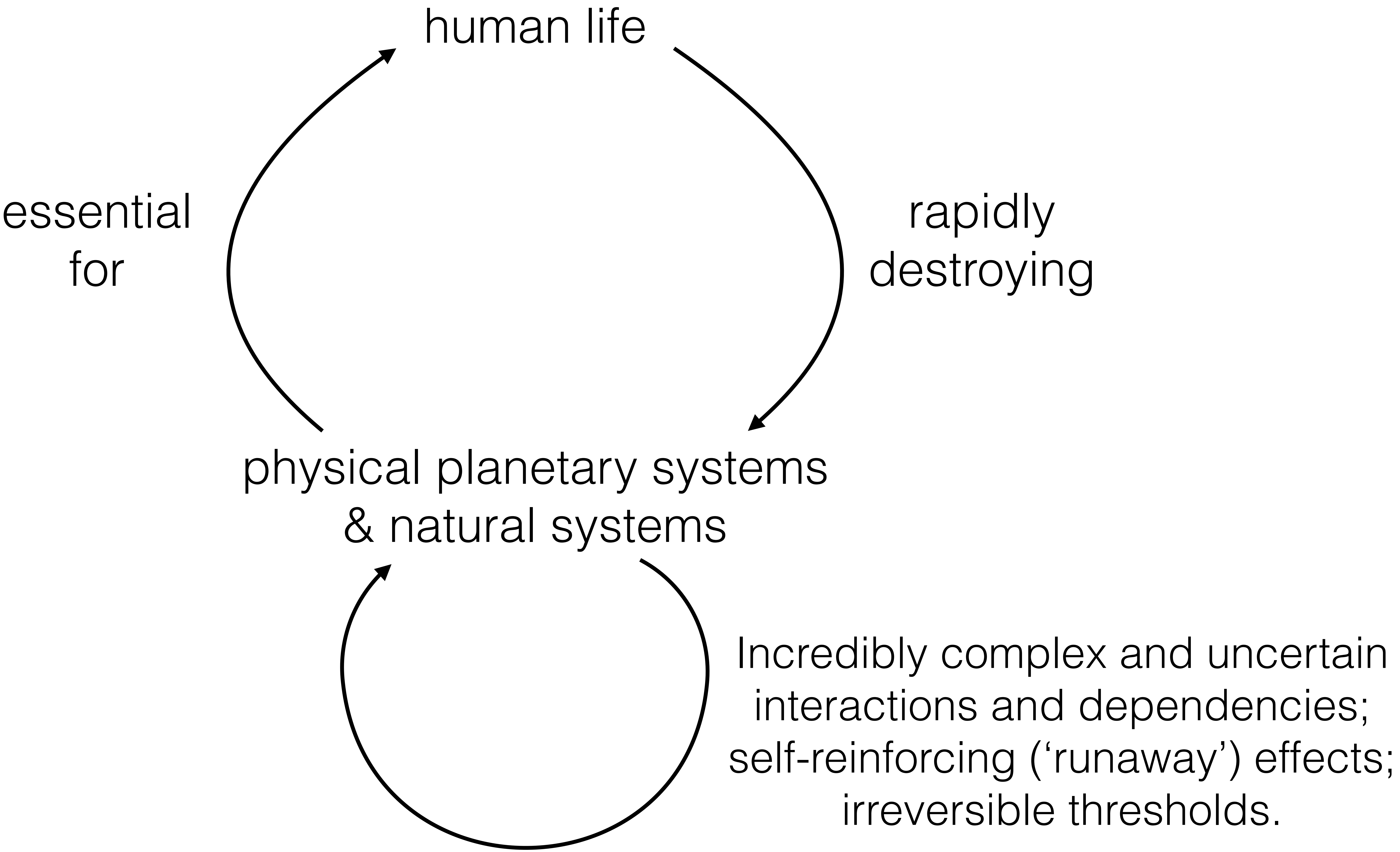
Climate change, and how we're fucking up the planet and nature generally

Chris Wymant

Disclaimer: this is not my area of expertise

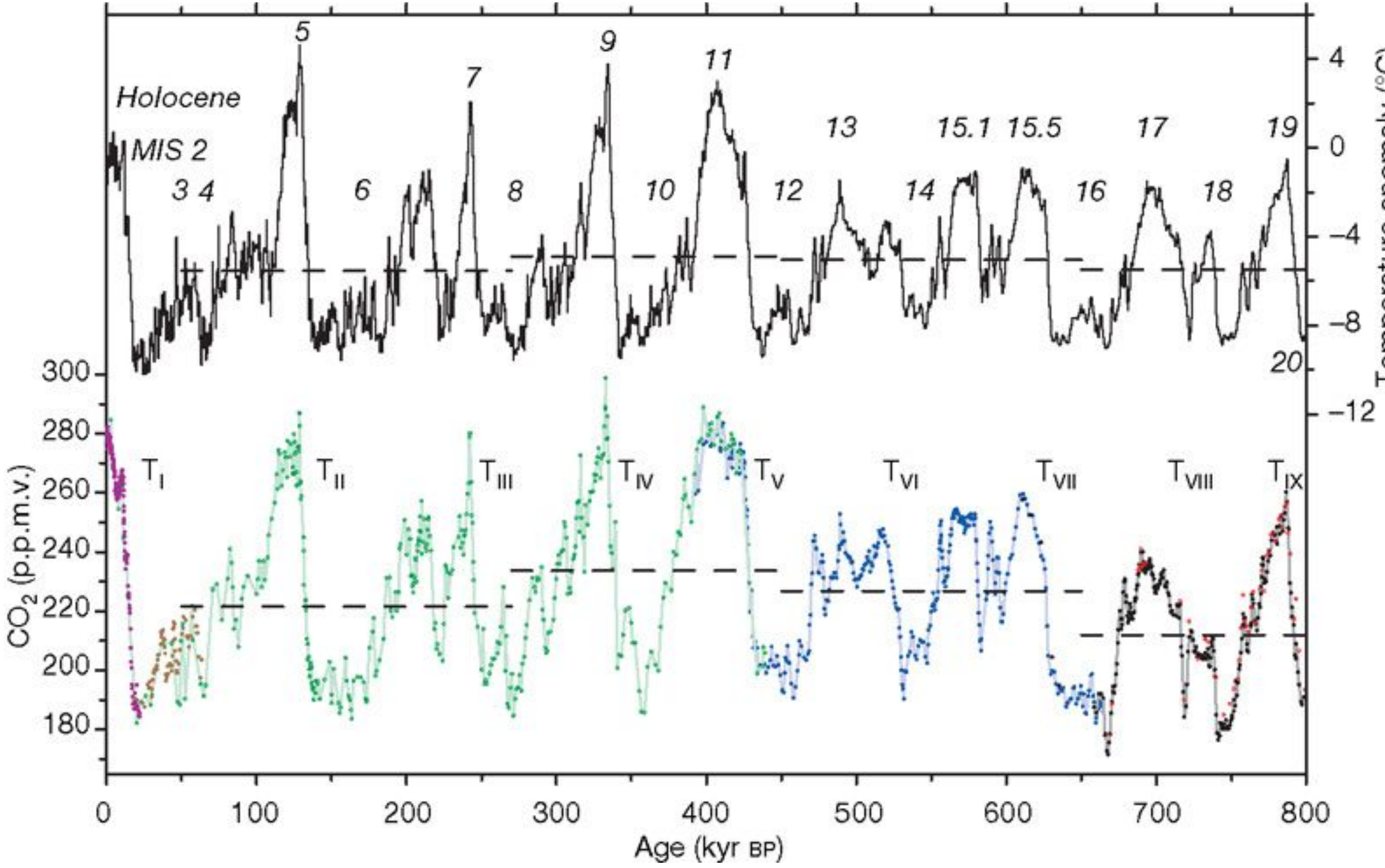

human life
essential for
rapidly destroying
physical planetary systems & natural systems
Incredibly complex and uncertain interactions and dependencies; self-reinforcing (‘runaway’) effects; irreversible thresholds.

Climate change

The Greenhouse Effect:

tl,dr; greenhouse gasses (GHG) act as insulation.

- GHG molecules block electromagnetic radiation (e.g. converting to vibrational/ rotational energy) more strongly at the longer wavelengths emitted by the Earth than the shorter wavelengths coming in from the Sun.
- At increasing altitutudes, the atmosphere gets less dense.
- At increasing altitutudes, the atmosphere gets cooler.
- Radiation can only escape into space once the density of GHG molecules (obstacles in its path) is low enough, i.e. from a high enough altitutude.
- Wien’s law: radiation a body emits proportional to temperature to fourth power.
- Increased density of GHG:
  → radiation escape occurs where it’s higher & cooler,
  → less radiation escapes,
  → imbalance with incoming radiation,
  → planet warms until balance restored.
- Balance (radiative forcing) relatively well pinned-down; resulting temperature at the planet’s surface is not: feedbacks.



time going backwards
kyr BP = 1000 years before present

Lüthi *et al.*, Nature 2008

Glacial-InterGlacial cycles: 32+ in last 2.5m years. T_i denotes *i*th G→IG transition before now.

G→IG fast: thousands of years (positive feedback, see later). IG→G slow: tens of thousands of years.

Temperature and CO2 (also methane, not shown) extremely tightly linked. Skeptics: reverse causal association. OUP Very Short Intro to Climate Change: wrong, "excellent evidence" that it's (mostly) causal.

Current interglacial, aka the Holocene, began 12k years ago (T_I).
Before this, km-thick ice sheets over Europe & North America. Then

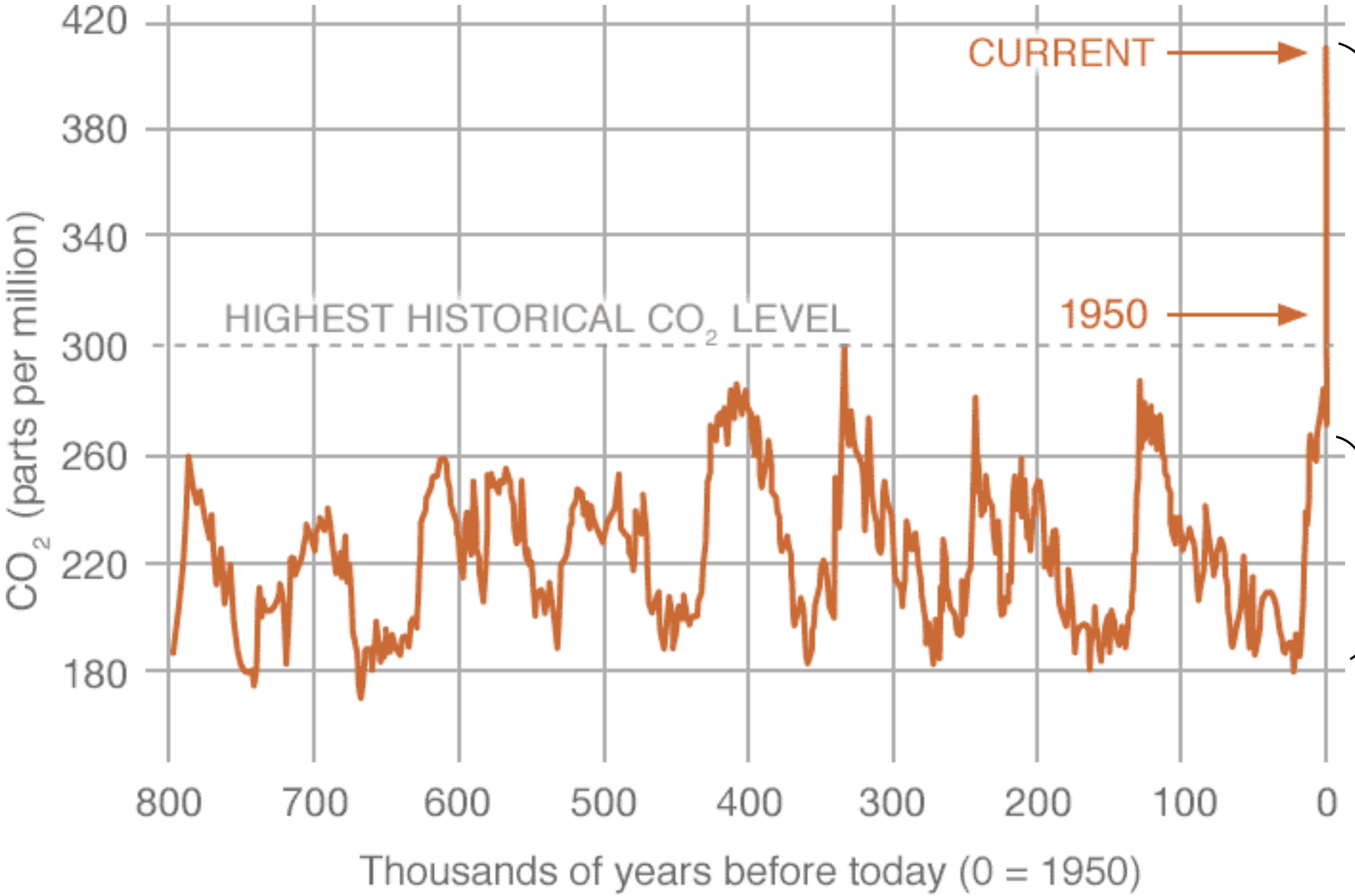
- CO2 180 → 260ppm,
- +6 °C,
- Sea level +120m,
- agricultural revolution,
- human civilisation.

Atmospheric CO2, in parts-per-million

Variations of

- size ~100ppm,
- within this ('usual') range,
- over 10,000s of years,

are the extremes of the planet's switching between glacial and interglacial phases…



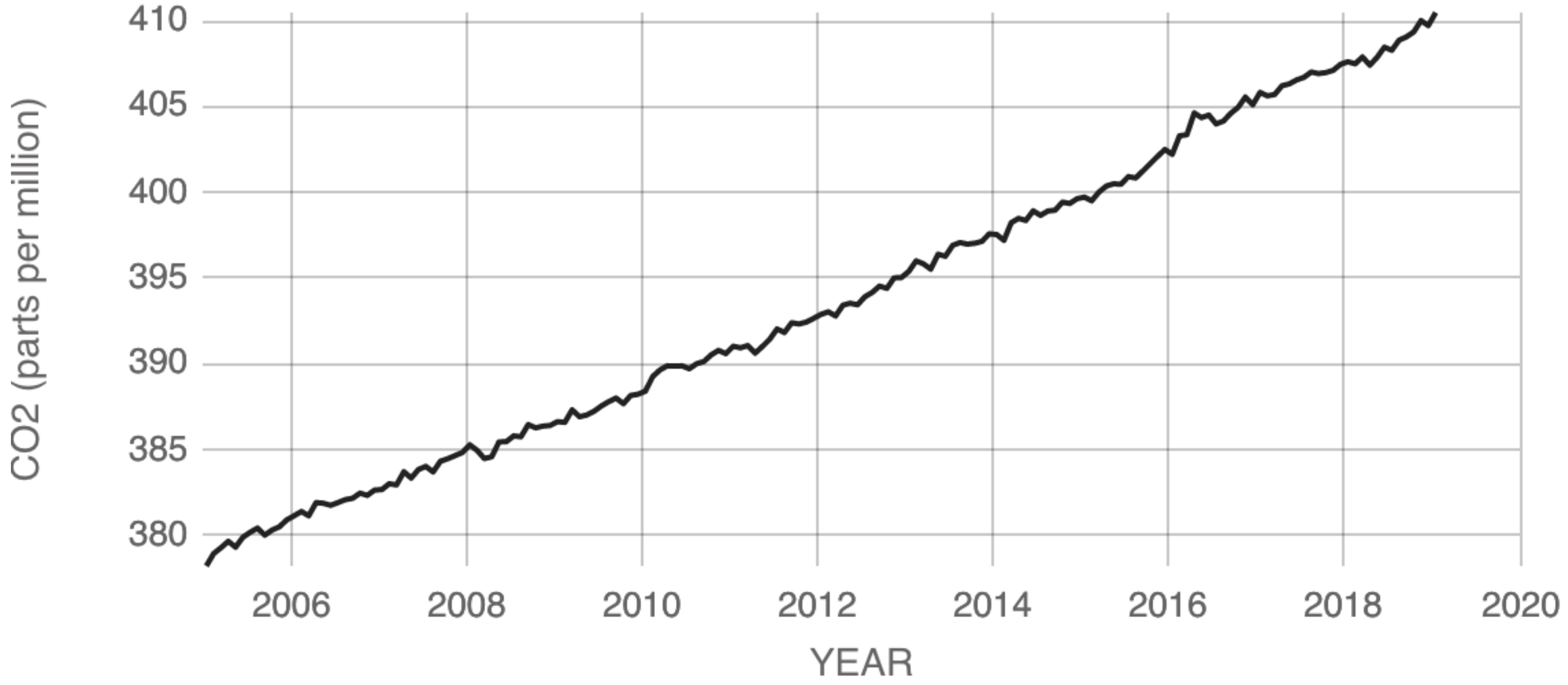
…c.f. variation of

- size ~120ppm,
- *on top of* the usual range of variation,
- occured from 1900 to 2022.

