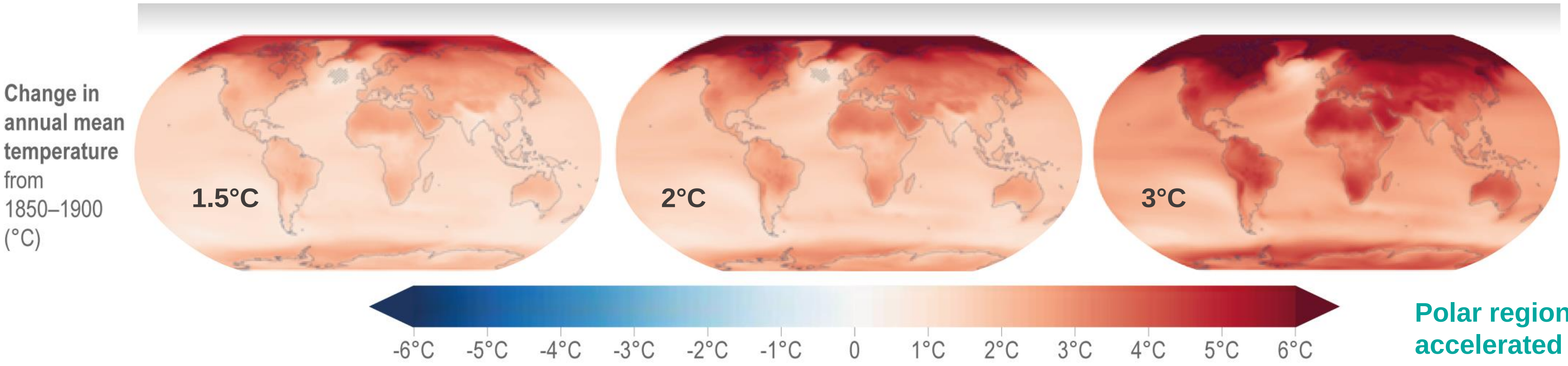
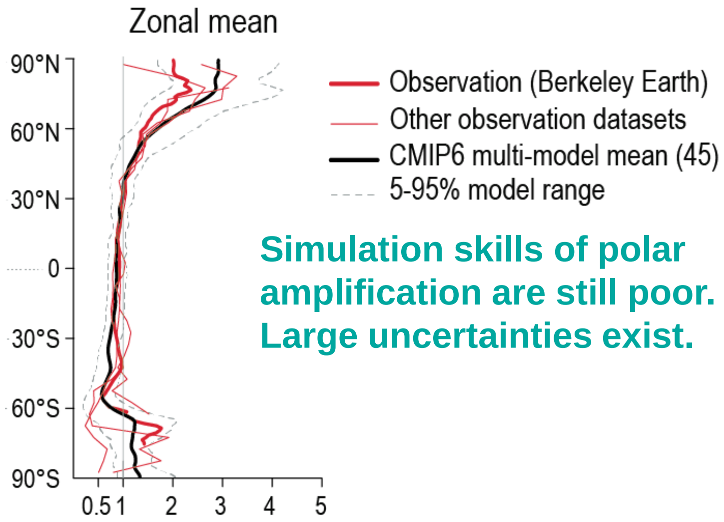
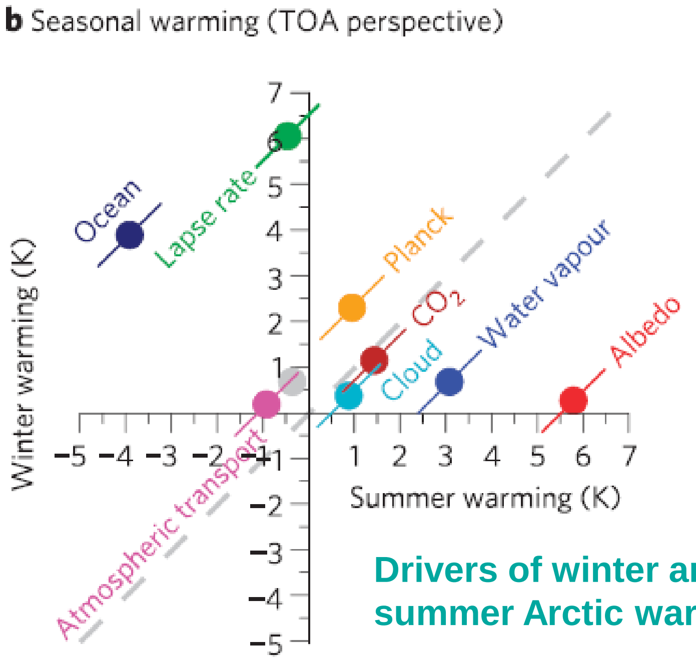
Recap from last lecture



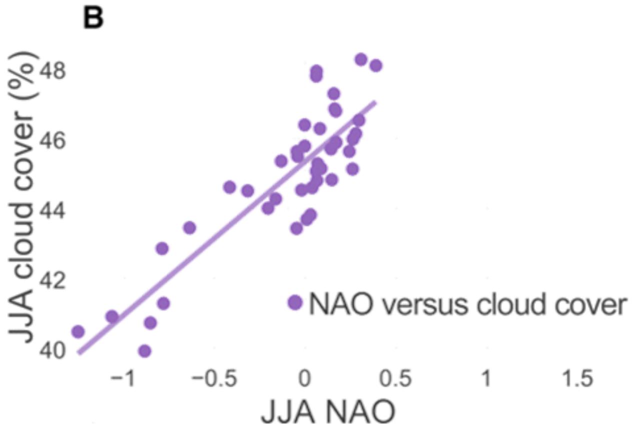
Polar regions experience accelerated warming due to physical feedback mechanisms and air mass transport.



Simulation skills of polar amplification are still poor. Large uncertainties exist.



Drivers of winter and summer Arctic warming.



Modes of climate variability play a role in accelerating or decelerating warming.

