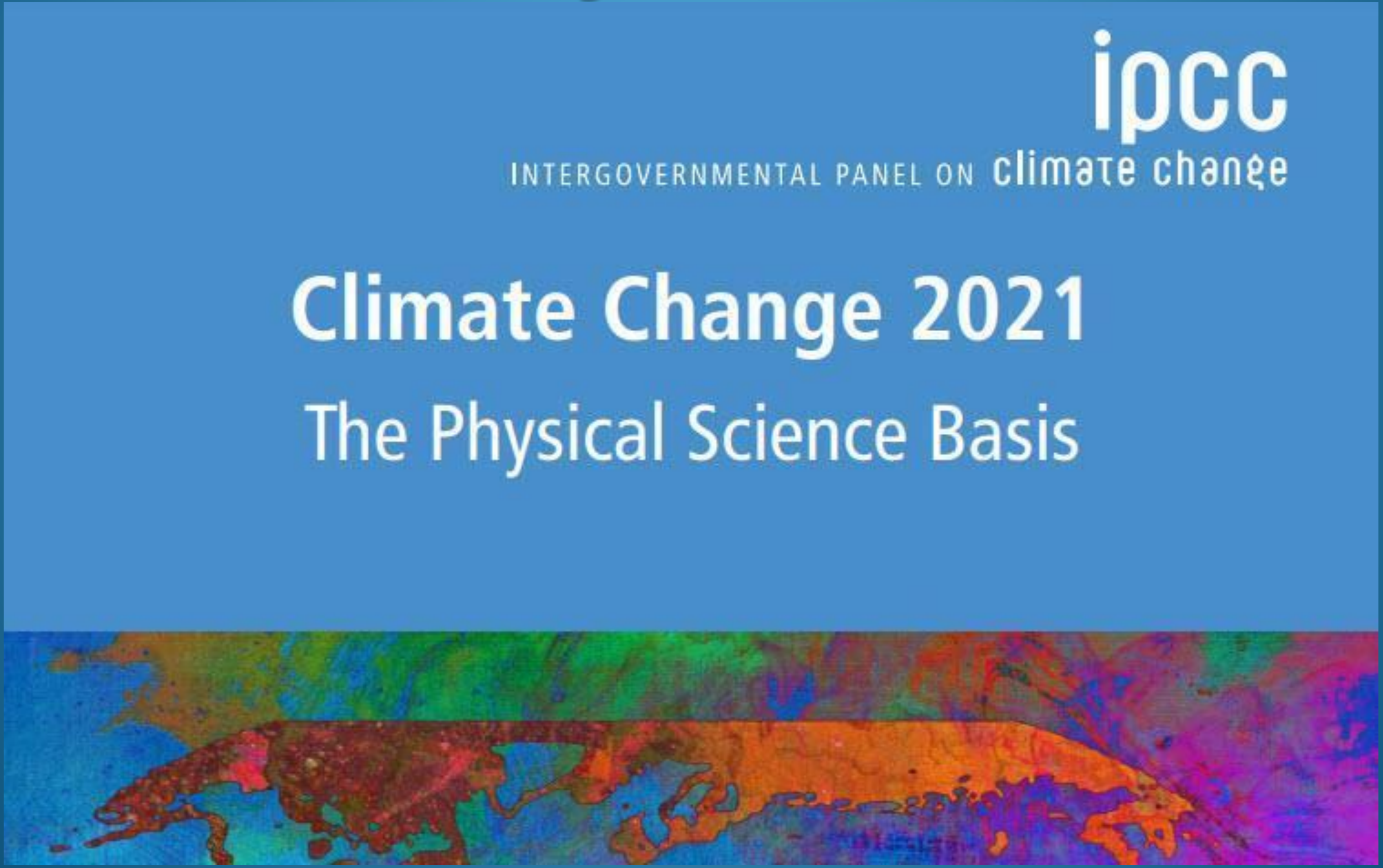
Lecture 17: Climate Change Projections



Today's Learning Outcomes

1. Know what each part of the IPAT approach to emissions projections are
2. Be able to explain the difference between EI (energy intensity) and CI (carbon intensity), which together make up T in the IPAT approach
3. Be able to explain the main differences among the shared socioeconomic pathways 1, 3, and 5
4. Be able to explain why even after emissions are cut temperature will continue to be elevated for centuries to millennia

Emission scenarios: This is how we predict the future radiative forcing from CO_2 and other greenhouse gases

- We create a range of possible greenhouse gas concentrations over future times
  - These are called **emission scenarios**.

- By making estimates of world population, wealth, and technology, we can estimate future greenhouse gas concentrations.

$$I = P \times A \times T$$

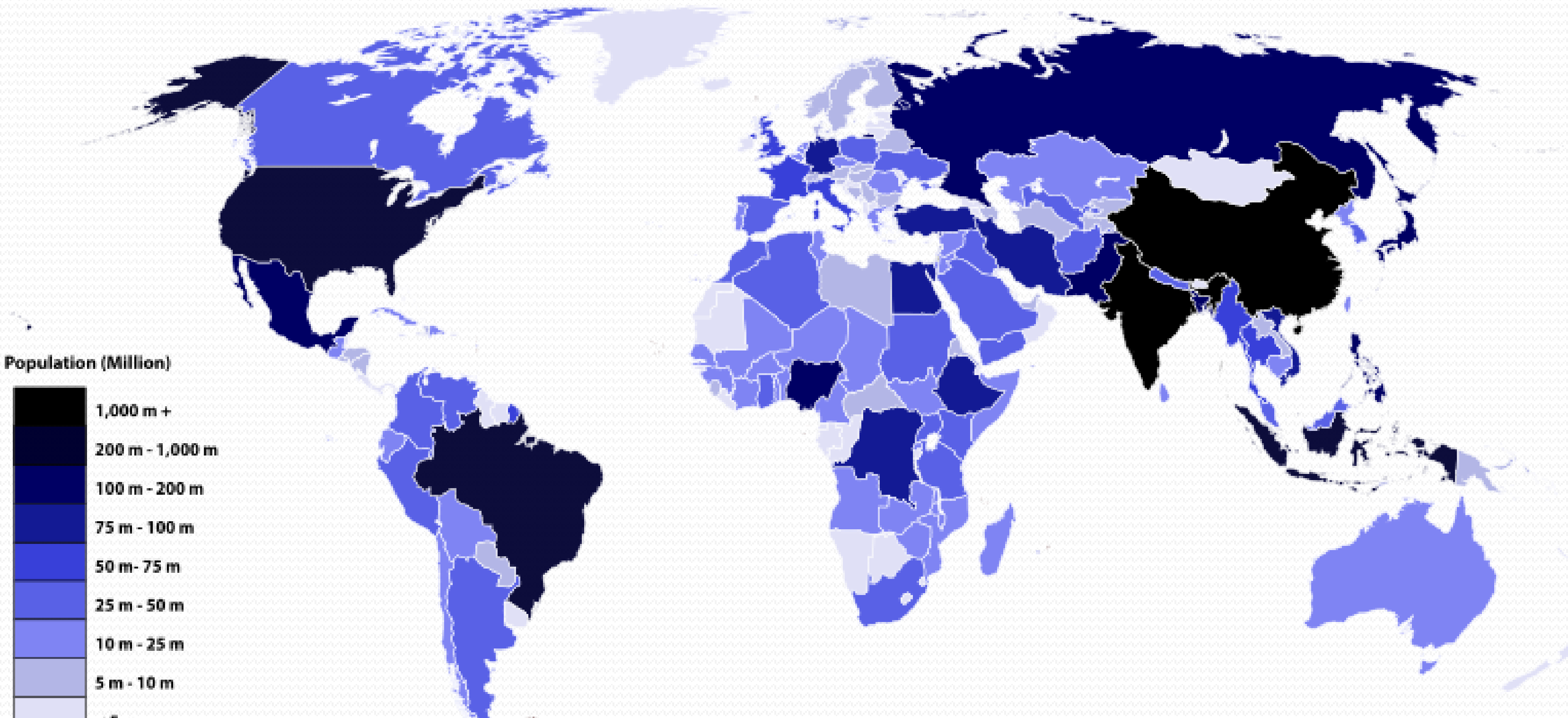
Emissions (CO_2)
(the I is for impacts)

Population

Affluence (wealth)

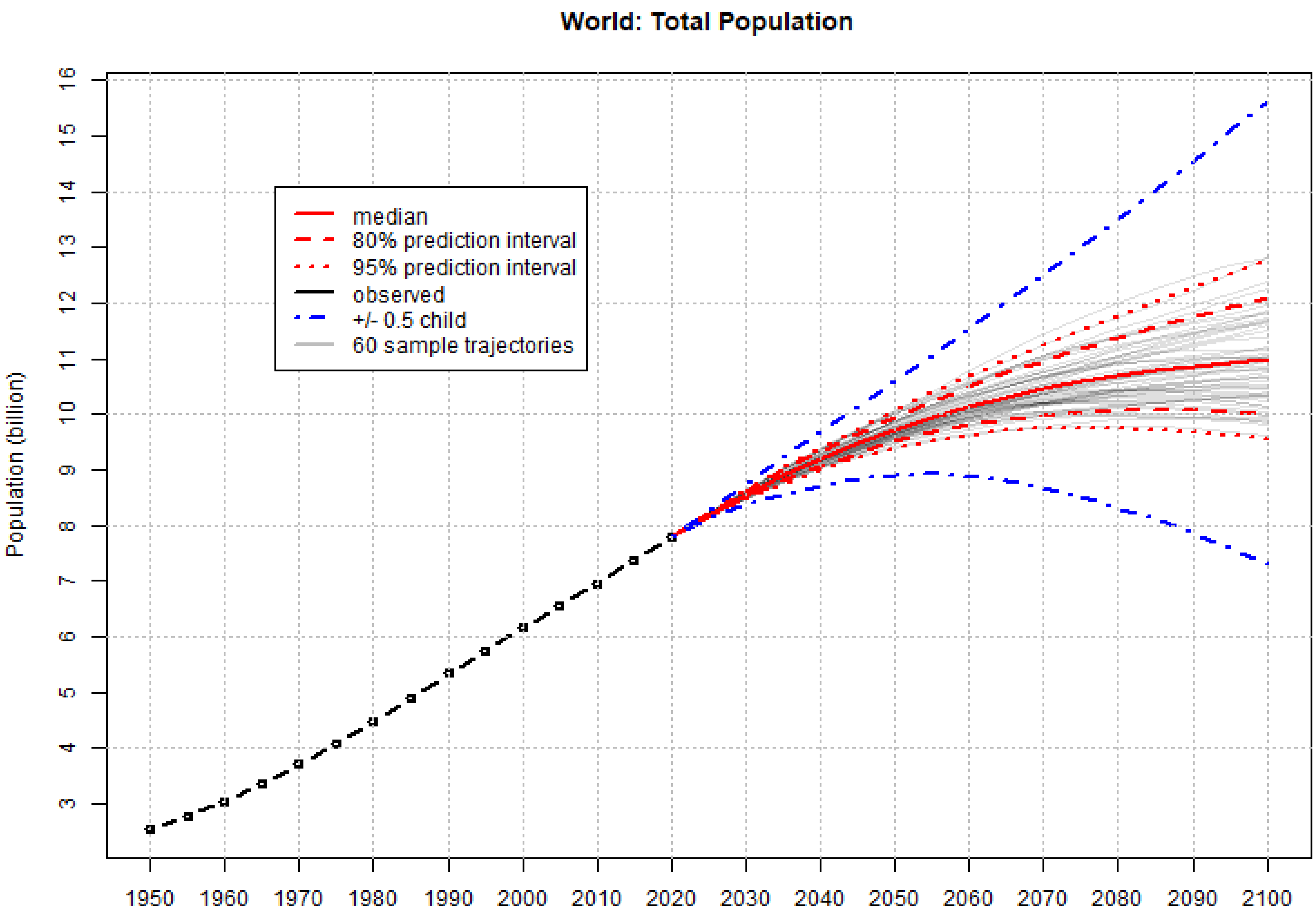
Greenhouse gas intensity
(the T is for technology)

I = P × A × T (P is population, number of people)



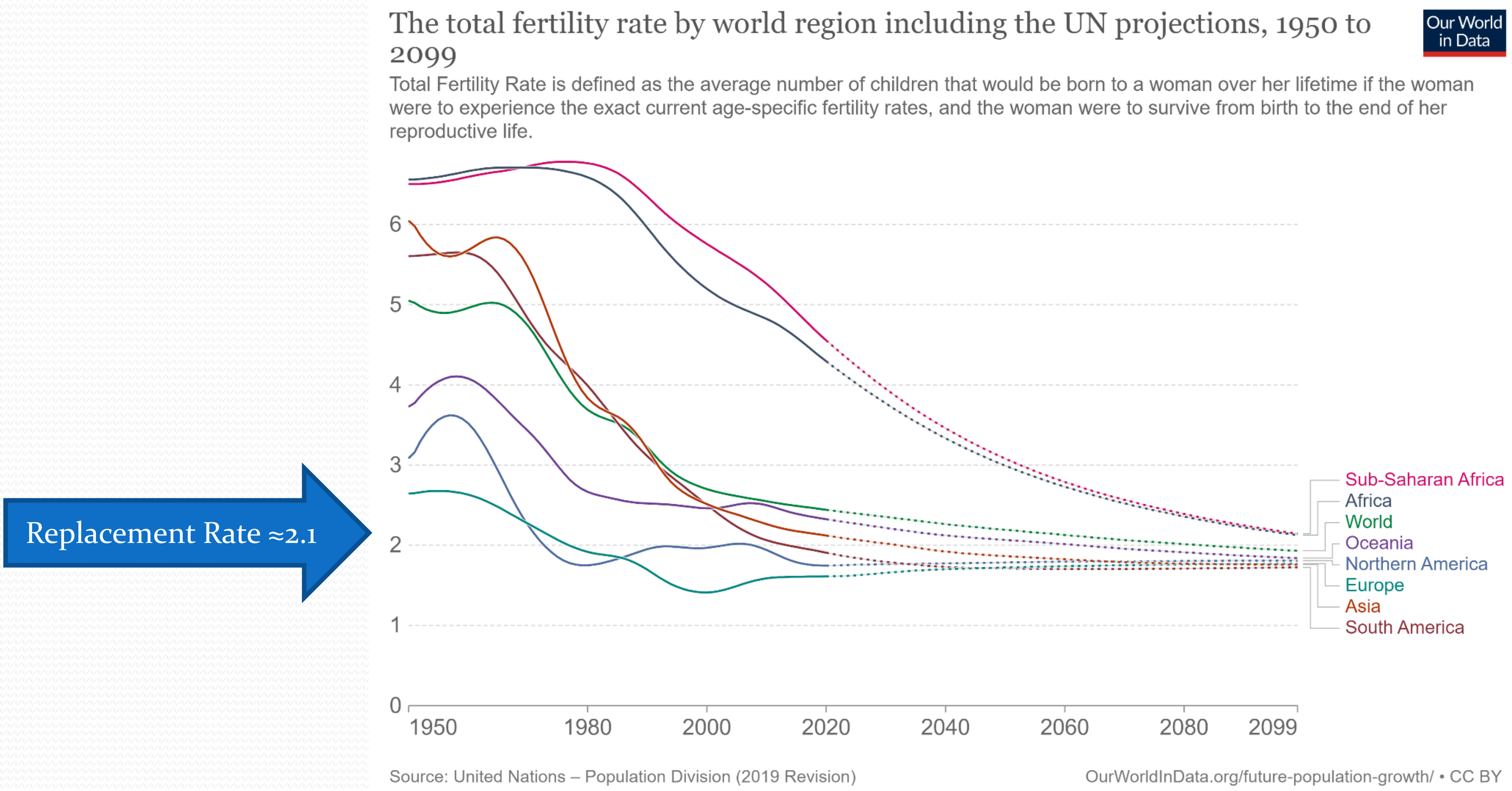
Countries and Dependencies by Population in 2014

