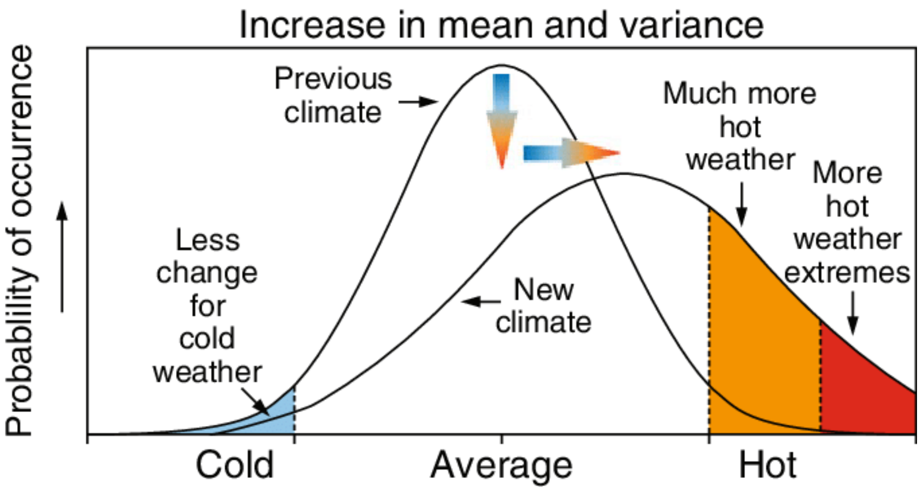
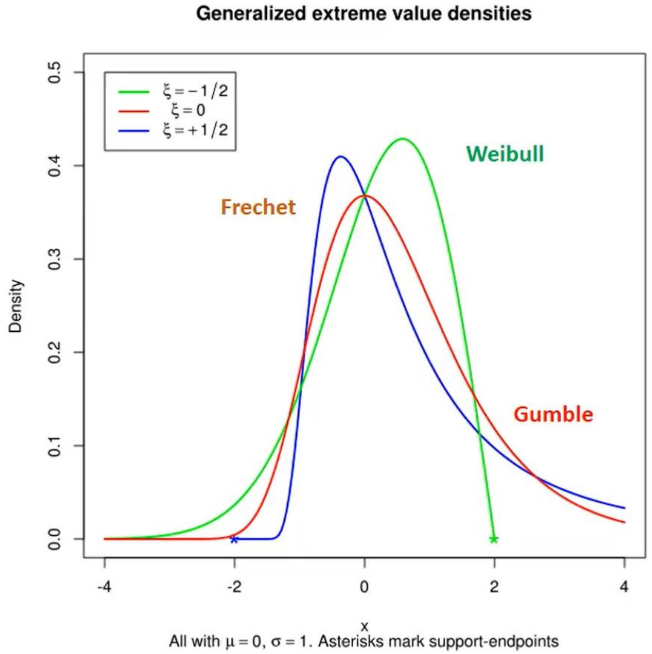
Recap of previous lecture

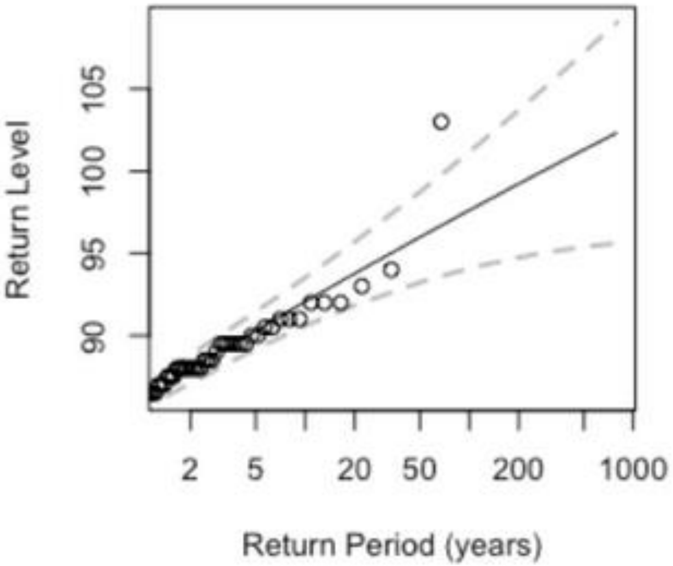


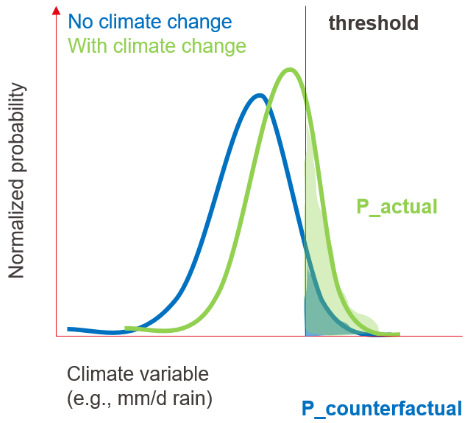
A changing climate invokes a shift in the mean and a broadening of the distribution



Extreme values can be characterized by three different types of distributions

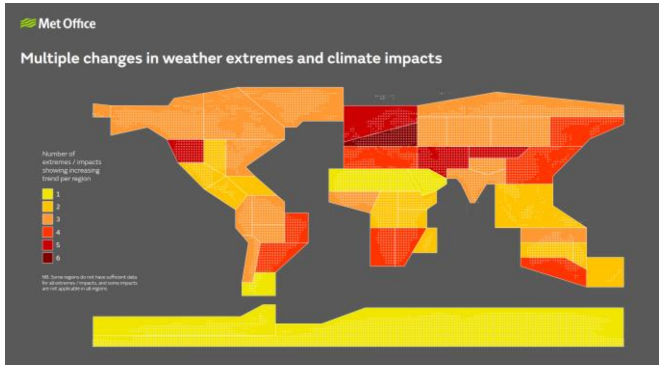
The statistical evaluation of extremes allows to calculate return periods





- P_actual > P_counterfactual
- Probability ratio: P_actual/P_counterfactual > 1
- Fraction of attributable risk (FAR)= 1- p_counterfactual/p_actual

Risk of extreme events can be attributed to climate change through comparison with counterfactual model simulations



Extreme events can occur simultaneously or in sequence with other extreme events, where impact increases: compound events

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General outline

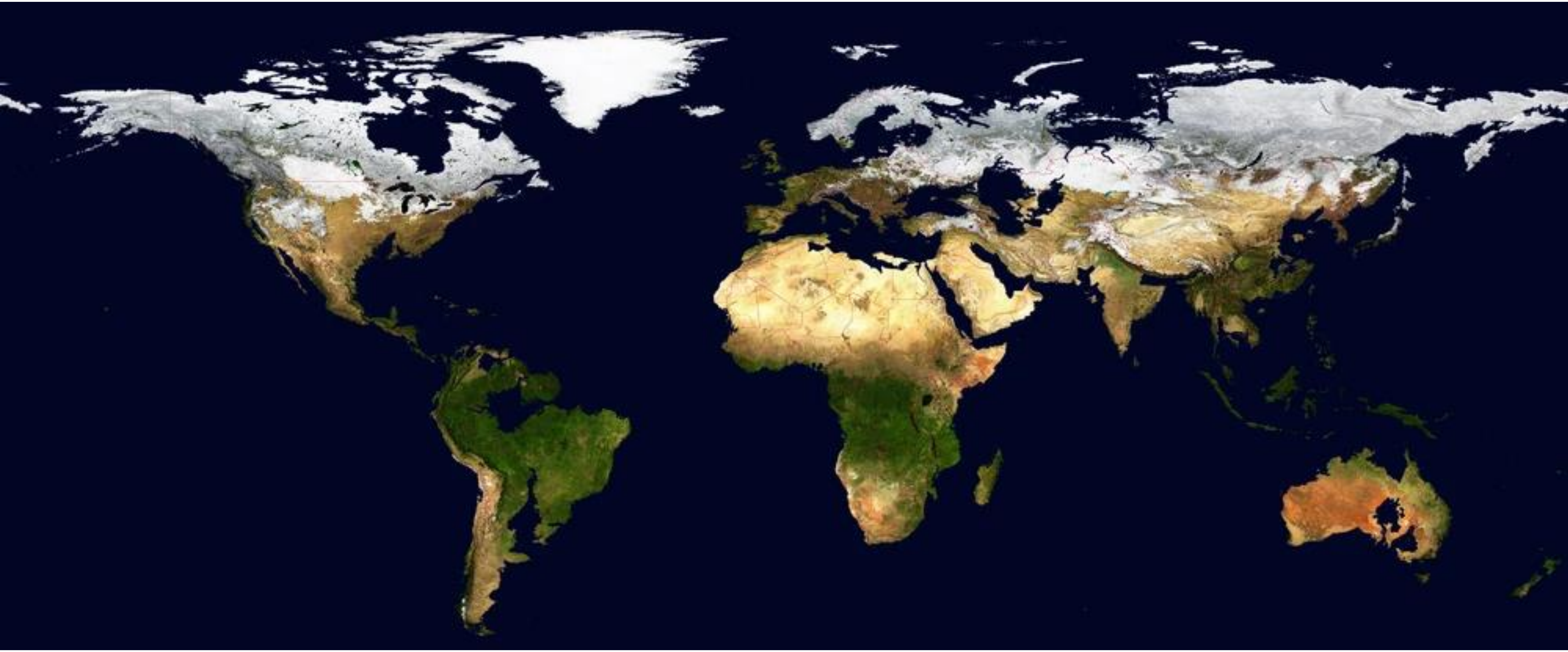
Basics

Present and future Climate change

Actions

No.	Date	Topics	Deadlines
1.	12.09.2024	Introduction	fill in Questionnaire in exercises (not graded)
2.	19.09.2024	Climate System, Radiation, Greenhouse effect	
3.	26.09.2024	Earth's energy balance, Radiative transfer,	
4.	03.10.2024	Aerosols & clouds, Radiative Forcing	Launch of poster assignment
5.	10.10.2024	Feedback mechanisms, Climate Sensitivity	
6.	17.10.2024	Emergent Constraints, Paleoclimate	submission of Poster proposal (01.11.2024)
7.	31.10.2024	Climate variability	
8.	07.11.2024	IPCC, present day climate change, Paris Agreement, Emissions Gap, COP	
9.	14.11.2024	Extreme Events, COP29	
10.	21.11.2024	**Climate scenarios, Tipping elements, Carbon Budget, Metrics**	submission of Poster draft
11.	28.11.2024	carbon offsets, metrics	submission of assignment (graded)
12.	05.12.2024	Regional climate change	
13.	12.12.2024	Mitigation and adaptation, Climate Engineering	**Poster Conference** (graded)
14.	19.12.2024	Recapitulation of key points, questions and answers session	fill in Questionnaire in exercises (not graded)

How will our planet look like in 2100 and beyond?

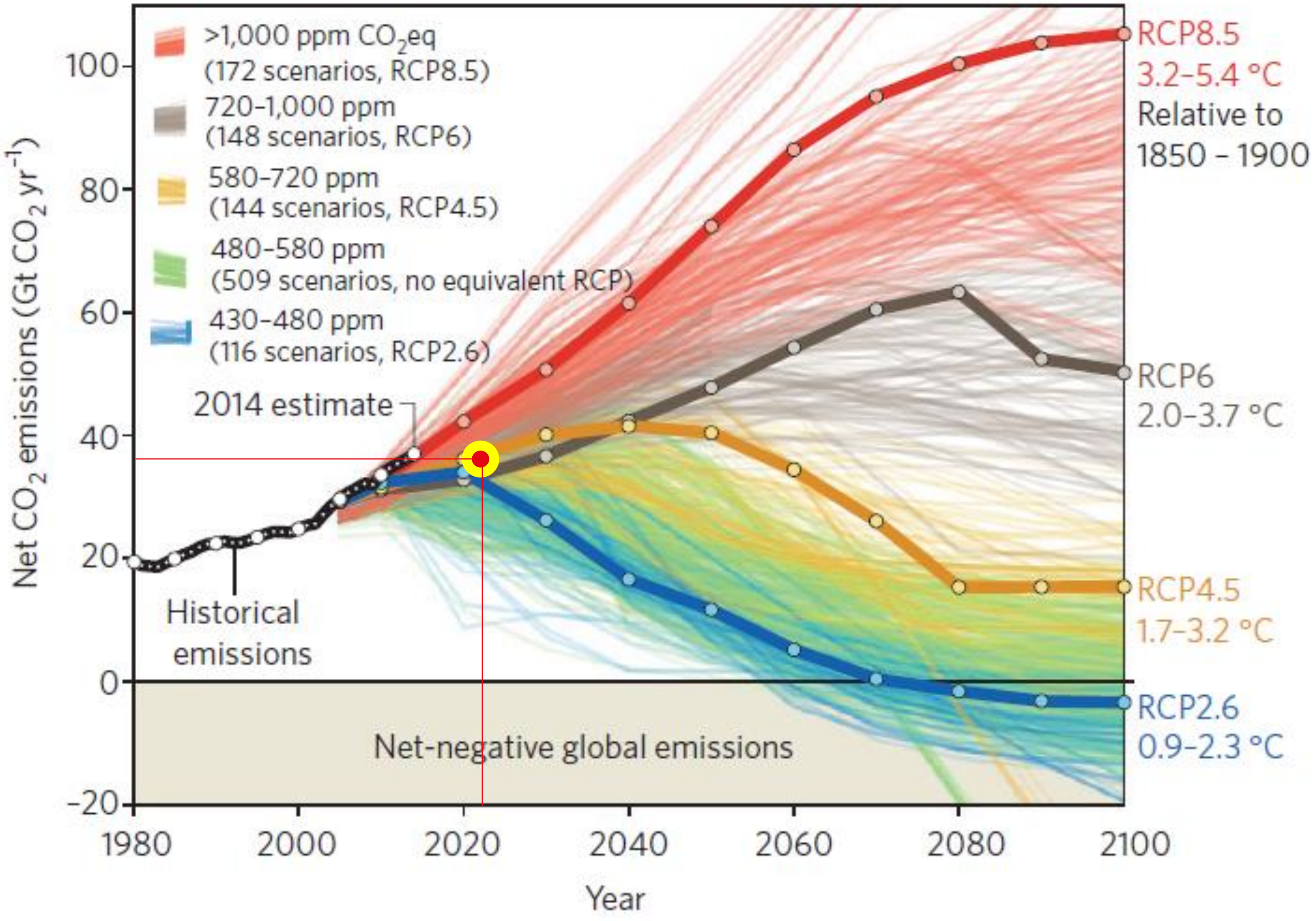


- https://thefutureofeuropes.fandom.com/wiki/Rise_of_the_Seas:_2100_(Map_Game)?file=Sattelite2100.png

Representative Concentration Pathways (RCPs)

- Used up until the Couple Model Intercomparison Project 5 (CMIP5). Corresponds to IPCC AR5.
- Focus on atmospheric CO_2 concentrations.
- They focus on anthropogenic emissions and do not include changes in natural drivers such as solar or volcanic forcing or natural emissions, for example, of CH_4 and N_2O.
- They are identified by their **approximate total radiative forcing** in year 2100 relative to 1750:
  - 2.6 W m^{-2} for RCP2.6 – in 2100: 430-480 ppm CO_2 (mitigation scenario)
  - 4.5 W m^{-2} for RCP4.5 – in 2100: 480 - 720 ppm CO_2 (stabilization scenario)
  - 6.0 W m^{-2} for RCP6.0 – in 2100: 720 - 1000 ppm CO_2 (stabilization scenario)
  - 8.5 W m^{-2} for RCP8.5 – in 2100: > 1000 ppm CO_2 (“uncontrolled growth”)

CO_2 emissions of RCPs



2019: 36.4 Gt
2020: 34.8 Gt
2021: ~36.4 Gt
2022: ~37.5 Gt
2023: ~37.5 Gt
Global Carbon Project

Anything that strikes you in this graph?

Negative emissions needed to stay < 2 °C.

- Fuss et al., 2014, Nat. Clim. Change

Shared Socioeconomic Pathways (SSPs)

- SSPs are scenarios of projected socioeconomic global changes up to 2100. They are used to derive greenhouse gas emissions scenarios with different climate policies.
- Used since IPCC AR6
- **SSPs** are:
  - narratives describing alternative socio-economic developments.
  - qualitative description of logic relating elements of the narratives to each other.
  - quantitative elements: they provide data accompanying the scenarios on national population, urbanization and GDP (per capita).