Last update on poster conference

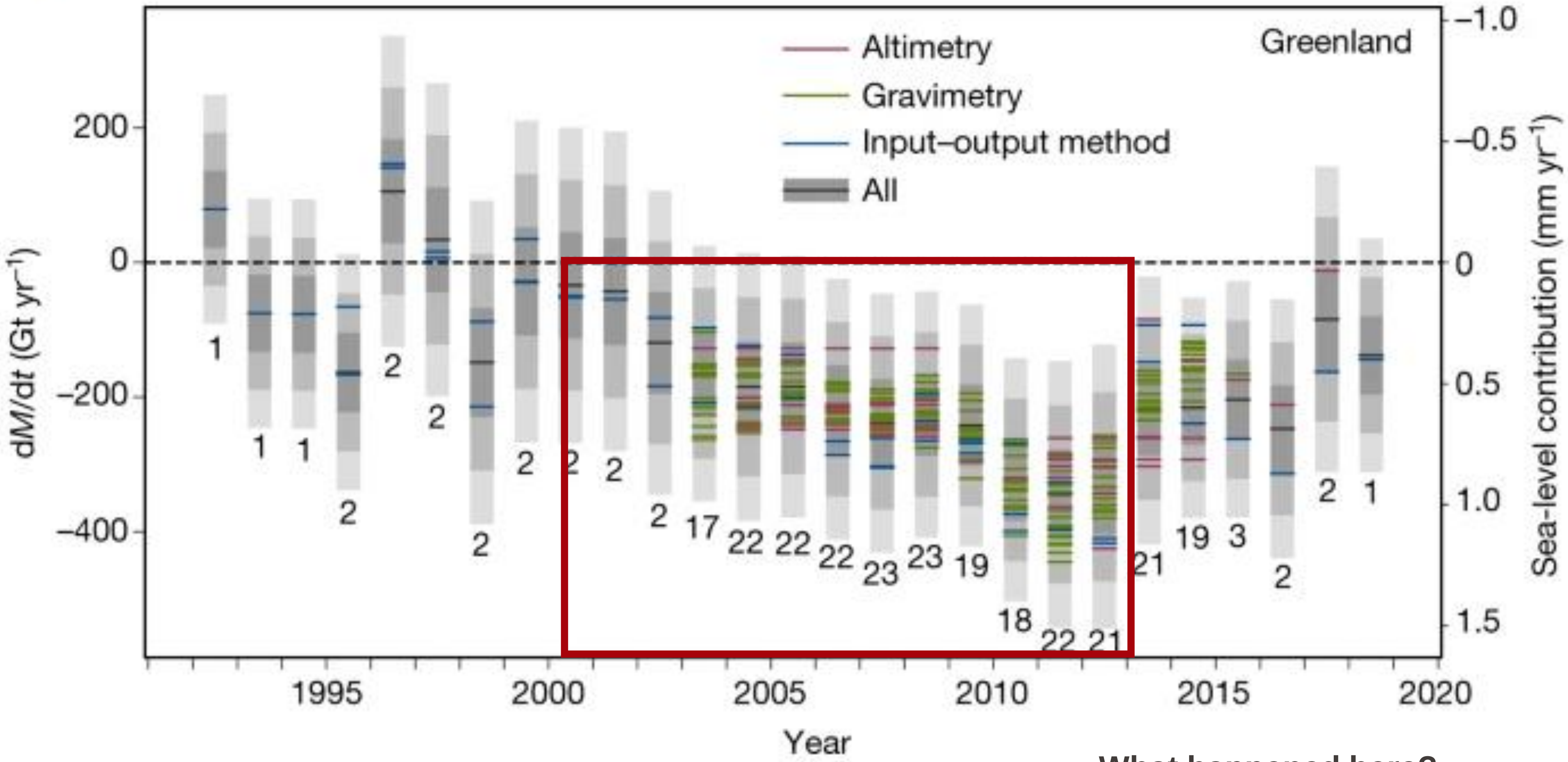
- Please be there 3 pm sharp or even a bit earlier
- Hang up your poster on any board and add the group number (you'll get a printed number)
- Schedule
  - 3 – 3.15 pm put up poster
  - 3.15 – 3.20 Welcome and instructions
  - 3.20 – 3.40 Round 1 (first student presents)
  - 3.45 – 4.05 Round 2 (second student)
  - 4.10 – 4.30 Round 3 (third student)
  - 4.35 – 4.55 Round 4 (forth student or repeat)
  - 5.00 Closing words and surprise
  - 5.15 aperitif

General outline

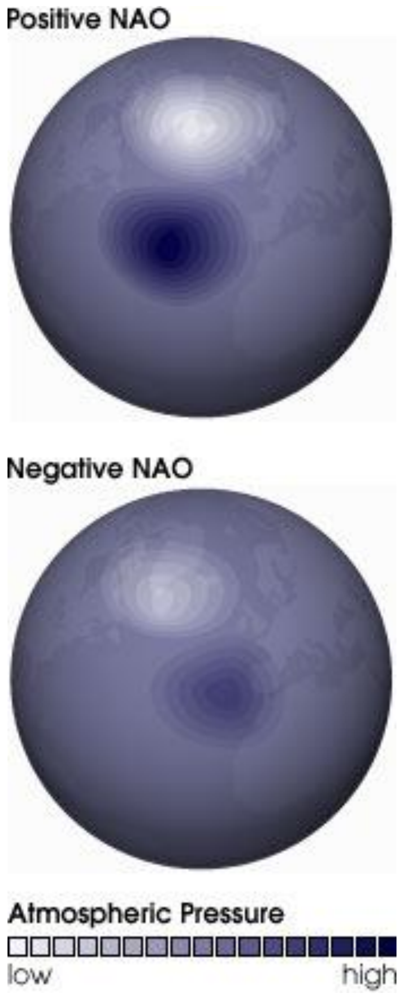
	No.	Date	Topics	Deadlines
Basics	1.	12.09.2024	Introduction	fill in Questionnaire in exercises (not graded)
	2.	19.09.2024	Climate System, Radiation, Greenhouse effect	
	3.	26.09.2024	Earth's energy balance, Radiative transfer,	
	4.	03.10.2024	Aerosols & clouds, Radiative Forcing	Launch of poster assignment
	5.	10.10.2024	Feedback mechanisms, Climate Sensitivity	
	6.	17.10.2024	Emergent Constraints, Paleoclimate	submission of Poster proposal (01.11.2024)
Present and future Climate change	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	submission of Poster draft
	11.	28.11.2024	Metrics, carbon offsets	submission of assignment (graded)
Actions	12.	05.12.2024	**Carbon offsets, Polar 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)

Greenland

Fig. 2: Greenland Ice Sheet mass balance.