Population is expected to level off around 11 billion around 2100



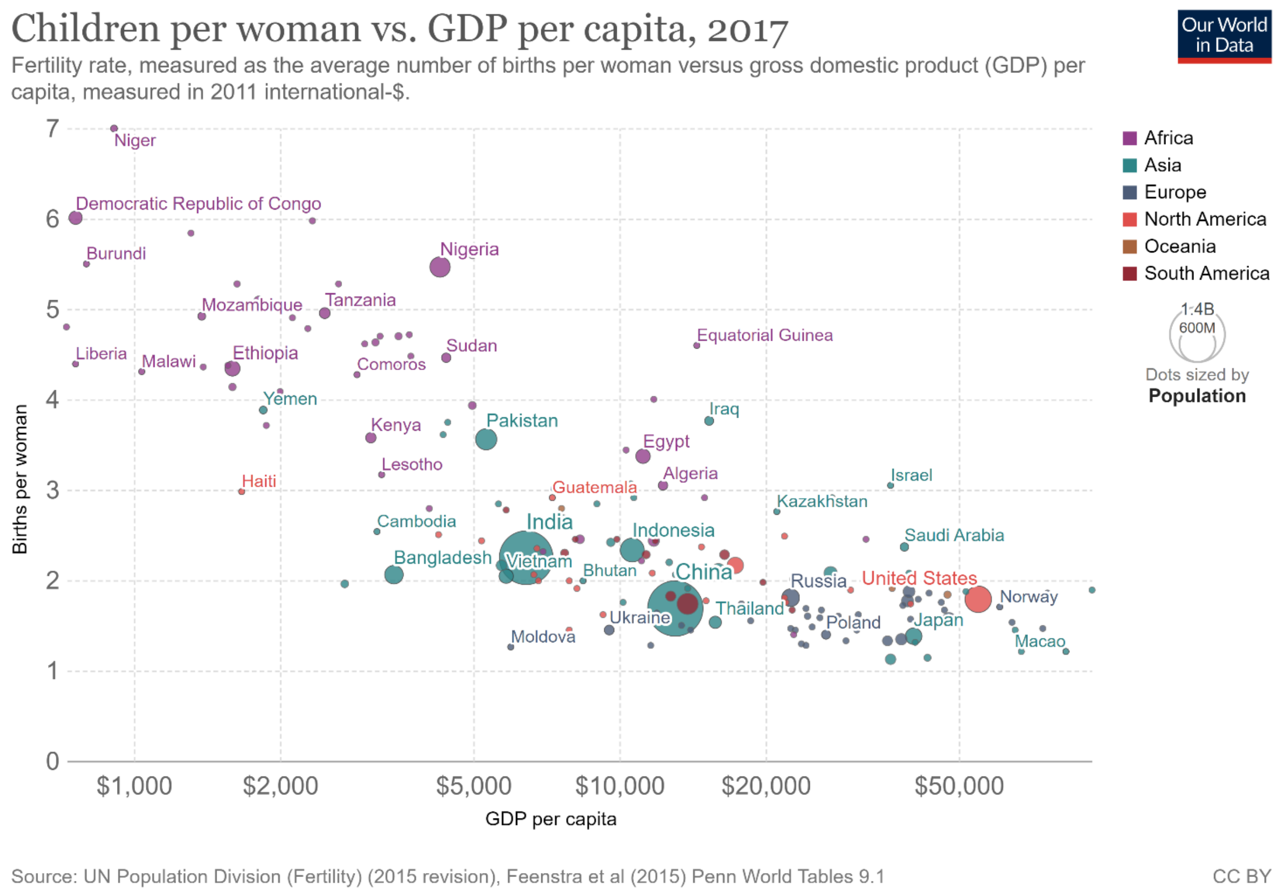
United Nations, DESA, Population Division. *World Population Prospects 2019*. http://population.un.org/wpp/

Global fertility rates are plummeting



Why is Fertility Falling?

- Women attaining more education and economic opportunities ($$$) + access to birth control



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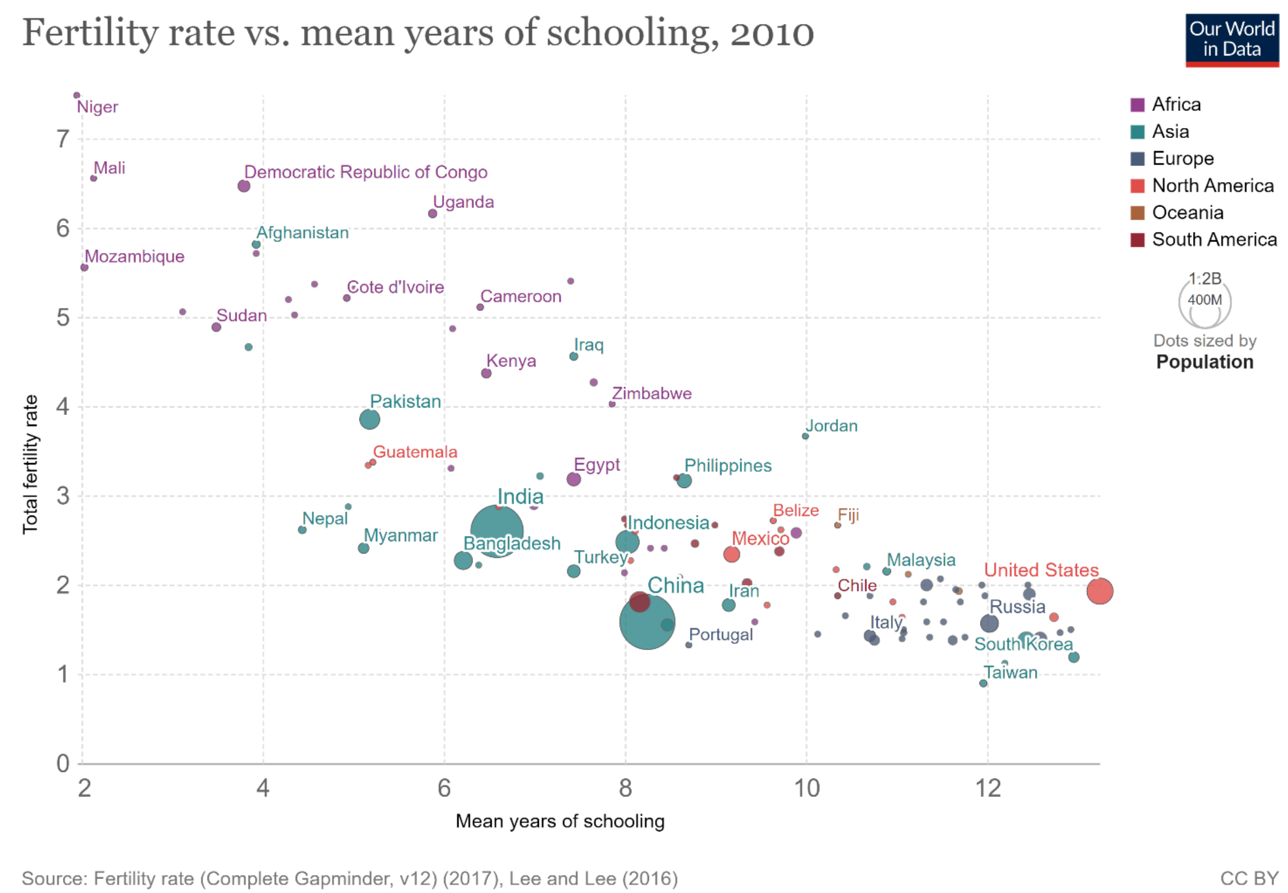
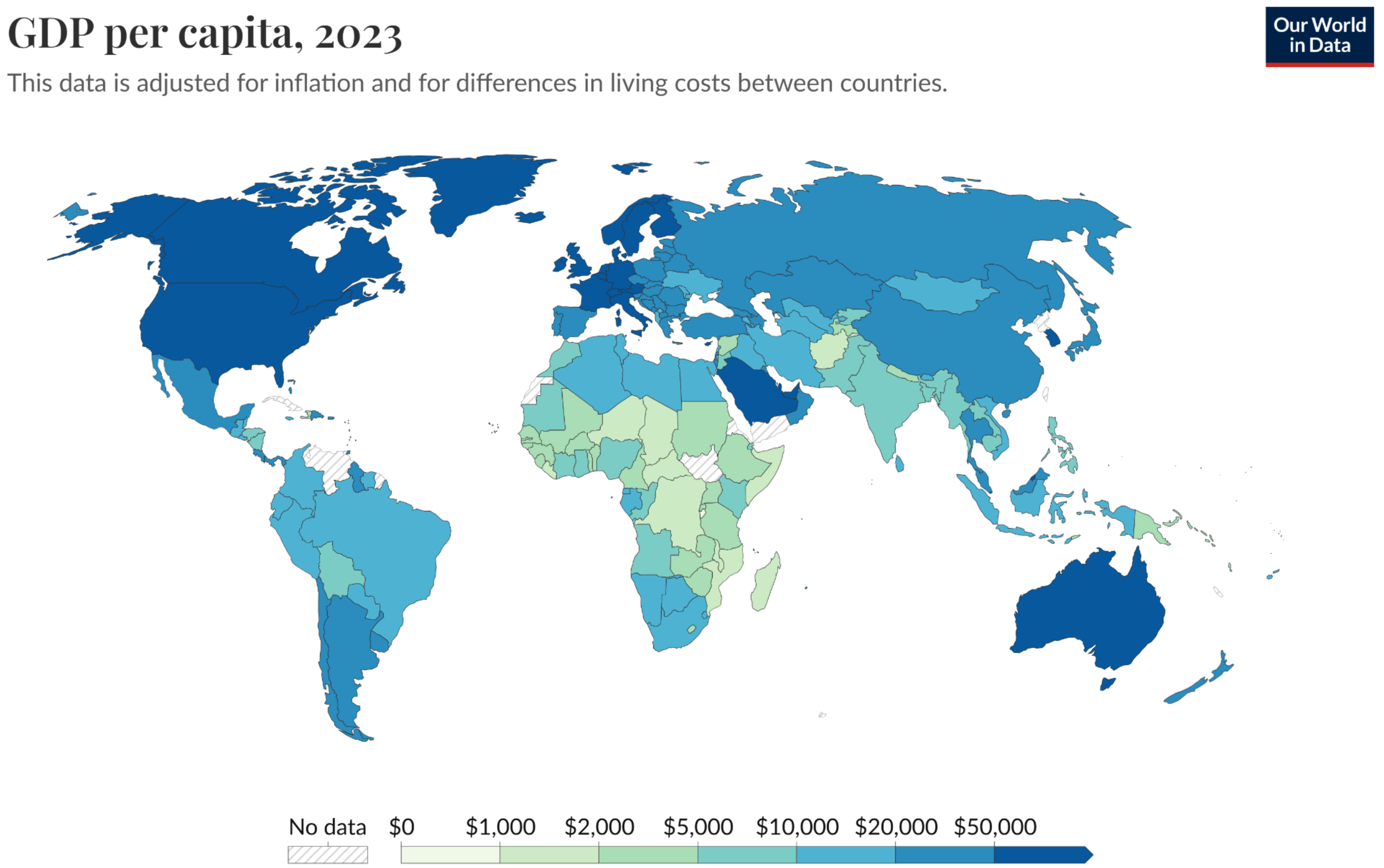
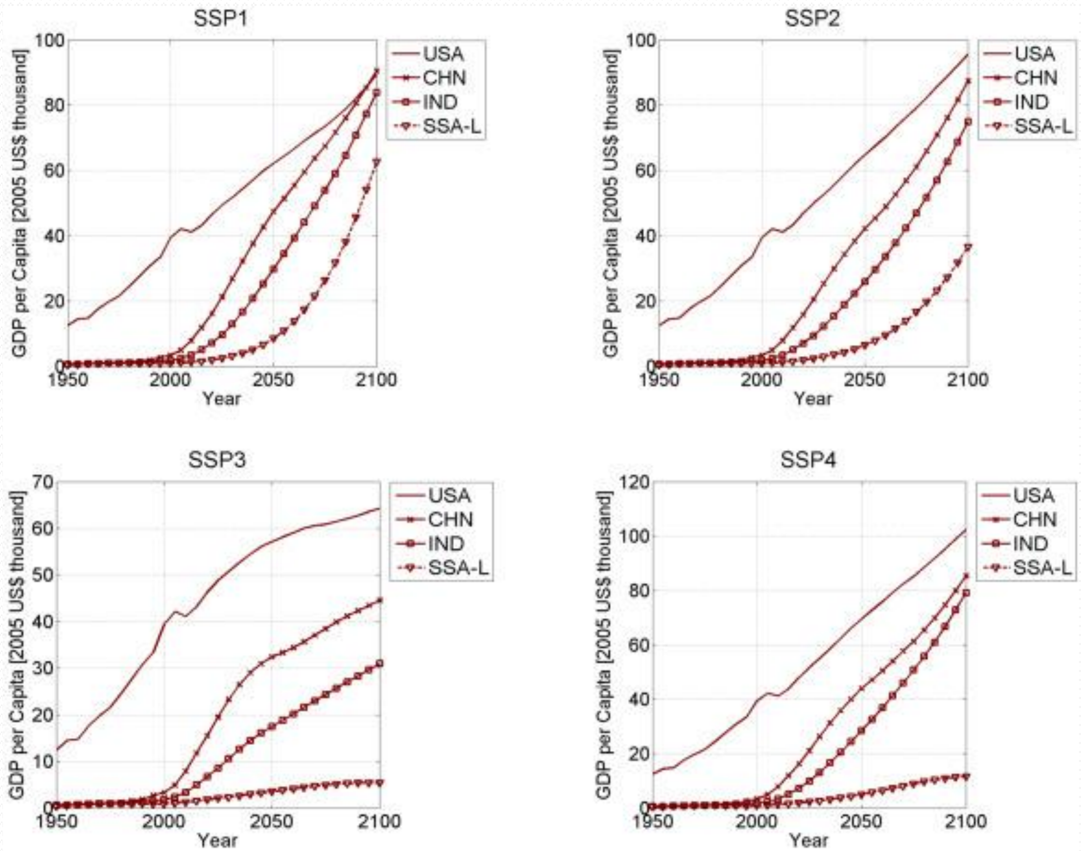