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Shared Socio-economic Pathways (SSPs)

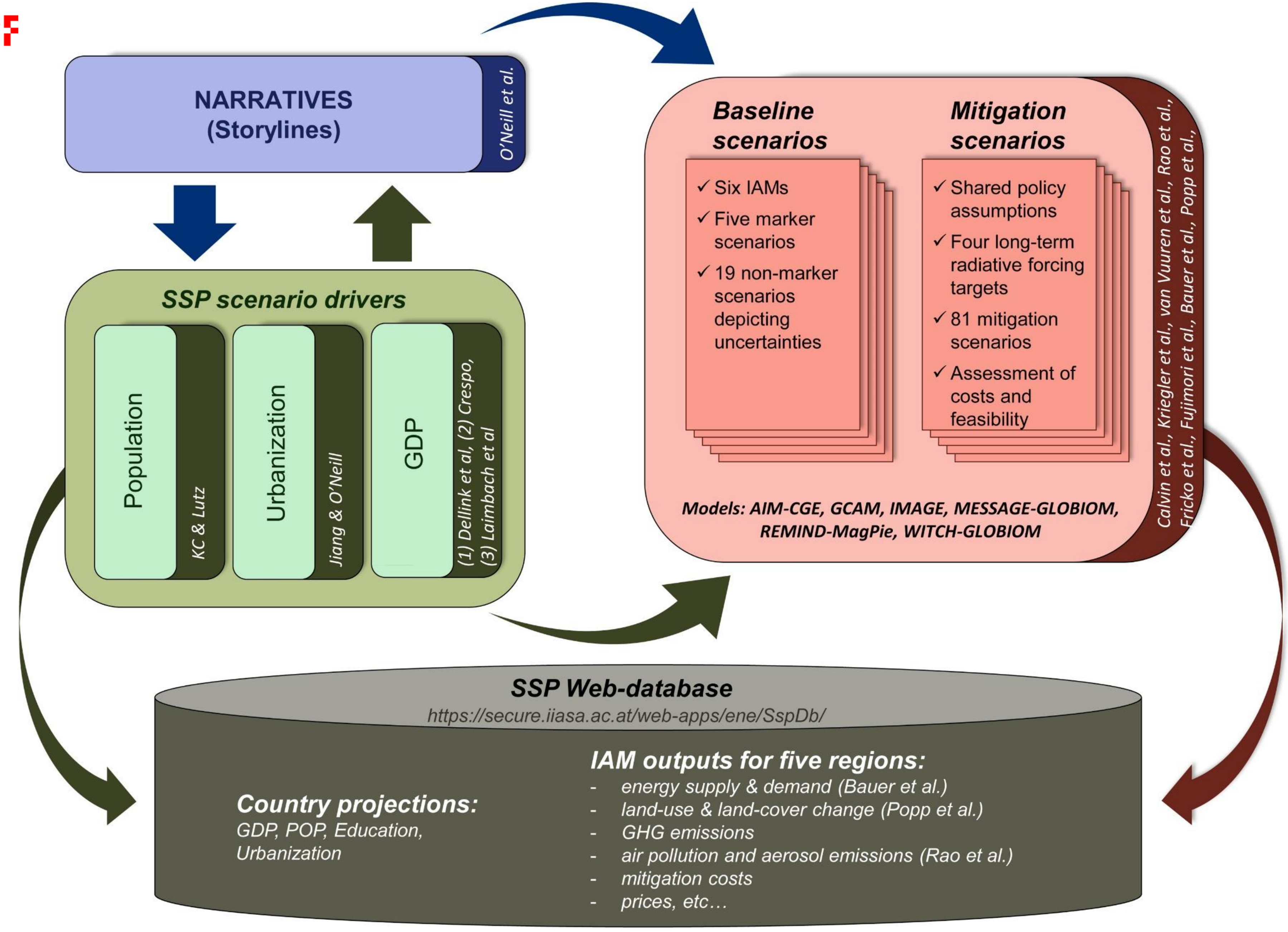
This world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development.

The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development.

A path in which social, economic, and technological trends do not shift markedly from historical patterns.

A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues.

Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries.

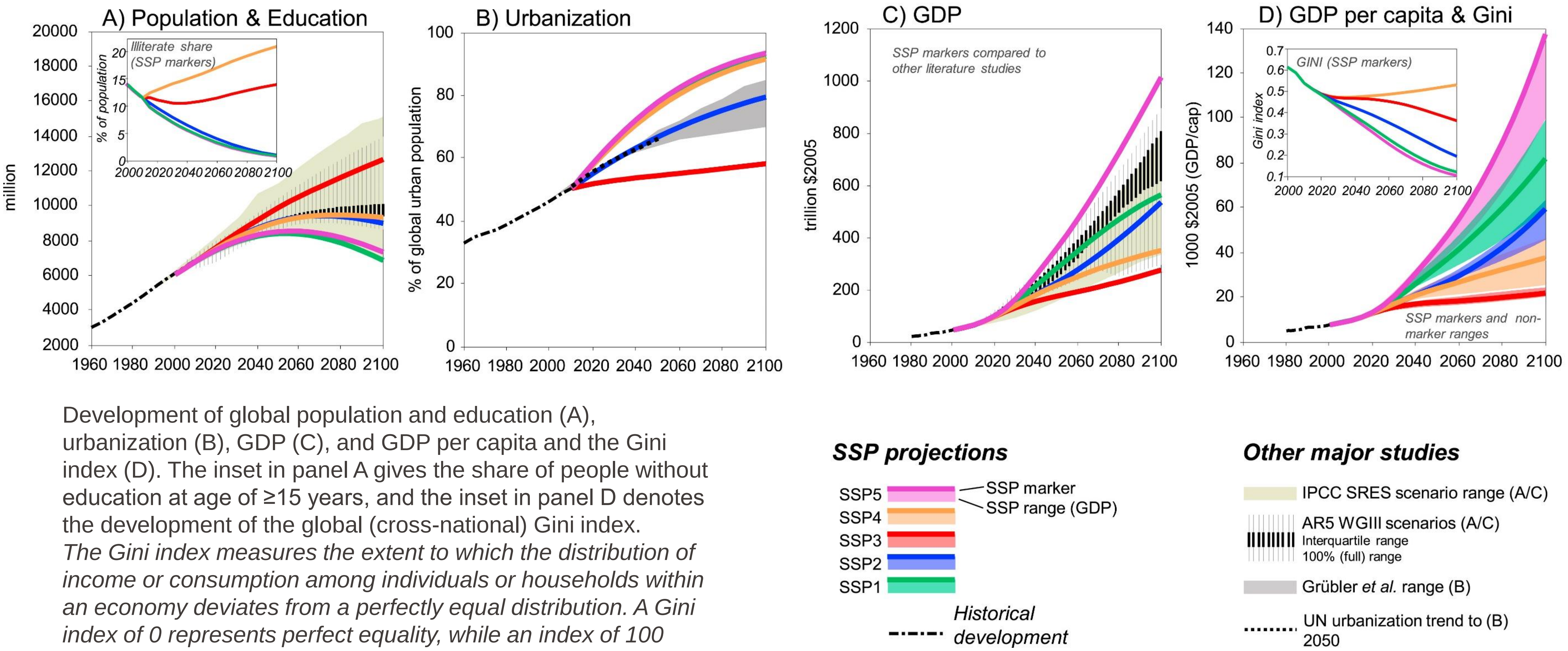


Six integrated assessment models (IAMs) were run to develop 24 baseline scenarios across all SSPs for no mitigation and mitigation scenarios.

IAMs add aspects of society to an energy systems model, simulating how population, economic growth and energy use affect – and interact with – the physical climate. They produce scenarios of how greenhouse gas emissions may vary in future based on underlying socioeconomic factors – and how energy use, production and economic activity may change to meet climate mitigation targets.

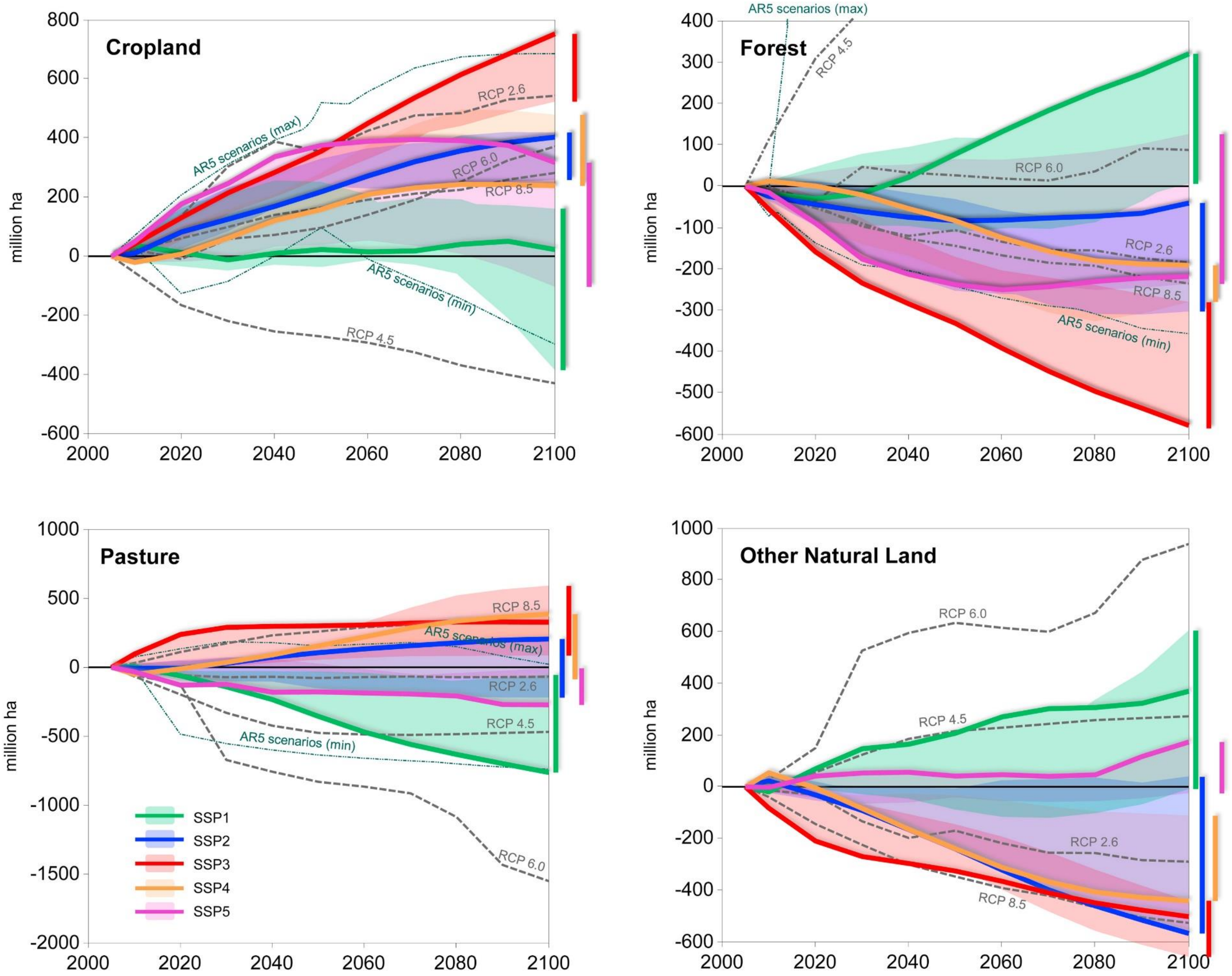
- https://www.sciencedirect.com/science/article/pii/S0959378016300681#fig0005

SSPs are driven by socio-economic factors



Development of global population and education (A), urbanization (B), GDP (C), and GDP per capita and the Gini index (D). The inset in panel A gives the share of people without education at age of ≥15 years, and the inset in panel D denotes the development of the global (cross-national) Gini index.
The Gini index measures the extent to which the distribution of income or consumption among individuals or households within an economy deviates from a perfectly equal distribution. A Gini index of 0 represents perfect equality, while an index of 100 implies perfect inequality.

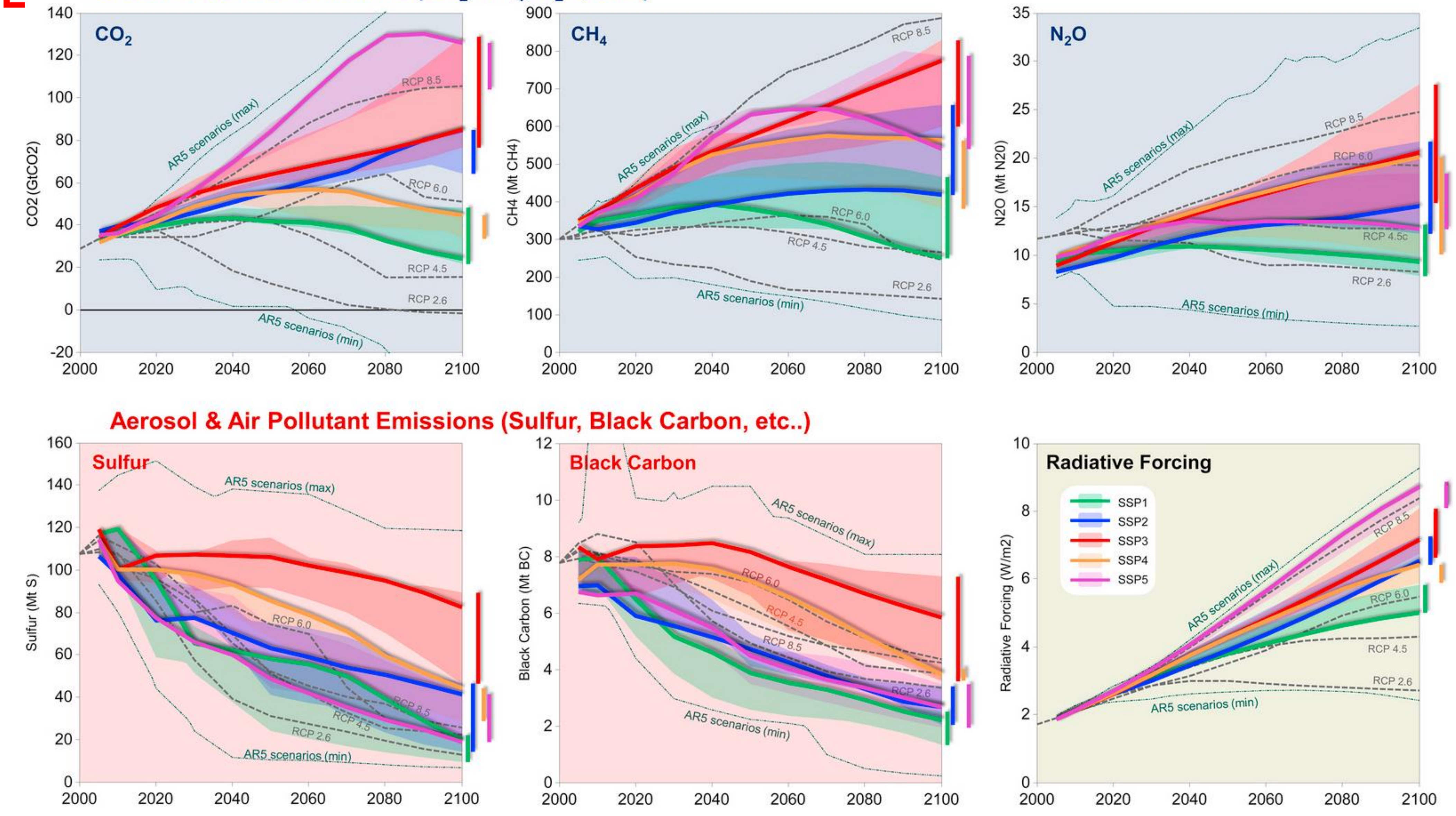
- https://www.sciencedirect.com/science/article/pii/S0959378016300681#fig0005



Changes in cropland, forest, pasture and other natural land for the SSP marker baseline scenarios (thick lines) and ranges of other non-marker scenarios (colored areas). Changes are shown relative to the base year of 2010 = 0.