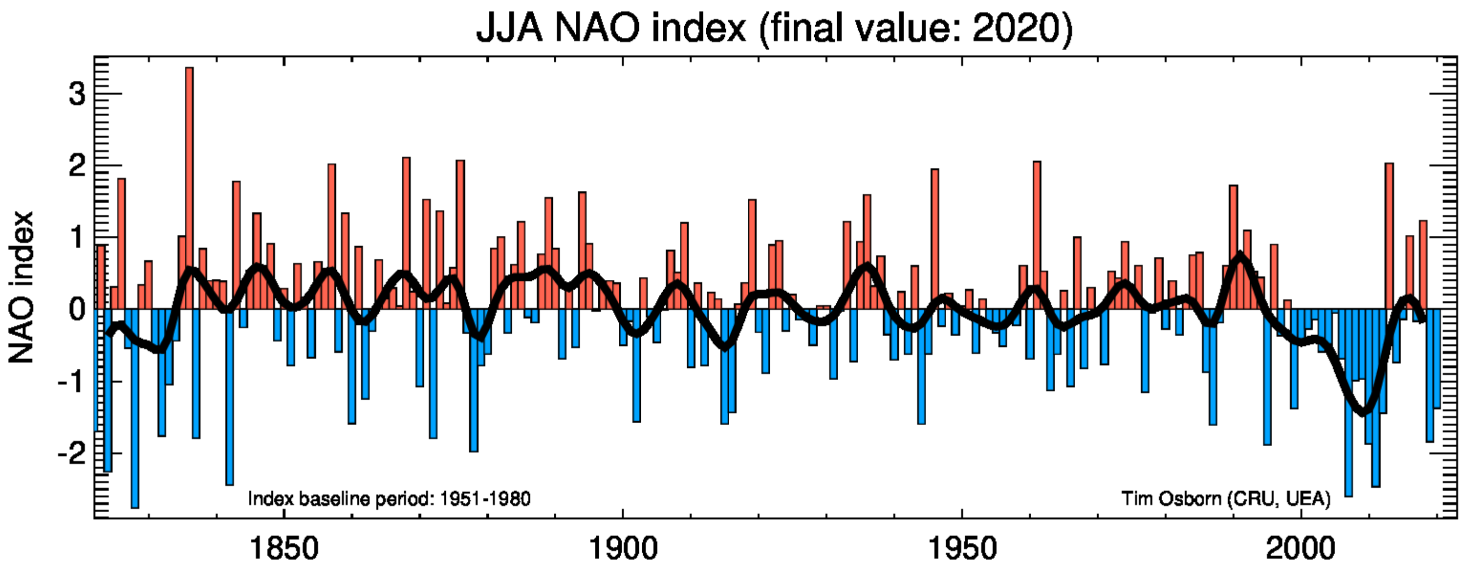
What happened here?



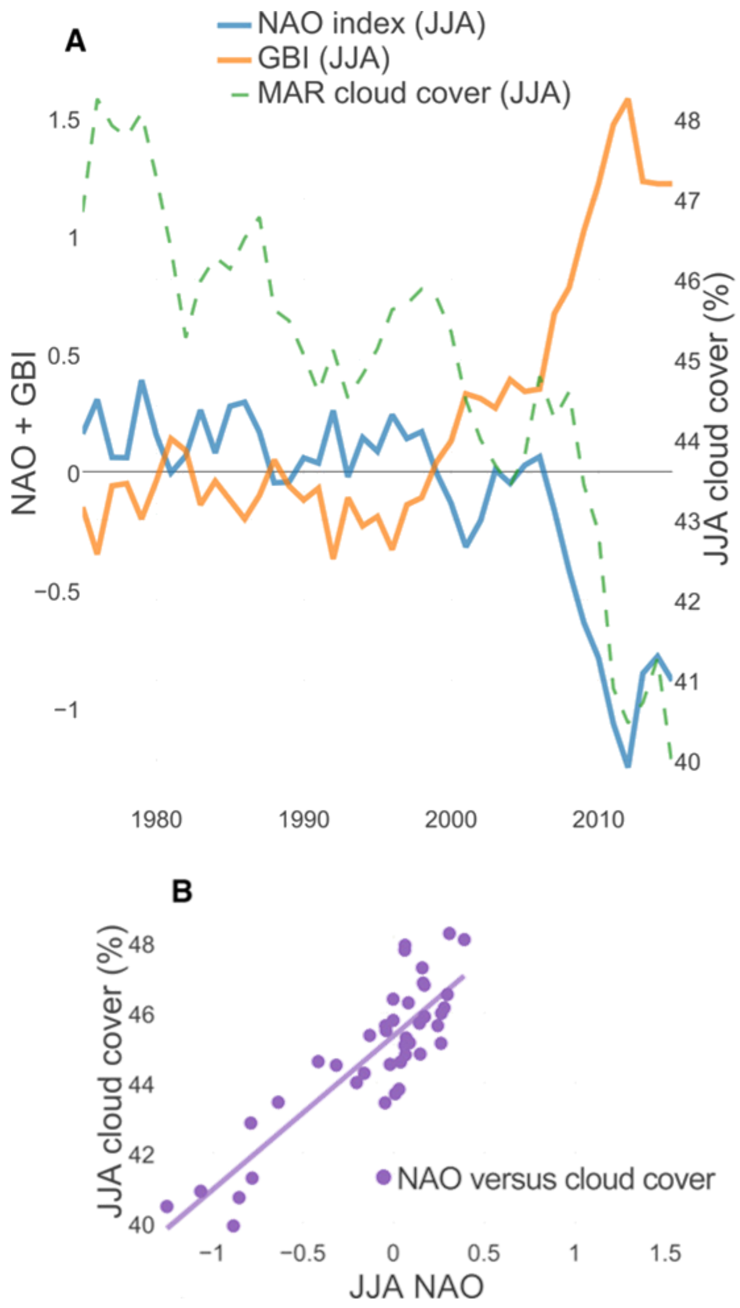
Oscillation between pressures states of the Icelandic Low and Azores High. Their state influences the location and strength of the jet stream.