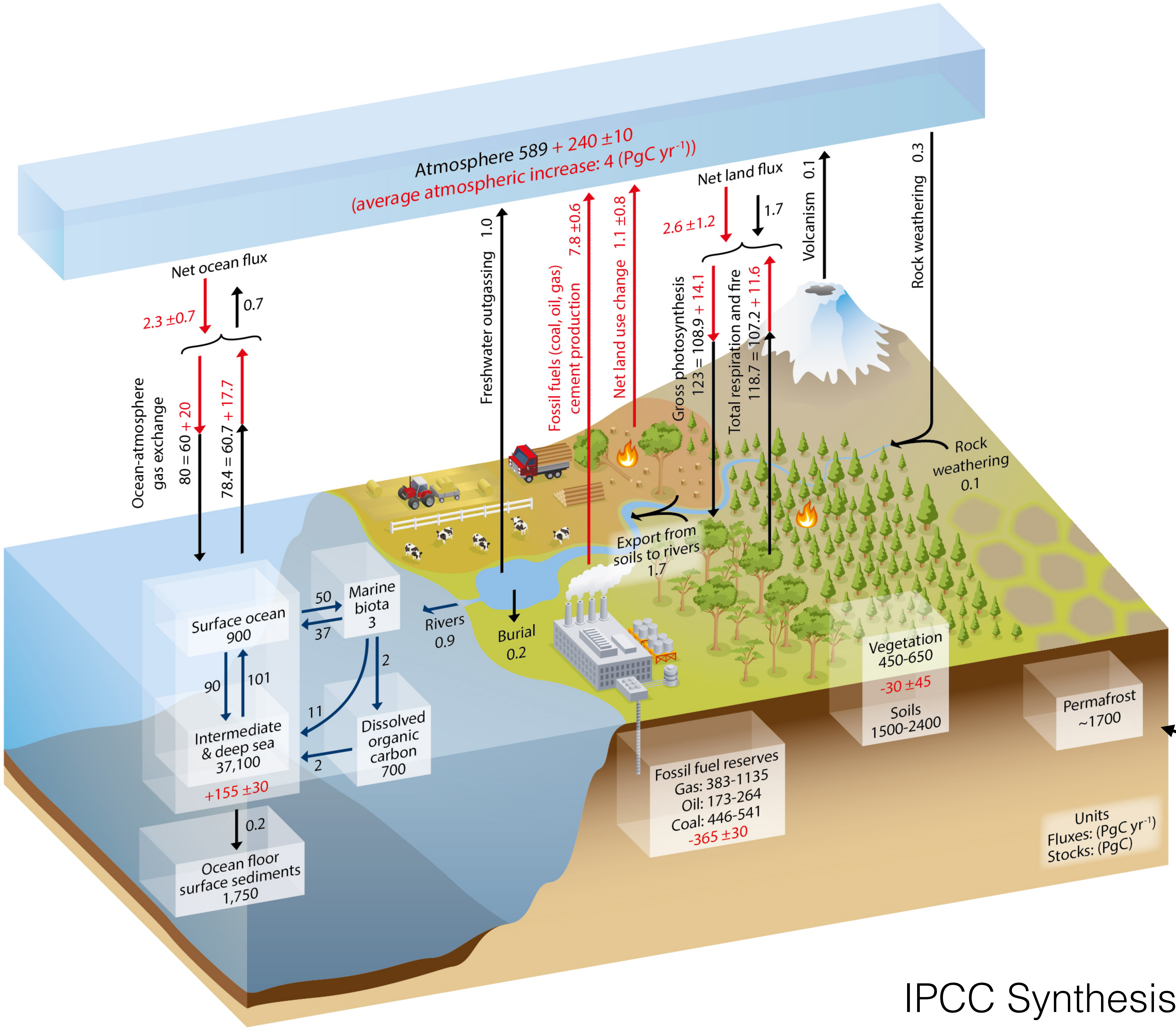
What will the planet do next?

At the last planetary transition, 12,000 years ago:

- CO_2 increased by 80ppm,
- The planet warmed by 6°C,
- km-thick ice sheets over Europe & North America melted,
- sea level rose 120m,
- then the agricultural revolution,
- then human civilisation started.



Source: climate.nasa.gov



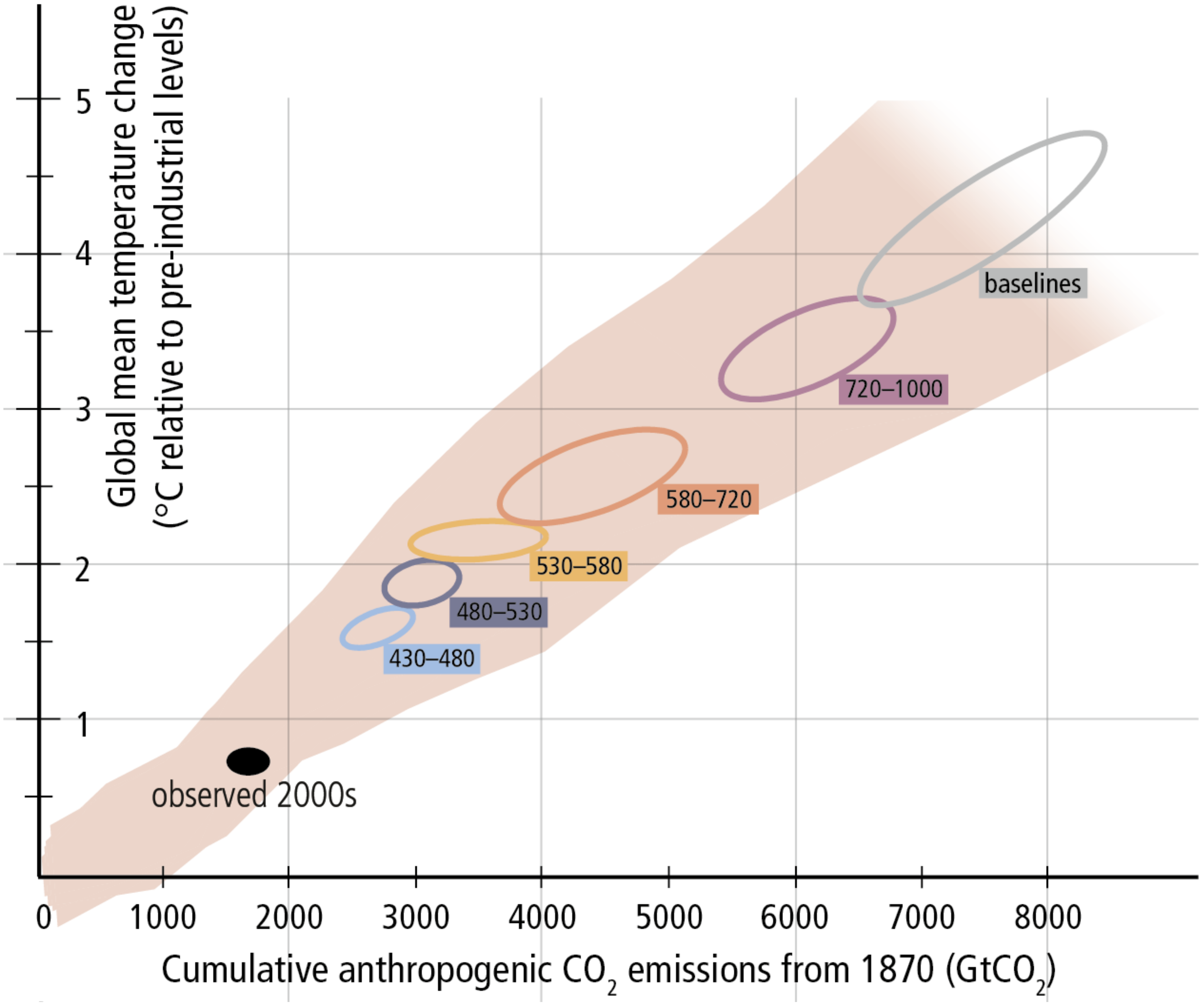
Carbon Cycle: interplay between atmosphere, oceans, geology, biosphere.

anthropogenic
natural

Model this…

Large trapped reservoir of CO2 and methane. Melting.

IPCC Synthesis Report AR5



IPCC Synthesis Report AR5

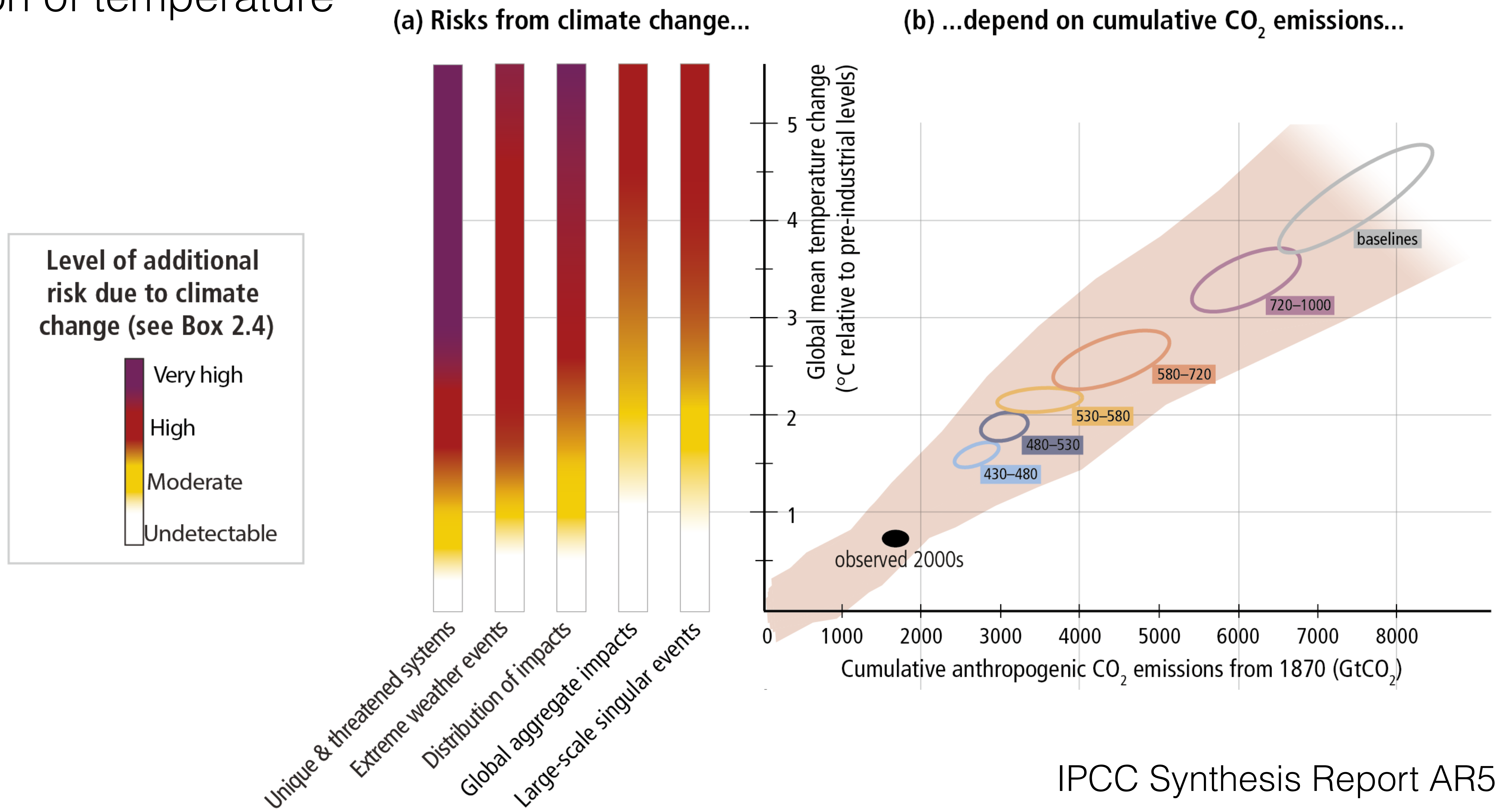
…find simple result: temperature depends (linearly) on cumulative emissions.

Implies we must reduce emissions to net-zero (or the temperature rises indefinitely).

Choose target temperature, read off corresponding x-axis value: your *carbon budget.*

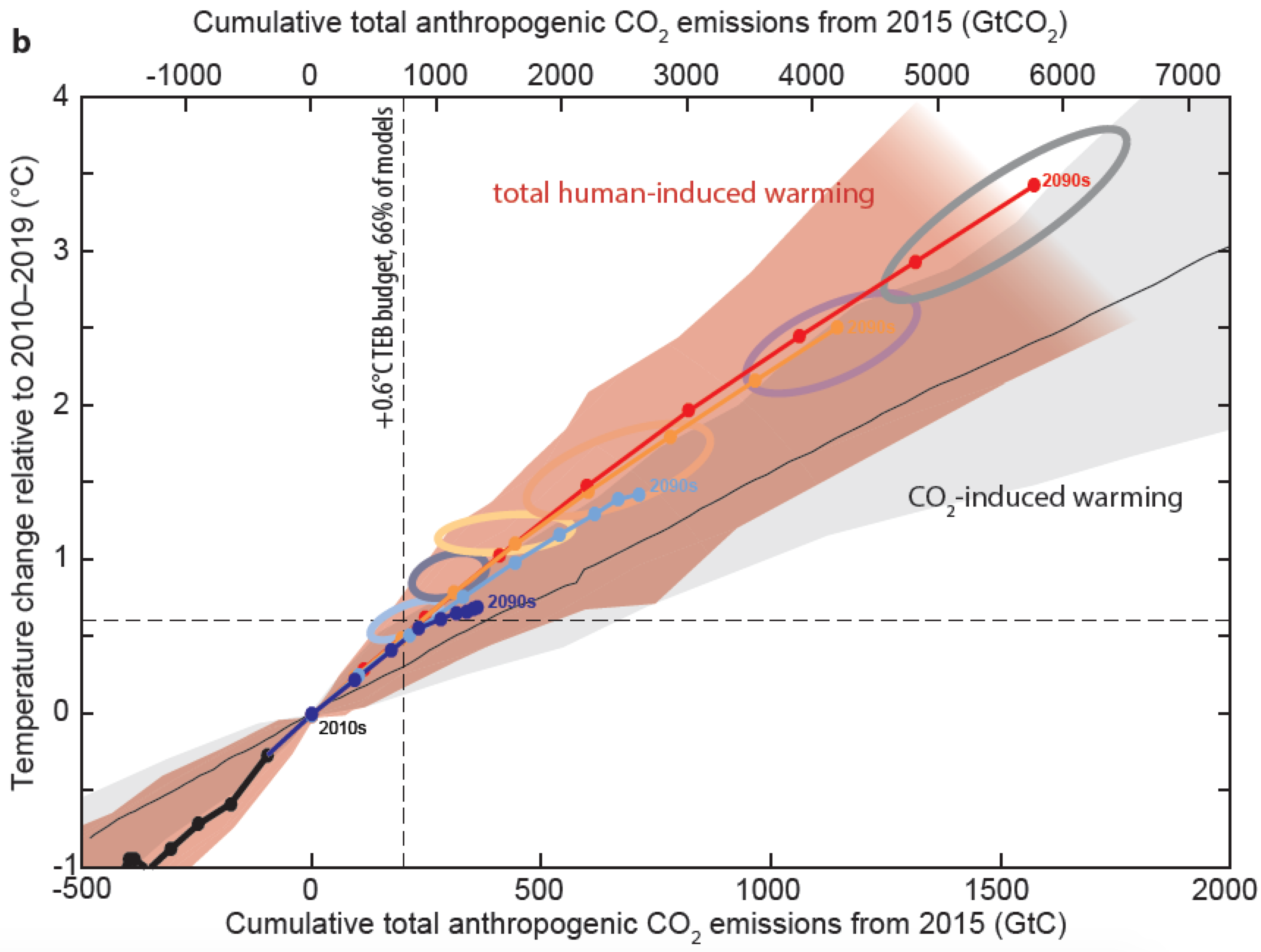
How to choose?