- https://www.sciencedirect.com/science/article/pii/S0959378016300681#fig0005

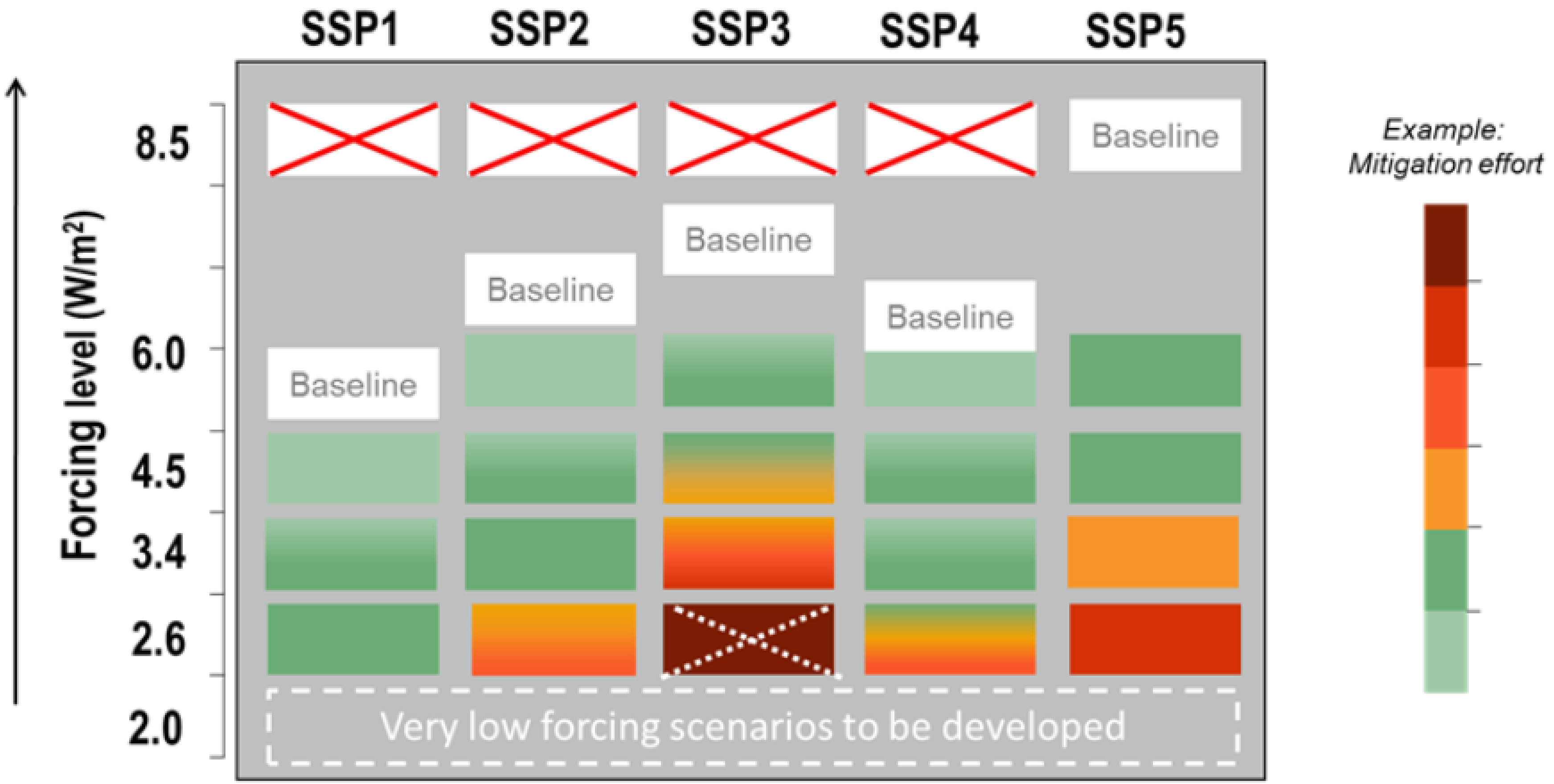
Greenhouse Gas Emissions (CO_2, CH_4, N_2O, etc..)



- https://www.sciencedirect.com/science/article/pii/S0959378016300681#fig0005

SSPs …

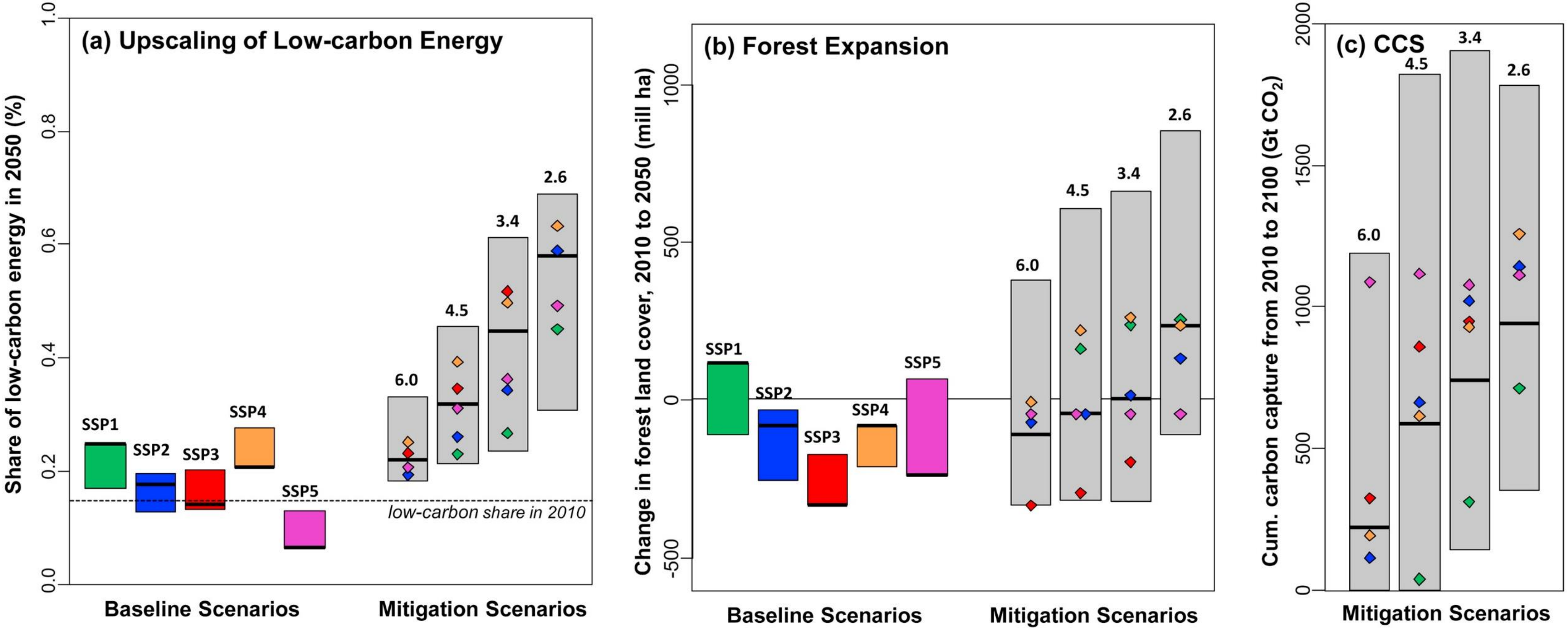
- …relate to previous generation of emissions scenarios (RCPs) and climate projections (CMIP5) for seamless transition of impacts, adaptation, vulnerability (IAV) analysis,
- …Are based on a **scenario matrix architecture**
- Basic SSPs consist of a narrative outlining broad characteristics of the global future and country-level population, GDP, urbanisation projections
- …are not scenarios themselves, but their building blocks
- It is distinguished between baseline scenarios without and mitigation scenarios with mitigation policies.



Scenario matrix specified by SSPs and forcing levels. Scenarios populate individual cells providing information about **mitigation benefits and costs (shown here as example)**.

- https://unfccc.int/sites/default/files/part1_iiasa_rogelj_ssp_poster.pdf

Baseline and mitigation scenarios



Major mitigation options in the energy and land-use sector: (a) upscaling of low carbon energy by 2050, (b) expansion of forest land-cover by 2050, and (c) contribution of cumulative CCS over the course of the century. The range of the SSP baseline scenarios are shown as colored bars. Horizontal black lines within the colored bars give the relative position of the SSP baseline marker scenarios. The full range of results for the mitigation scenarios are shown as grey bars. Colored symbols within the grey bars denote the relative position of the marker mitigation scenarios and the horizontal black lines within the grey bars denote the median across the mitigation scenarios. Note that the number of scenarios differs across the different baseline and mitigation bars.

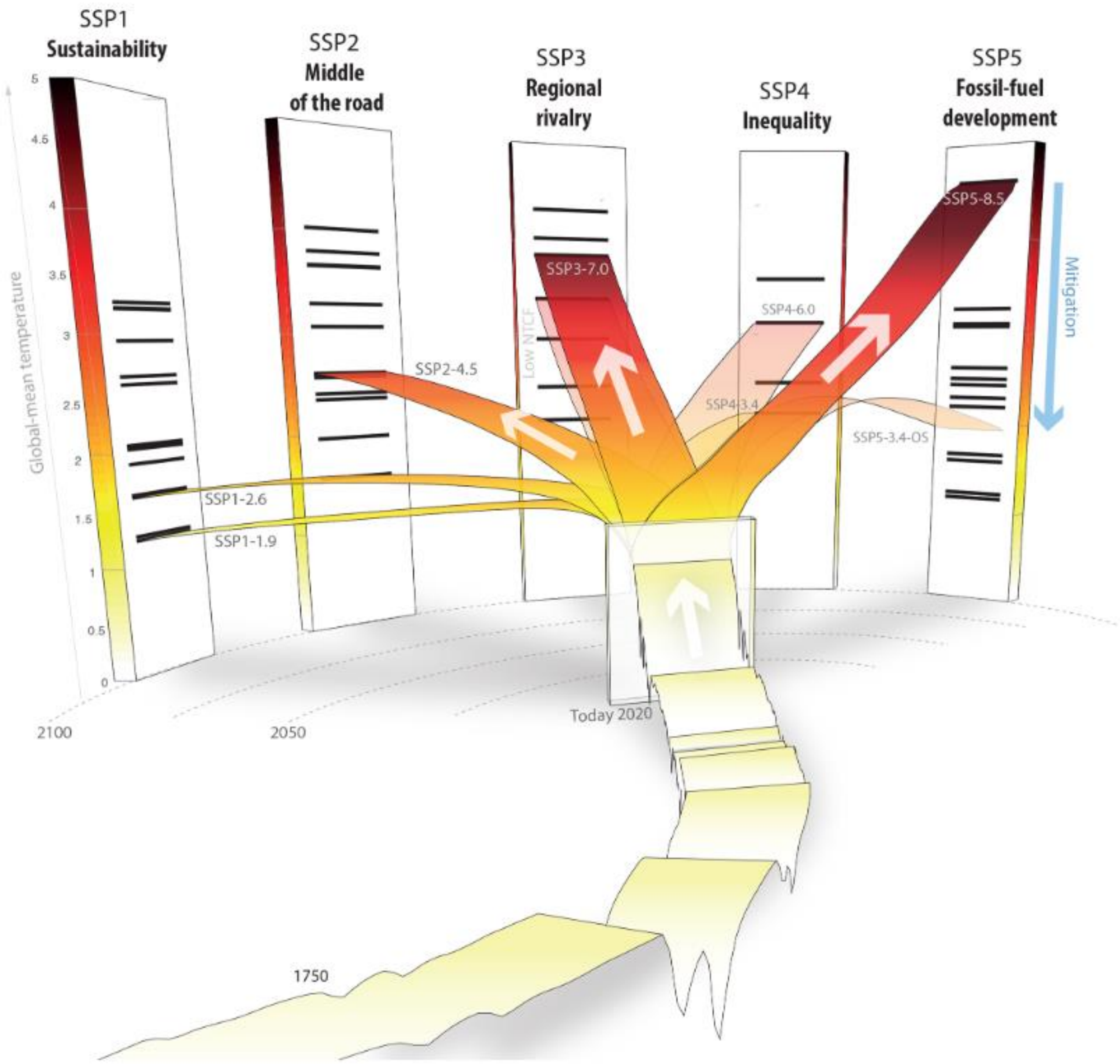
- https://www.sciencedirect.com/science/article/pii/S0959378016300681#fig0005

Intended use of SSPs

- SSPs aim not directly at decision makers but at climate change analysts preparing climate policy analysis based on the SSPs
- Link IAV and mitigation analysis more explicitly to socio-economic development
- Enable better integration of mitigation, adaptation and climate impact research in future assessments (AR6, 7…)
- Initiate open community process to build richer socio-economic data repository for climate change research.

IPCC priority scenarios

For your reference, no discussion now.



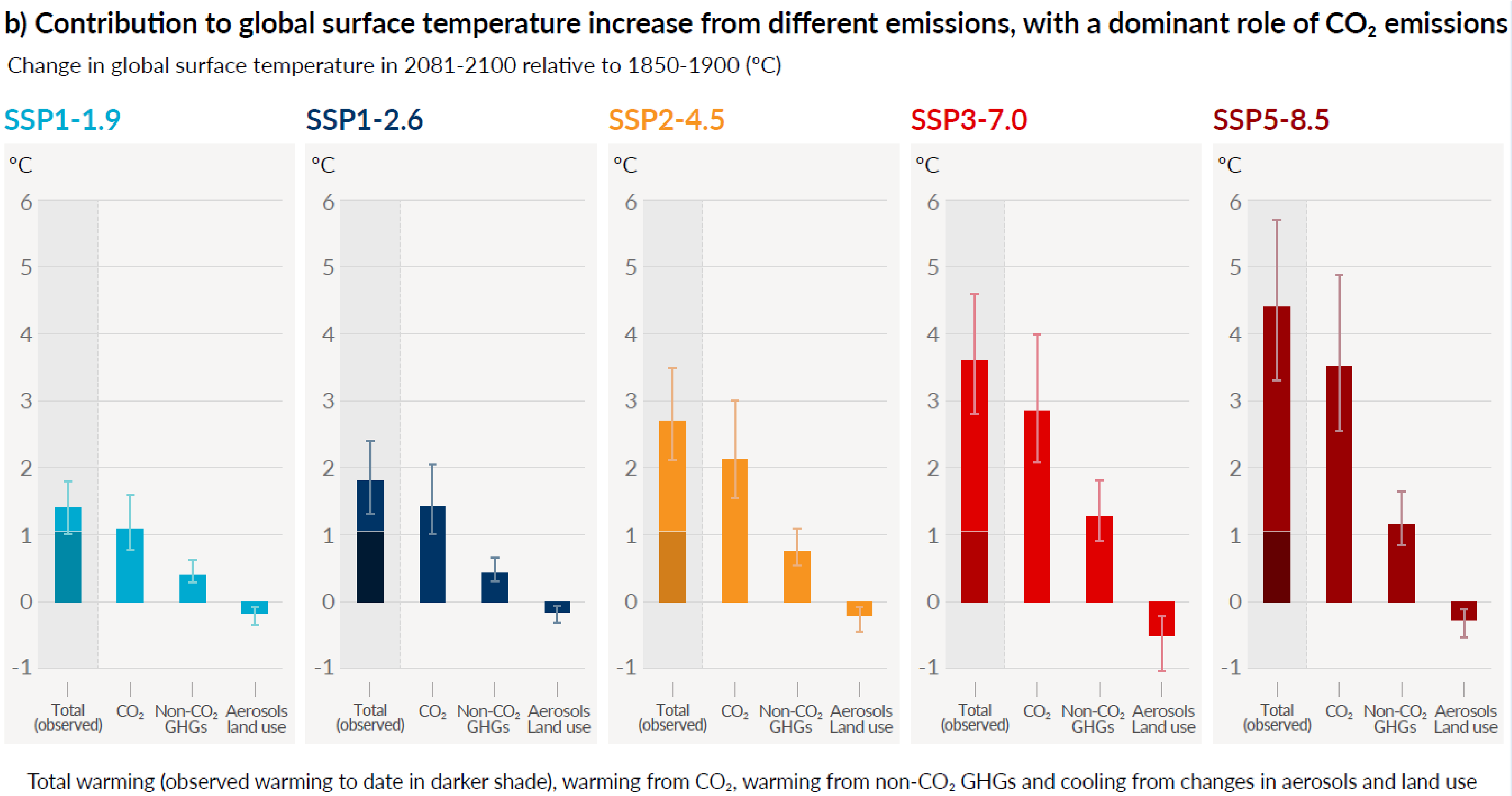
There are 23 SSP “marker” scenarios. These are the **5 IPCC priority** scenarios.

- **SSP5-8.5** represents the high end of the range of future pathways, corresponding to RCP8.5.
- **SSP3-7.0** lies between RCP6.0 and RCP8.5, and represents the medium to high end of the range of future forcing pathways.
- **SSP2-4.5** represents the medium part of the range of future forcing pathways and updates RCP4.5.
- **SSP1-2.6** is similar to RCP2.6. It is anticipated that it will produce a multi-model mean of less than 2°C warming by 2100.
- **SSP1-1.9** are scenarios with very low and low GHG emissions, and CO2 emissions declining to net zero around or after 2050, followed by varying levels of net negative CO2 emissions.