- IMBIE Team, Nature, 2019, https://www.nature.com/articles/s41586-019-1855-2

Greenland



https://crudata.uea.ac.uk/cru/data/nao/viz.htm



- Hofer et al., Sci. Advances, 2017, https://advances.sciencemag.org/content/3/6/e1700584

NAO: North Atlantic Oscillation
GBI: Greenland Blocking Index

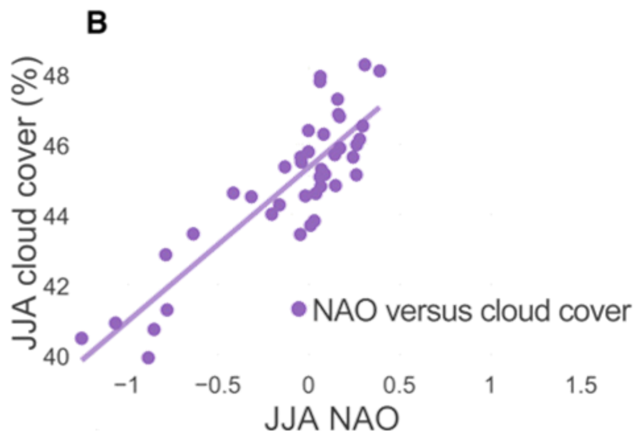
What is the mechanism that has led to more melt?

Responseware.eu; env-410

A. A negative NAO index means more clouds, so more longwave radiation heating.

B. A negative NAO index means less clouds, so there is less precipitation and therefore more melt.

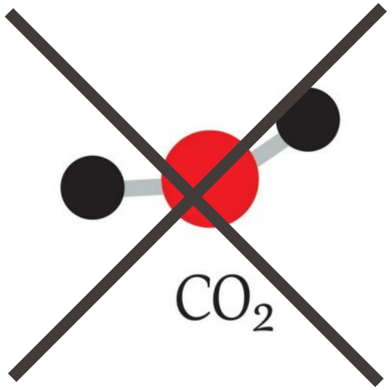
C. A negative NAO index means less clouds and therefore more shortwave radiation on the ice sheet that leads to melting.



Offset strategies and sectors

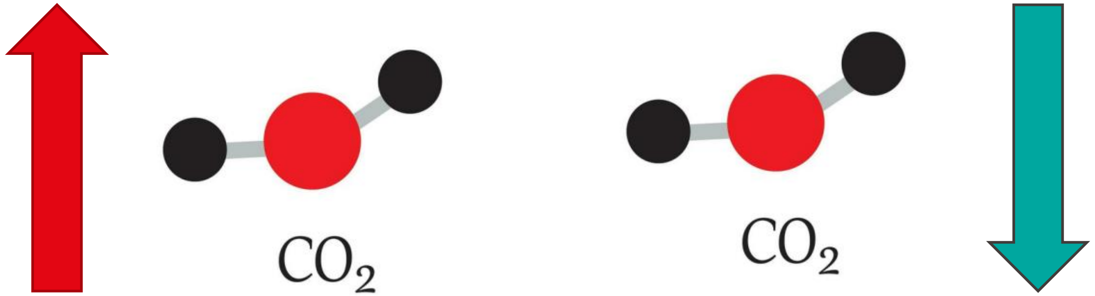
- There are two strategies that work with different sectors.

Avoidance



CO_2 is not released.

Removal



CO_2 is released AND removed.

Because CO_2 is globally distributed, emission and avoidance or removal can happen anywhere across the world.

Avoidance

- These projects **prevent carbon emissions** that would have been released into the atmosphere. It can be divided into 4 categories:
  1. **Renewable Energy**
     e.g., renewable power infrastructures that contribute to the decarbonization of the local energy grid.
  2. **Energy Efficiency and Fuel Switching**
     e.g., energy-saving measures that reduce carbon emissions and replace fossil fuels with sustainable energy sources.
  3. **Household Devices**
     e.g., efficient cookstoves that significantly reduce wood consumption. Or individual biogas digesters that provide sustainable fuel to local communities, prevent deforestation, and avoid GHG emissions.
  4. **Water Management**
     e.g., projects that supply clean water to households in rural communities, remove the need to boil water, and reduce GHG emissions.

Removal

- These projects **reduce carbon emissions** by absorbing them from the atmosphere. It can be divided into 3 categories:

1. **Agriculture**
   e.g., agricultural practices that store carbon in soils while restoring biodiversity and developing new sources of income for smallholders.
2. **Forestry and Land Use**
   e.g., projects that protect and restore existing forest areas threatened by deforestation.
3. **Waste Management**
   e.g., landfill projects designed to capture the methane released by waste disposal, which can turn it into clean fuel.

Isn't it wonderful?

- Strong emitters are regulated in mandatory carbon credit systems.
- The rest of the world can get ahead of time and engage in voluntary carbon reduction.
- We'll be at net-zero in no time!

Too good to be true

- Voluntary carbon offsets have grown into a multi-billion-dollar industry.
- Many companies take advantage of voluntary carbon offsets, and more than a few claim this makes them climate neutral.
- The skyrocketing demand for cheap offsets incentivizes project developers to scale up projects with increasing speed.

- https://ethz.ch/en/news-and-events/eth-news/news/2023/07/blog-voluntary-carbon-offsets-often-fail-to-deliver-what-they-promise.html