Estimate impacts as function of temperature



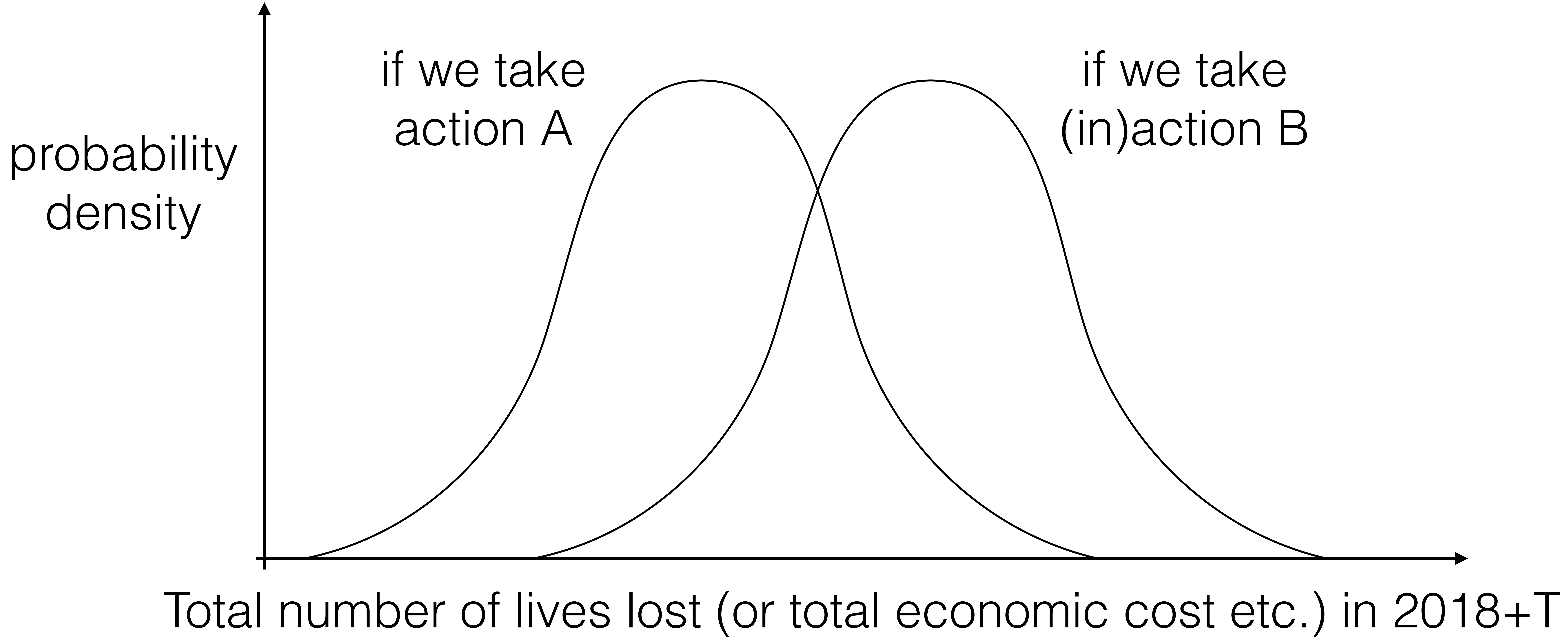
IPCC Synthesis Report AR5

If we re-plot this figure relative to the 2010-2019 period...
Budget for "likely" (2-in-3 odds) temperature rise less than 0.6°C above the current decade: 800 $GtCO_2$ (~ 200 GtC) from 2015

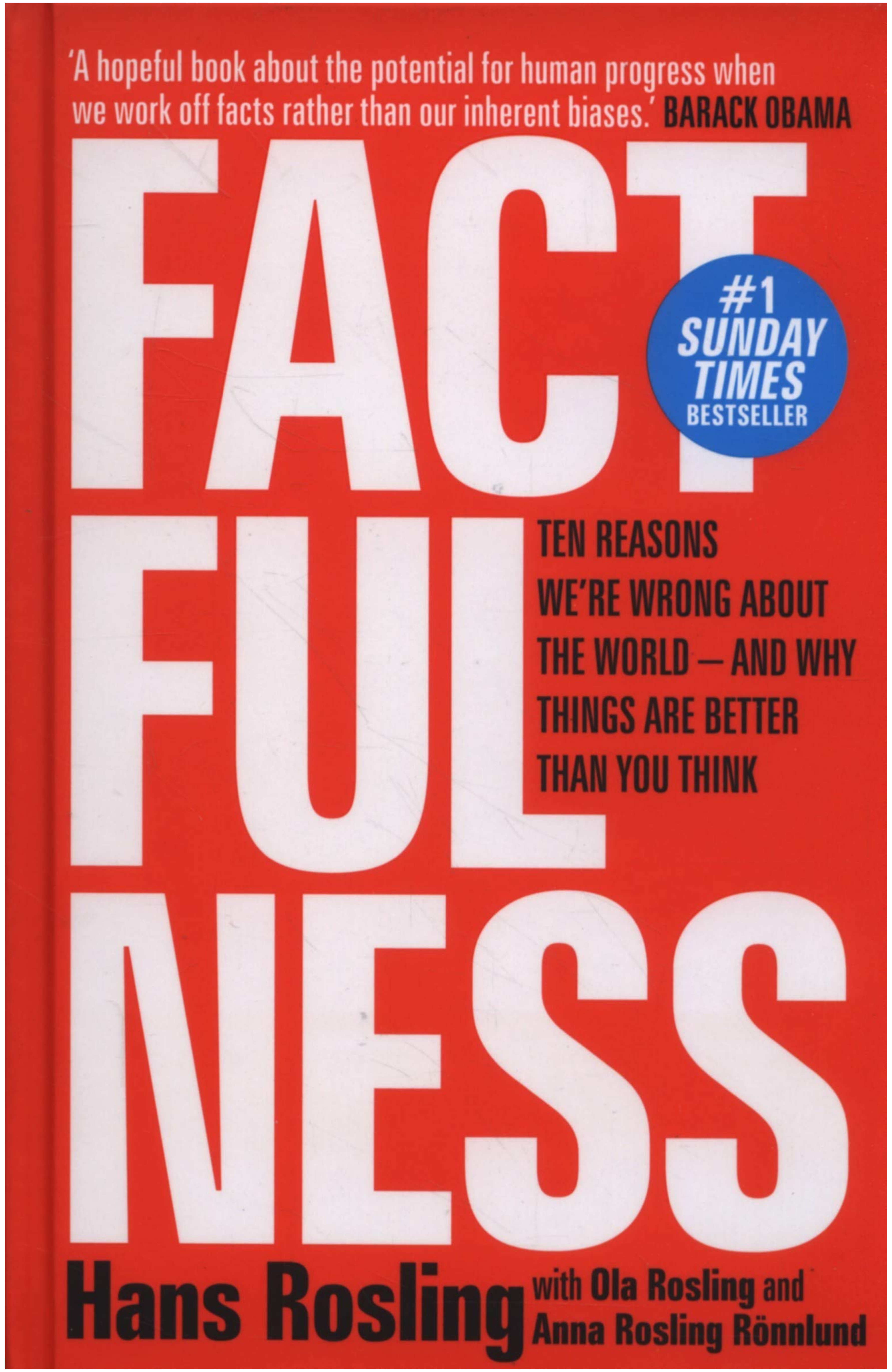


Millar et al. 2017
Nature Geosciences
Slide courtesy
Helen Johnson

How to calculate this?



Could imagine, for careful A and careless B,
a difference of O(10% world population).
Extremely hard to calculate. But not calculating it → inaction



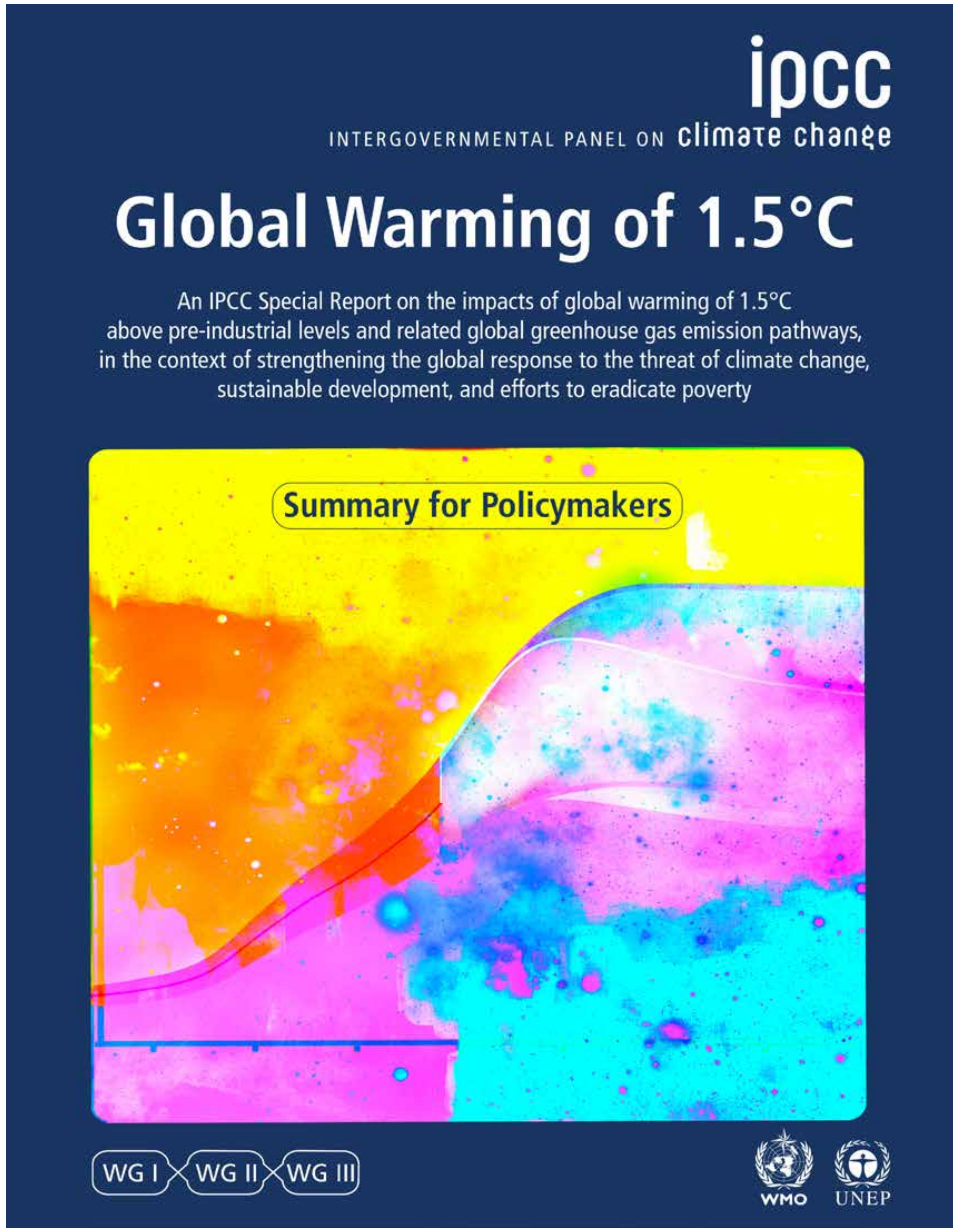
"Saving poor children *just* increases the population" sounds correct, but the opposite is true. Delaying the escape from extreme poverty *just* increases the population. Every generation kept in extreme poverty will produce an even larger next generation. The only proven method for curbing population growth is to eradicate extreme poverty... when it comes to child mortality we don't have to choose between the present and the future, or between our hearts and our heads: they all point in the same direction. We should do everything we can to reduce child mortality, not only as an act of humanity for living suffering children but to benefit the whole world now and in the future.

+many more excellent points about helpful views for global wellbeing.

Minor criticism:

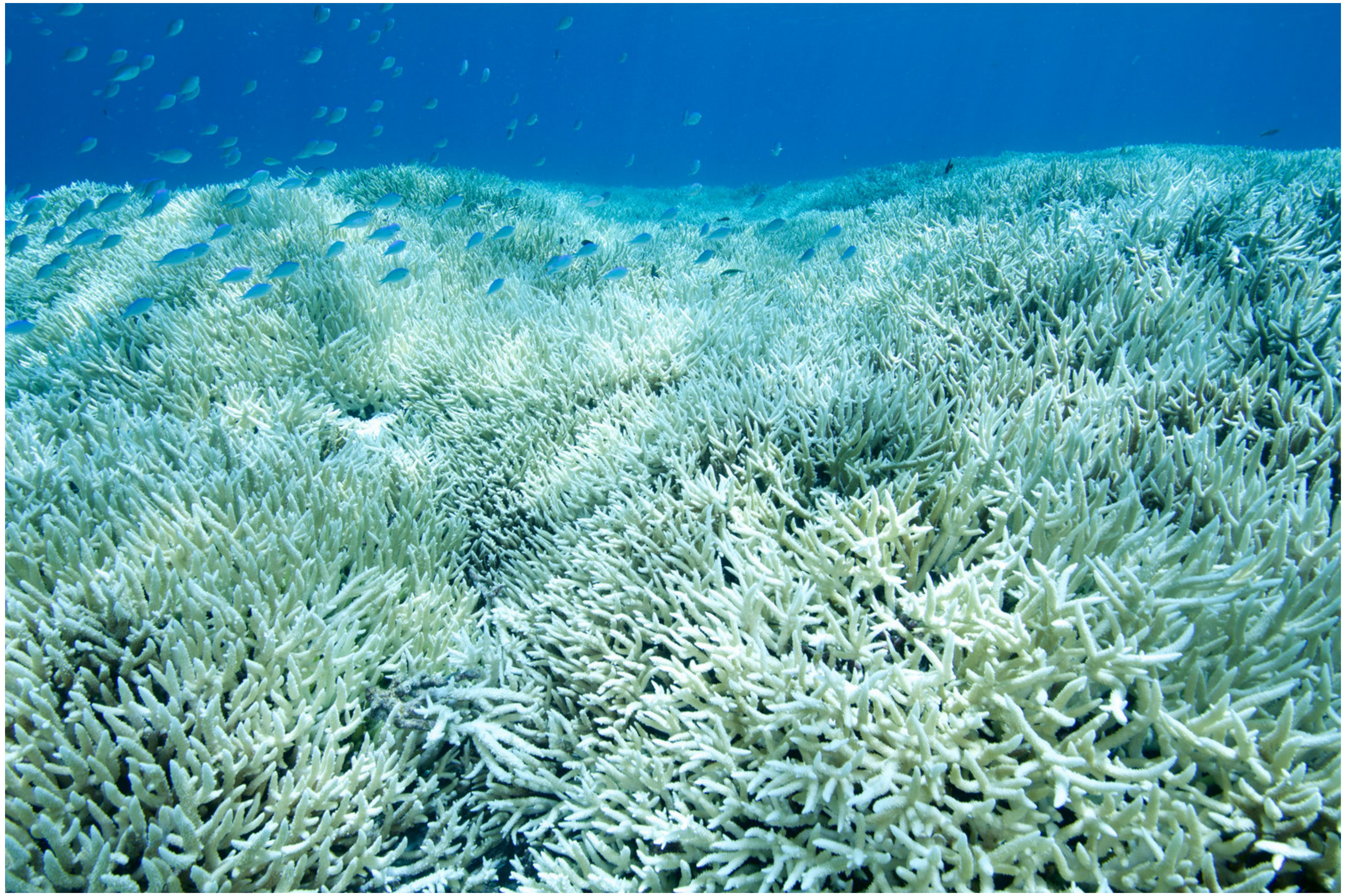
- Warns against inappropriate linear extrapolation of the past into the future*.
- Warns against inappropriate comparison of averages (variance may be large).
- Warns against exaggerated calls for urgent action.
- Climate change included as top five risk, but downplayed even so. Says ‘climate refugee’ is an invented term for an invented problem.

*c.f. Thomas Hardy, Far From the Madding Crowd: “so greatly are people's ideas of probability a mere sense that precedent will repeat itself.”