Less warming

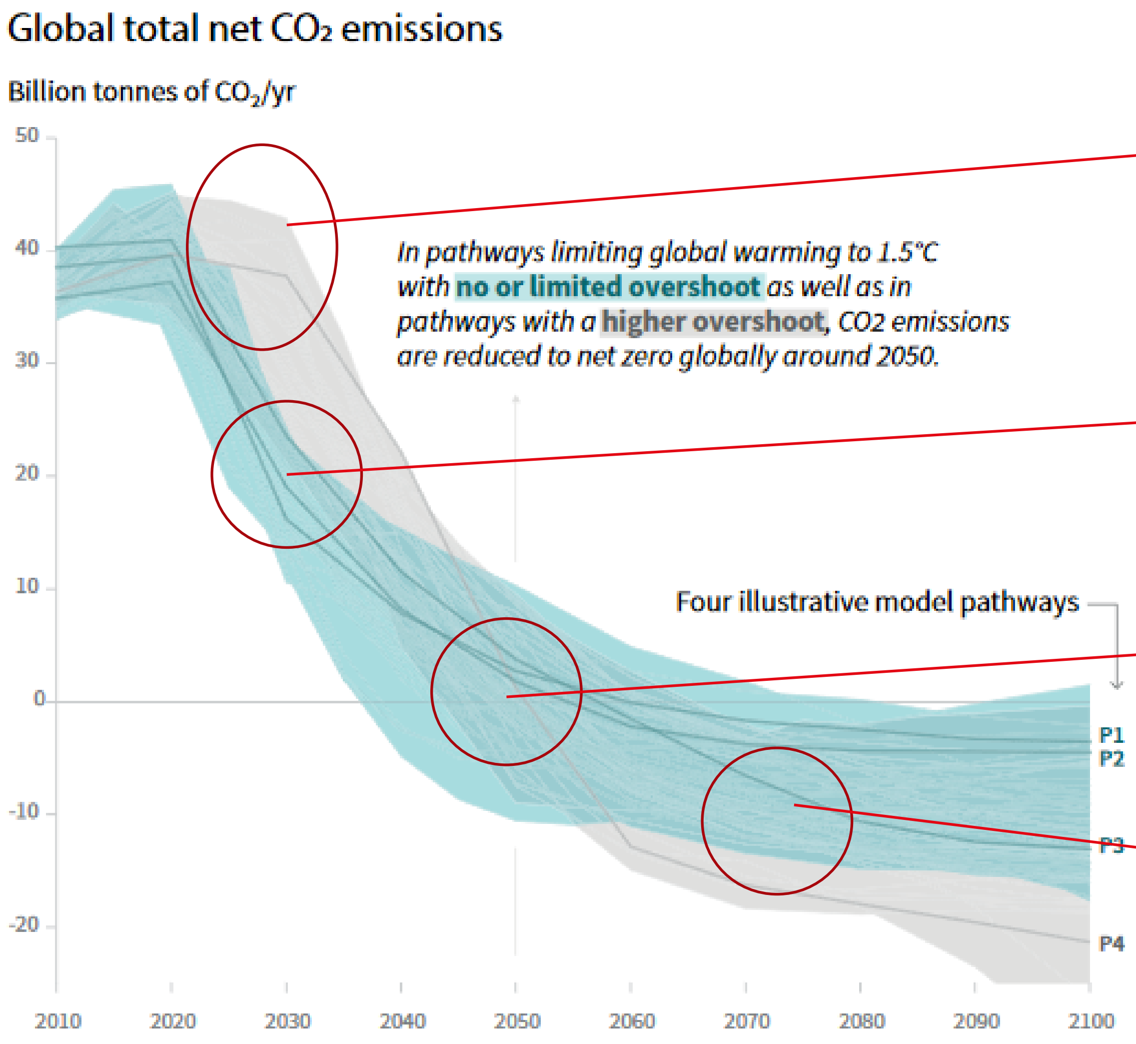
https://doi.org/10.5194/gmd-13-3571-2020

Contribution to warming



- Figure SPM.4

Reducing emissions



«overshoot», followed by steeper reduction

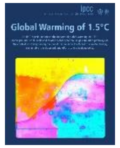
In 2030 only 50 % of emissions compared to 2010

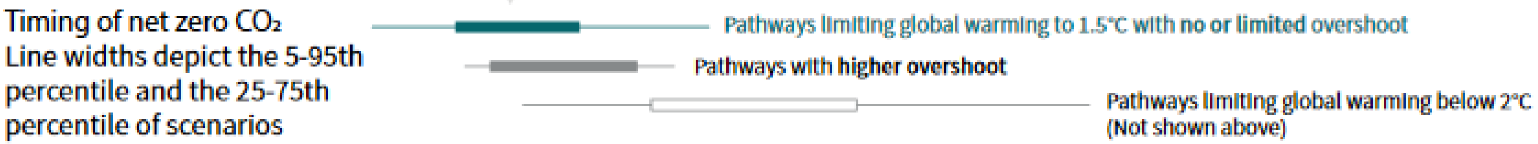
Decisive Decade

Net-zero at the latest in 2040-2050

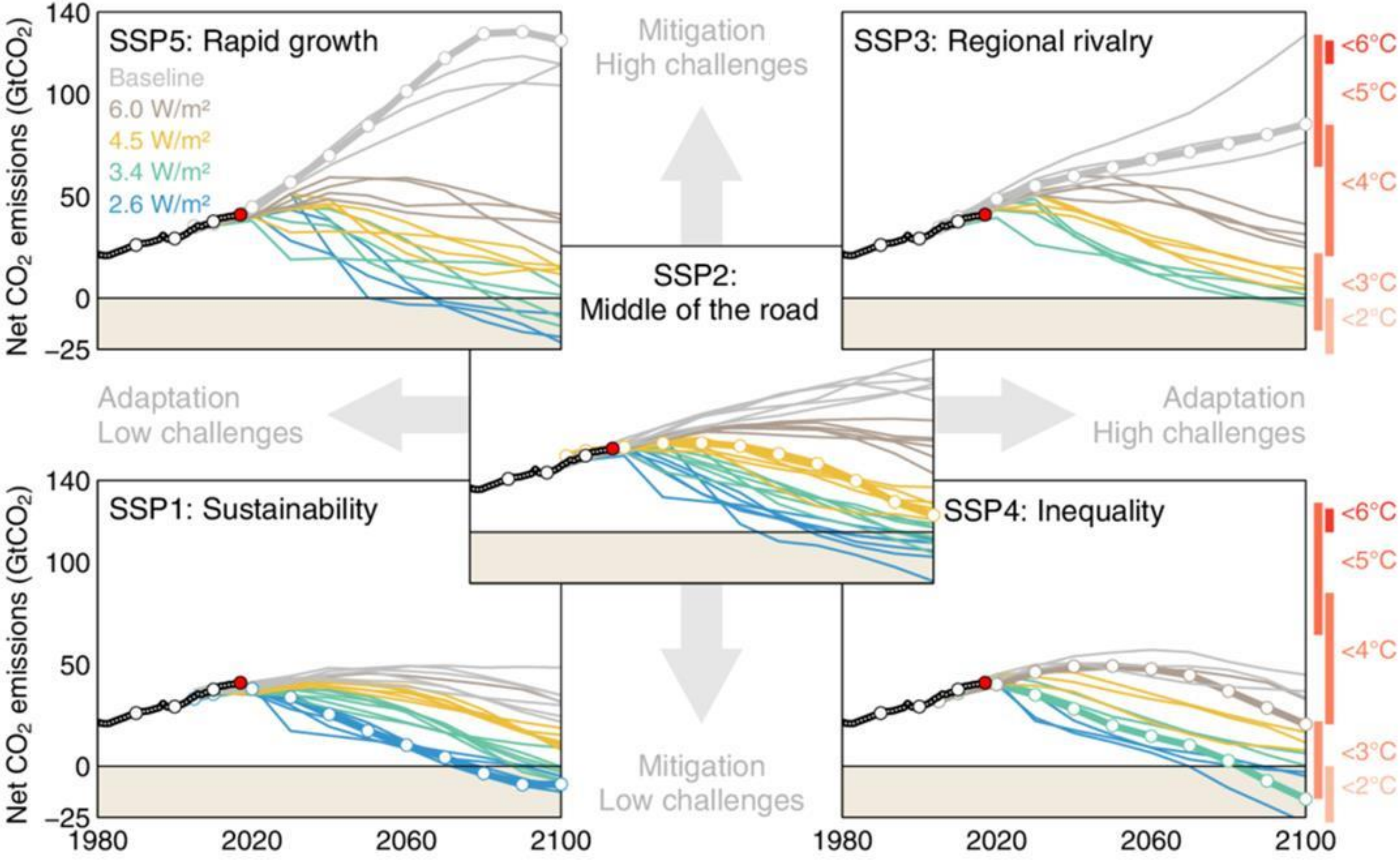
«negative emissions» about 25 % of present-day emissions!

IPCC, SP1.5





Which path are we on right now?



Tipping elements

- Climate tipping points (CTPs) are a source of growing scientific, policy, and public concern.
- They occur when change in large parts of the climate system—known as tipping elements—become self-perpetuating beyond a warming threshold.
- Triggering CTPs leads to significant, policy-relevant impacts, including substantial sea level rise from collapsing ice sheets, dieback of biodiverse biomes such as the Amazon rainforest or warm-water corals, and carbon release from thawing permafrost.

Armstrong McKay et al., 2022, Science

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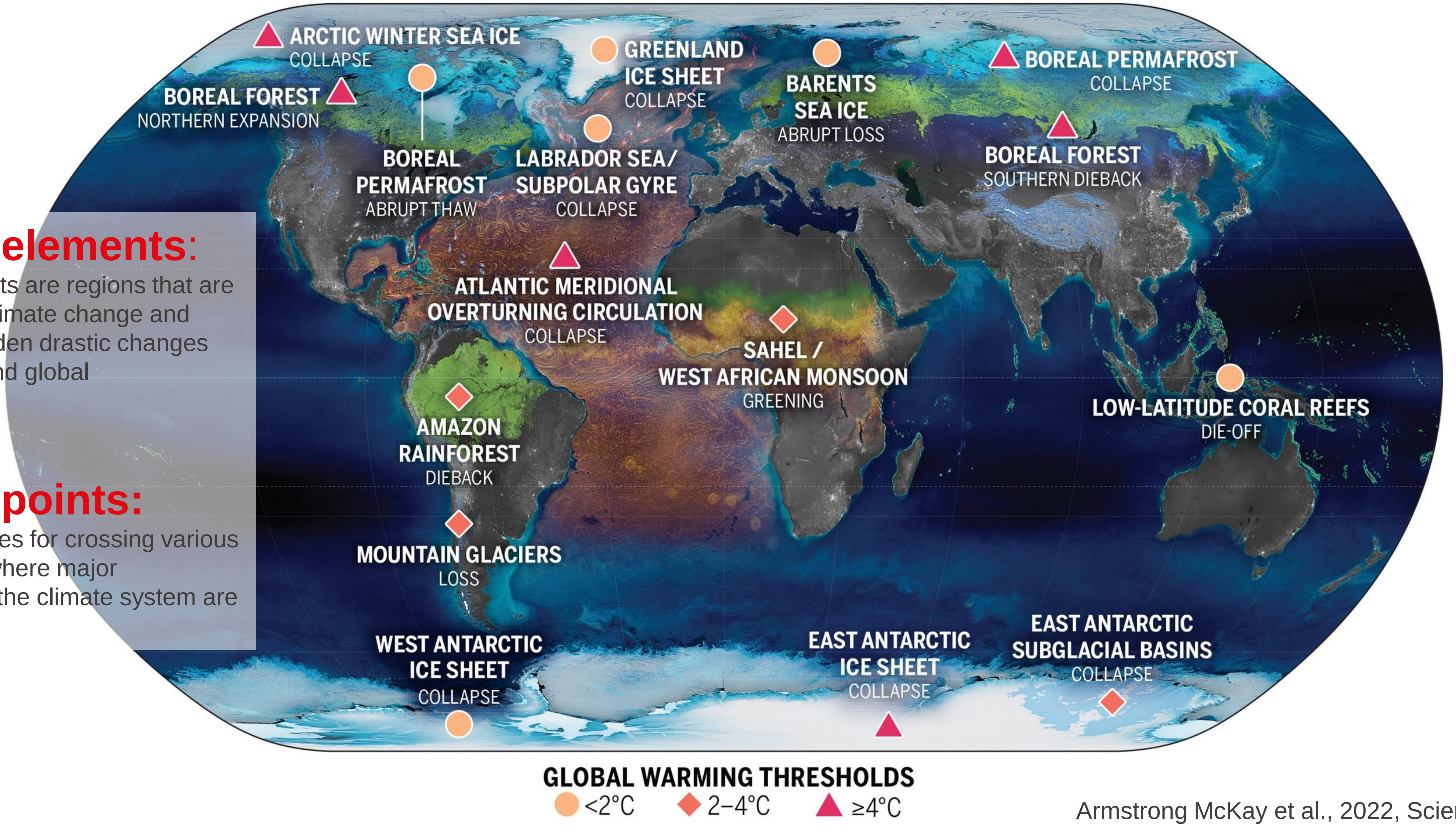
Tipping points: What is at stake?

Tipping elements:

Tipping elements are regions that are vulnerable to climate change and capable of sudden drastic changes with regional and global consequences.

Tipping points:

Threshold ranges for crossing various tipping points where major subsystems of the climate system are destabilized.



Armstrong McKay et al., 2022, Science

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Global and Regional Tipping Elements

- Identified nine **global "core" tipping elements** which contribute substantially to Earth system functioning and seven **regional "impact" tipping elements** which contribute substantially to human welfare or have great value as unique features of the Earth system.
- Their estimated CTP thresholds have significant implications for climate policy:
  - Current global warming of ~1.1°C above pre-industrial already lies within the lower end of five CTP uncertainty ranges.
  - Six CTPs become likely (with a further four possible) within the Paris Agreement range of 1.5 to <2°C warming, including collapse of the Greenland and West Antarctic ice sheets, die-off of low-latitude coral reefs, and widespread abrupt permafrost thaw.
  - An additional CTP becomes likely and another three possible at the ~2.6°C of warming expected under current policies.

Armstrong McKay et al., 2022, Science

Global and Regional Tipping Elements

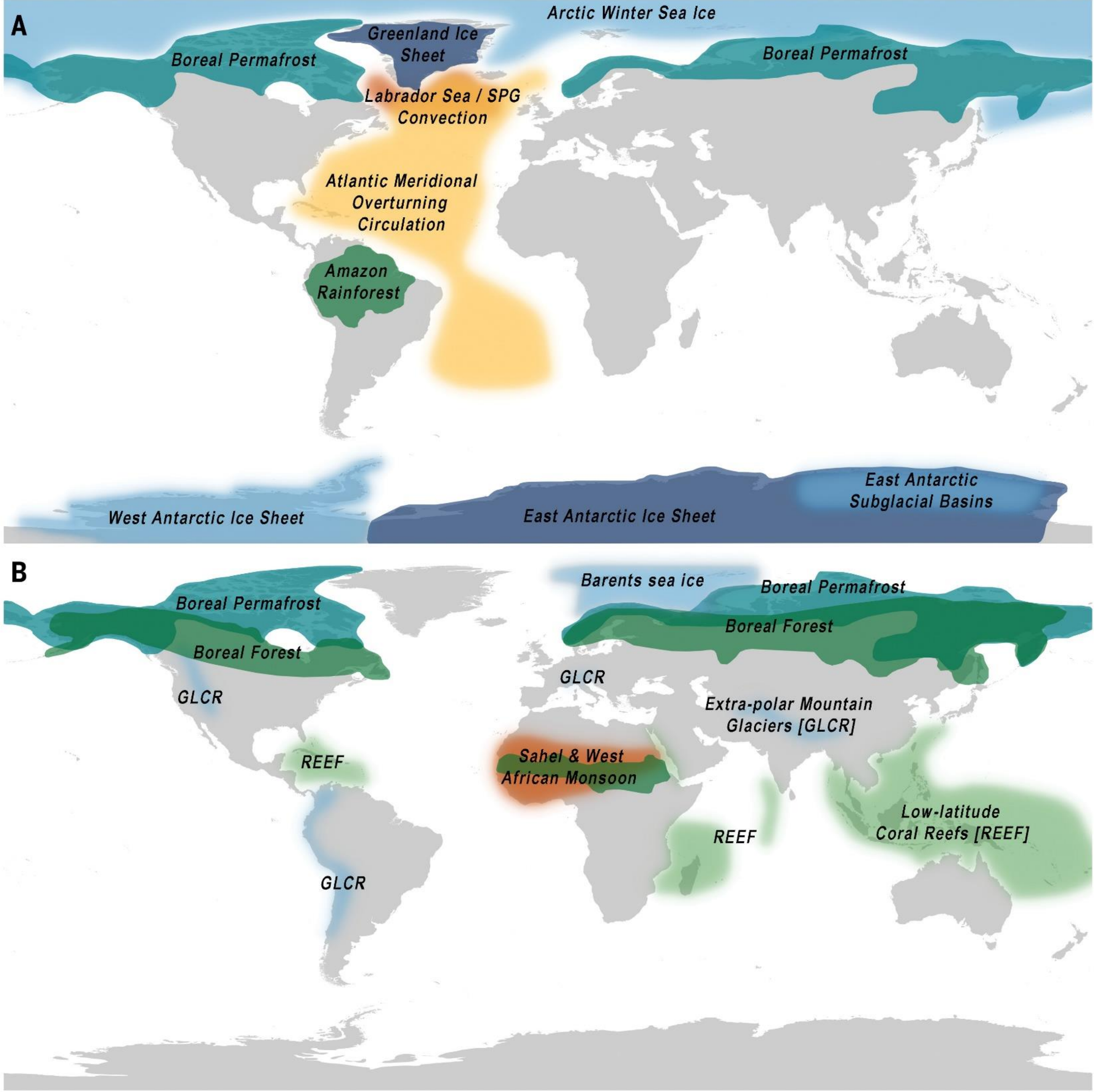
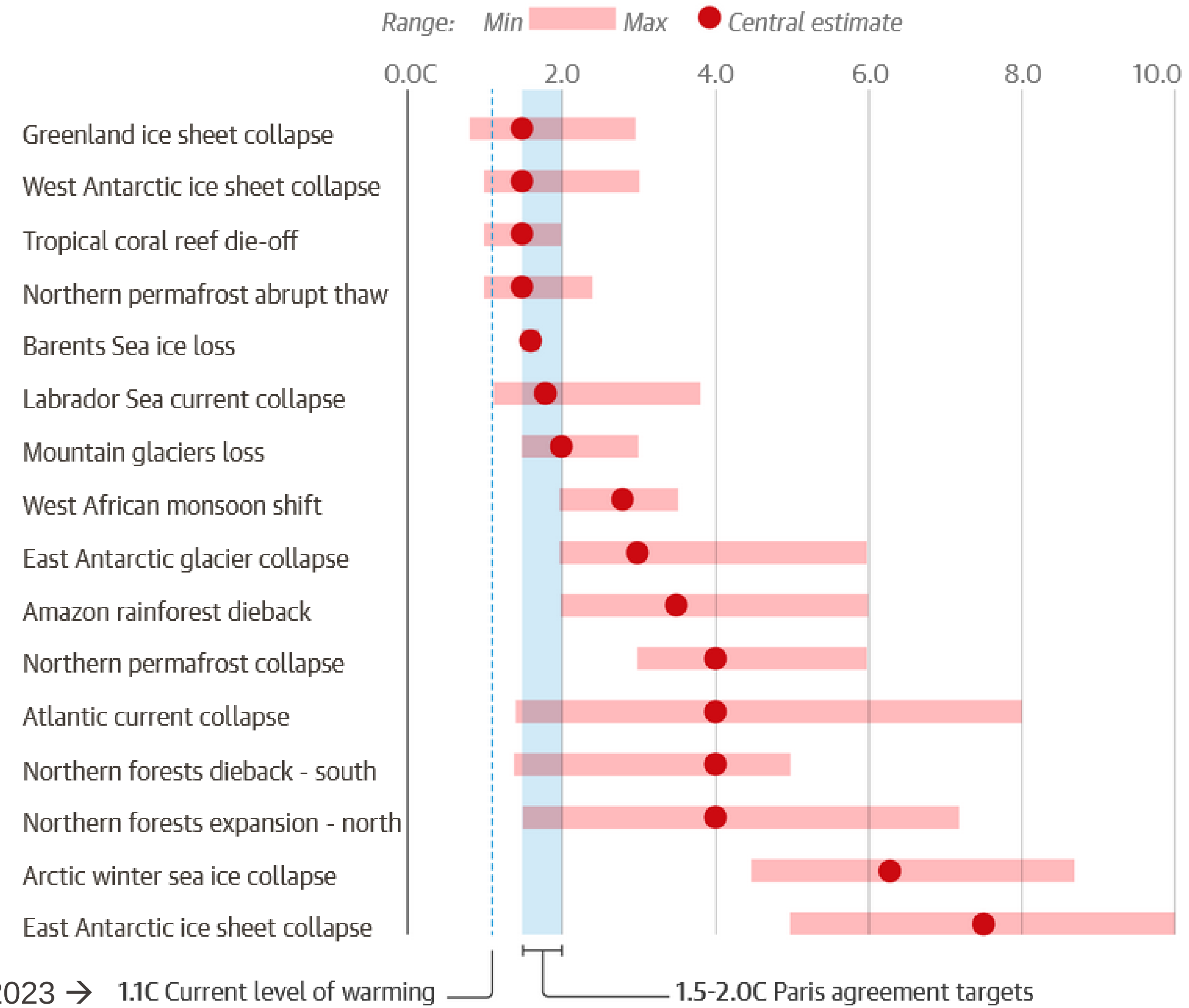