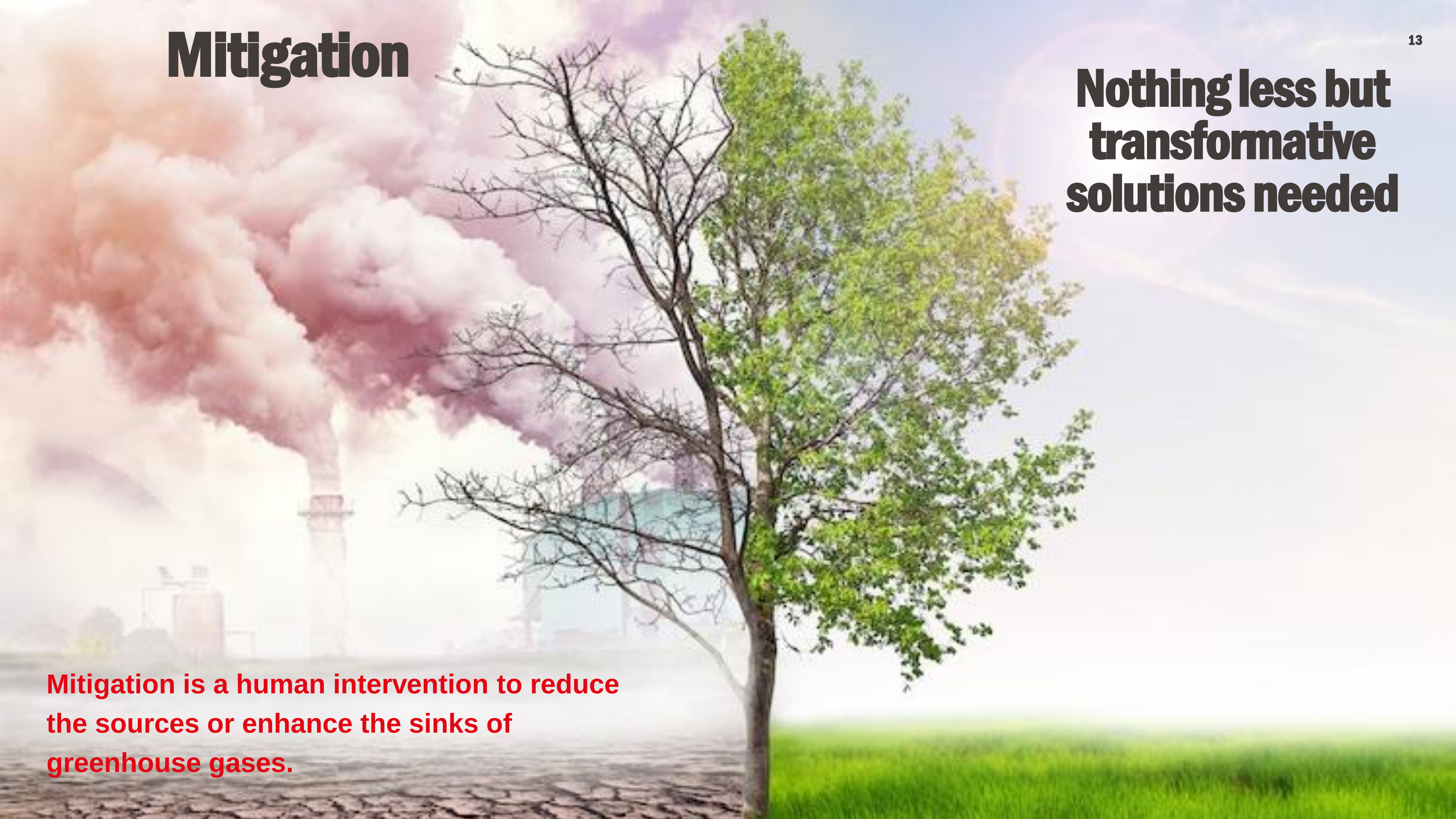
Reasons for failure

1. **Additionality**
   - The most prominent reason why carbon projects fail is that they are not additional, meaning that the project does not contribute to achieving additional climate benefits - compared to if the project had not existed.
2. **There are significant risks to forests**
   - There are significant risks to forests after a project ends, as any carbon sequestered is likely to be released back into the atmosphere. This risk can manifest in several different ways, from natural disasters to illegal logging - especially in countries with unstable political situations.
3. **Unreliable baseline inflate emissions promises**
   - A common issue seen in many projects is artificially inflating baseline emissions in order to generate more carbon credits for the project, thus taking credit for what the project did not do.
4. **Carbon credits cause community conflicts**
   - In some cases, in order to establish projects that generate carbon credits, landowners (such as governments) may forcefully evict people living on the project area territory.
5. **Emission reductions rely on vague predictions**
   - Credits promising that emission reductions will materialise in future are often referred to as 'ex-ante credits'.

~84% of voluntary projects fail

- https://www.euronews.com/green/2023/01/10/the-five-biggest-reasons-carbon-offsetting-schemes-can-fail, https://www.nature.com/articles/s41467-024-53645-z

Mitigation



Nothing less but transformative solutions needed

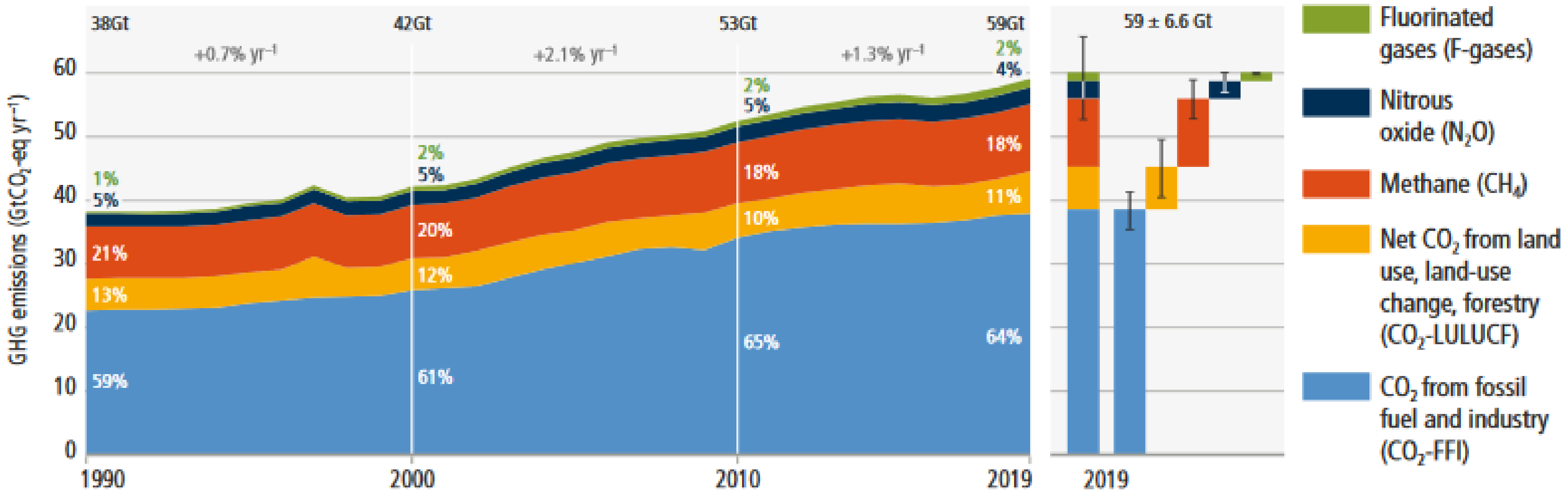
Mitigation is a human intervention to reduce the sources or enhance the sinks of greenhouse gases.