IPCC Special Report on 1.5°C; handy Technical and Policymaker Summaries

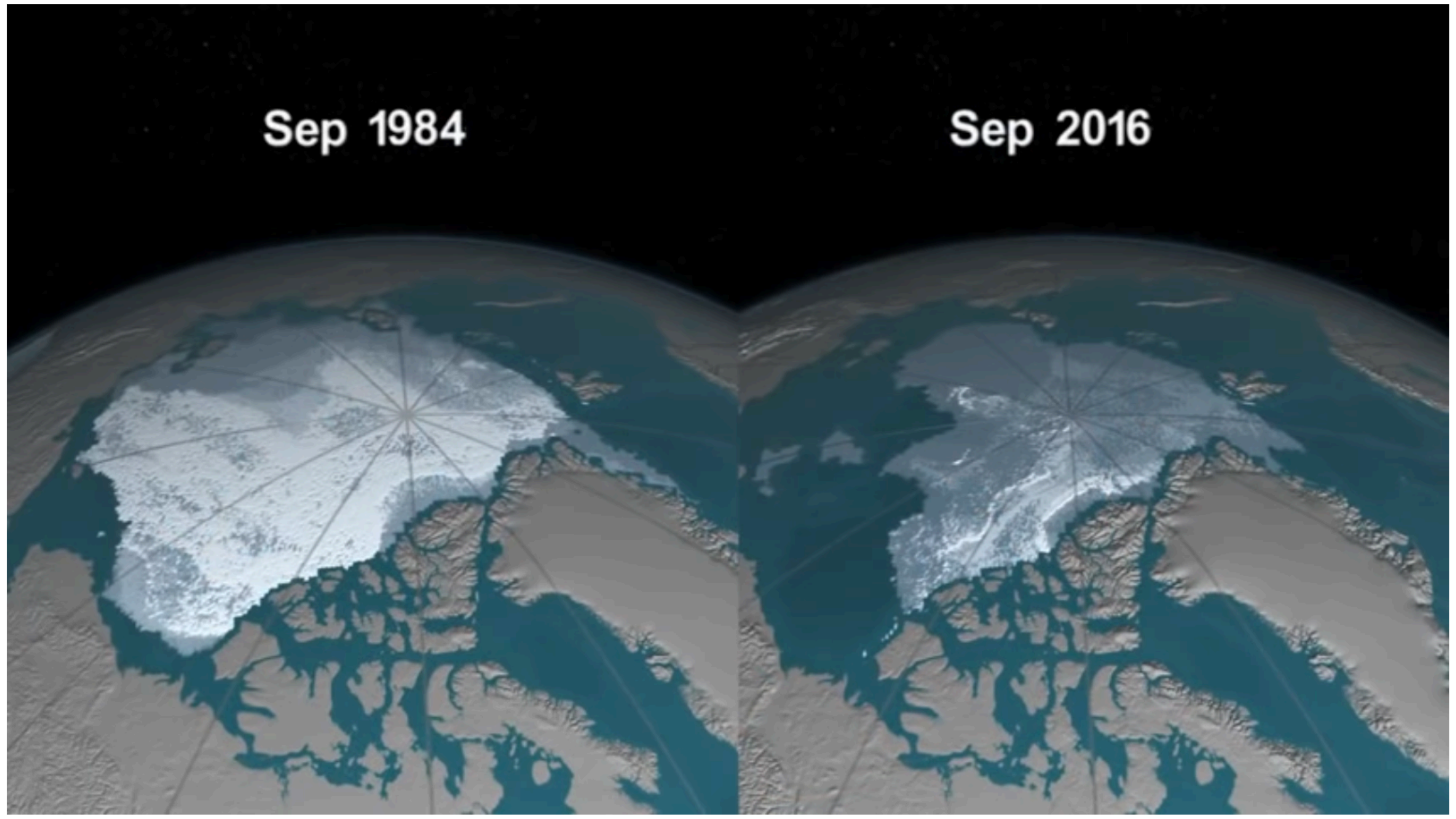
- Limiting global warming to 1.5°C instead of 2°C could result in around 420 million fewer people being frequently exposed to extreme heatwaves
- ocean acidification and changes to carbonate chemistry that are unprecedented in 65 million years at least (high confidence)… Ocean ecosystems are experiencing large-scale changes, with critical thresholds expected to be reached at 1.5°C and above (high confidence)
- limiting global warming to 1.5°C, compared with 2°C, could reduce the number of people both exposed to climate-related risks and susceptible to poverty by up to several hundred million by 2050 (medium confidence)
- limiting global warming to 1.5°C compared to 2°C may reduce the proportion of the world population exposed to a climate change-induced increase in water stress by up to 50%



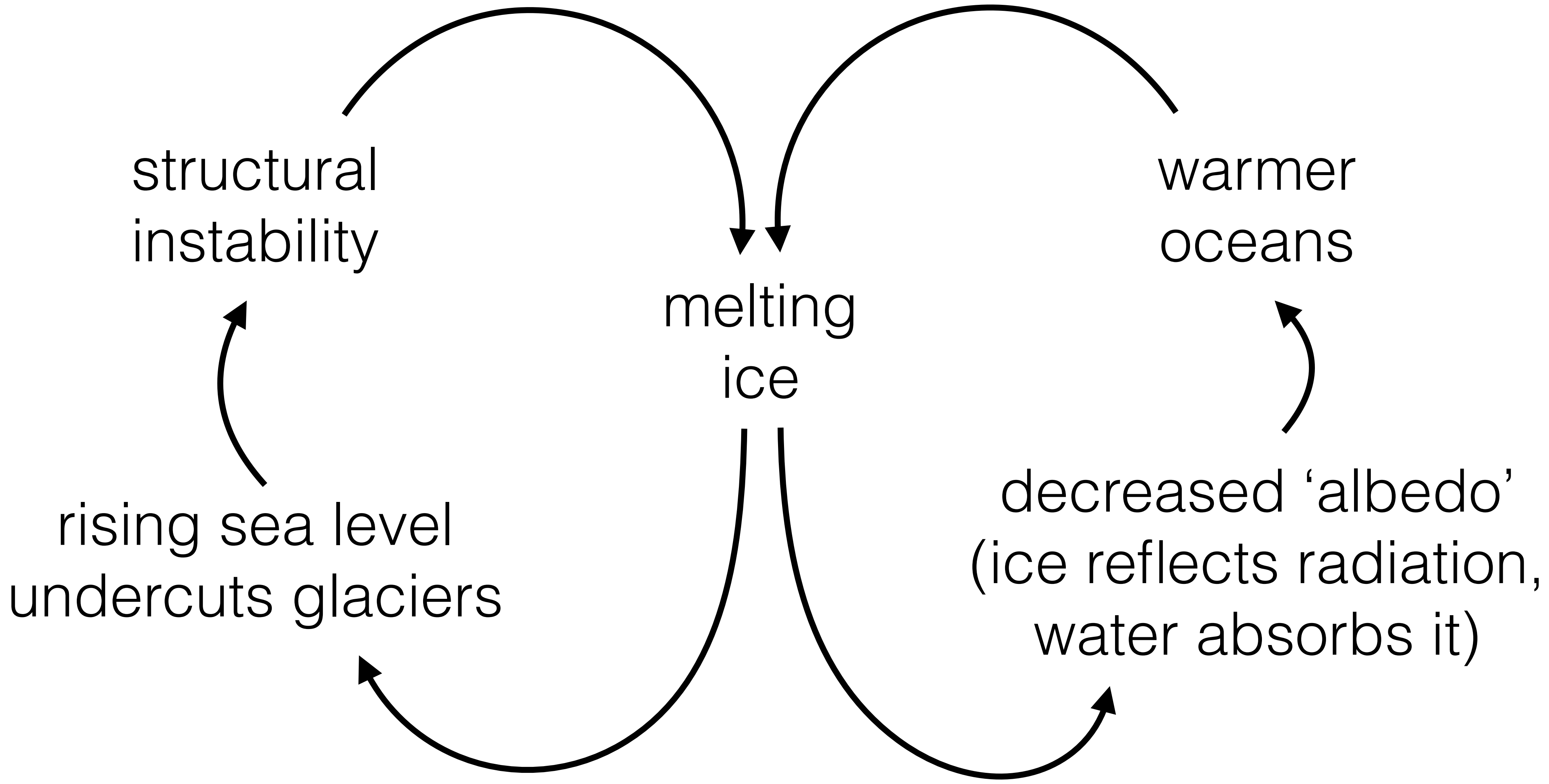
www.savingthegreatbarrierreef.org

1.5°C warming: 70–90% decline in coral reefs
2°C warming: >99%
IPCC Special Report on 1.5°C

“Nearly 200 million people depend on coral reefs to protect them from storm surges and waves. Coral reefs support more than a quarter of marine life. The implications of [a 90% decline] for the planet and all of humanity are vast.”
WWF 2018 Living Planet Report



Arctic Ocean. Time-lapse at https://svs.gsfc.nasa.gov/4510

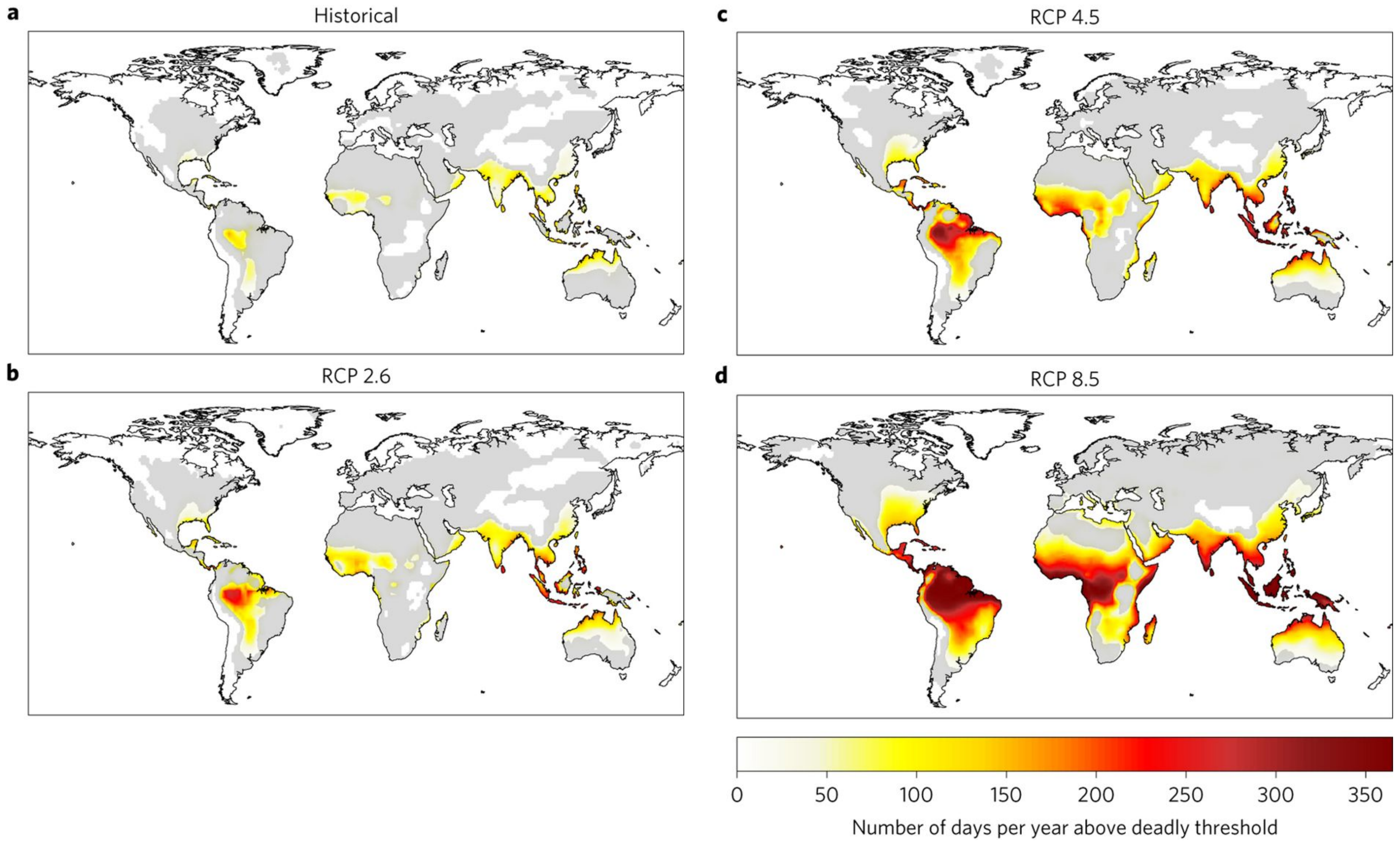


Melting of the East Antartic ice sheet would raise sea levels by 65m, but this is unlikely.

"Instabilities exist for both the Greenland and [West] Antarctic ice sheets that could result in multi-meter rises in sea level on centennial to millennial timescales. There is medium confidence that these instabilities could be triggered under 1.5° to 2°C of global warming." IPCC 1.5° Report

~10% of the world population live <10m above sea level (UN).

Mora et al. 2017
Nature Climate Change:



Mora *et al.* 2018 Nature Climate Change: identified “467 pathways by which human health, water, food, economy, infrastructure and security have been recently impacted by climate hazards”. Caveat: no event attribution here. *Potential* pathways for increased damage.

“Problems don’t add, they multiply” - my dad.

https://www.carbonbrief.org/mapped-how-climate-change-affects-extreme-weather-around-the-world

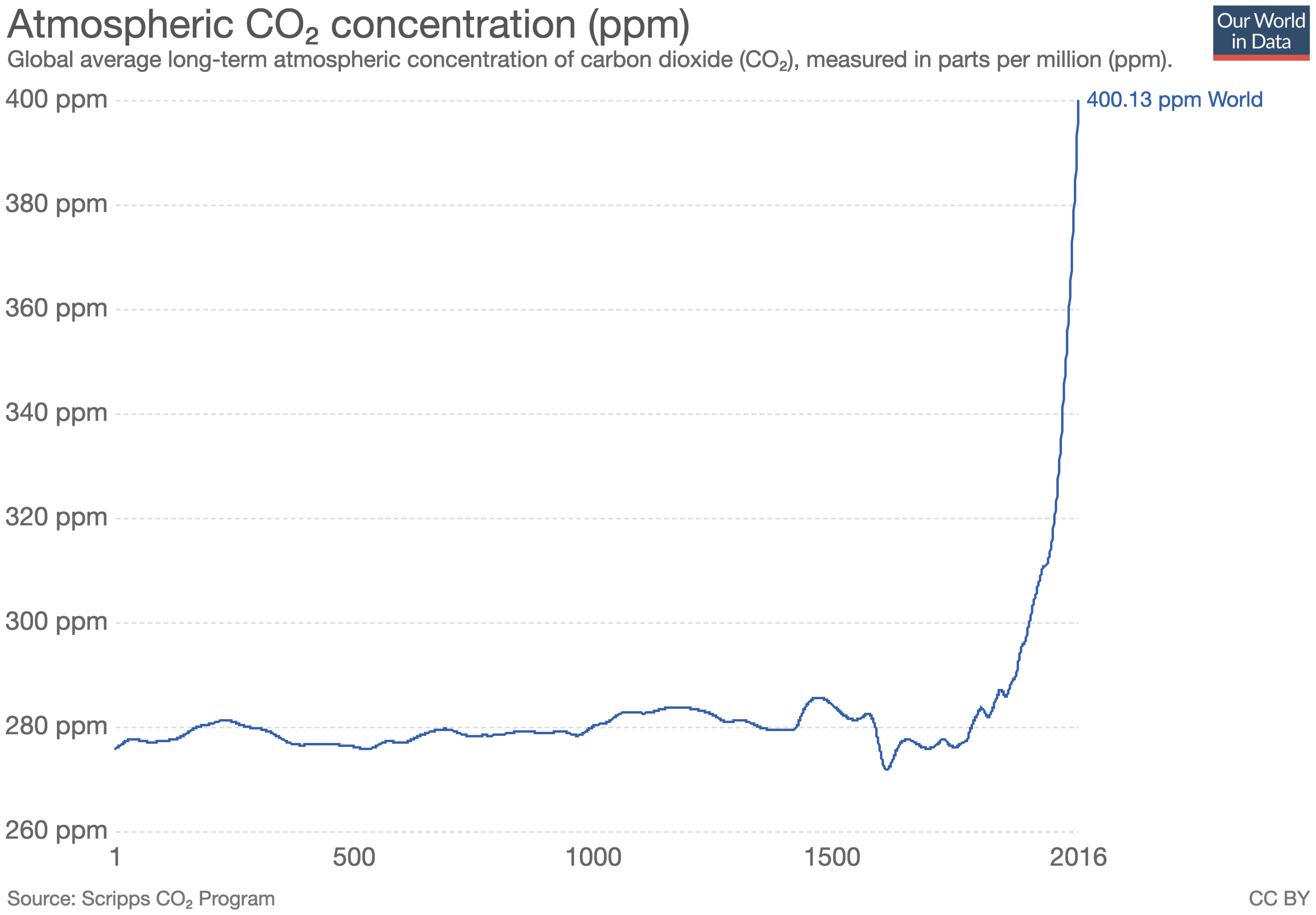
Emerging field of extreme weather event attribution strong in Oxford (Friederike Otto, Myles Allen *et al.*)

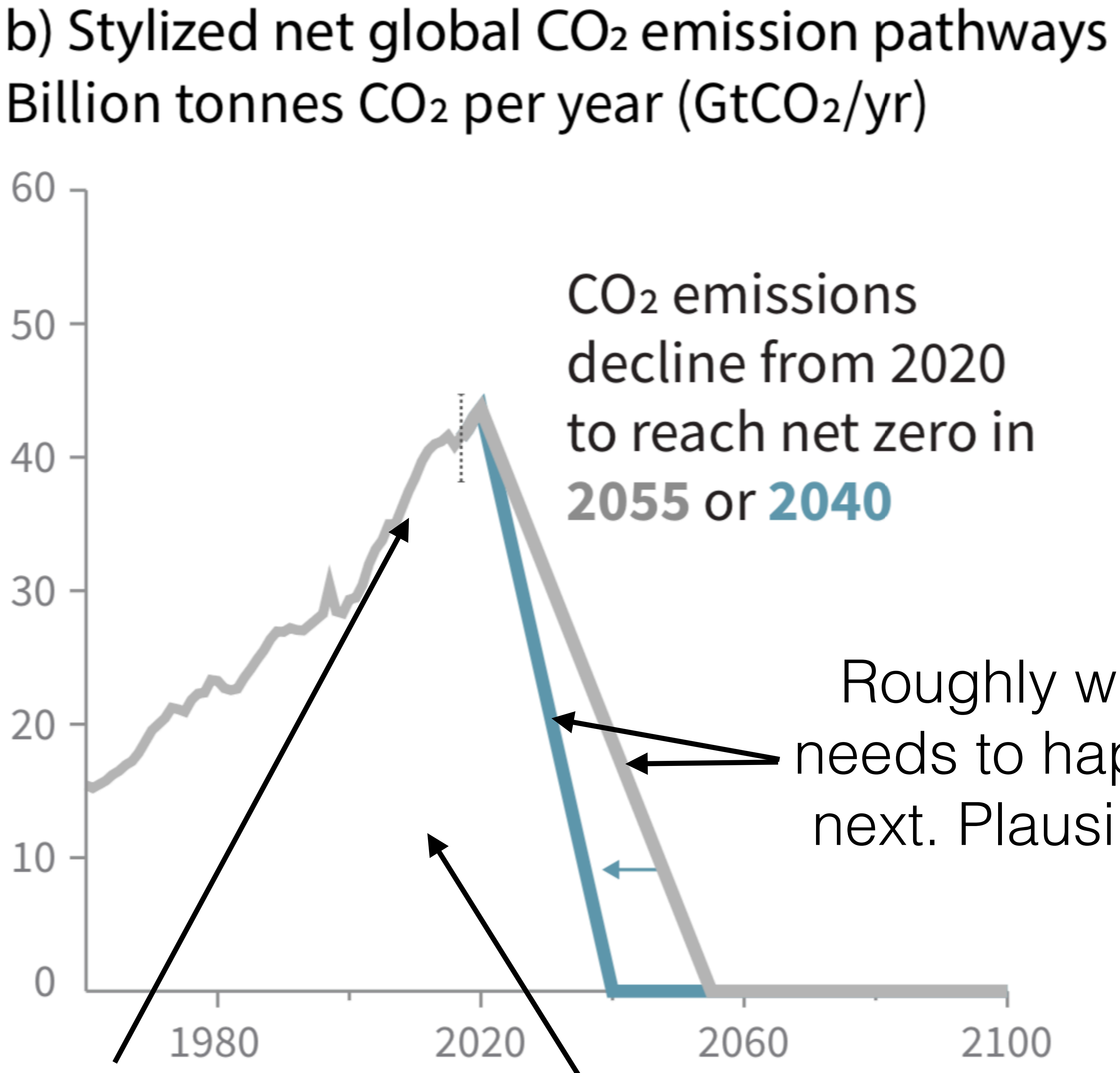
Amount of CO2
needs to become constant.
It is not only increasing,
but accelerating.

differentiate →

← integrate

Rate of CO2 emission
needs to become zero.
It is not only positive,
but increasing.