Fig. 1. Maps showing the global core (**A**) and regional impact (**B**) climate tipping elements identified in this study.
Blue - cryosphere, green - biosphere, and orange - ocean-atmosphere elements.

What can the Paris Agreement prevent?

Most of the tipping points are related to polar regions. We will treat several of them in the lecture on polar regions.

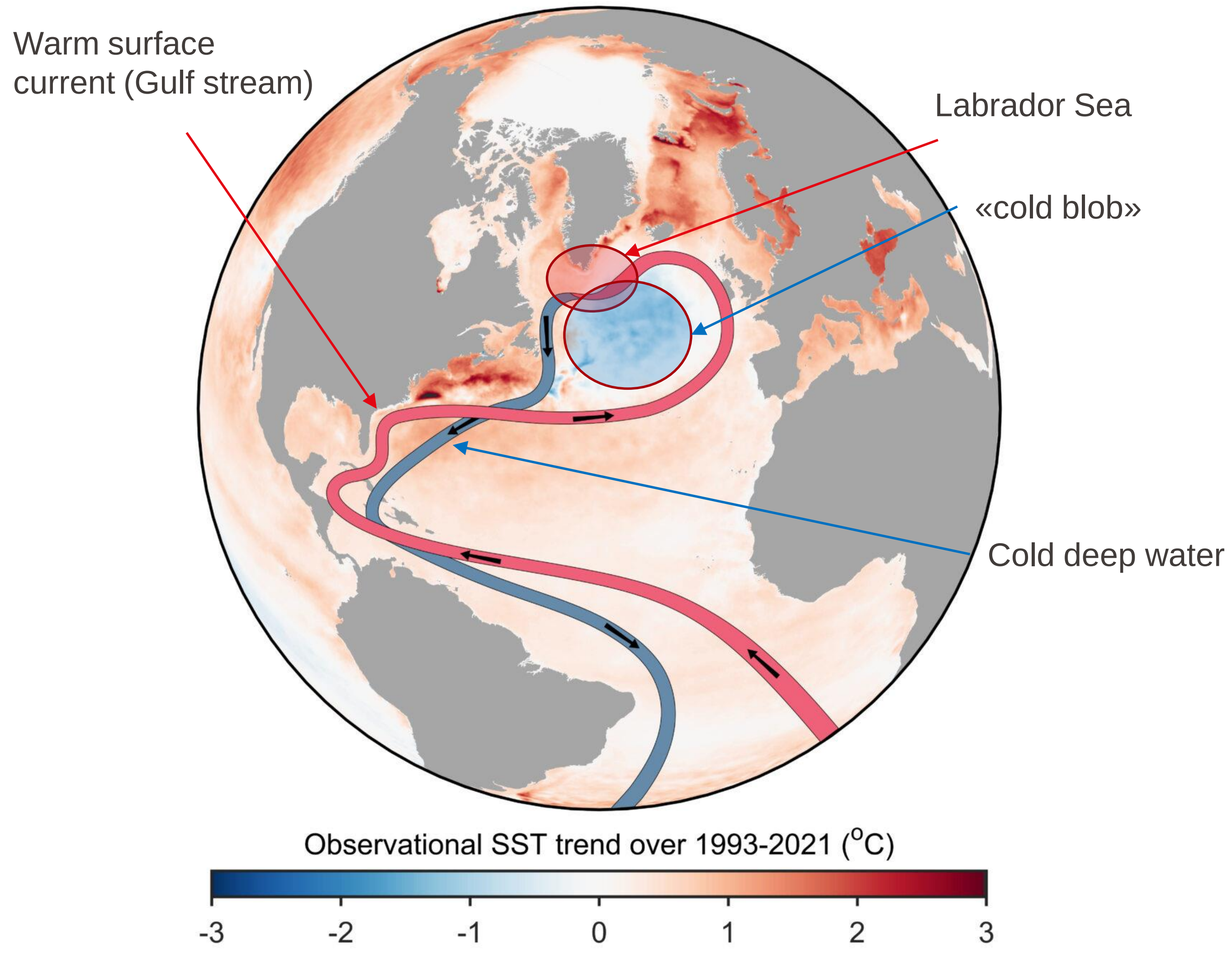


1.2 °C in 2023 →

Guardian graphic. Source: Armstrong McKay et al, Science, 2022. Note: Current global heating temperature rise 1.1C Paris agreement targets 1.5-2.0C

Labrador sea current collapse?

Also called: Atlantic Meridional Overturning Circulation



- How it works:
  - Warm and salty water moves northward, where it cools down and sinks.
  - With sea ice melt and strong precipitation the water becomes less salty and cooler, so it becomes lighter and will not sink.

- Consequence:
  the circulation grinds to a hold

- https://www.realclimate.org

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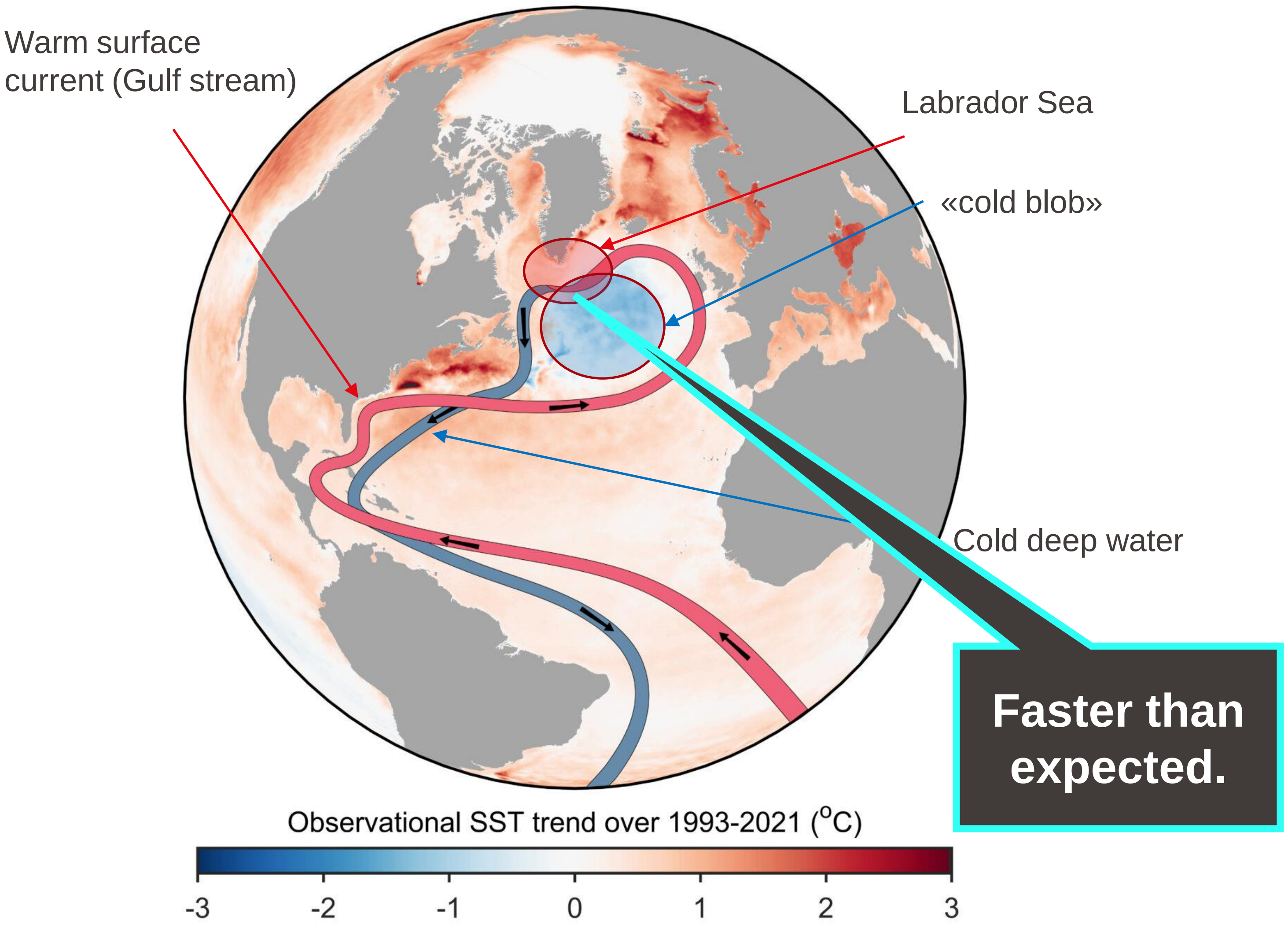
Labrador sea current collapse?

Also called: Atlantic Meridional Overturning Circulation



- The circulation is now weaker than any time in the past millennium. The weakening is anthropogenic.
- Current debate on when the tipping point is reached:
  - IPCC: collapse in 21st century is very unlikely (they neglect meltwater off Greenland ice sheet)
  - Several new studies point towards the tipping point being reached within the 21st century, even by 2050
- Importance for climate:
  - Europe: cooling, less precipitation, extreme events → **detrimental to agriculture**

- https://www.realclimate.org

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Positive Tipping Points

- D.1.1. We are now so close to Earth system tipping points that positive tipping points to accelerate **social change are the only realistic systemic risk governance option**.
- D.1.2. Positive tipping points don't just happen, **they need to be actively enabled**. Most positive tipping points require interventions – technological innovation, political and social action, behaviour/norm change, and financial investment – **that create the enabling conditions and alter the balance of feedback for tipping to occur**.
- D.3.1. The **power sector** in many countries recently passed a tipping point of cost parity for renewable power generation. Declining prices of renewable electricity below cost parity with fossil-fuelled power generation further reinforce exponential growth. Over 80% of new electricity generation in 2022 was solar and wind.
- D 3.2. Affordable renewable electricity supply is **driving tipping points across systems and technologies** such as EVs and heat pumps.

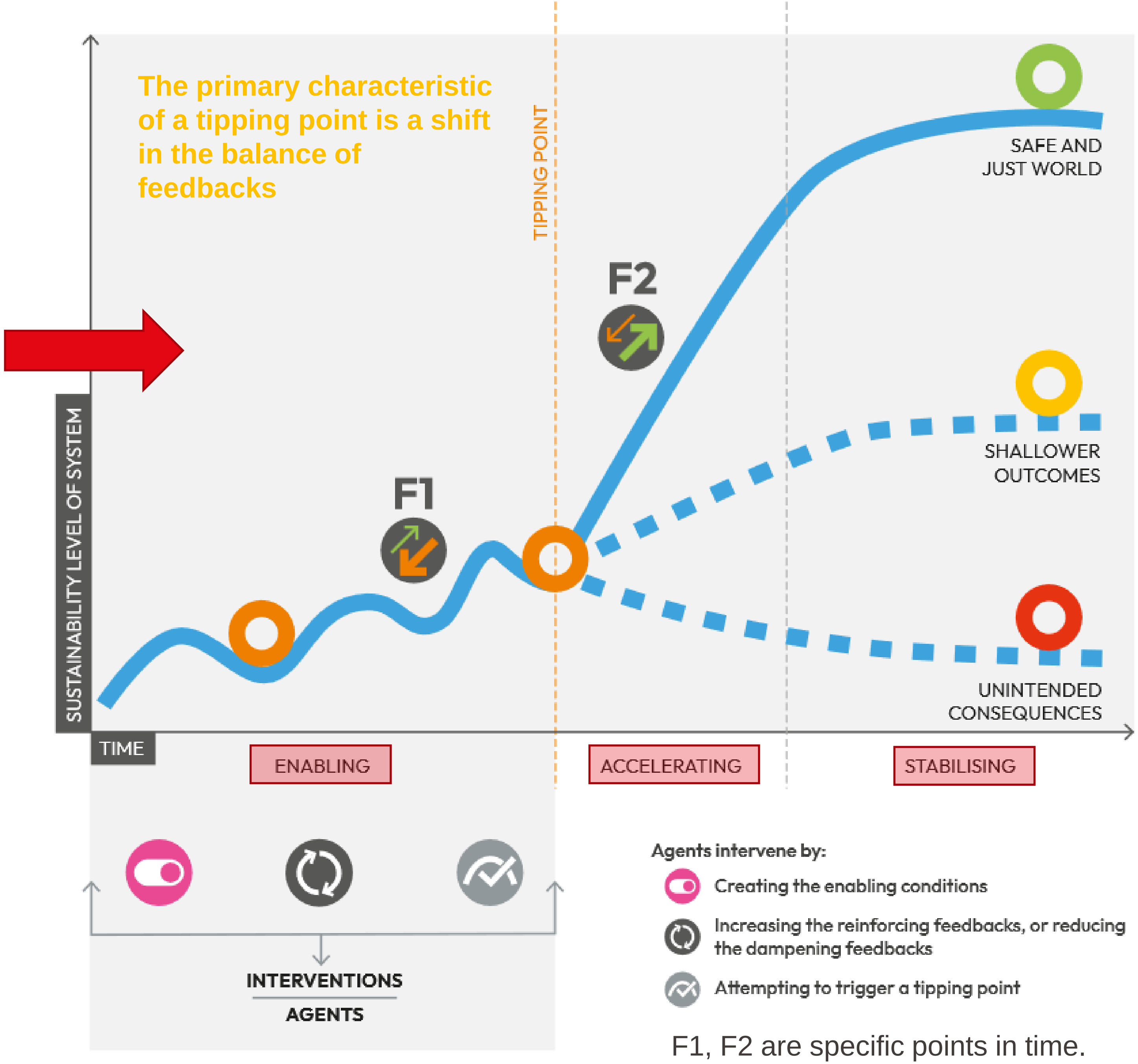
https://report-2023.global-tipping-points.org/summary-report/narrative-summary/

Concept of positive tipping points

Enabling phase:

1) Creating the enabling conditions;
2) Increasing the amplifying feedbacks that increase instability/decreasing the dampening feedbacks that maintain stability;
3) Attempting to trigger the positive tipping point.

Point F1: prior to the tipping point, dampening feedbacks are dominant and system stability is maintained;
Point F2: beyond the tipping point, amplifying feedbacks are temporarily dominant and change accelerates exponentially.