EPFL

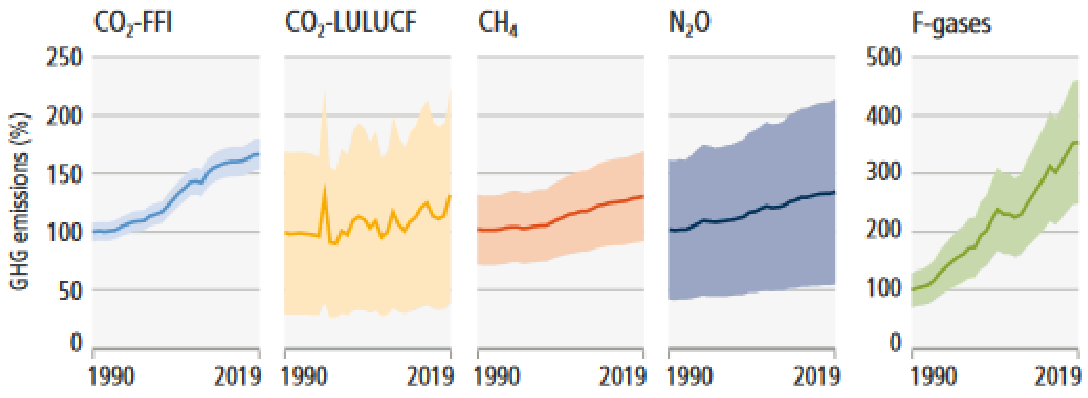
Global Emission of GHG

Global net anthropogenic emissions have continued to rise across all major groups of greenhouse gases.

a. Global net anthropogenic GHG emissions 1990–2019 (5)



b. Global anthropogenic GHG emissions and uncertainties by gas – relative to 1990



	2019 emissions ($GtCO_2$-eq)	1990–2019 increase ($GtCO_2$-eq)	Emissions in 2019, relative to 1990 (%)
CO_2-FFI	38 ± 3	15	167
CO_2-LULUCF	6.6 ± 4.6	1.6	133
CH_4	11 ± 3.2	2.4	129
N_2O	2.7 ± 1.6	0.65	133
F-gases	1.4 ± 0.41	0.97	354
Total	59 ± 6.6	21	154

The solid line indicates central estimate of emissions trends. The shaded area indicates the uncertainty range.

Knowing the emissions gives hints on the mitigation options.

CO_2-FFI: Fossil fuel and industry

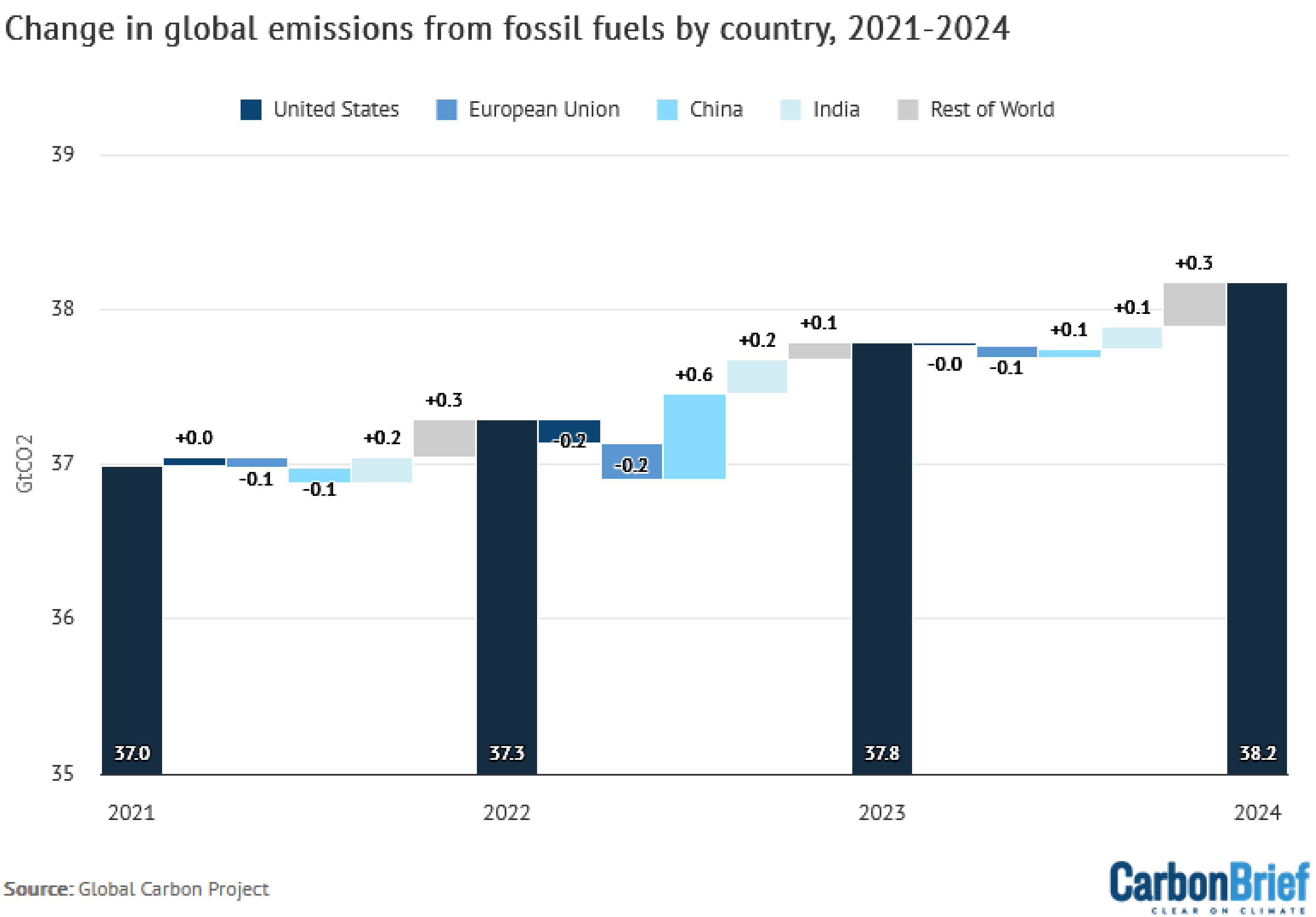
CO_2 – LULUCF: forestry and land-use change