Roughly what
needs to happen
next. Plausible?

IPCC 1.5°C report

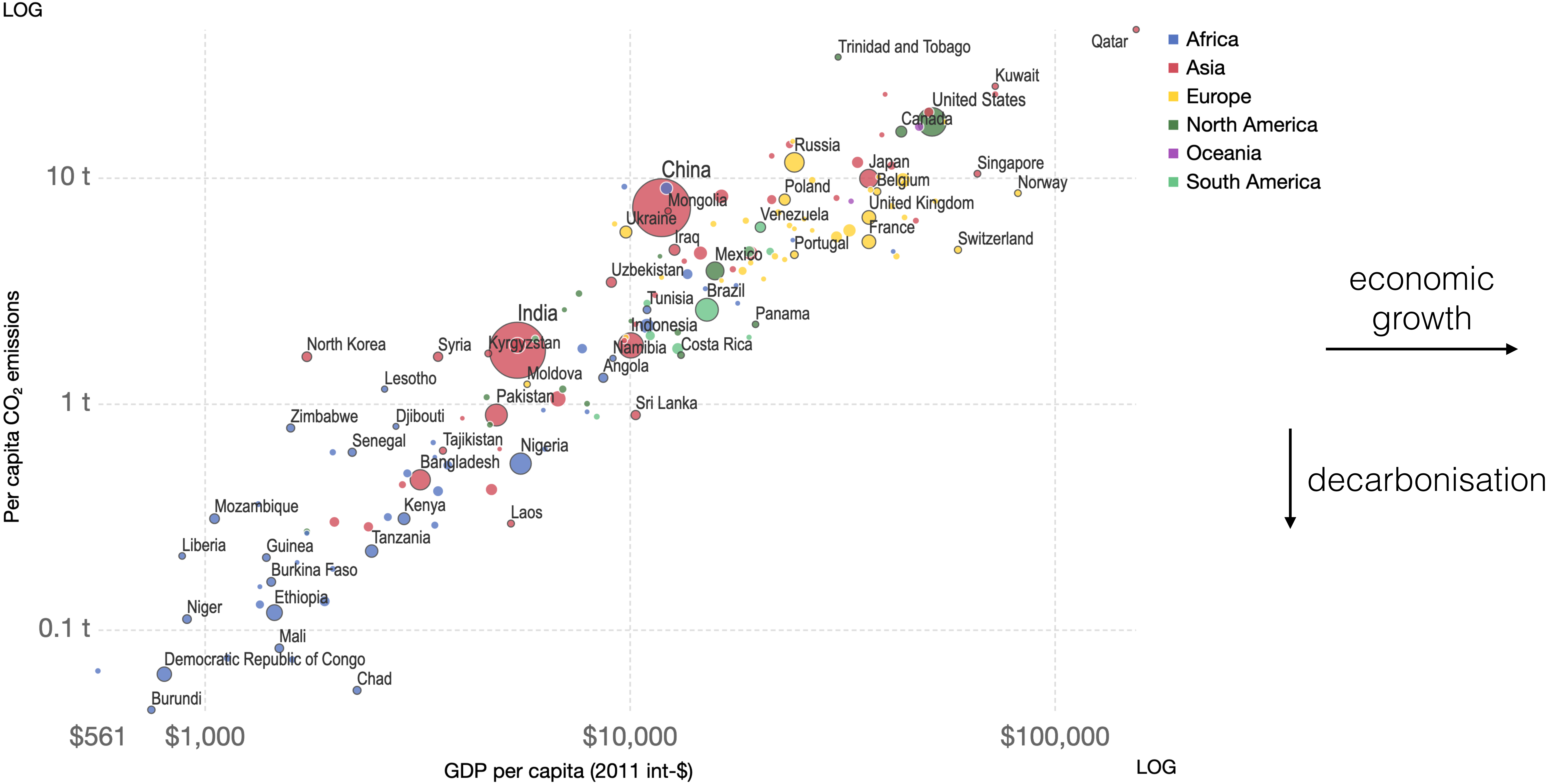
2018 rate: 37 billion tonnes per year
= 7.7 billion people ×
4.8 tonnes per person per year

Areas = carbon budgets

CO_2 emissions per capita vs GDP per capita, 2014

Our World in Data

Carbon dioxide (CO_2) emissions per capita, measured in tonnes per person per year, versus gross domestic product (GDP) per capita, measured in 2011 international-$.



Other aspects of environmental and natural degradation

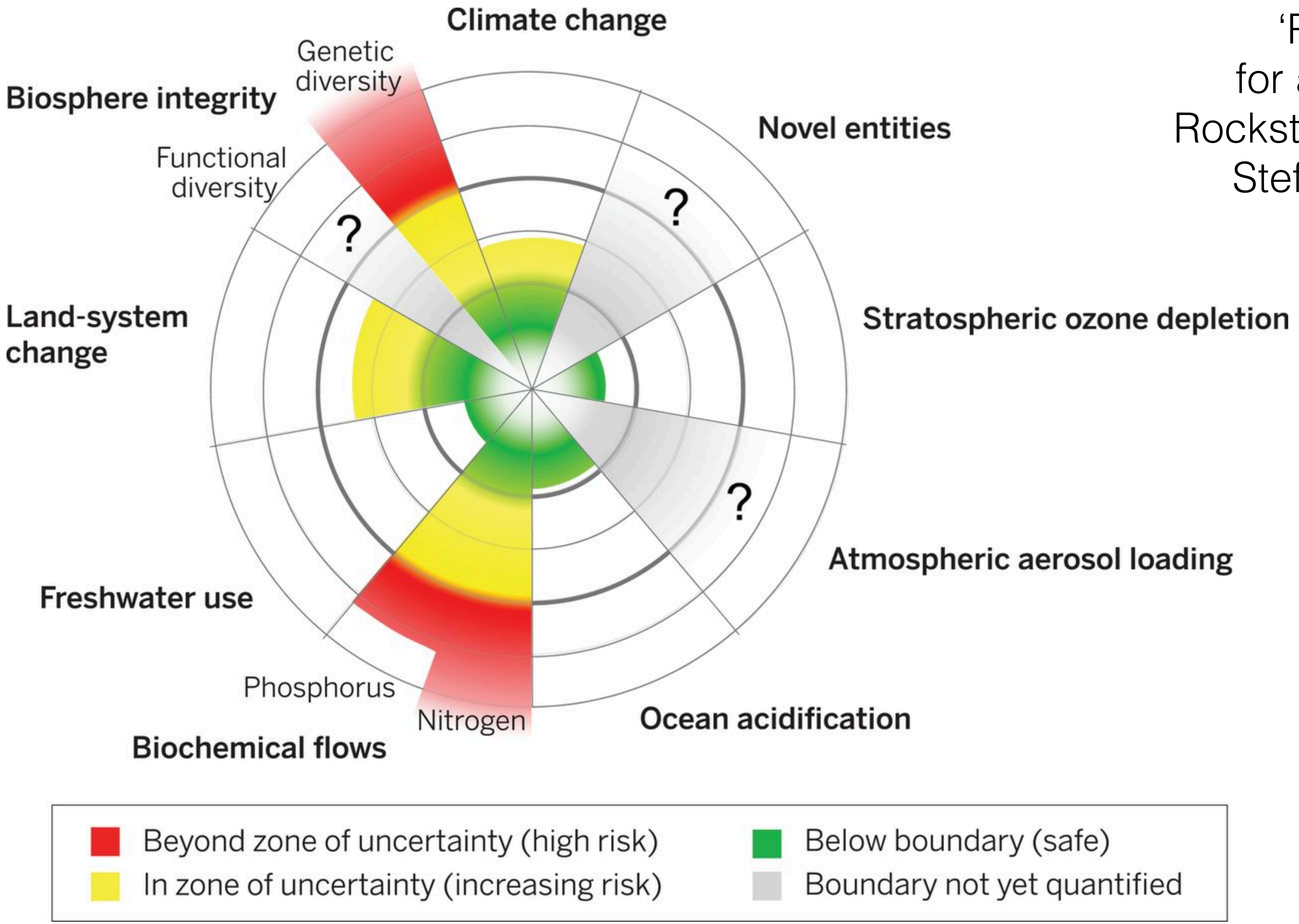
Annual plastics production:
- in 1964, 15 million tonnes;
- in 2014, 311 million tonnes;
- expected to double in next 20 years.

“32% of plastic packaging escapes collection systems, generating significant economic costs by reducing the productivity of vital natural systems… The cost of such after-use externalities… is conservatively estimated at USD 40 billion annually — exceeding the plastic packaging industry’s profit pool.”

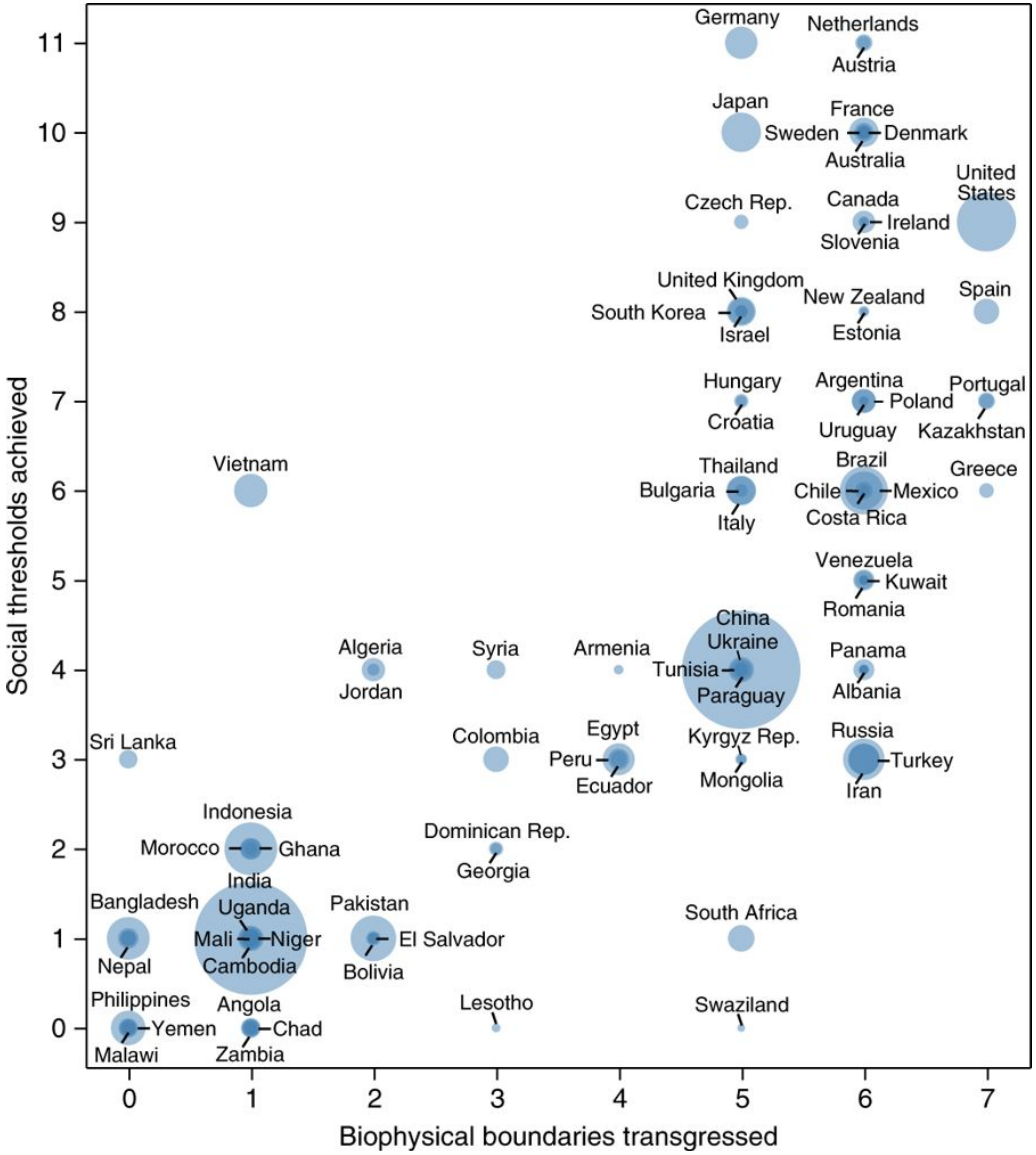
“Each year, at least 8 million tonnes of plastics leak into the ocean.” Business as usual: doubled by 2030, quadrupled by 2050, at which point there will be more plastic than fish.

Ellen MacArthur Foundation & World Economic Forum

1960: 5% of the world’s seabirds have fragments of plastic in their stomachs
today: 90%
WWF 2018 Living Planet Report



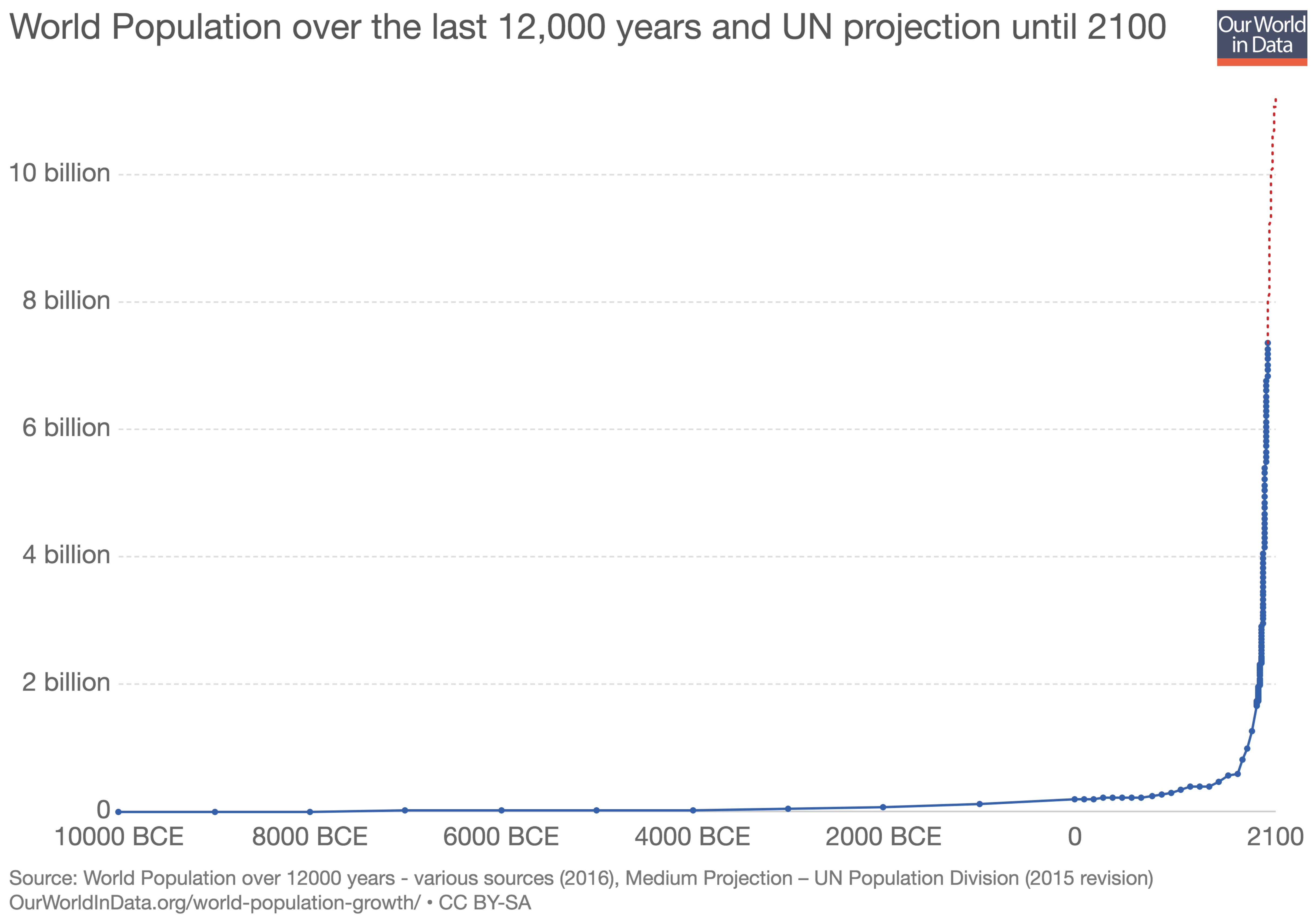
'Planetary Boundaries'
for a safe operating space.
Rockström *et al.*, Ecol. Soc. 2009;
Steffan *et al.*, Science 2015