$I = P \times A \times T$ (A is affluence, $ / person)



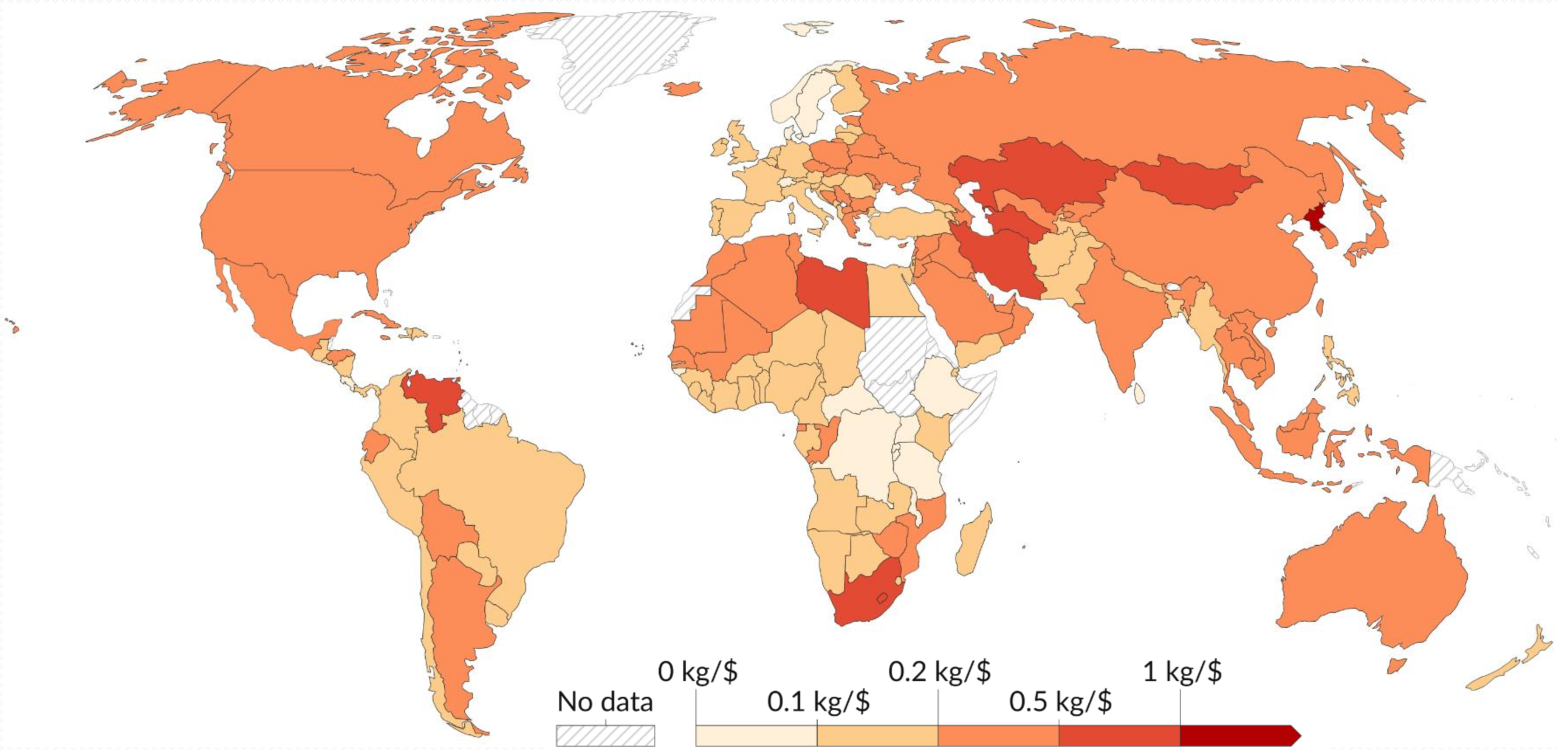
Gross Domestic Product per capita

- Total economic output of a country/population
    - Inflation-adjusted here
- Increasing globally
- Countries catching up with USA in many scenarios
    - Obviously, hard to predict



I = P × A × T (T is greenhouse gas intensity, CO_2 / $)

- T (technology) = emissions required to produce value



How to calculate emissions scenarios, I

$$I = P \times A \times T$$

$$CO_2 = People \times \frac{GDP}{people} \times \frac{CO_2}{GDP}$$

Gross Domestic Product
(the size of a country's economy)

Carbon dioxide emissions
=
how many people in the world
*
how wealthy people are
*
how much carbon it takes to create wealth

How to calculate emissions scenarios, I

$$I = P \times A \times T$$

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Gross Domestic Product
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Greenhouse gas intensity, T, can be subdivided into 2 parts

$$I = P \times A \times T$$

T is how much carbon gets emitted in the process of running the economy: $\frac{CO_2}{GDP}$

T can be broken down into two parts:
1) How much energy it takes to make money: "**energy intensity**"
2) How much carbon is emitted to make energy: "**carbon intensity**"

$$T = EI \times CI$$

Energy intensity **Carbon intensity**

Greenhouse gas intensity, T, can be subdivided into 2 parts

$$T = EI \times CI$$

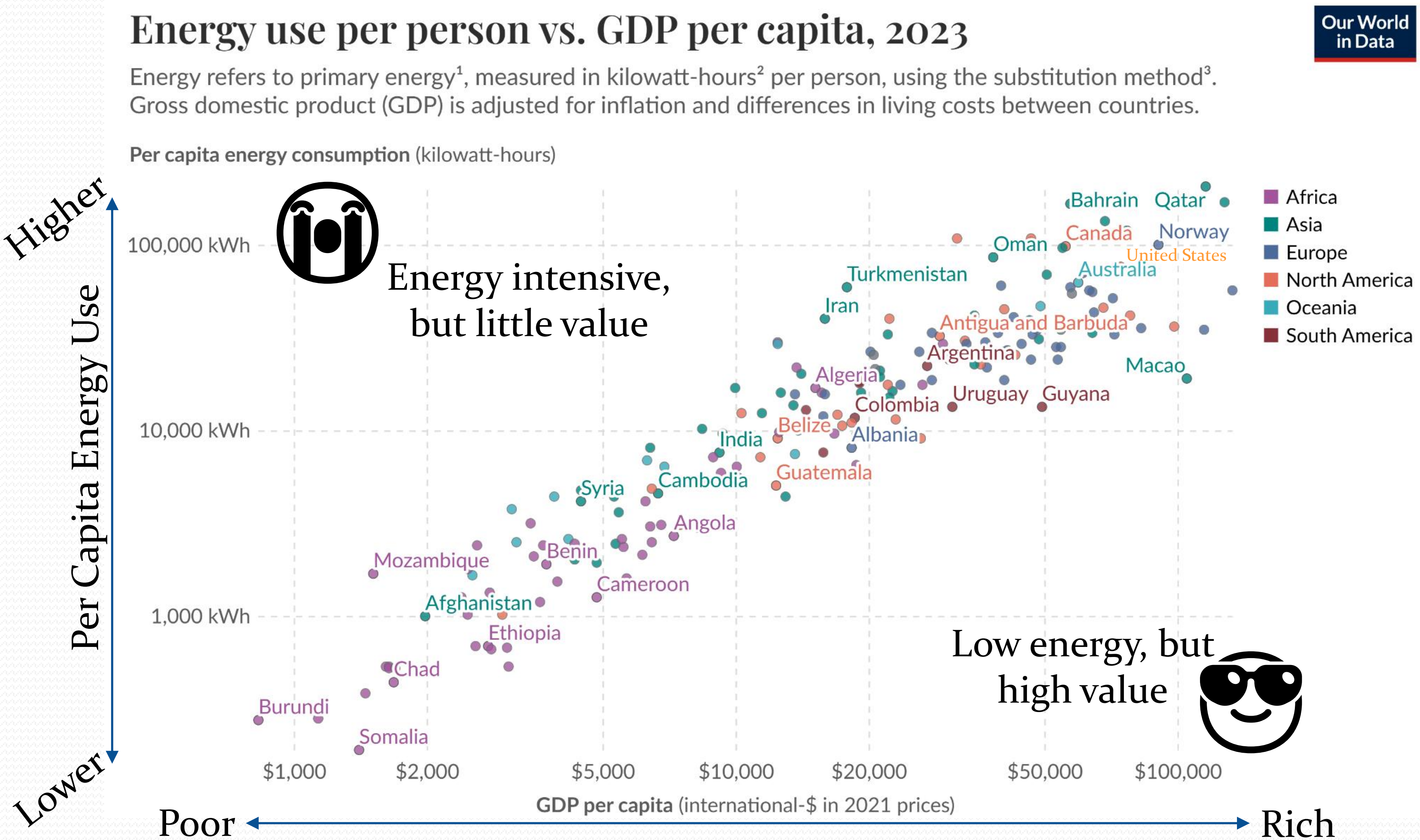
$$\text{Greenhouse gas intensity} = \frac{\text{Energy}}{\text{GDP}} \times \frac{\text{Carbon}}{\text{Energy}} = \frac{\text{Carbon}}{\text{GDP}}$$

Energy intensity: how <u>inefficiently</u> we <u>use</u> energy.

EI depends on what economic activities create $

EI depends on the technology that is using energy (e.g. electric motor)

Energy Intensity



Greenhouse gas intensity, T, can be subdivided into 2 parts

$$T = EI \times CI$$

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Energy intensity: how <u>inefficiently</u> we <u>use</u> energy.

EI depends on what economic activities create $

EI depends on the technology that is using energy (e.g. electric motor)

Carbon intensity: how <u>inefficiently</u> we <u>create</u> energy

CI depends on how the energy was generated (e.g., coal power plant)

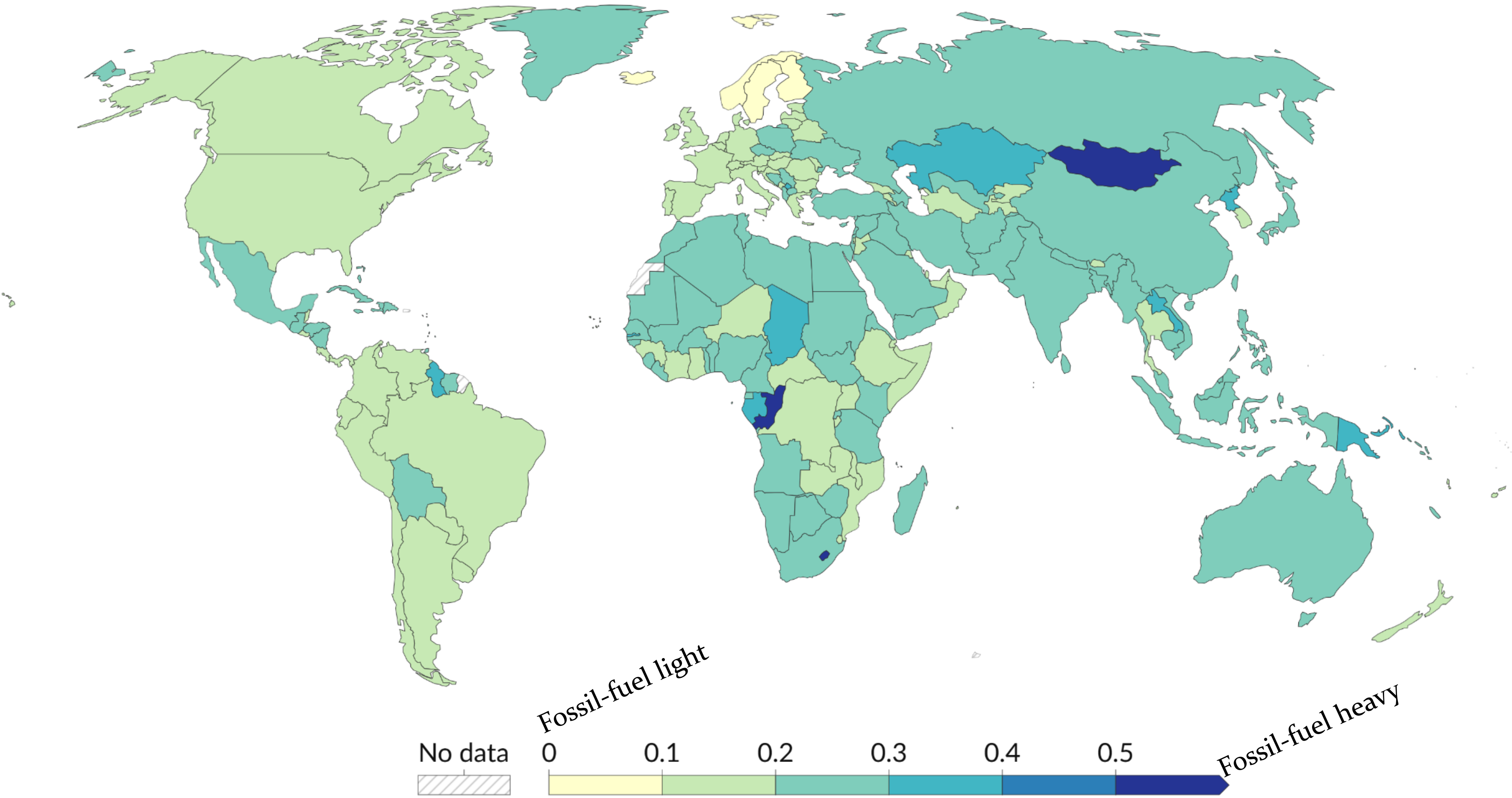
What is the carbon intensity of various energy sources?