F-gases: HFCs, PFCs, SF_6, NF_3

- AR6, WGIII, SPM.1

Emissions are still on the rise

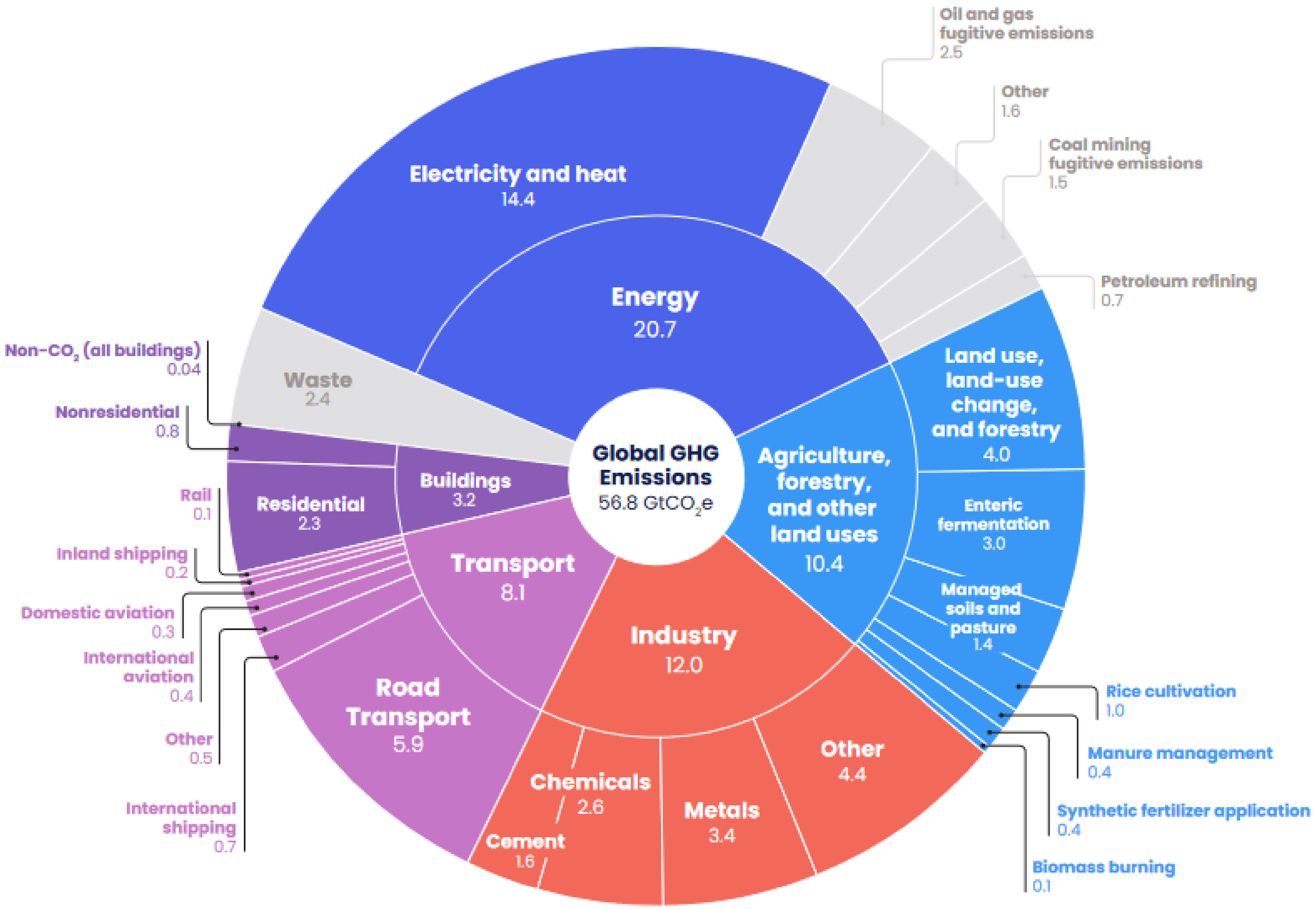
Change in global emissions from fossil fuels by country, 2021-2024



- https://www.carbonbrief.org/analysis-global-co2-emissions-will-reach-new-high-in-2024-despite-slower-growth/

Emissions by sector

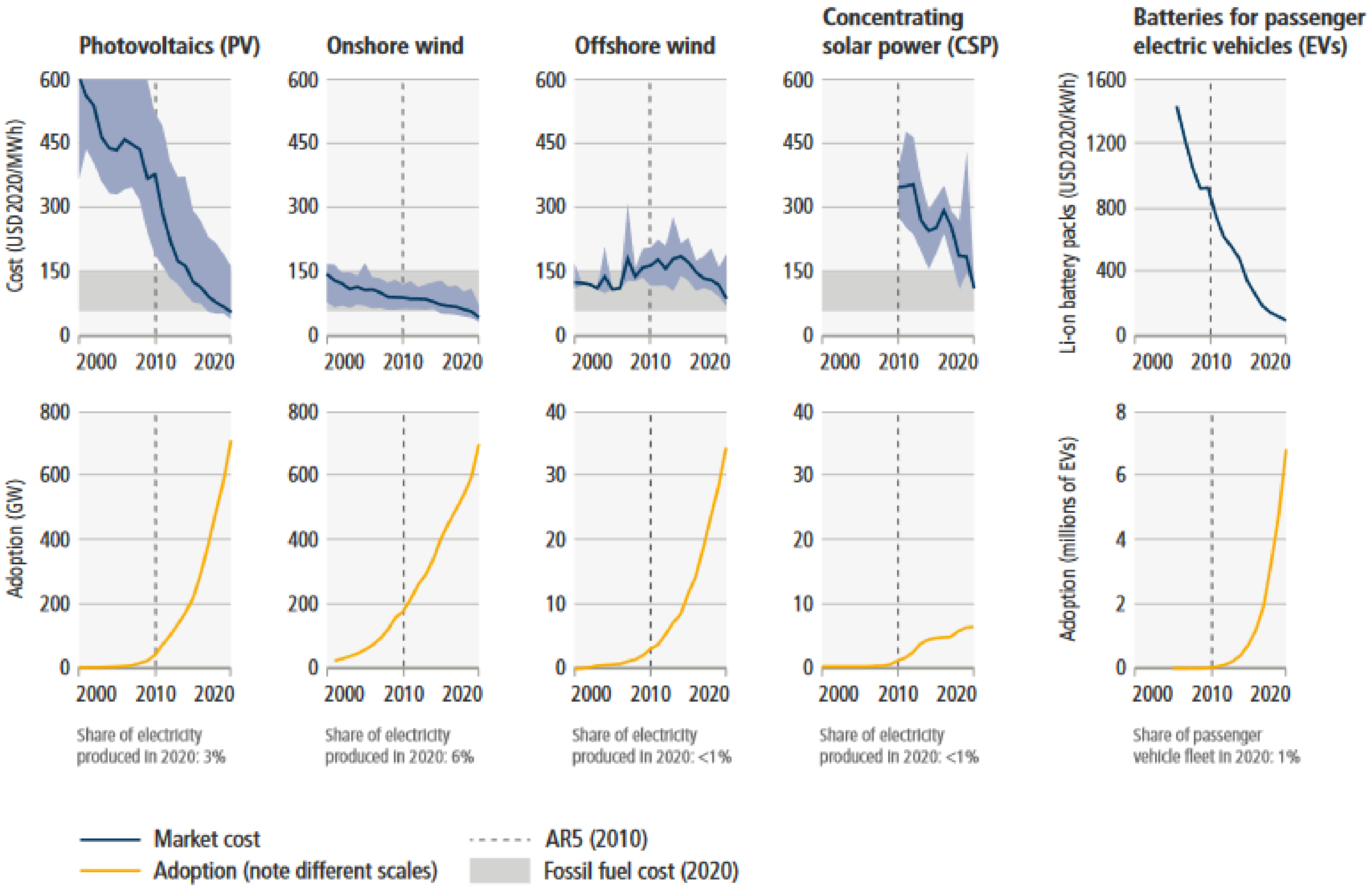
FIGURE ES-1 | Global net anthropogenic GHG emissions by sector in 2021