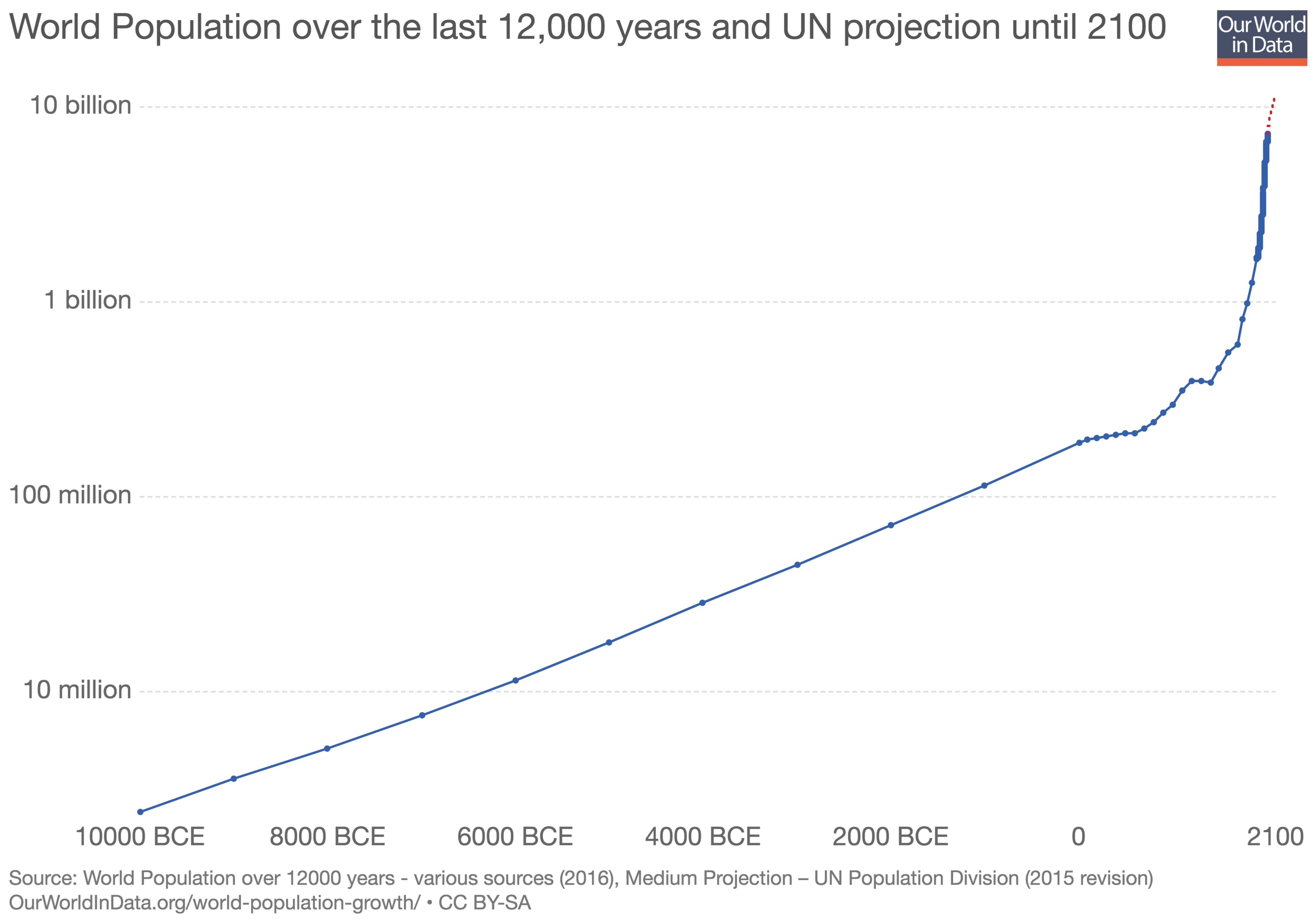


basic
human
needs

sustainability

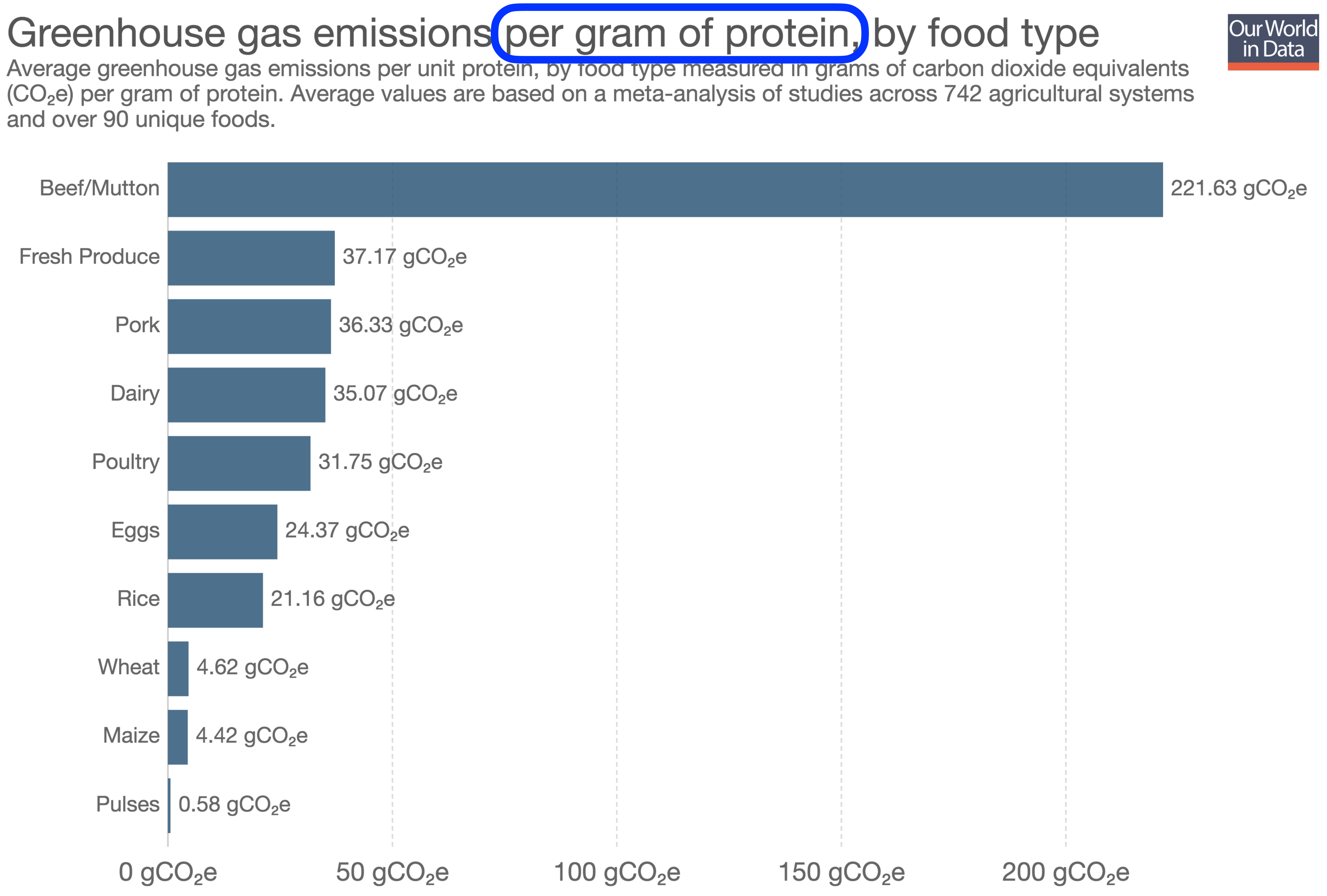
O'Neil *et al.*, Nature Sustainability 2018

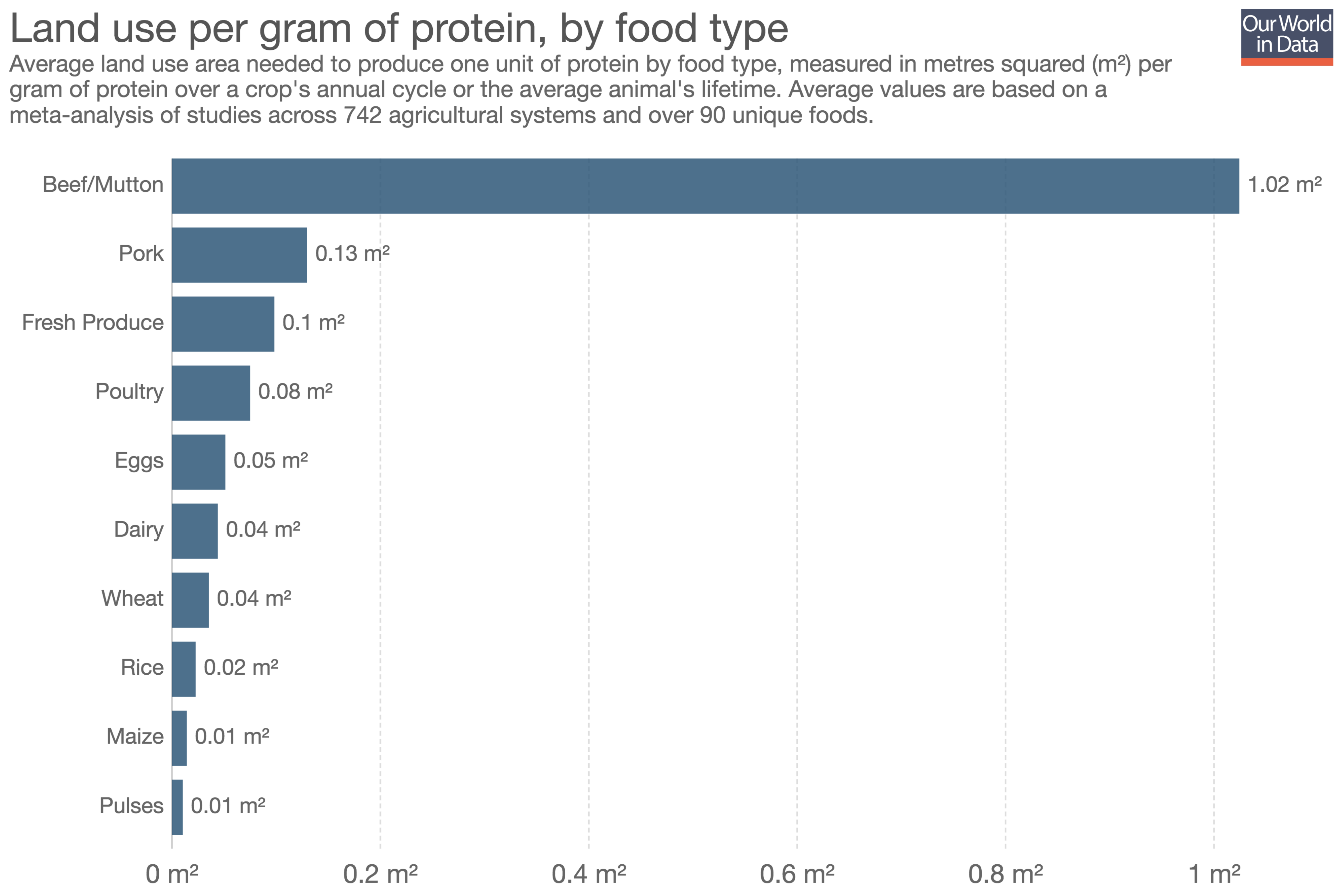




ourworldindata.org

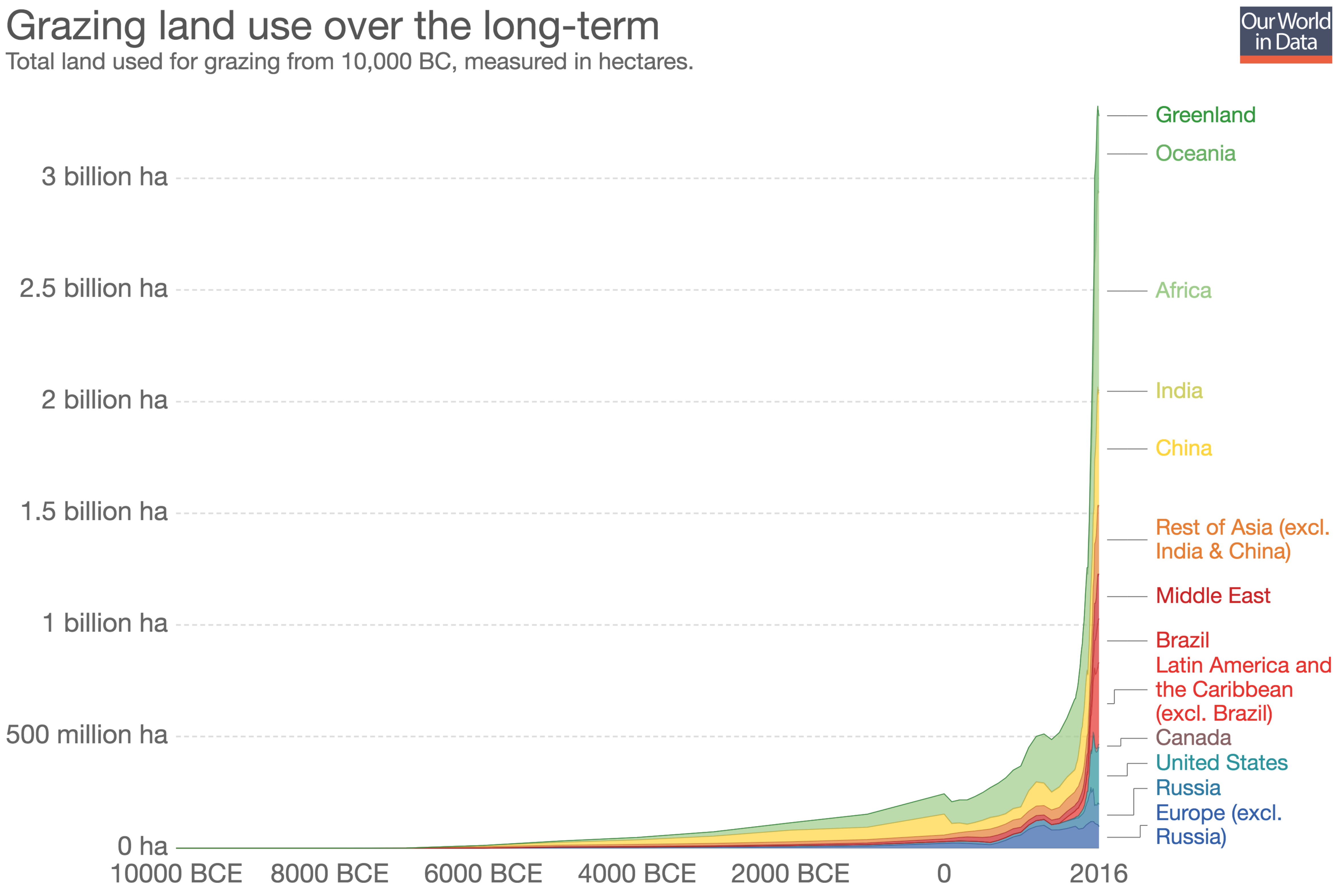
not per gram of food!