Technology	grams of CO_2 per kilowatt-hour
Coal	820
Natural gas	490
Biomass	230
Solar photovoltaic	48
Geothermal	38
Concentrated solar power	27
Hydropower	24
Wind Offshore	12
Nuclear	12
Wind Onshore	11

Fossil fuels

Carbon intensity of energy production, 2023

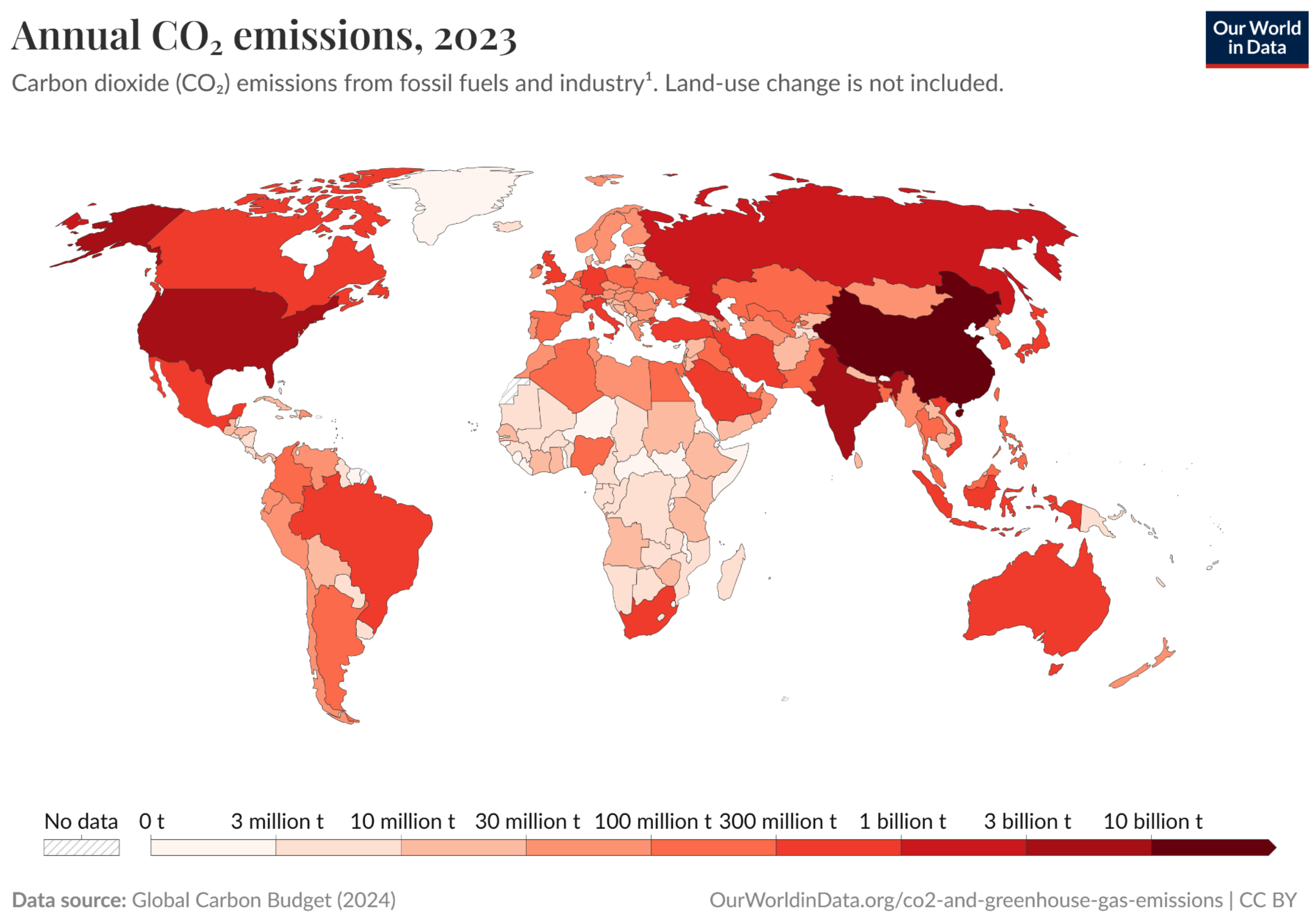
Amount of carbon dioxide emitted per unit of energy production, measured in kilograms of CO_2 per kilowatt-hour.



Data source: Global Carbon Budget (2024); U.S. Energy Information Administration (2023); Energy Institute - Statistical Review of World Energy (2024)

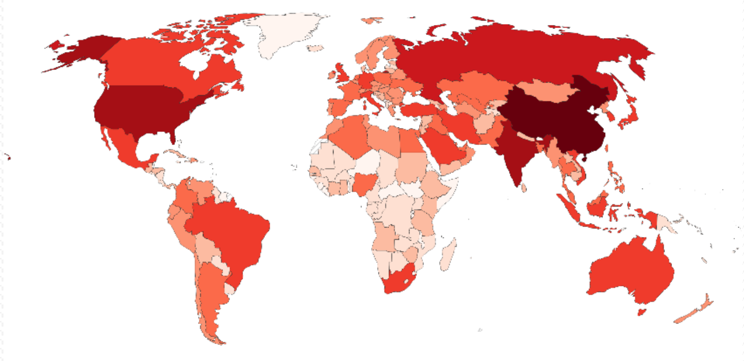
OurWorldinData.org/co2-and-greenhouse-gas-emissions |

$I = P \times A \times T$ (Total CO_2 emissions)



Emissions: $I = P \times A \times T$

Emissions



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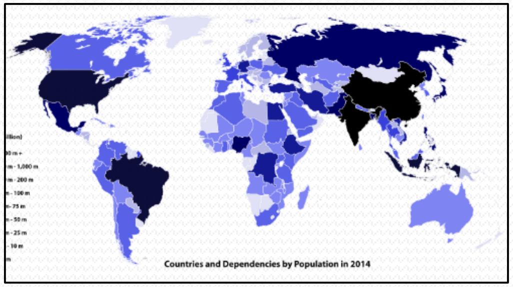

Population

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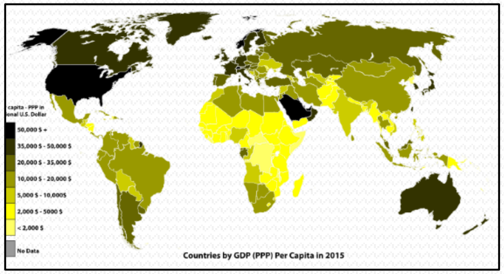

Affluence

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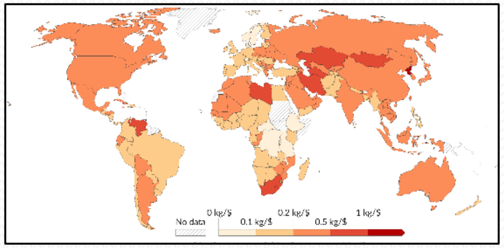
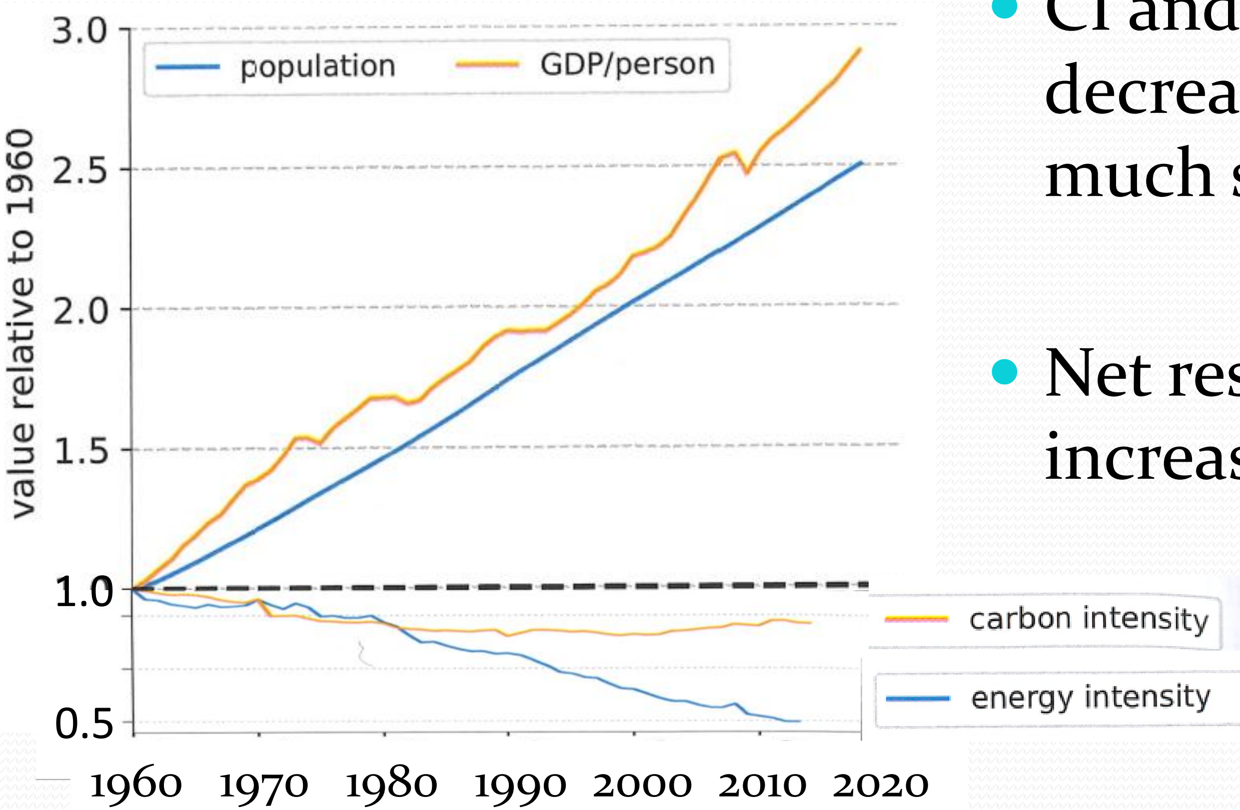


GHG intensity

Emissions components (I = P × A × T) over the past 50 years

- Population and affluence are both more than 2.5x greater than in 1960



- CI and EI have decreased but at a much slower rate

- Net result is large increase in emissions

Making an Emissions Model

1. Estimate how you think population, affluence, energy intensity, and carbon intensity will change in the future, worldwide
    - Lots of models on models on models since we cannot measure everything all the time

2. Multiply them together

$$I = P \times A \times T$$

$$I = P \times A \times EI \times CI$$

Shared Socioeconomic Pathways (SSPs)

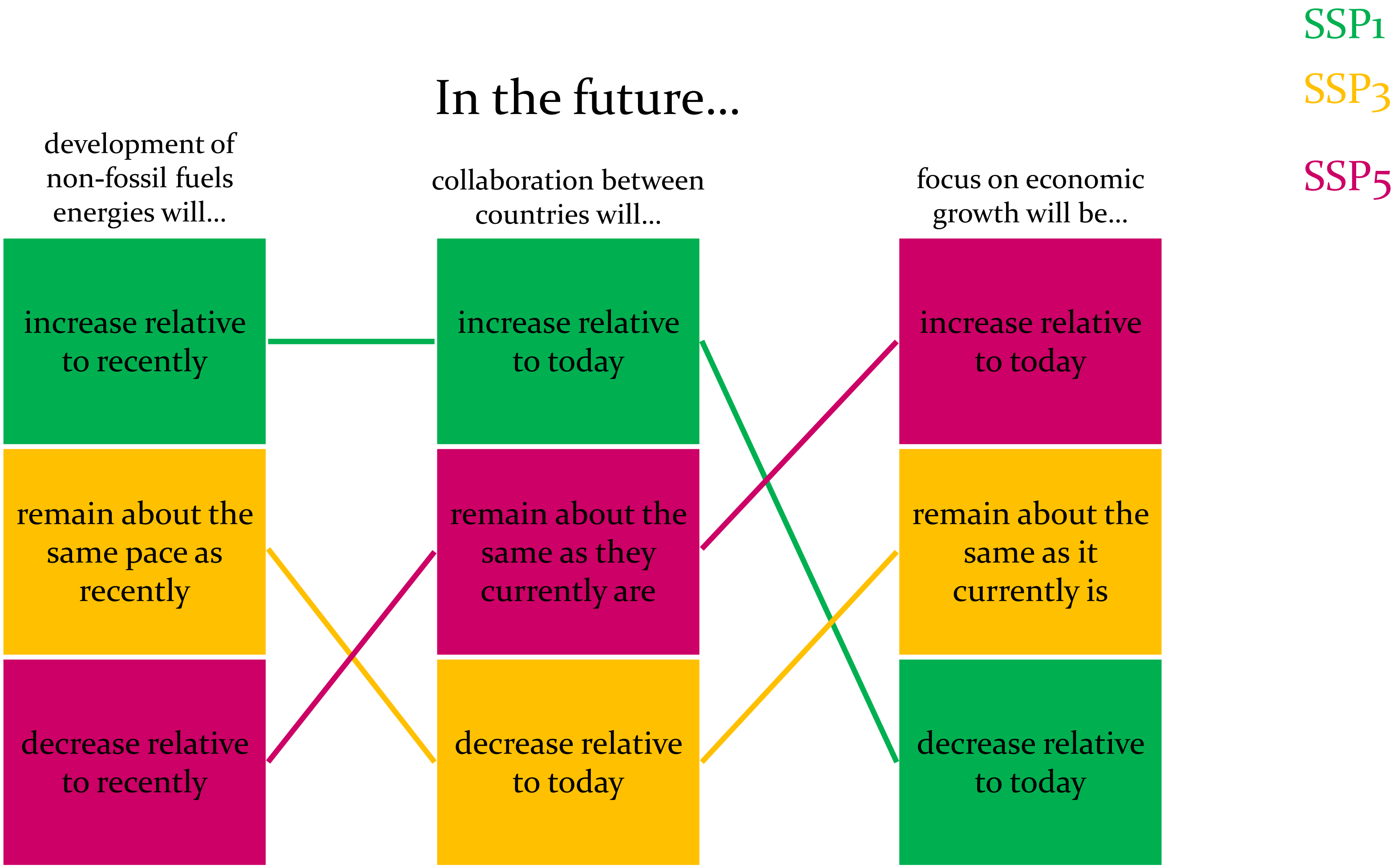
- Series of models assuming different paths of economic and social development in the future
- Differences in global connectivity, equitability of economic growth, and adoption of low carbon energy sources
  - Create an internally consistent set of scenarios that acknowledges factors are interconnected
  - Formalized in Riahi et al. 2018

Plain-language (but loaded) explanations of SSPs

Shared Socioeconomic Pathways (SSPs)

SSP	Challenges	Illustrative starting points for narratives
SSP1	Low for mitigation and adaptation	Sustainable development proceeds at a reasonably high pace, inequalities are lessened, technological change is rapid and directed toward environmentally friendly processes, including lower carbon energy sources and high productivity of land.
SSP2	Moderate	An intermediate case between SSP1 and SSP3—perhaps can be viewed as business-as-usual.
SSP3	High for mitigation and adaptation	Unmitigated emissions are high due to moderate economic growth, a rapidly growing population, and slow technological change in the energy sector, making mitigation difficult. Investments in human capital are low, inequality is high, a regionalized world leads to reduced trade flows, and institutional development is unfavorable, leaving large numbers of people vulnerable to climate change and many parts of the world with low adaptive capacity.
SSP4	High for adaptation, low for mitigation	A mixed world, with relatively rapid technological development in low carbon energy sources in key emitting regions, leading to relatively large mitigative capacity in places where it matters most to global emissions. However, in other regions development proceeds slowly, inequality remains high, and economies are relatively isolated, leaving these regions highly vulnerable to climate change with limited adaptive capacity.
SSP5	High for mitigation, low for adaptation	In the absence of climate policies, energy demand is high and most of this demand is met with carbon-based fuels. Investments in alternative energy technologies are low, and there are few readily available options for mitigation. Nonetheless, economic development is relatively rapid and itself is driven by high investments in human capital. Improved human capital also produces a more equitable distribution of resources, stronger institutions, and slower population growth, leading to a less vulnerable world better able to adapt to climate impacts.