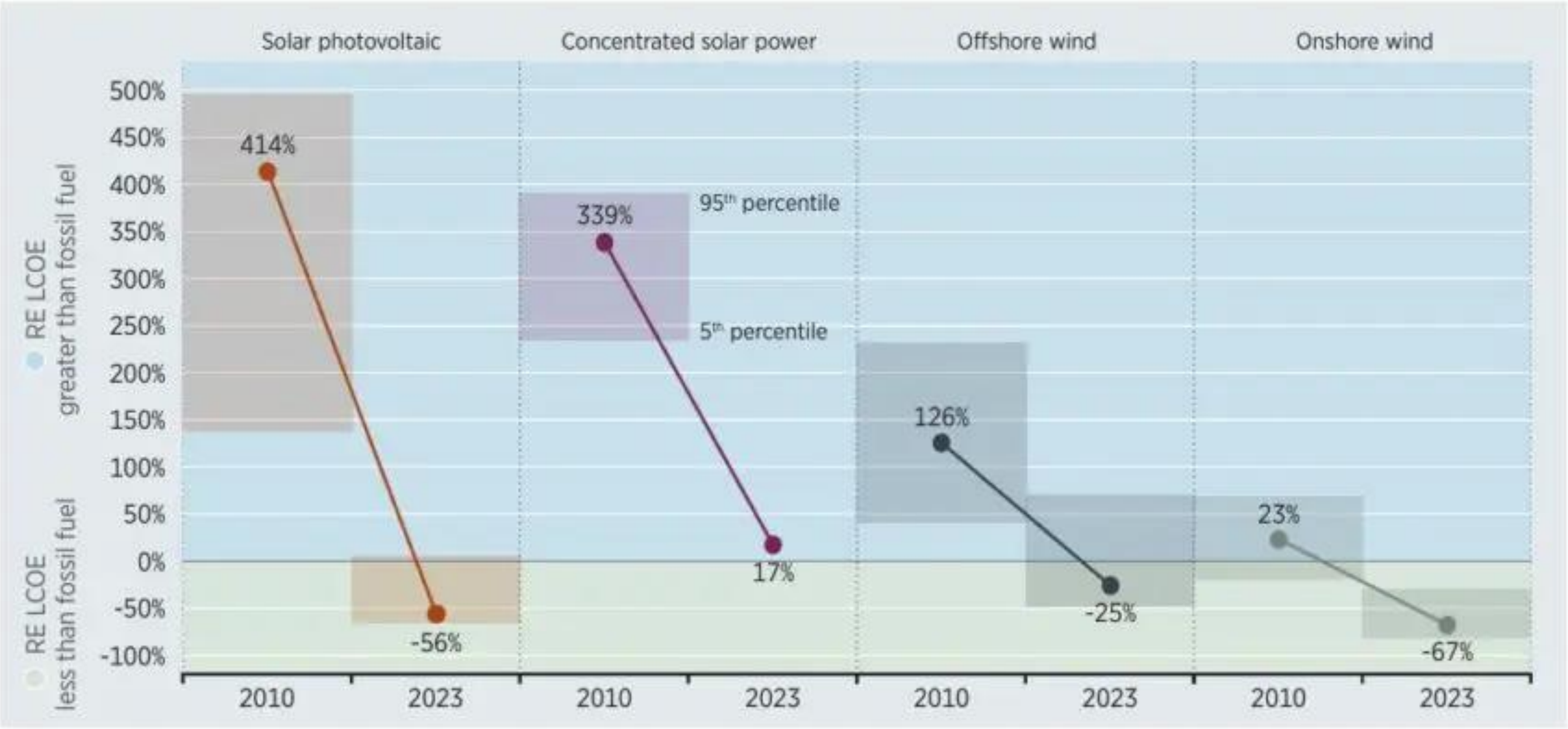


F1, F2 are specific points in time.

https://report-2023.global-tipping-points.org/summary-report/narrative-summary/

Example of positive tipping point

Figure S1 Change in global weighted average LCOE for solar and wind compared to fossil fuels, 2010-2023



Note: RE = renewable energy.

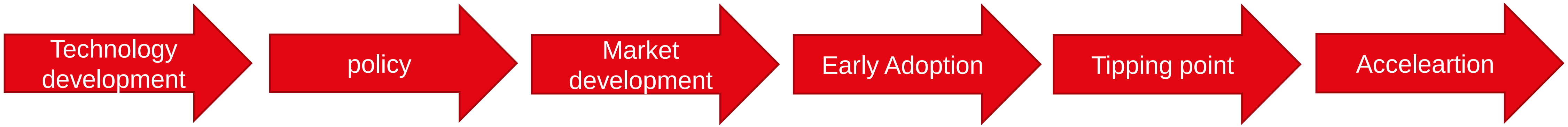
D.3.1. The power sector in many countries recently passed a tipping point of cost parity for renewable power generation. Declining prices of renewable electricity below cost parity with fossil-fuelled power generation further reinforce exponential growth. Over 80% of new electricity generation in 2022 was solar and wind. https://report-2023.global-tipping-points.org/summary-report/narrative-summary/

- https://reneweconomy.com.au/solar-and-wind-less-than-half-the-cost-of-fossil-fuels-as-price-falls-continue/

levelized cost of electricity (LCoE)

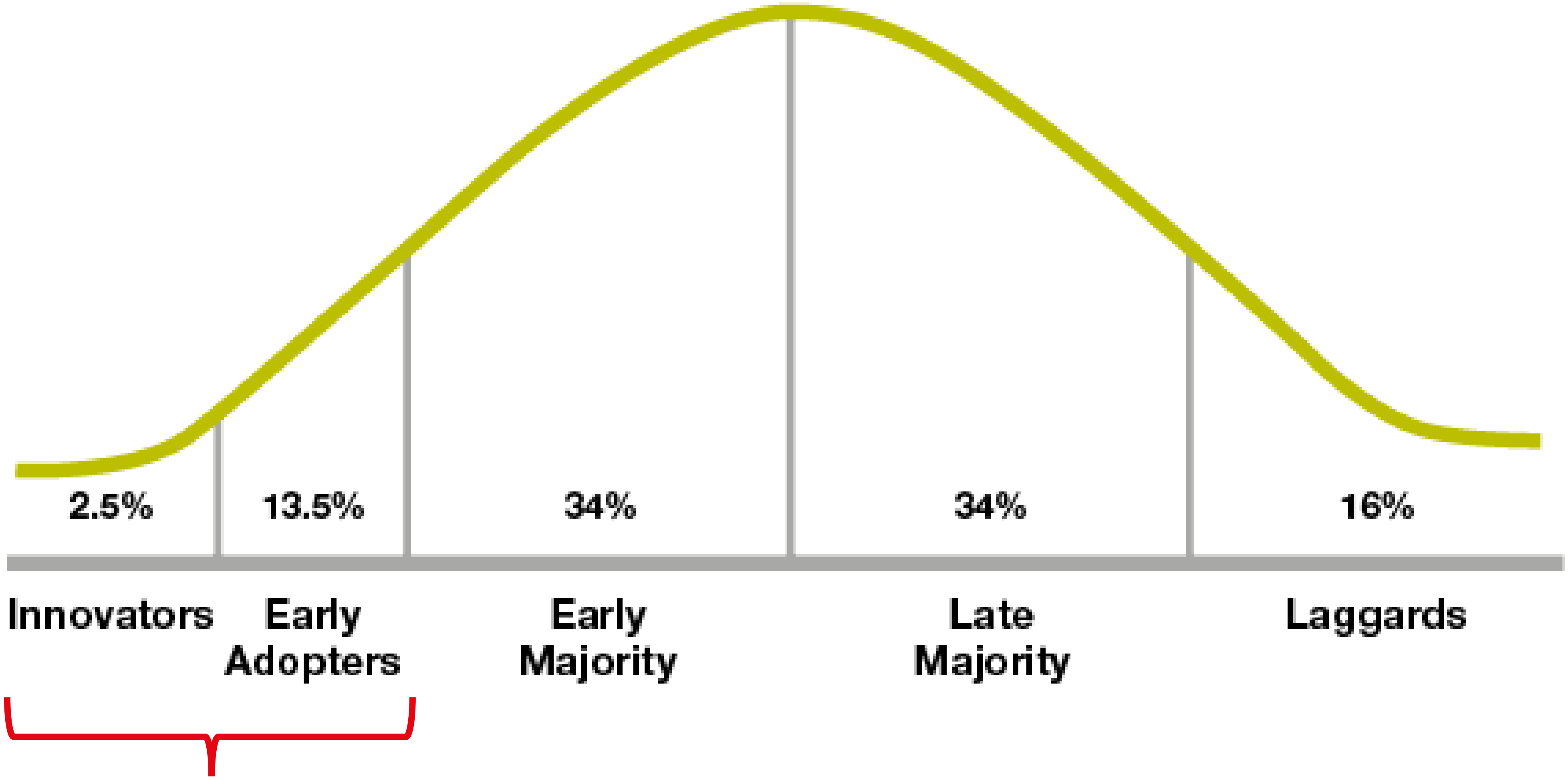
Social tipping dynamics

- **Can the fast growth in renewable energy technologies trigger social tipping dynamics that potentially accelerate a system-wide energy transition?**
- The tipping dynamics in wind and solar power create potential for cascading effects to energy demand sectors, including household energy demand.
  - These most likely start with **shift actions and adoption of household-scale batteries and heat pumps**.
  - **Key enablers** are strong regulations incentivising reductions in demand and setting minimum efficiency levels for buildings and appliances.
  - While there is **evidence of spillovers** to more environmentally friendly behaviour, the extent of these and the key leverage points to bring them about present a **knowledge gap**.
  - These behavioural feedback loops **require strong additional policy support** to “make them stick”.
  - Understanding the economic and social tipping dynamics in a system can empower decision-makers, fostering realistic energy transition policies.



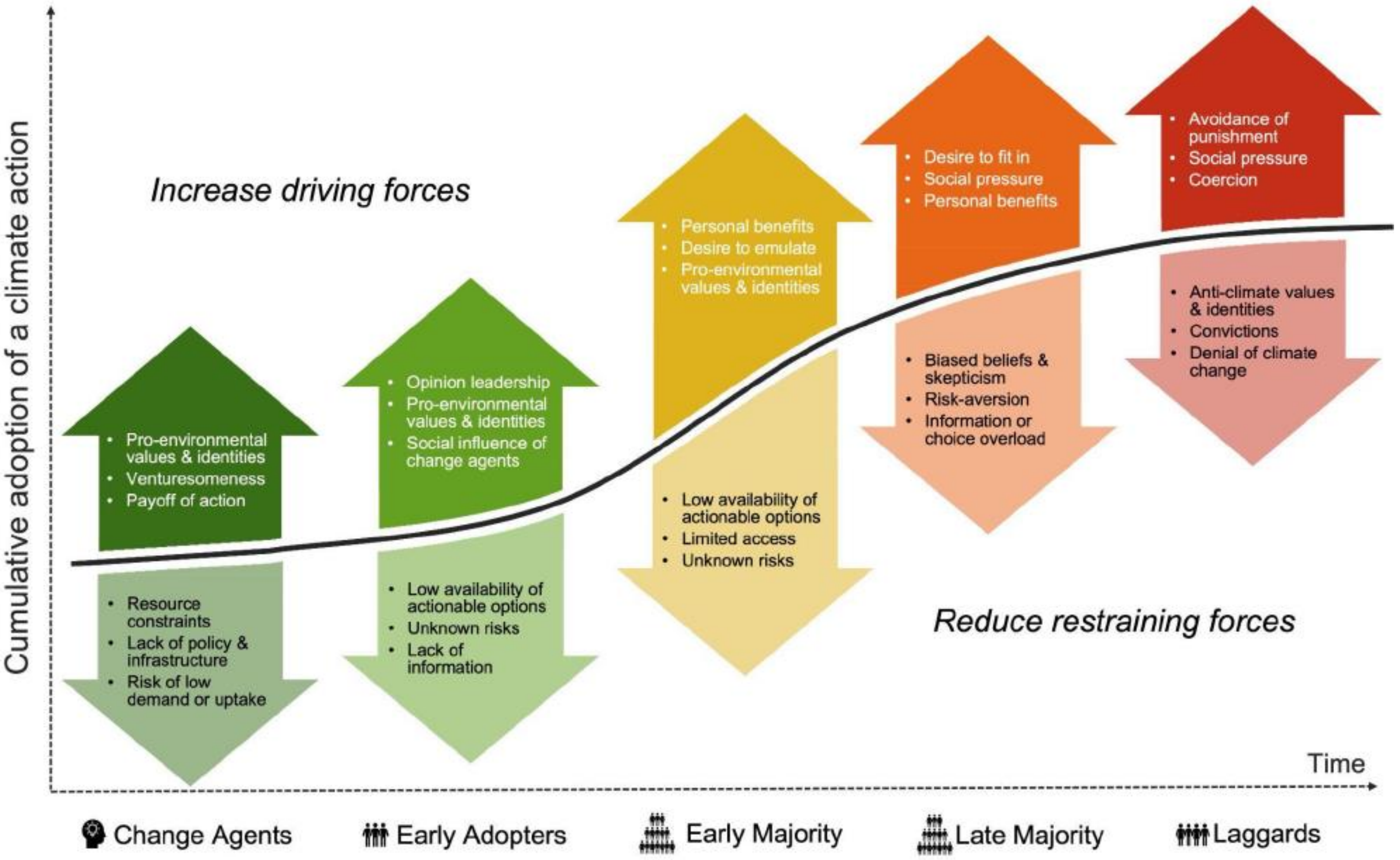
- https://esd.copernicus.org/articles/15/485/2024/

5 stages of change adoption



Need 16% to launch change

5 Stages of Climate change mitigation action adoption



- https://sdg-action.org/getting-everyone-to-act-on-climate-change/

Remaining carbon budget

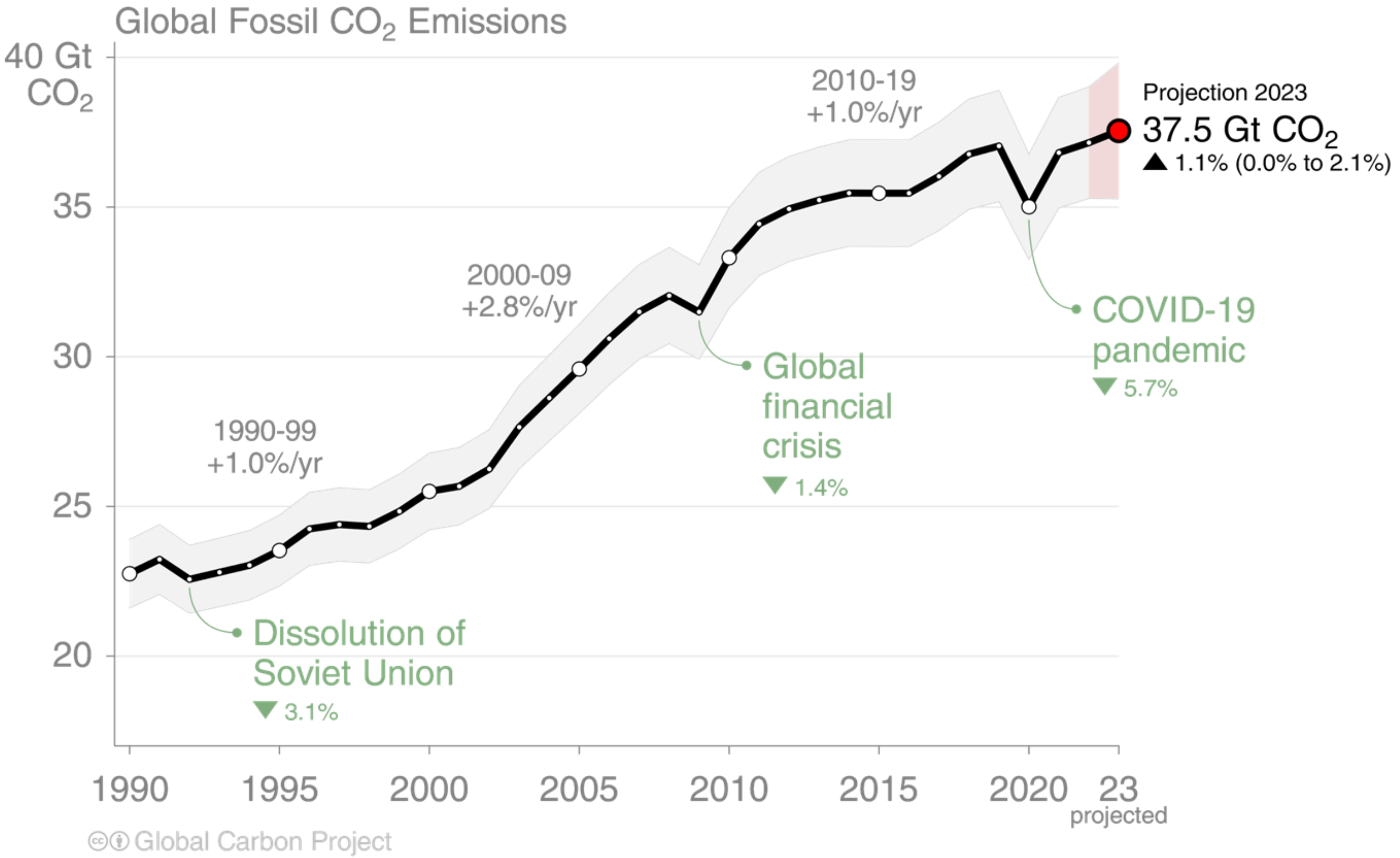
GLOBAL CARBON PROJECT

Global Fossil CO_2 Emissions

Global fossil CO_2 emissions: 37.1 ± 2 $GtCO_2$ in 2022, 63% over 1990

Projection for 2023: 37.5 ± 2 $GtCO_2$, 1.1% [0.0% to +2.1%] higher than 2022

Covid was a tiny dent.