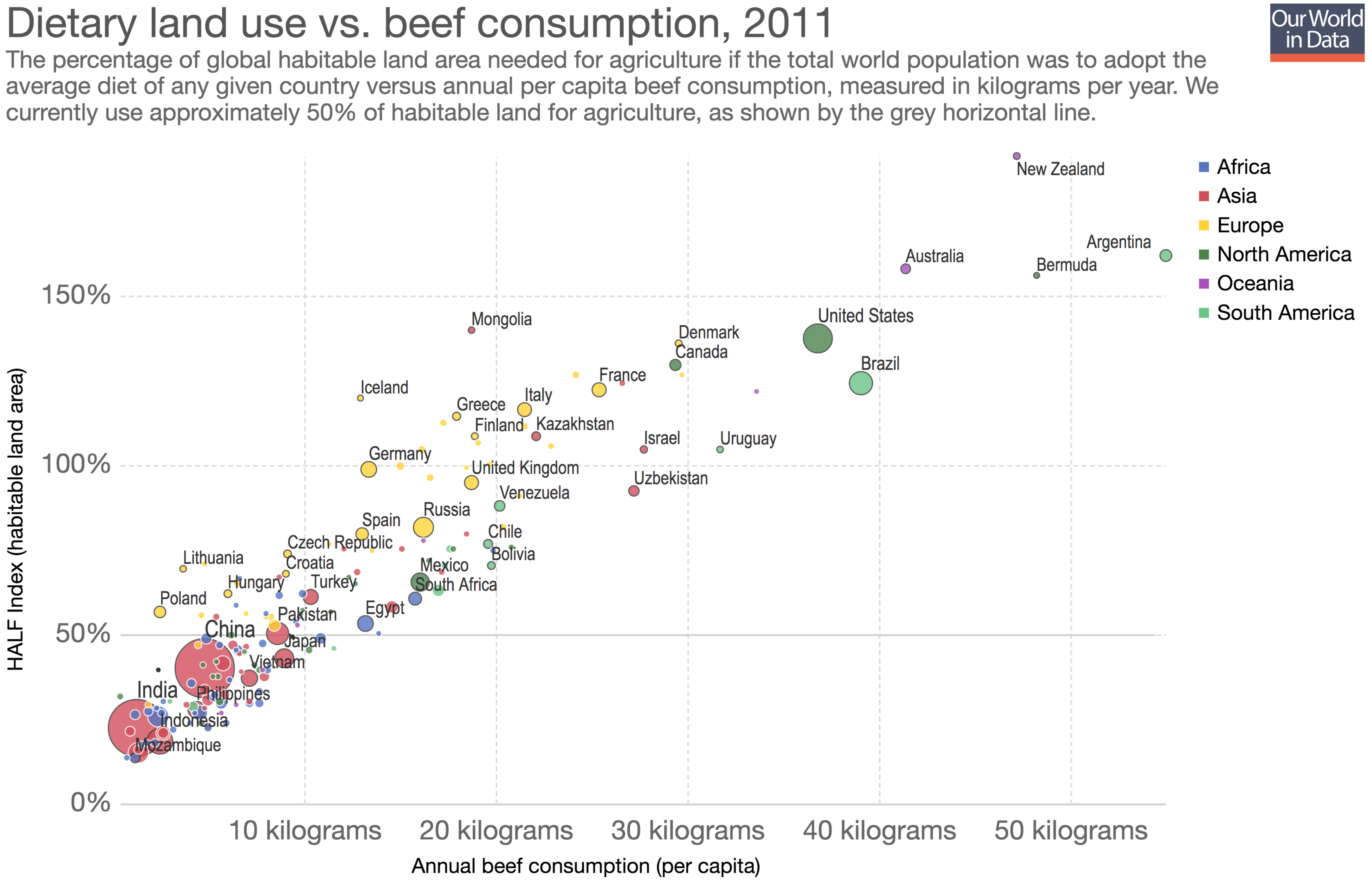


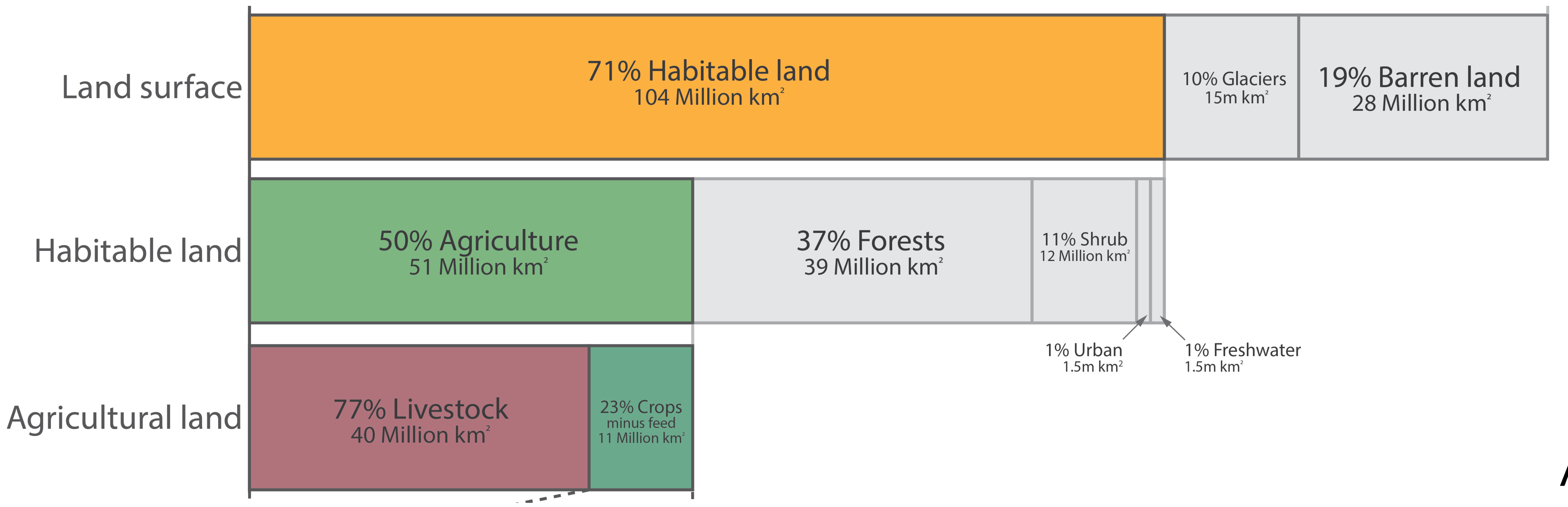


Caveat: radiative forcing of methane c.f. CO2 is time-dependent.

Data: Clark & Tilman, Env. Res. Letters 2017
See also Poore & Nemecek, Science 2018

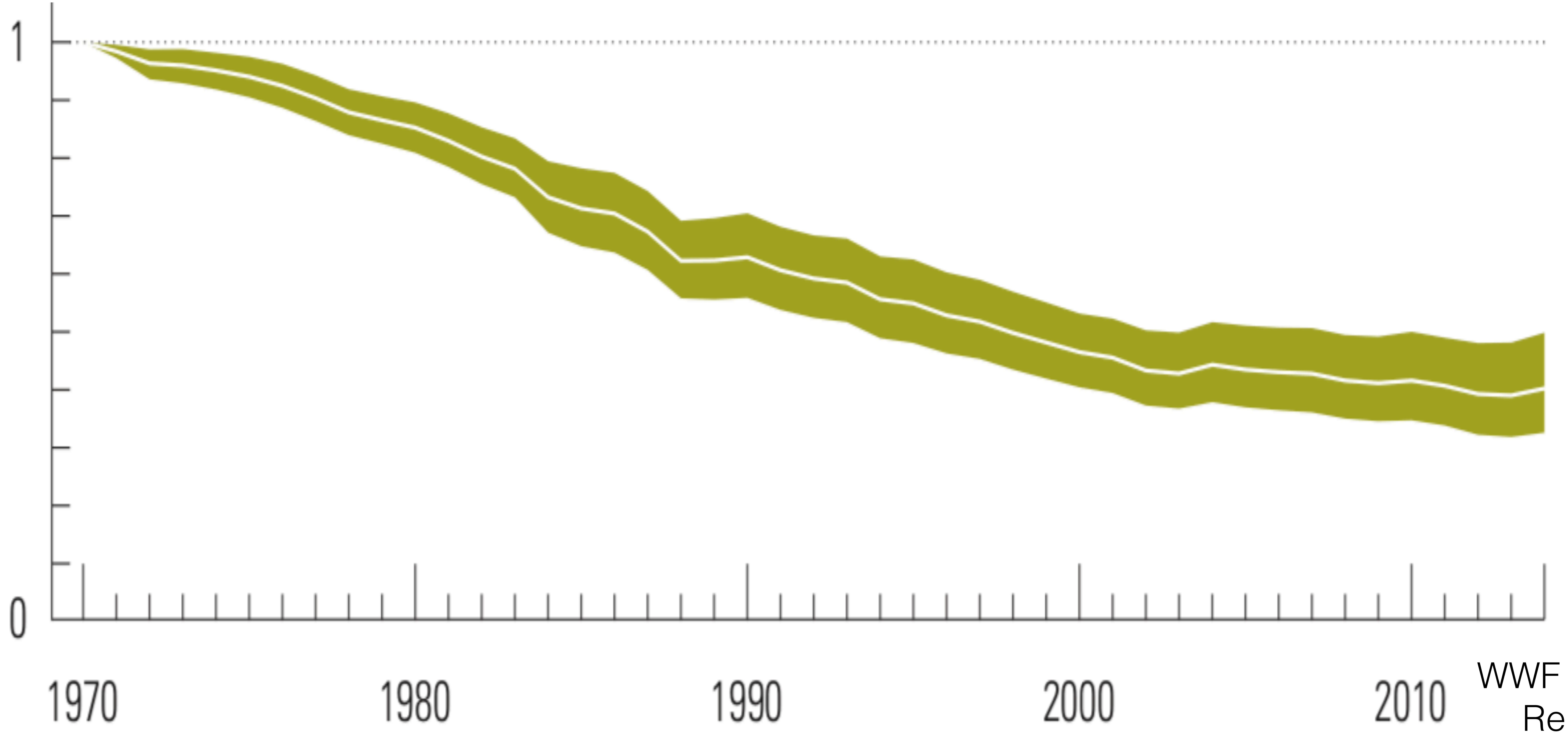






Alexander et al. 2016

Land Use Data - HYDE (2017)



WWF Living Planet Report, 2018
My notes: https://tinyurl.com/y4pb4f6w

Global population abundance of mammals, birds, fish, reptiles and amphibians: 60% decrease from 1970 to 2014.
Equivalent loss of human life: everyone in Europe, North America, South America, Africa, China and Oceania*.
Driven by habitat destruction.

*The Guardian

Some ways of thinking about solutions
(highly idiosyncratic selection)

Economics: the study of the allocation of scarce resources.

Purely descriptive capacity: how scarce resources *are* allocated.

Advisory capacity: how scarce resources *should be* allocated.
Unavoidability of normative decisions, e.g. the value of one year of life, now.

Natural capital: “the world's stock of natural resources, which includes geology, soils, air, water and all living organisms.” (Wikipedia)
→ environmental & ecological economics.

Difficulties:

Running out of a manufactured product may be OK. Running out of natural capital is not.
Too few iPhones for sale → market adjustment (price goes up) → demand matches supply.
Too little natural capital available → market adjustment → even higher incentive to consume it. A positive feedback loop towards an irreversible threshold: total depletion.

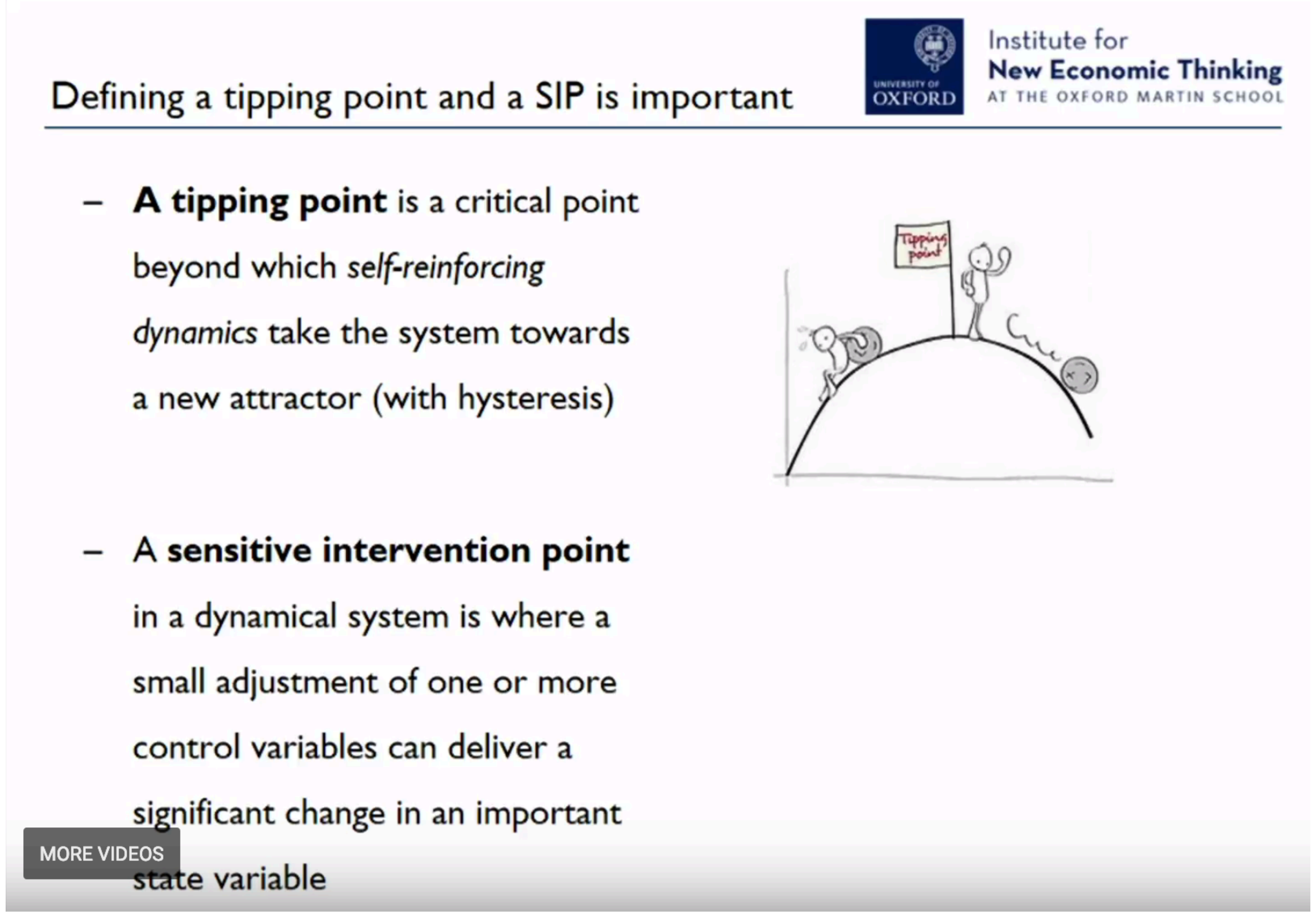
Fossil fuels and other sources of pollution are ‘scarce’ not because there is too little to meet demand, but because consuming them causes damage we want to limit.
Local, quick-acting pollutant: incentive for local, quick-acting solution to limit damage.
CO_2: damage dispersed globally and over centuries: interspatial, intergenerational tragedy of the commons.
Ditto biodiversity: its value is long-term and highly unpredictable (e.g. crop resistance to new pathogens, interconnectedness of ecosystems).

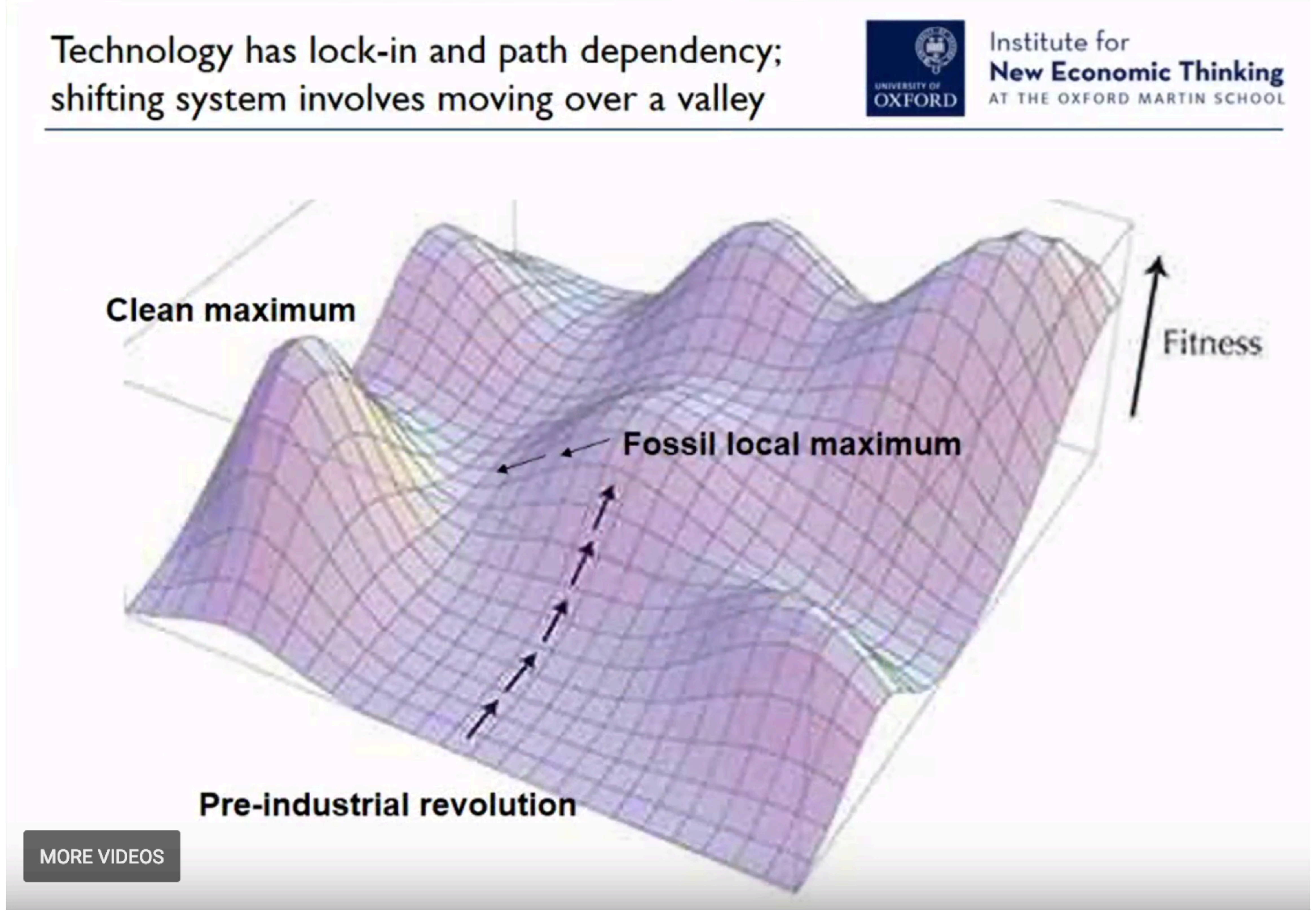
Doyne Farmer
Co-Director, Oxford Martin Programme on the Post-Carbon Transition

Cameron Hepburn
Co-Director, Oxford Martin Programme on the Post-Carbon Transition

Oxford Martin Programme on the Post-Carbon Transition

https://www.oxfordmartin.ox.ac.uk/research/programmes/post-carbon
↑ includes one-hour life-changing (for me) lecture
“How do we identify, model, and trigger *sensitive intervention points* to rapidly transition to a post-carbon society? …in the technological, psychological, socio-political or economic domains, among others.”