In the future…



SSP	Challenges	Illustrative starting points for narratives
SSP1	Low for mitigation and adaptation	Sustainable development proceeds at a reasonably high pace, inequalities are lessened, technological change is rapid and directed toward environmentally friendly processes, including lower carbon energy sources and high productivity of land.

World agrees to work collaboratively to address climate change

SSP3	High for mitigation and adaptation	Unmitigated emissions are high due to moderate economic growth, a rapidly growing population, and slow technological change in the energy sector, making mitigation difficult. Investments in human capital are low, inequality is high, a regionalized world leads to reduced trade flows, and institutional development is unfavorable, leaving large numbers of people vulnerable to climate change and many parts of the world with low adaptive capacity.

World overall becomes less connected with countries fending for themselves mostly

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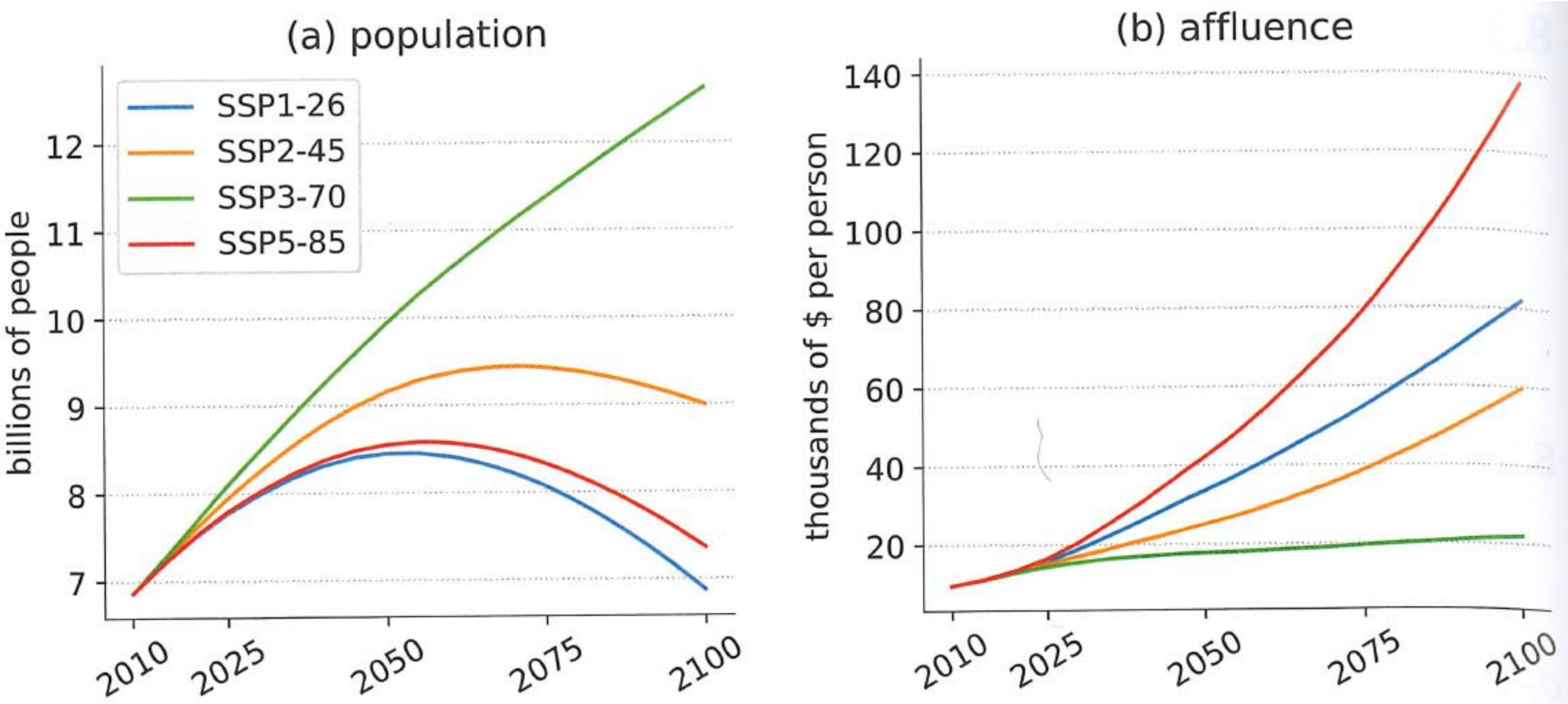
World disregards climate change and prioritizes economic development

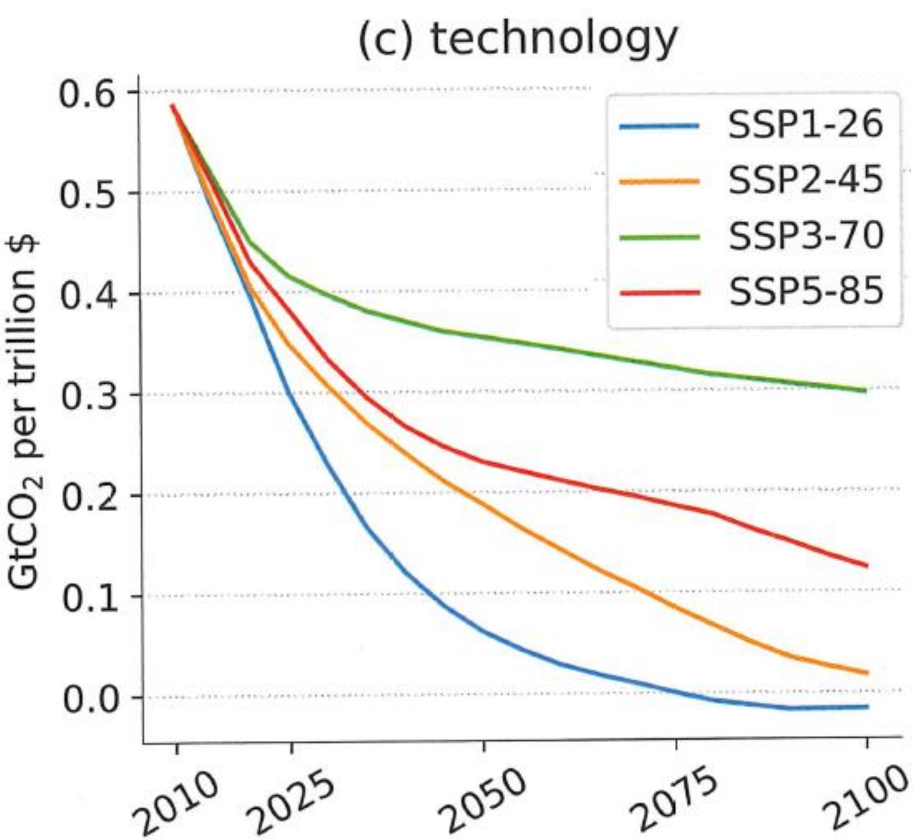
Population & Affluence SSPs

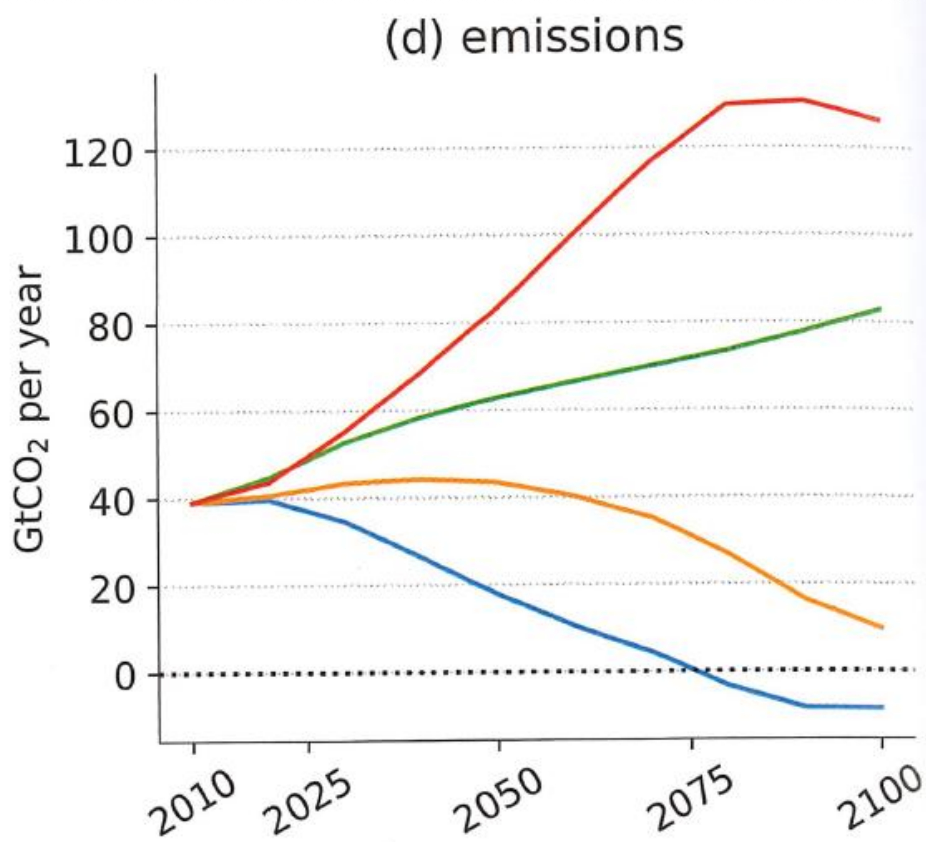
- Population grows fastest due to deepening inequality in SSP3, but global wealth is low



Technology & Emissions SSPs

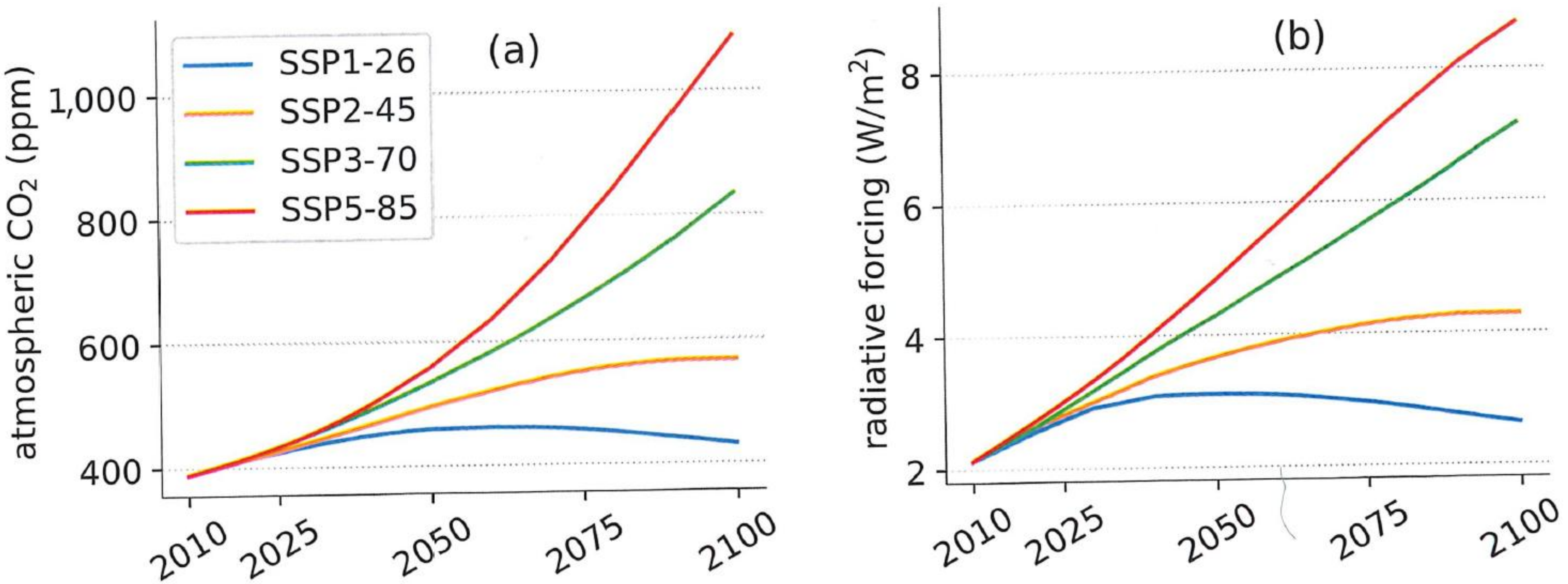
- Technology least efficient in SSP3
- SSP5 projects the highest overall emissions