Uncertainty is ±5% for one standard deviation (IPCC "likely" range)

When including cement carbonation, the 2022 and 2023 estimates amount to 36.4 ± 2 $GtCO_2$ and 36.8 ± 2 $GtCO_2$ respectively

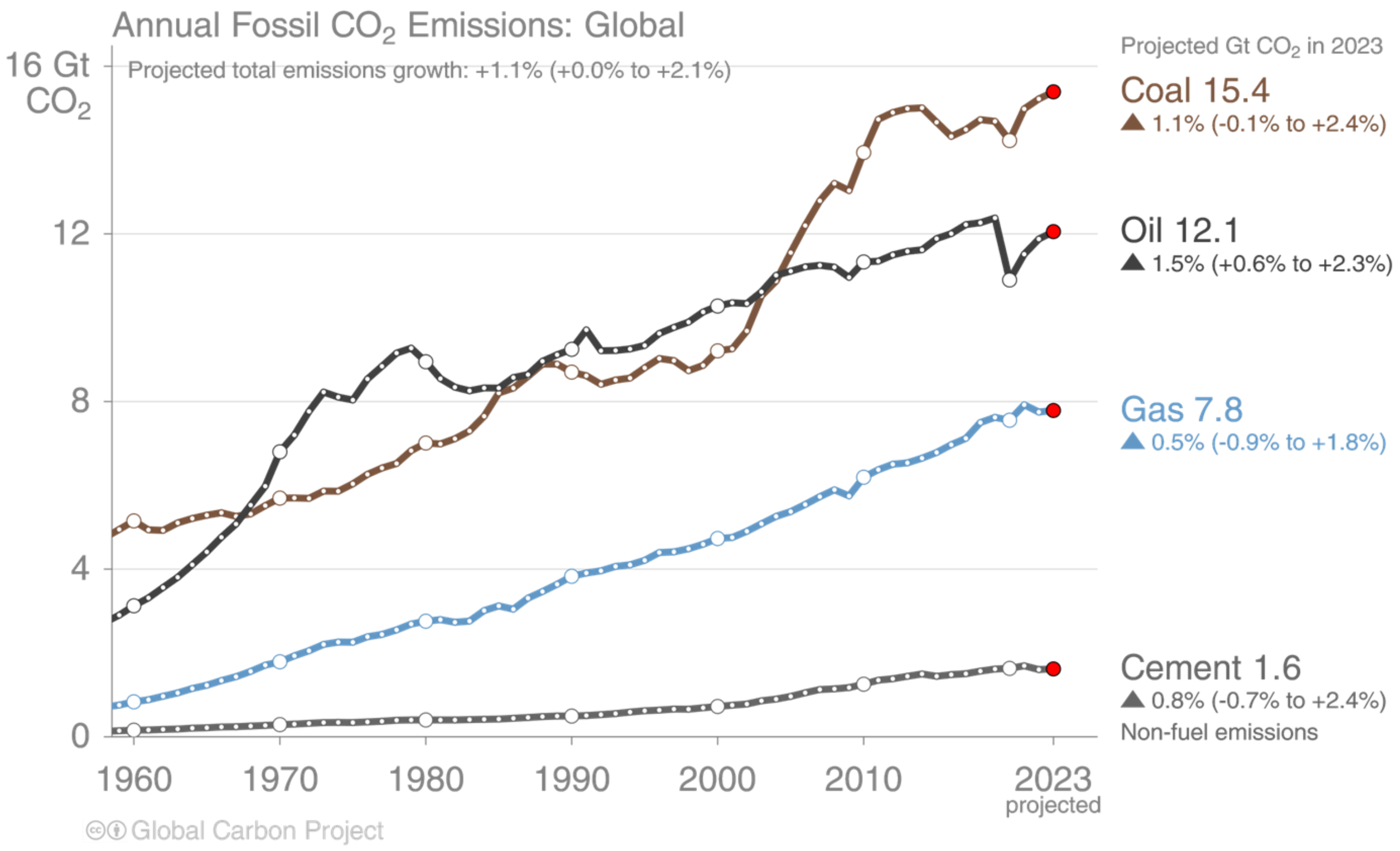
The 2023 projection is based on preliminary data and modelling.

Source: Friedlingstein et al 2023; Global Carbon Project 2023

Fossil CO_2 emissions by source

Share of global fossil CO_2 emissions in 2023: coal (41%), oil (32%), gas (21%), cement (4%), flaring and others (2%, not shown)

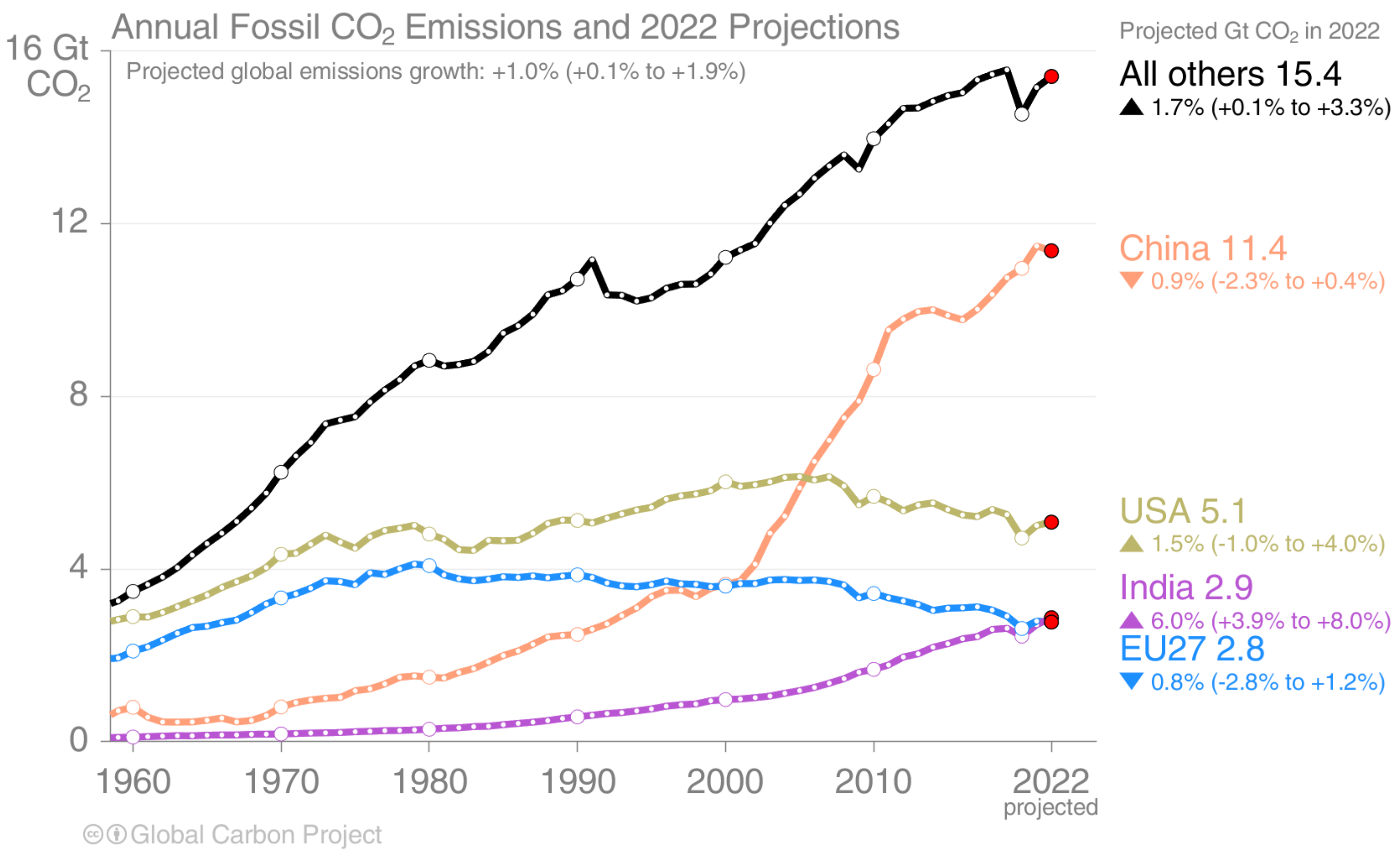
Fossil fuel emissions on the rise, still.



The 2023 projection is based on preliminary data and modelling.
Source: Friedlingstein et al 2023; Global Carbon Project 2023

Emissions per region

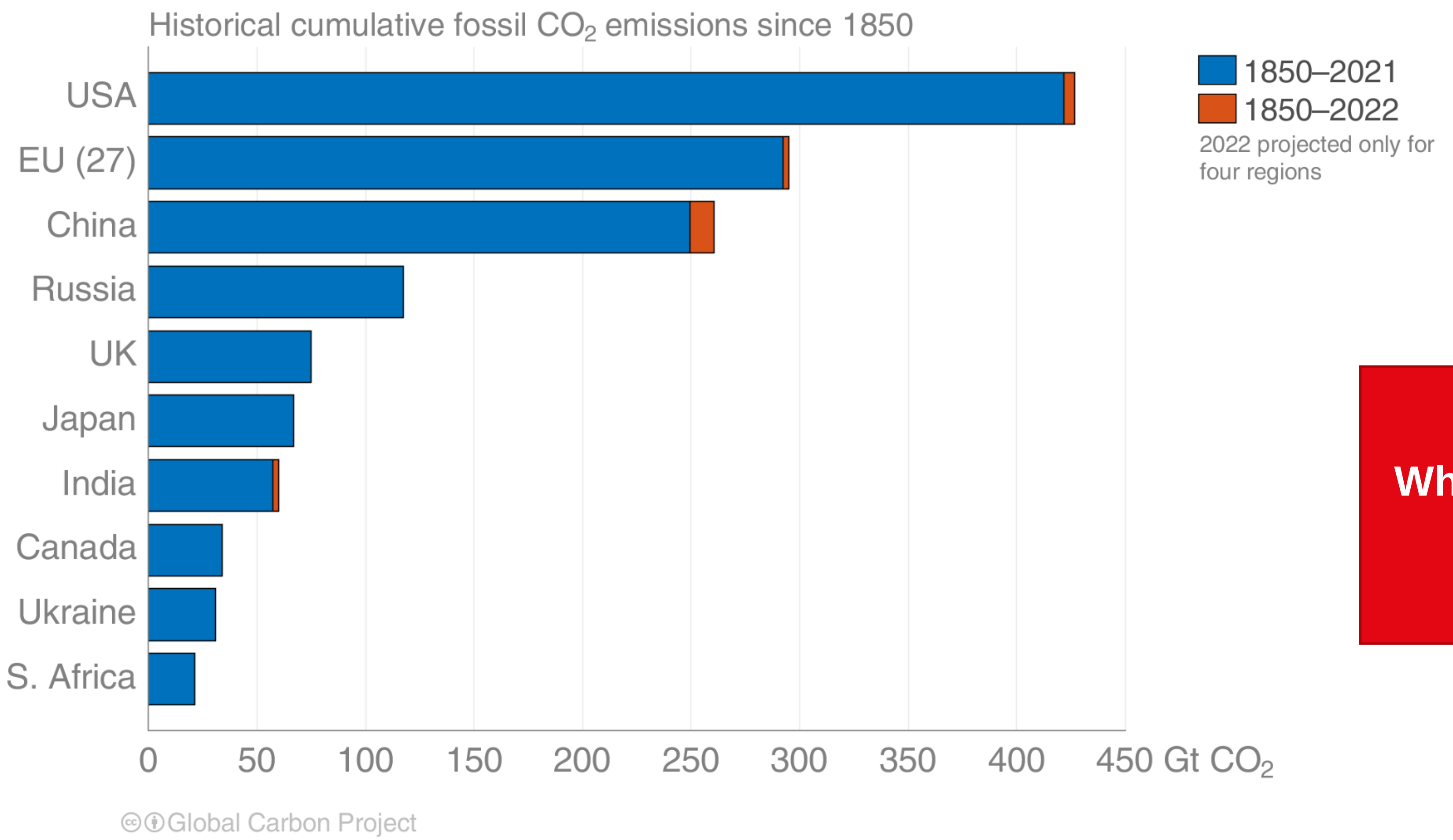
Global fossil CO_2 emissions are projected to increase by 1.0% [0.1% to 1.9%] in 2022



The 2022 projections are based on preliminary data and modelling.
Source: Friedlingstein et al 2022; Global Carbon Project 2022

Historical cumulative fossil CO_2 emissions

The USA and EU have the highest accumulated fossil CO_2 emissions since 1850, but China is not far behind.



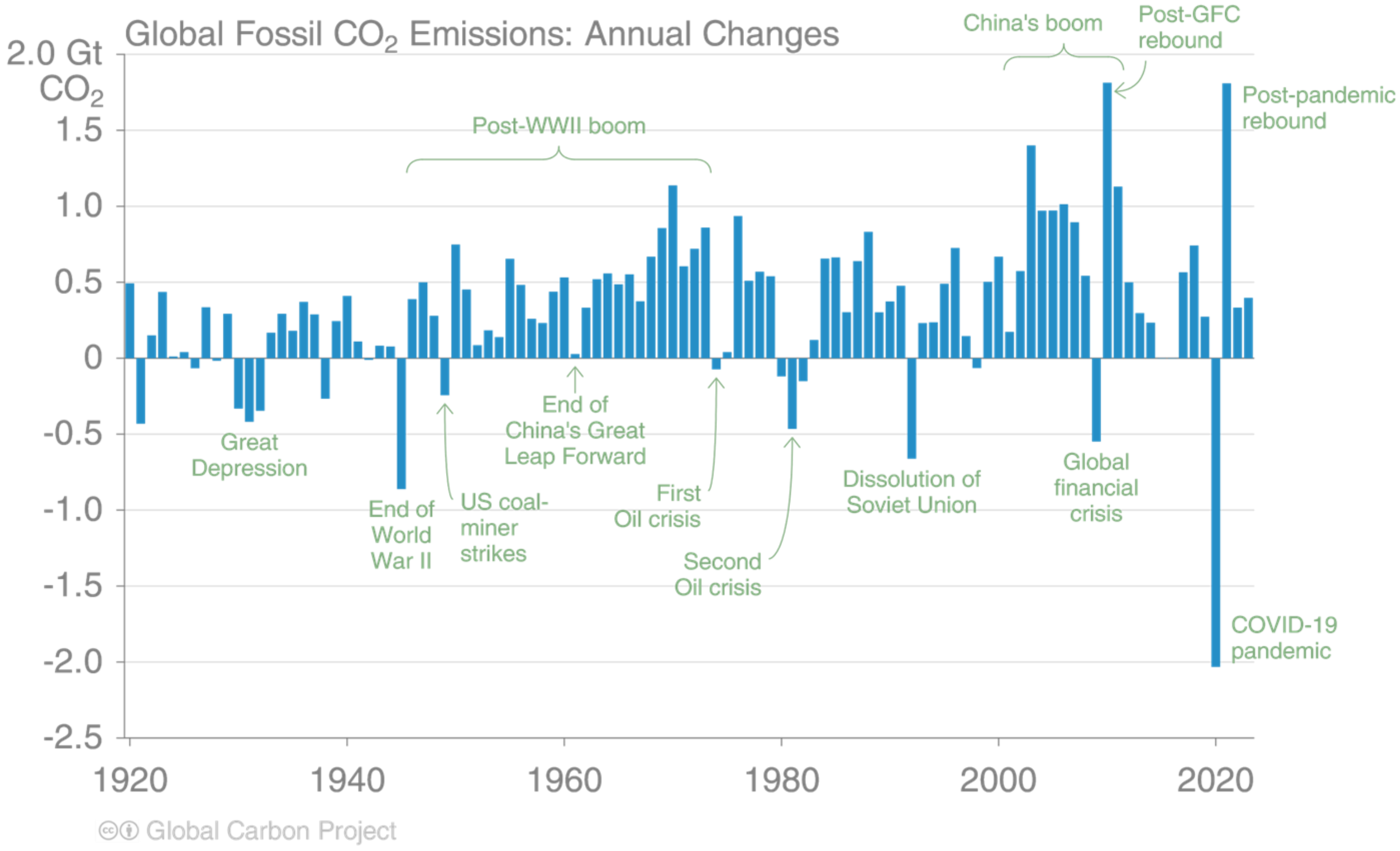
Who needs to act?

Calculated using territorial emissions.
Source: Friedlingstein et al 2022; Global Carbon Project 2022

Global fossil CO_2 emissions

For the last 100 years, it has generally taken a crisis to drive global emissions reductions.
To stabilise temperatures, intentional, planned, sustained global reductions must begin.

Humanity always needed a crisis to reduce emissions.