Integrative Assessment Models (IAMs): combined models of the economy and the environment to inform e.g. optimal carbon tax to balance fossil-fueled-growth and resulting damage*.

Farmer, Hepburn *et al.* 2015 Environ Resource Econ:
Four main shortcomings of existing IAMs:

- Deep uncertainty in both the relevant physical and economic systems (small but non-negligible risk of catastrophic change even at 2 degrees warming). Only considering the average of possibilities is dangerous. Need to keep uncertainty explicit and allow room to adapt.
- Inappropriate 'representative agent' assumption: need heterogeneity in behaviour and effects. Heterogenous damage may be worse: conflict.
- Innapropriate modelling of technology change as exogenous, not endogenous. Learning by doing; path-dependence/lock-in.
- "damage functions… take a very aggregated form… and are built on meagre empirical evidence. Typically, they model damages in period t as an arbitrary convex function"

…

*https://www.carbonbrief.org/qa-how-integrated-assessment-models-are-used-to-study-climate-change

…Other shortcomings:

- ‘maximum utility framework’ not valid. People are not rational.
- Assume the market is at equilibrium.
- Don’t model finance. Issue of stranded assets; investment for new projects.
- “many IAMs are rarely re-run to see whether the model under accurate parameter values would have predicted the current state of the economy and climate if it were run starting sometime in the past. This process of checking for historical consistency is known as “back testing”… several reasons for this, including unavailability of long-run socio-economic time-series, structural changes in the world economy and biases arising from using the same data to estimate structural parameters and make predictions.” **!!!**

Proposed way forward: stochastic agent-based modelling.

@JKSteinberger
↑ highly recommended

"…the shameful borrowing of physics by economics (they seemed to like the equations more than the reality-based empirical testing part, though)… economics is not a science, not predictive, not equilibrium or smooth, like they like to present themselves. Neoclassical economics is one big pile of disproven axioms built upon a seemingly plausible facade of neatly balanced equations." (Personal communication)

Living Well Within Limits project https://lili.leeds.ac.uk/

- What are the biophysical resources (energy etc.) needed for human well-being?
- Influence of social and technical provisioning systems have this?
- Best allocation of scarce natural resources to balance planetary boundaries and well-being (c.f. *Donut Economics**, Kate Raworth)?
- How are different countries doing so far? (O'Neil *et al.* paper from earlier slide.)

Different definitions of well-being. Common in economics: maximising consumption. Can define in a negative sense: the absence of obstacles (ill health, poor education, hazardous environment) to social participation (Doyal & Gough*, 1984, 1991)

* I haven't read these yet

In the quantities we emit it, CO_2 is a harmful pollutant and should be treated as such by institutional policy, especially for academia* and health providers**. e.g. Manchester University, the Tyndall Centre†.

c.f. ecosystem conservation:

- first *avoid* activities likely to cause damage,
- then *mitigate* damage that wasn't avoided,
- finally *compensate* damage that wasn't mitigated.

Carbon offsetting effectiveness has been strongly criticised (Anderson, Nature 2014; Hyams & Fawcett, Wiley Interdisc. Rev. Clim. Change 2013). Difficult counterfactual forecasting; biased incentives.
Low-hanging fruit: would have been picked soon anyway?

* Jean & Wymant, Science 2019;   Anglaret, Wymant, Jean, The Conversation 2019
** Solomon & LaRocque, NEJM 2019
† http://www.sustainability.manchester.ac.uk/travel/staff/business-travel/
  https://tyndall.ac.uk/travel-strategy

van der Ploeg & Rezai, Environmental and Resource Economics 2018

“Our main objective is to offer an easy back-on-the-envelope analysis, which can be used for teaching and communication with policy makers.”

Result A1: Our simple rule for the optimal carbon price is given by (7) in Result 1. The time paths for the optimal sequestration and share of renewables in the energy mix are

$$a_t = \left(\frac{\tau_t - \theta_{Vt}}{A_1 V_t^{\beta_2}}\right)^{\varepsilon_a} e^{r_A \varepsilon_a t}, \quad 0 \le t < \min[T, T'], \tag{25}$$

$$m_t = \left(\frac{G_0 e^{-r_F t}[1 + e(1 - S_t/S_0)] + \frac{1}{\theta_a} A_0 e^{-r_A t} a_t^{\theta_a} V_t^{\beta_2} - H_0 + X_t}{H_1 e^{-r_R t} B_t^{-\beta_3}}\right)^{\varepsilon_m}, \quad 0 \le t < T \text{ and } m(t) = 1,\ t \ge T, \tag{26}$$

where $X_t \equiv \tau_t + \theta_{St} + \theta_{Bt} - (\tau_t - \theta_{Vt})a_t$ and $\theta_S(t)$, $\theta_V(t)$ and $\theta_B(t)$ are the scarcity value of in situ fossil fuel, the social cost of sequestrating an additional unit of carbon, and the social benefit of learning by doing in renewable energy production at time t, respectively.

Proof The Hamiltonian function is

$$\mathrm{H}^{extended} \equiv \frac{1}{1 - IIA} c_t^{1-IIA} + \lambda_{Pt}\beta_0(1 - a_t)(1 - m_t)\gamma_0 e^{-r_\gamma t} + \lambda_{Tt}\left((1 - \beta_0)(1 - a_t)(1 - m_t)\gamma_0 e^{-r_\gamma t} - \beta_1 E_t^T\right) + \tilde{\lambda}_t(E_t - \tilde{E}_t)/Tlag + [-\lambda_{St}(1 - m_t) + \lambda_{Vt} a_t(1 - m_t) + \lambda_{Bt} m_t]\gamma_0 e^{-r_\gamma t} Y_0 e^{gt},$$

where $\tilde{\lambda}$, λ_S, λ_V and λ_B are the co-states for $\tilde{E}$, S, V and B respectively, and

$$c_t = 1 - d\tilde{E}_t - \left(G_0 e^{-r_F t}\left[1 + e\frac{S_0 - S_t}{S_0}\right] + \frac{1}{\theta_a} A_0 e^{-r_A t} a_t^{\theta_a} V_t^{\beta_2}\right)(1 - m_t)\gamma_0 e^{-r_\gamma t} - H_0 m_t \gamma_0 e^{-r_\gamma t} - \frac{1}{\theta_m} m_t^{\theta_m} H_1 e^{-r_R t} B_t^{-\beta_3} \gamma_0 e^{-r_\gamma t}.$$

The first-order optimality conditions are (12), (13), (14),

$$\frac{\partial \mathrm{H}^{extended}}{\partial a_t} = -c_t^{-IIA} A_0 e^{-r_A t} a_t^{\theta_a - 1} V_t^{\beta_2}(1 - m_t)\gamma_0 e^{-r_\gamma t} - [\beta_0 \lambda_{Pt} + (1 - \beta_0)\lambda_{Tt}](1 - m_t)\gamma_0 e^{-r_\gamma t} + \lambda_{Vt}(1 - m_t)\gamma_0 e^{-r_\gamma t} Y_0 e^{gt} = 0, \tag{27}$$

$$\frac{\partial \mathrm{H}^{extended}}{\partial m_t} = c_t^{-IIA}\gamma_0 e^{-r_\gamma t}\left(G_0 e^{-r_F t}\left[1 + e\frac{S_0 - S_t}{S_0}\right] + \frac{1}{\theta_a} A_0 e^{-r_A t} a_t^{\theta_a} V_t^{\beta_2} - m_t^{\theta_m - 1} H_1 e^{-r_R t} B_t^{-\beta_3} - H_0 + P_t(1 - a_t)\right) - (\lambda_V a - \lambda_S - \lambda_B)\gamma_0 e^{-r_\gamma t} Y_0 e^{gt} = 0, \tag{28}$$

$$r\lambda_{St} - \dot{\lambda}_{St} = \frac{\partial \mathrm{H}^{extended}}{\partial S_t} = c_t^{-IIA} G_0 e^{-r_F t}\frac{e}{S_0}(1 - m_t)\gamma_0 e^{-r_\gamma t}, \tag{29}$$

$$r\lambda_{Vt} - \dot{\lambda}_{Vt} = \frac{\partial \mathrm{H}^{extended}}{\partial V_t} = -\frac{\beta_2}{\theta_a} A_0 e^{-r_A t} a_t^{\theta_a} V_t^{\beta_2 - 1}(1 - m_t)\gamma_0 e^{-r_\gamma t} c_t^{IIA}, \tag{30}$$

$$r\lambda_{Bt} - \dot{\lambda}_{Bt} = \frac{\partial \mathrm{H}^{extended}}{\partial B_t} = \frac{\beta_3}{\theta_m} m_t^{\theta_m} H_1 e^{-r_R t} B_t^{-\beta_3 - 1}\gamma_0 e^{-r_\gamma t} c_t^{IIA}. \tag{31}$$

Defining $P_t = \tau Y_0 e^{gt}$ and $\tau_t \equiv -c_t^{IIA}[\beta_0 \lambda_{Pt} + (1 - \beta_0)\lambda_{Tt}]Y_0 e^{gt}$ as in proof of Result 1, we get (7) from (12), (13) and (14). With $\theta_{St} \equiv c_t^{IIA}\lambda_{St} Y_0 e^{gt}$, $\theta_{Vt} \equiv -c_t^{IIA}\lambda_{Vt} Y_0 e^{gt}$ and $\theta_{Bt} \equiv c_t^{IIA}\lambda_{Bt} Y_0 e^{gt}$, we see that Eq. (23) yields

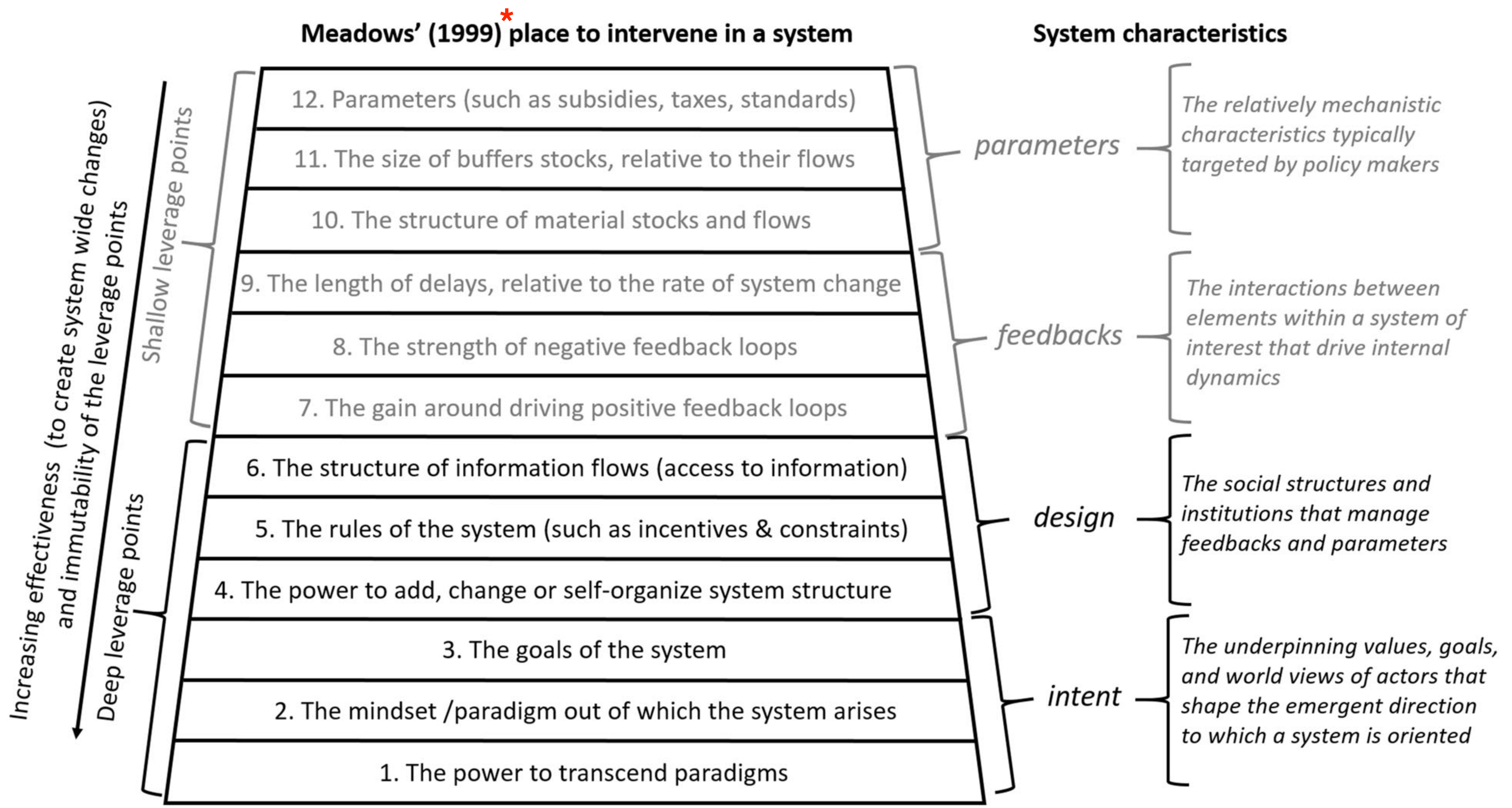
$$G_0 e^{-r_F t}\left[1 + e\frac{S_0 - S_t}{S_0}\right] + \frac{1}{\theta_a} A_0 e^{-r_A t} a_t^{\theta_a} V(t)^{\beta_2} - m_t^{\theta_m - 1} H_1 e^{-r_R t} B_t^{-\beta_3} - H_0 = -\tau(1 - a_t) - (\theta_V a + \theta_S + \theta_B). \tag{32}$$

Normalising individual action: getting the denominator right

Normalising action to impact:	**Costs**	**Benefits**
Individual / **I**ndividual	If I make this change, what's the cost for my happiness? (IIC)	If I make this change, what's the benefit for my individual footprint? (IIB)
Individual / **G**lobal	If I alone make this change, what's the cost for total world happiness? (IGC)	If I alone make this change, what's the benefit for the total world footprint? (IGB)
Global / **G**lobal	If everyone in the world makes this change, what's the cost for total world happiness? (GGC)	If everyone in the world makes this change, what's the benefit for the total world footprint? (GGB)

The IG values are tiny simply because humans are many.
Common view: IIC vs IGB. Seems not worth it.
But the problem and the required action both scale with number of people.
Should think about cost vs benefit *within the same row*.

Box 2 From twelve leverage points to four system characteristics



The four system characteristics represent a nested hierarchy of, tightly interacting, realms of leverage within which interventions in a given system of interest may be made. Deeper system characteristics constrain the types of interventions possible at shallower realms of leverage

The really deep questions?

Abson *et al.*, Ambio 2017

*http://donellameadows.org/archives/leverage-points-places-to-intervene-in-a-system/

Other things not referenced already:

Books:

- Mark Maslin, *Global Warming: A Very Short Introduction* (OUP series). My summary in 13 pages here https://tinyurl.com/yxj7b4ea with author's kind permission.
- David MacKay *Sustainable Energy Without The Hot Air* (free online)

Articles:

- Ripple *et al.* (15,364 scientist signatories) *World Scientists' Warning to Humanity: A Second Notice*, BioScience 2017

Talks:

- The Oxford School of Climate Change - 8 x 2 hours
- Myles Allen *Global Climate Change: A Summary for Policymakers* - new course happening now, slides at https://tinyurl.com/y56e2cvr
- Stern, *The Logic, Urgency and Promise of Tackling Climate Change* https://t.co/OuhX35UC1D
- lots of good talks at the Oxford Martin School, live & YouTube Channel

https://www.carbonbrief.org/
https://www.3quarksdaily.com/3quarksdaily/2018/12/academics-should-not-be-activists.html ???