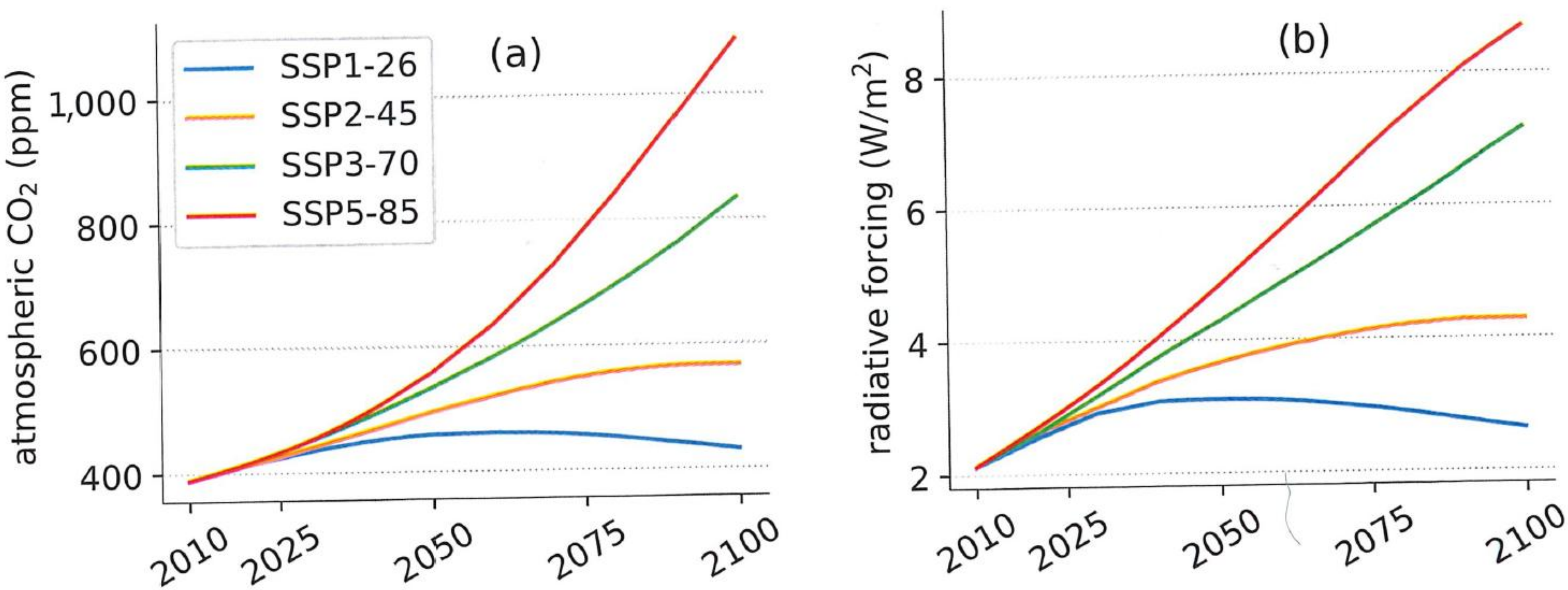
CO_2 (ppm) and Radiative Forcing SSPs

- Numbers after the models refer to the average radiative forcing under that model in 2100
  - i.e. SSP1-26 = 2.6 W/m^2 of radiative forcing in 2100



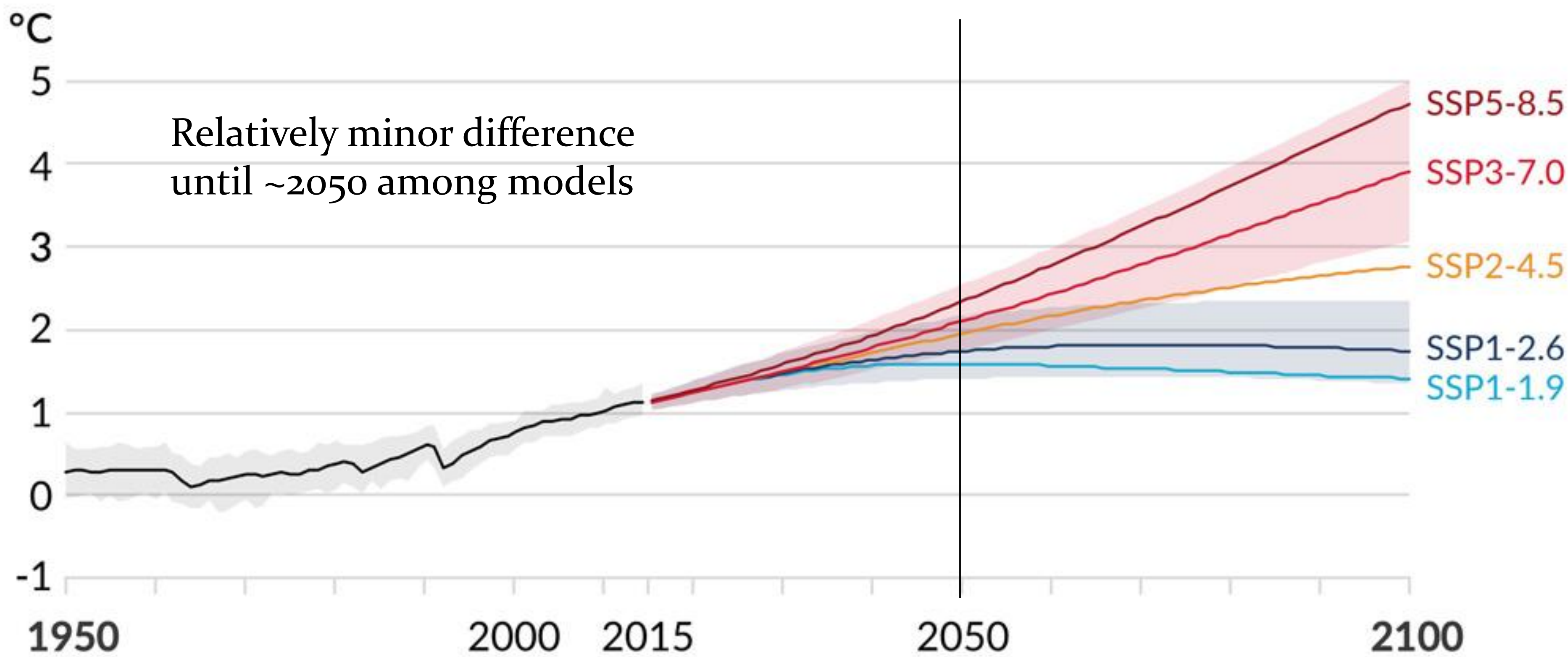
CO_2 (ppm) and Radiative Forcing SSPs

- In the worst case SSP5-85 CO_2 concentrations are 3x what they currently are
  - Also note that under none of these scenarios do we get back to baseline (= 0 radiative forcing) by 2100



Temperature Change SSPs

- Worst case is 5°C warming on average, while best-case is 1.9°C warming [right one the edge of Paris Climate Accord goal to avoid worse affect of climate change]



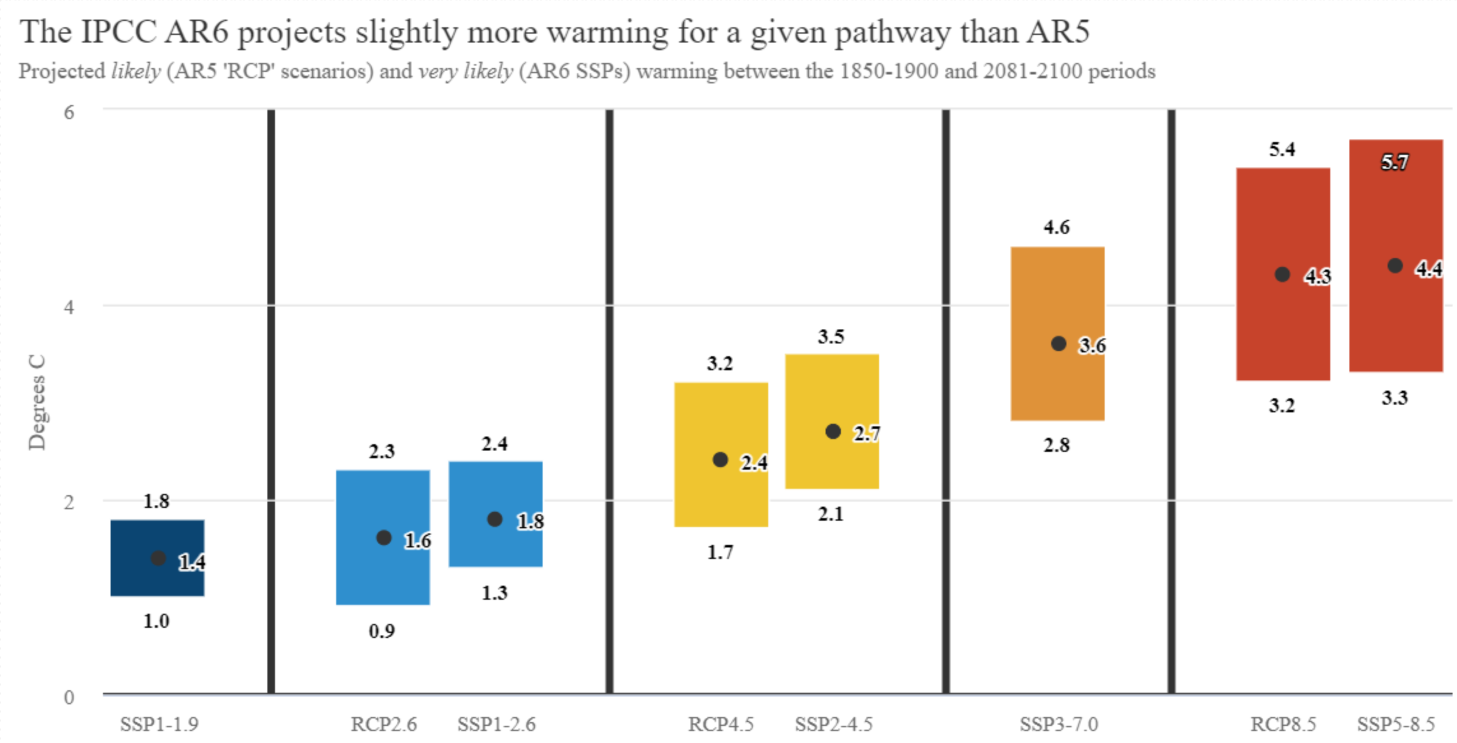
SSP Model Summary

- SSP1 and SSP5 are both highly unlikely
- SSP2 & SSP3 are the most likely paths

	Population Peak	CO2 Peak Year	CO2 Peak ppm	Average Temperature Rise by 2100, C
SSP1-1.9	2020	2020	440	1.4
SSP1-2.6	2050	2025	470	1.8
SSP2-4.5	2070	2040	580	2.7
SSP3-7.0	>2100	>2100	>820	3.6
SSP5-8.5	2060	2080	>1200	4.4

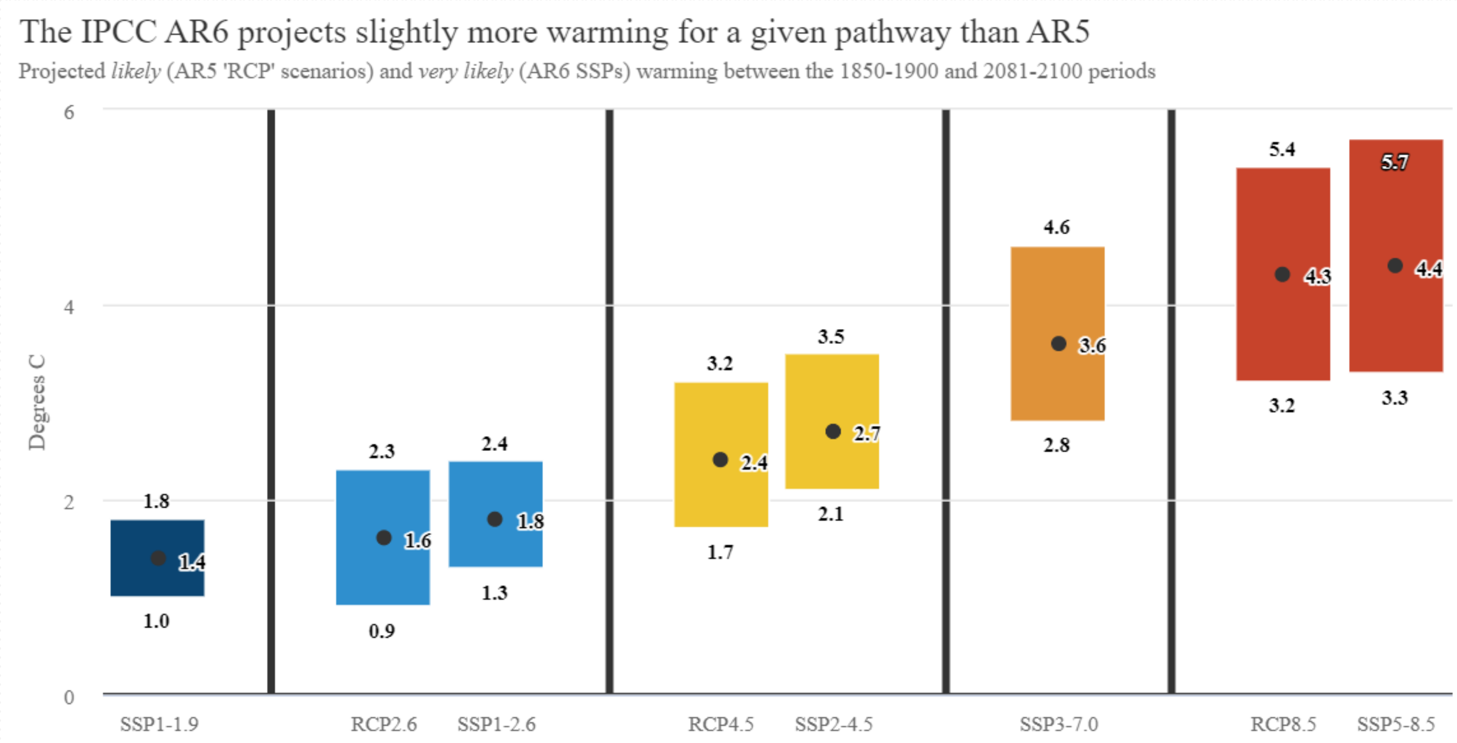
SSPs versus RCP

- Prior to AR6 (IPCC 2022 report) models were based only on reaching some amount of warming
  - Known as Representative Concentration Pathway (RCP)