The 2023 projection is based on preliminary data and modelling.
Source: Friedlingstein et al 2023; Global Carbon Project 2023

9 April 2024

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Swiss climate verdict: carbon budgets mattered to the judges

- On April 9, Europe’s top human rights court ruled in favour of a group of elderly Swiss women, the KlimaSeniorinnen, who said the government’s inadequate efforts to combat climate change put them at risk of dying during heatwaves.
- The European Court of Human Rights (ECHR) recently ruled that Switzerland had failed to meet its own climate targets and to set a national **carbon budget**.
- Ruling: Switzerland “**failed to quantify, through a carbon budget or otherwise, national greenhouse gas emissions limitations**”
- **Implication of a carbon budget**: There is a hard limit and emissions need to stay within it.

https://www.swissinfo.ch/eng/science/swiss-climate-verdict-strasbourg-echr-why-carbon-budgets-mattered-to-the-judges/76347450

What is a carbon budget and how do we define it?

- It tells us how much more carbon we can emit until we reach a certain level of warming.
- It is the accounting the helps us get to net-zero, because the rate of emissions is directly linked to the amount of carbon in the atmosphere and corresponding warming.
- It enables us to account for mitigation measures that avoid or sequester carbon emissions.

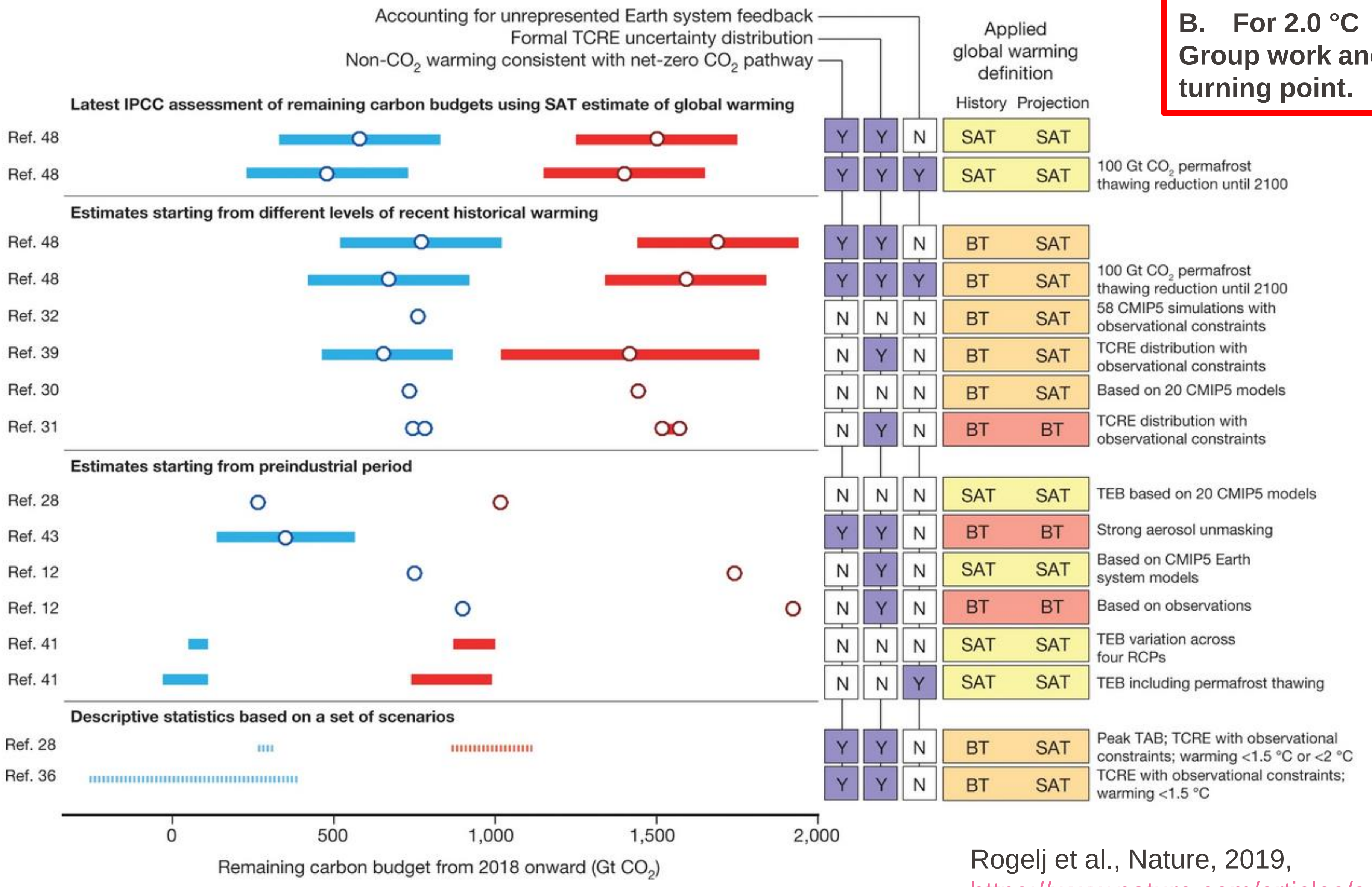
- Which country/company may emit how much more carbon?
  - What is fair?
- And how do we define «carbon»?

How much carbon budget is left?

How much time do we have left if we continue emissions at the rate of the past years?
A. For 1.5 °C
B. For 2.0 °C
Group work and answer on turning point.

1.5°C

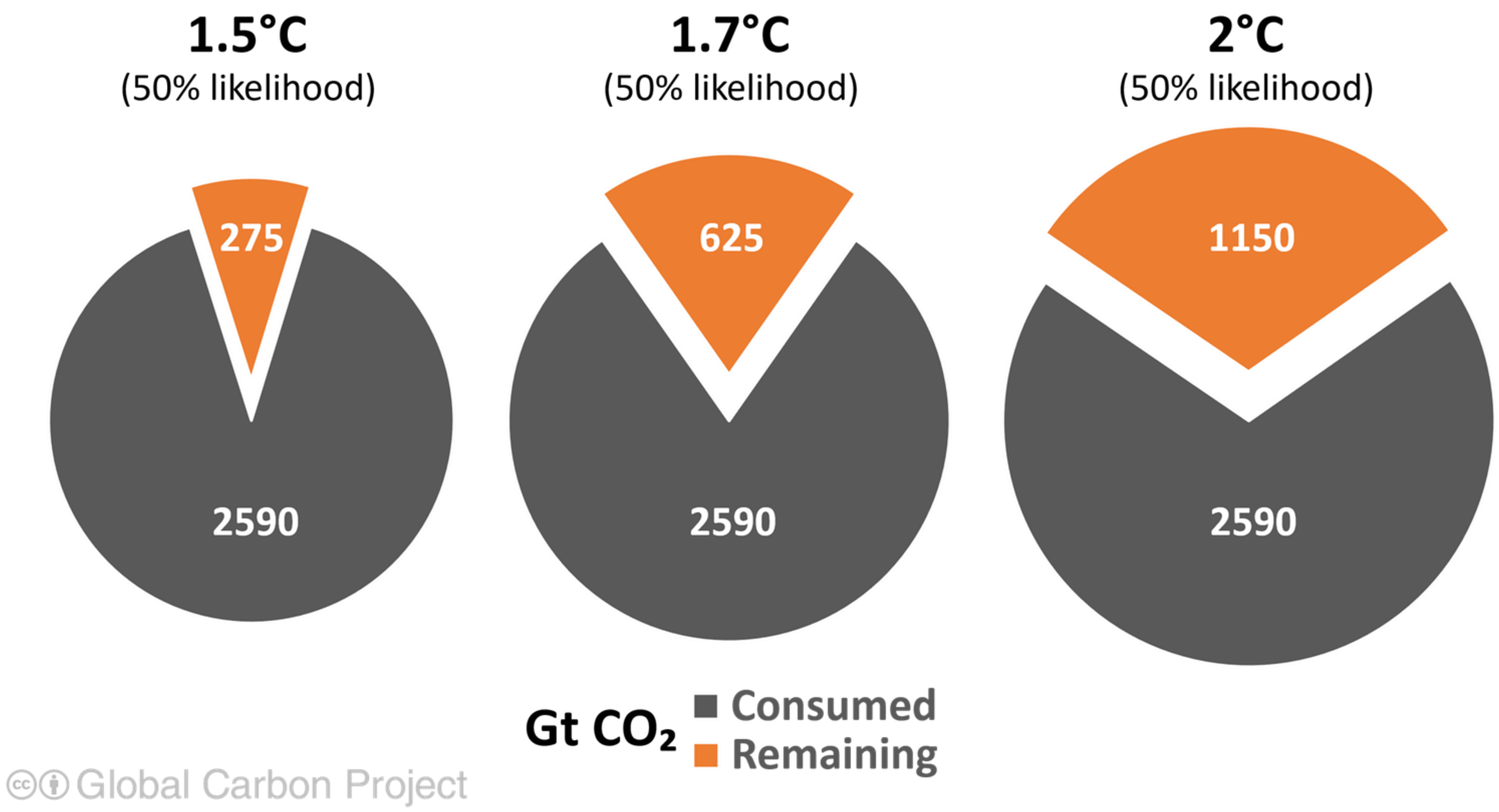
2.0°C



N, no; Y, yes; SAT, global near-surface air temperatures; BT, blended temperatures (surface air temperature over land and sea-ice regions combined with sea surface temperature over open ocean)

Rogelj et al., Nature, 2019, https://www.nature.com/articles/s41586-019-1368-z

Remaining carbon budget

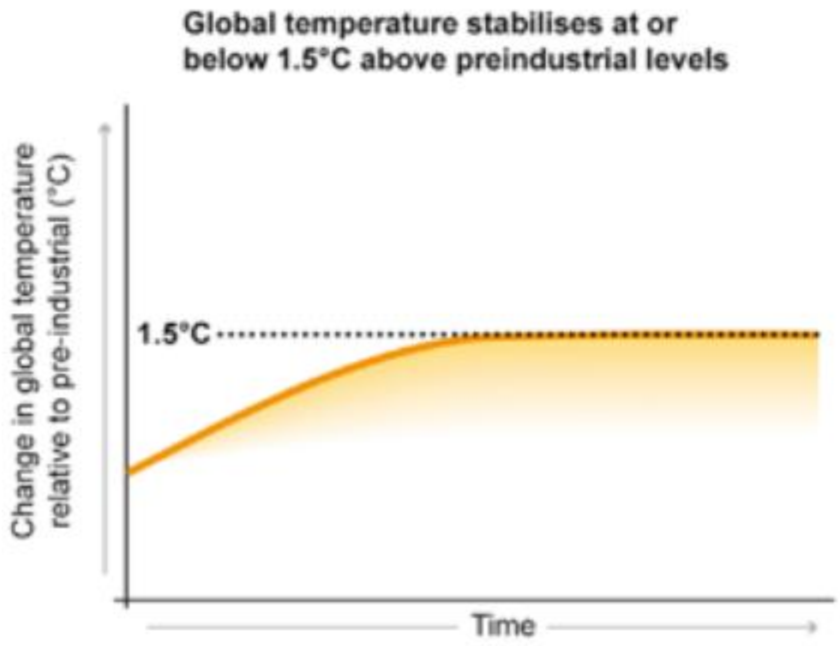


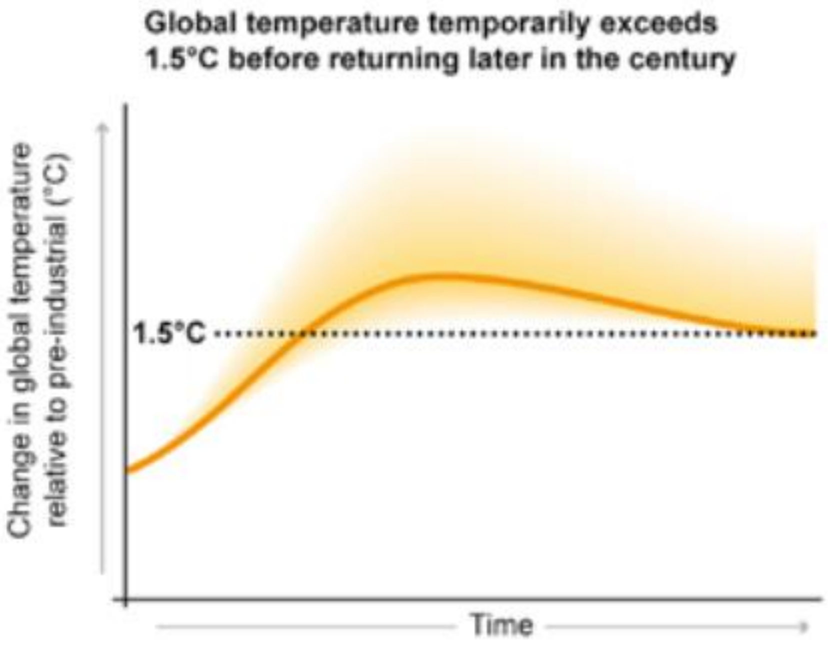
~7 years left

~ 15 years left

~ 28 years left

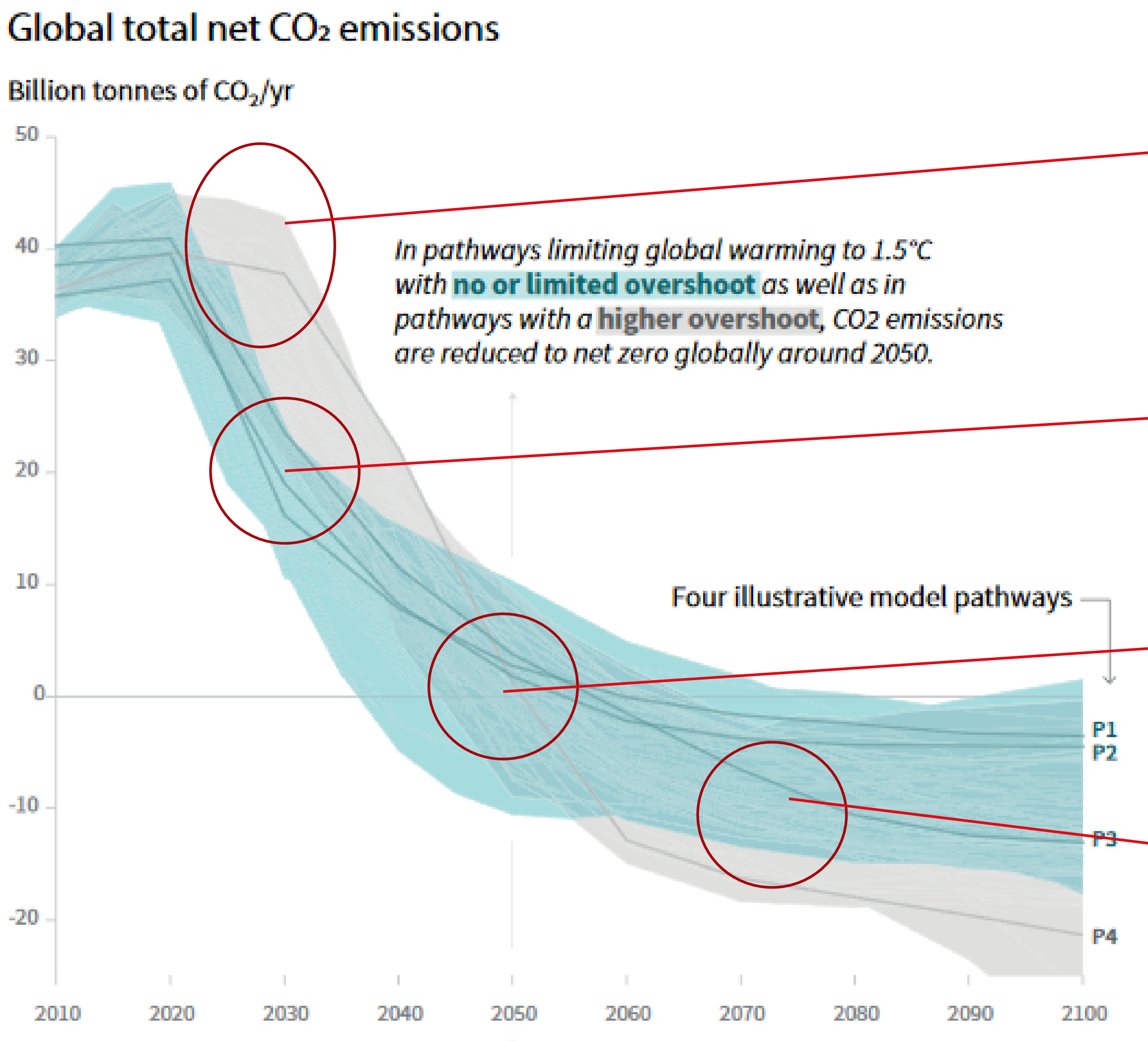
Conceptual pathways to reach the 1.5°C goal





IPCC SR1.5, FAQ2.1

Reducing emissions



«overshoot», followed by steeper reduction

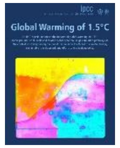
In 2030 only 50 % of emissions compared to 2010
Decisive Decade

Net-zero at the latest in 2040-2050

«negative emissions» about 25 % of present-day emissions!

Reducing methane now vigorously while keeping to reduce CO_2 can help tackle the challenge.

IPCC, SP1.5



Timing of net zero CO_2
Line widths depict the 5-95th percentile and the 25-75th percentile of scenarios

Pathways limiting global warming to 1.5°C with no or limited overshoot
Pathways with higher overshoot
Pathways limiting global warming below 2°C
(Not shown above)