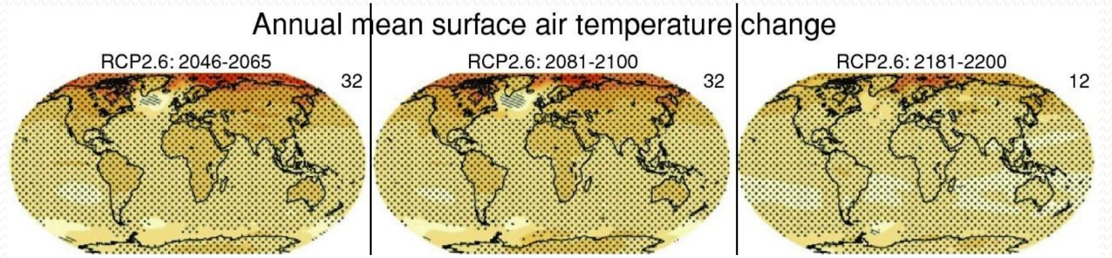


SSPs versus RCP

- Main difference from AR5 to AR6 was that the warming of each model are more constrained
  - Best- and worst-case scenarios less likely

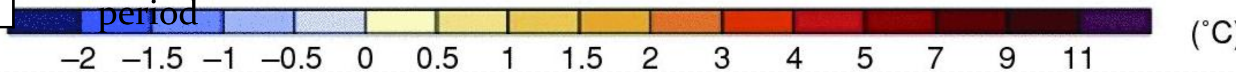


Years 2046-2065 (Our lifetimes)	Years 2081-2100 (Next generation)	Years 2181-2200 (Future generations)



How will temperatures change if we reduce CO_2 emissions *today*?	SSP1-2.6

Temperature change (anomaly), compared to 1986-2005 reference period



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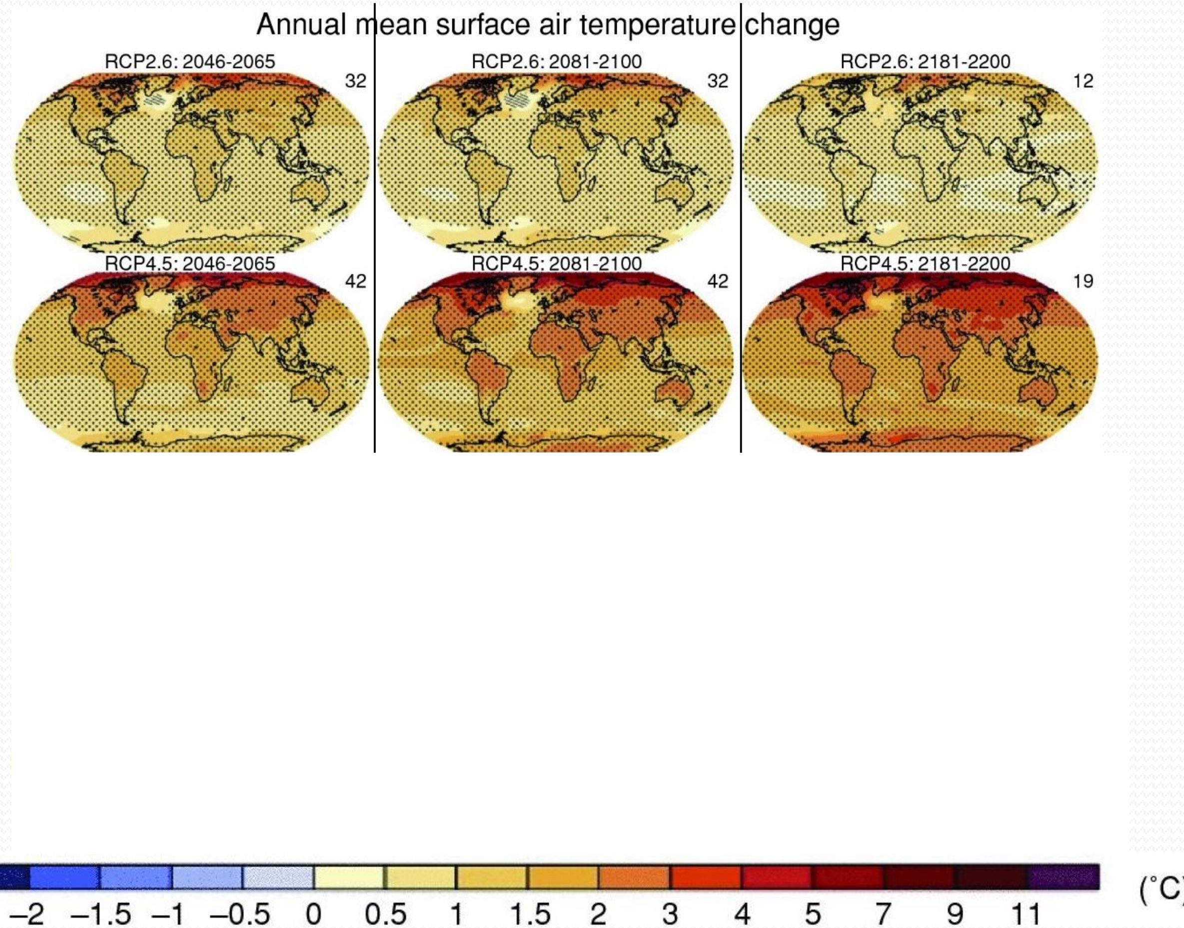
How will temperatures change if we reduce CO_2 emissions *today*?	SSP1-2.6
… if we reduce CO_2 emissions *later* (2040)?	SSP2-4.5



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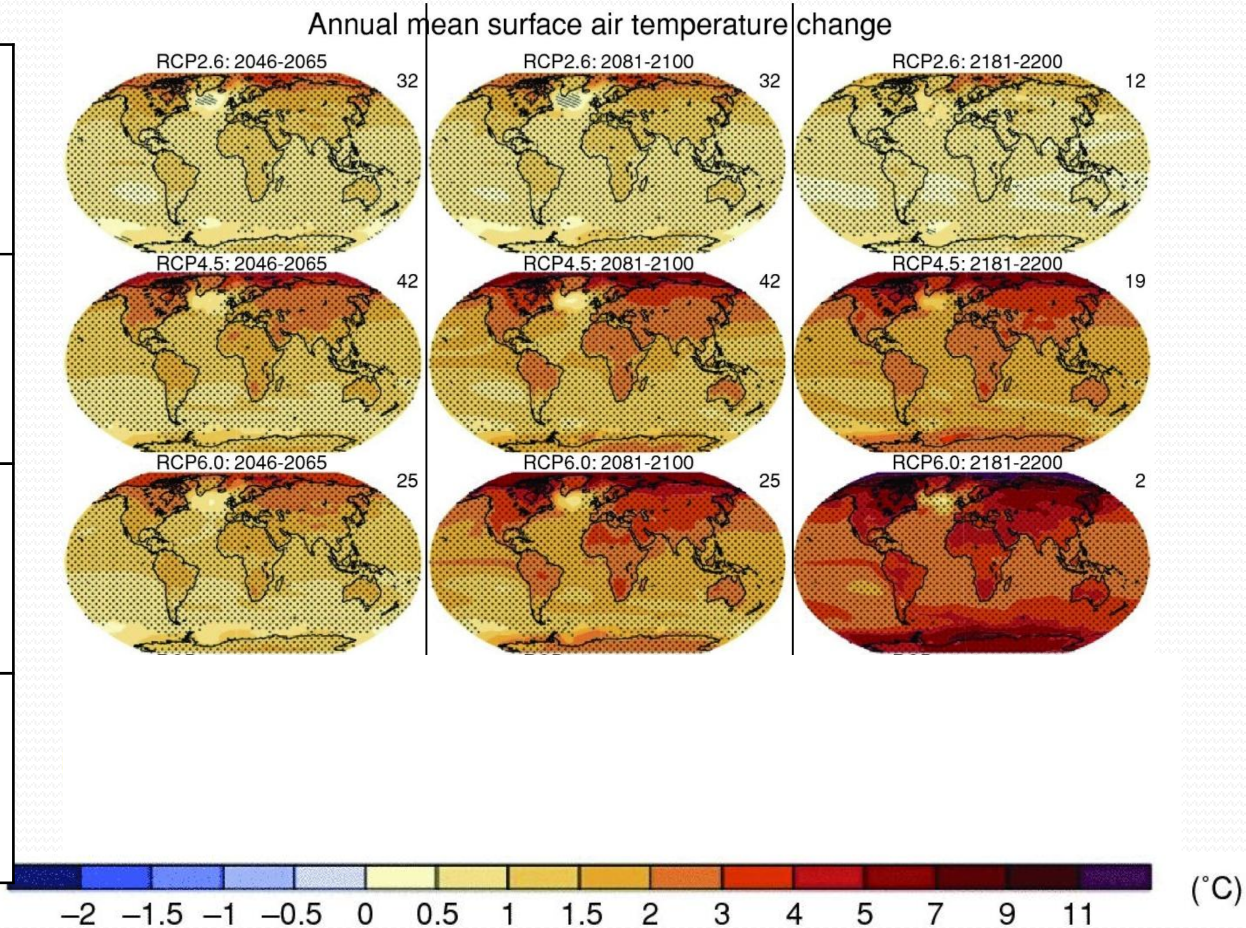
How will temperatures change if we reduce CO_2 emissions *today*?	SSP1-2.6
… if we reduce CO_2 emissions *later* (2040)?	SSP2-4.5
… if we do not reduce CO_2 emissions but our children do (2080)?	SSP3-6



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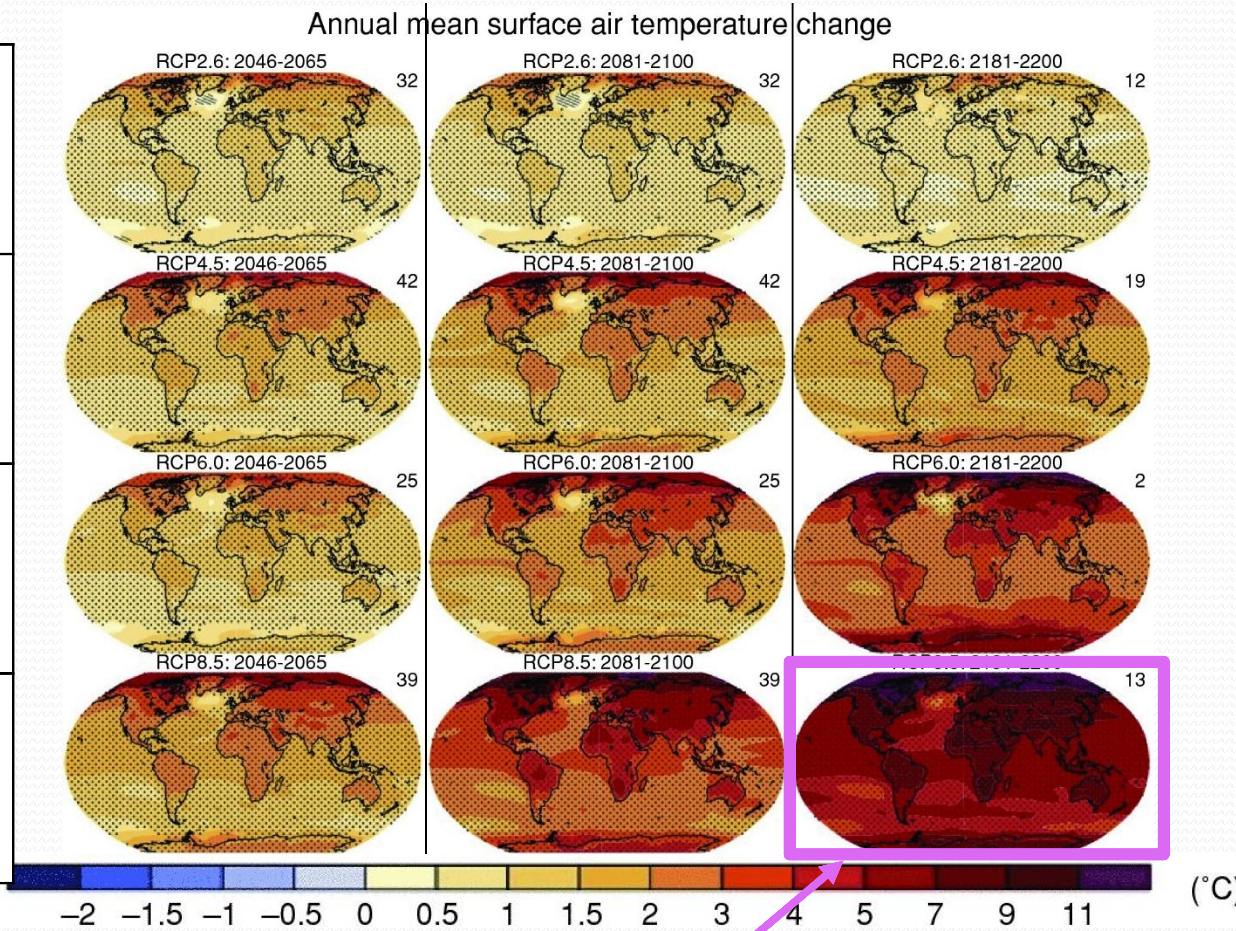
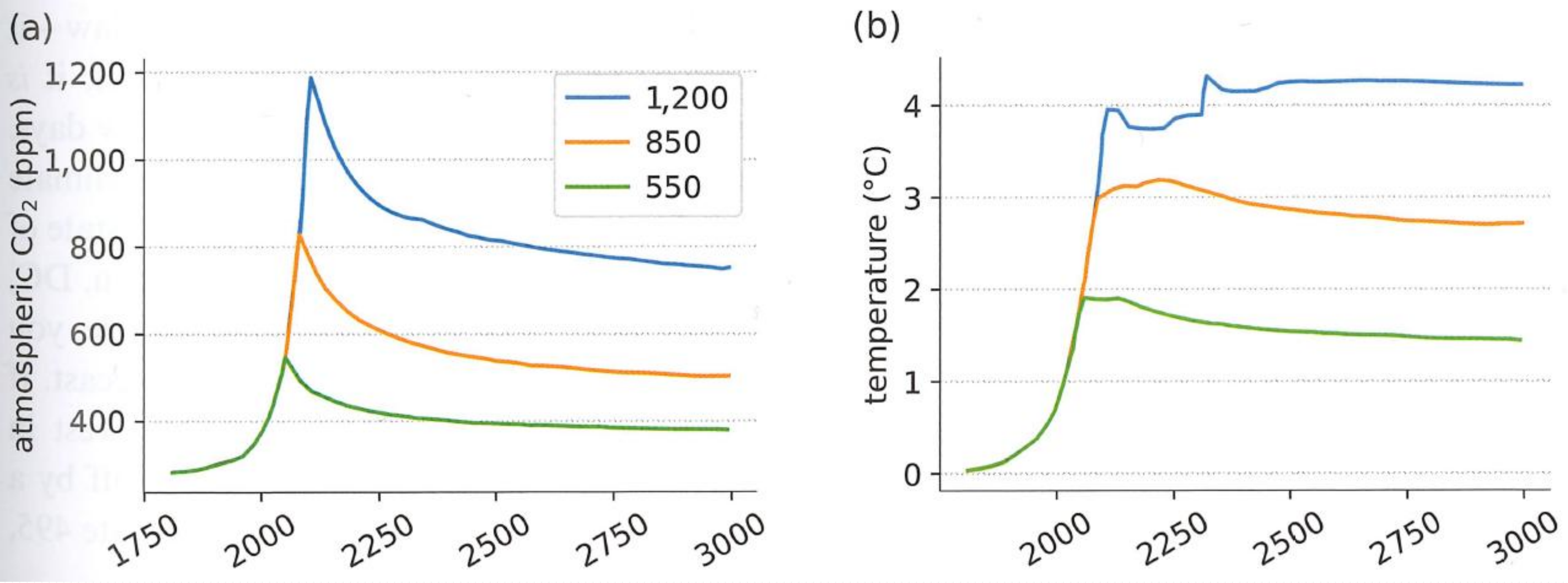
How will temperatures change if we reduce CO_2 emissions *today*?	SSP1-2.6
… if we reduce CO_2 emissions *later* (2040)?	SSP2-4.5
… if we do not reduce CO_2 emissions but our children do (2080)?	SSP3-6
… if we do not reduce CO_2 emissions? (“business as usual”)	SSP5-8.5



Approaching Permian Mass Extinction Levels of Warming

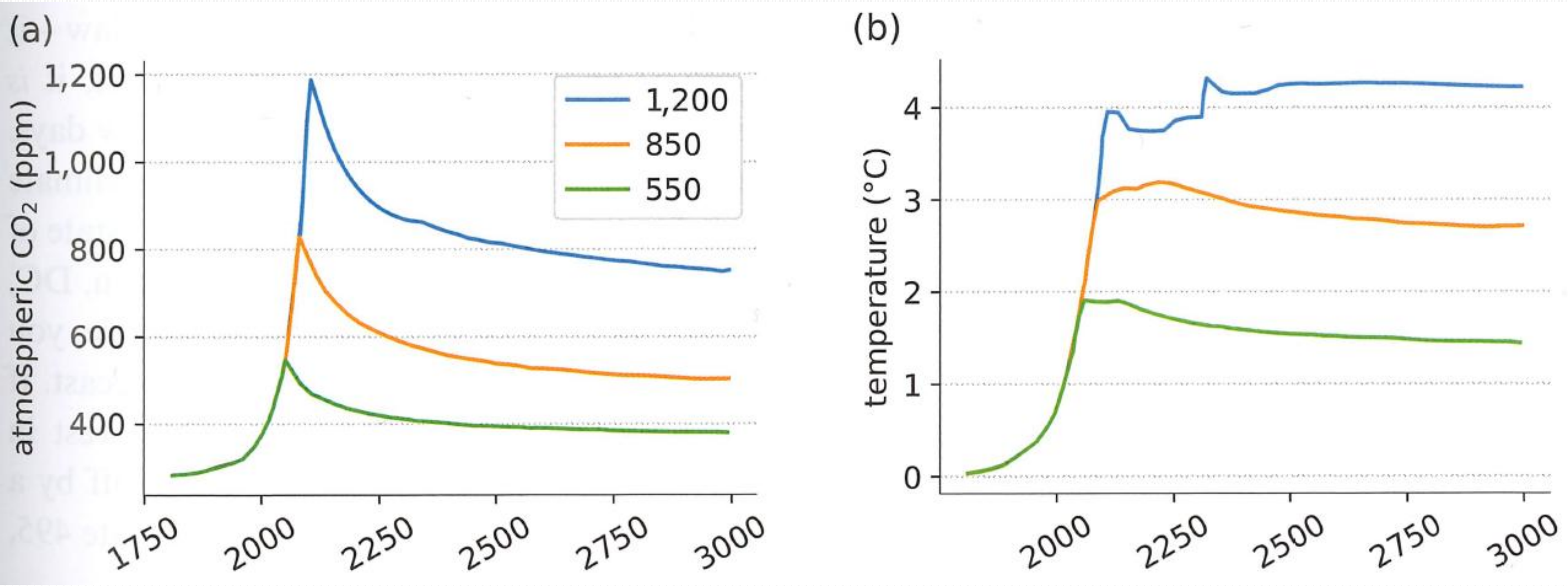
Long-term CO_2 and Temperature

- Decision today will affect Earth's climate for centuries due to three processes



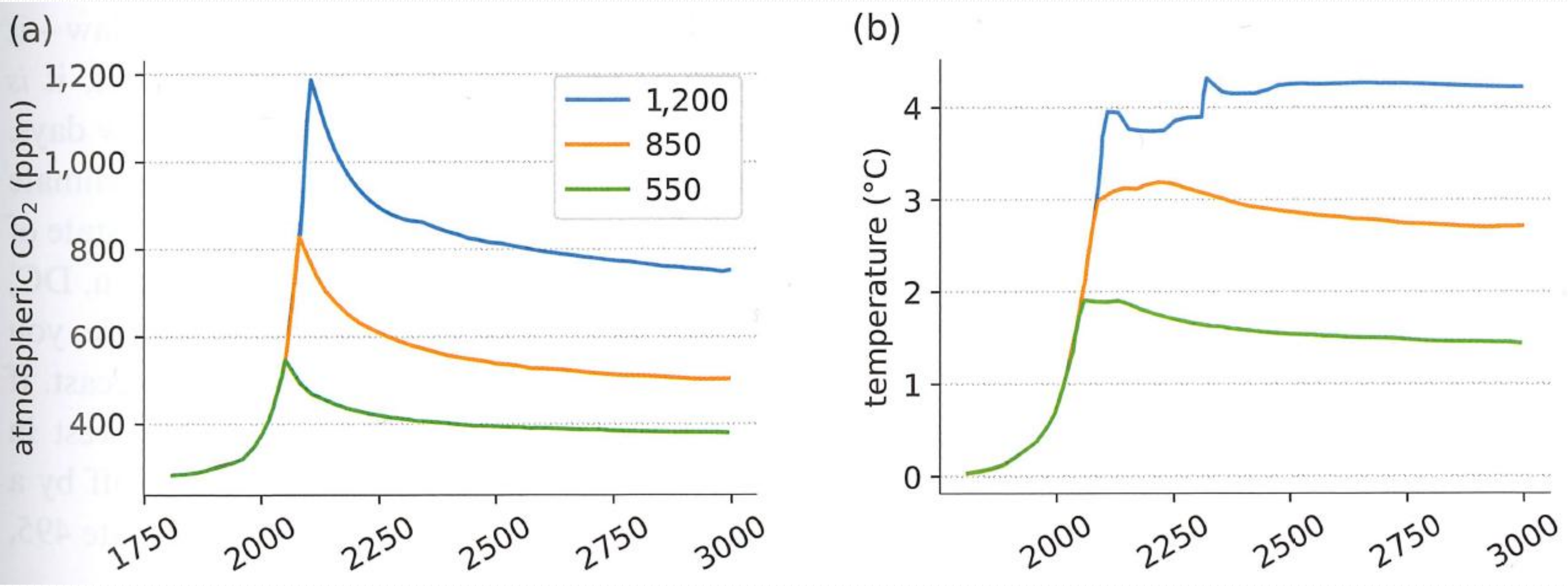
Long-term CO_2 and Temperature

1. CO_2 has a long residence time in the atmospheres and so even after we cut emissions the warming effect will continue for centuries



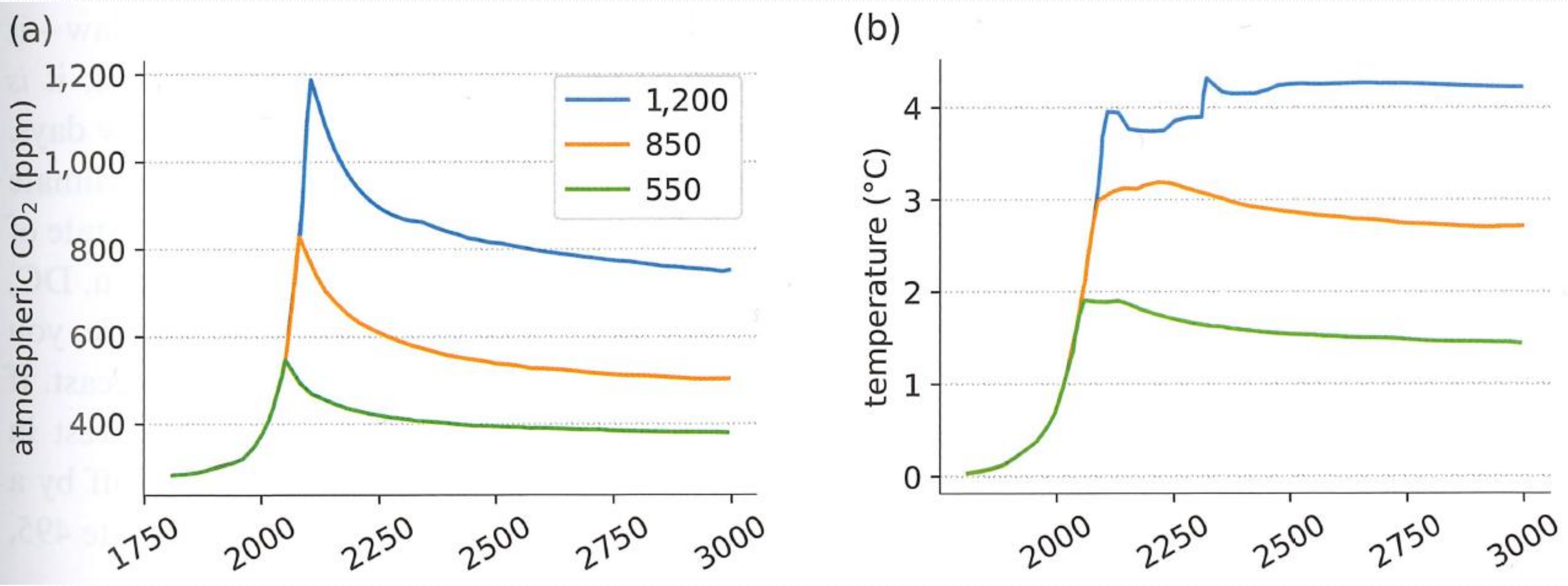
Long-term CO_2 and Temperature

2. Once CO_2 does start to drop the ocean's become a net source of CO_2 as it tries to maintain in equilibrium with the atmosphere



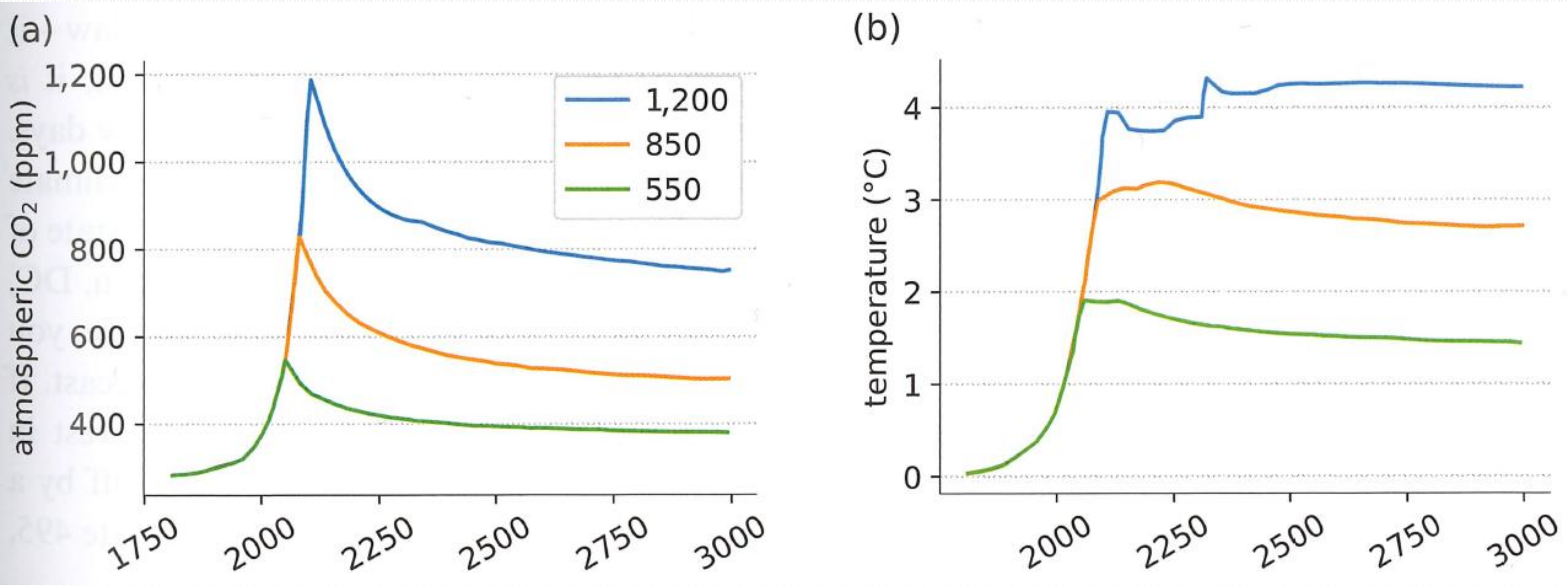
Long-term CO_2 and Temperature

3. Slow feedbacks, such as the melting of the polar ice sheets lowering albedo, will counteract cooling effects



Long-term CO_2 and Temperature

- Our choices this century will likely set global climate for hundreds, and likely thousands, of years into the future



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4. Be able to explain why even after emissions are cut temperature will continue to be elevated for centuries to millennia