https://www.wri.org/research/state-climate-action-2023

Costs and Adoption

The unit costs of some forms of renewable energy and of batteries for passenger EVs have fallen, and their use continues to rise.

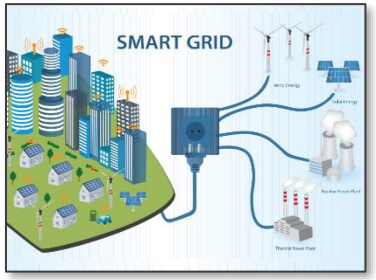


- AR6, WGIII, SPM.3

Relevant technology for mitigation

Solar

Fuel Cells



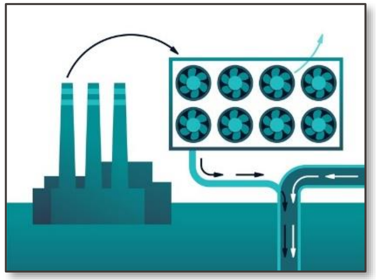
Smart Grids

Wind

Biogas

Alternative Fuels

Energy Storage



Carbon Capture

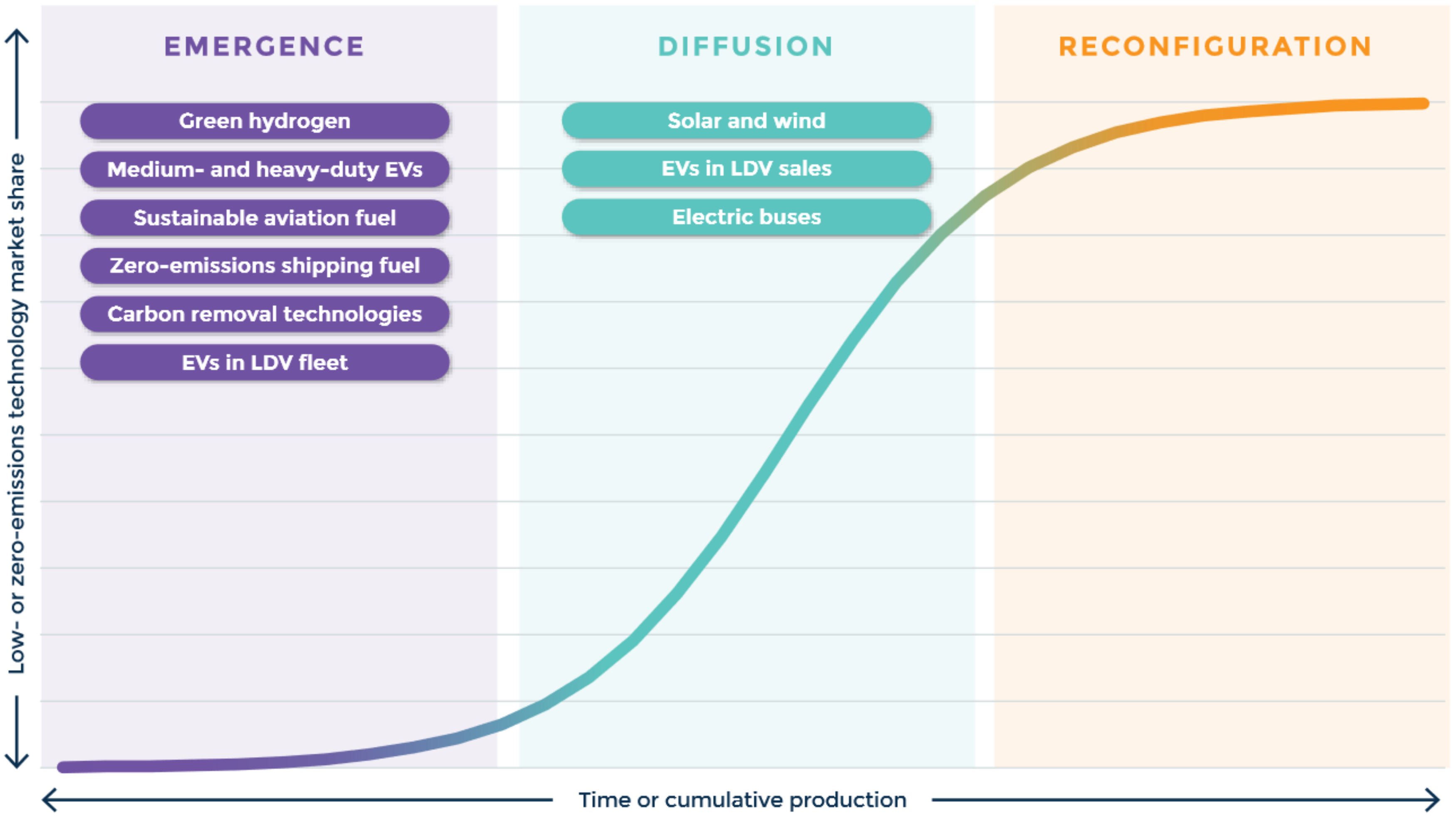
Small Modular Nuclear Reactors

Geo-thermal

EU Net-Zero Industry Act
Goal: reaching at least 40% of the Union’s deployment needs by 2030

https://single-market-economy.ec.europa.eu/industry/sustainability/net-zero-industry-act_en

Emission reduction is a function of technology adoption

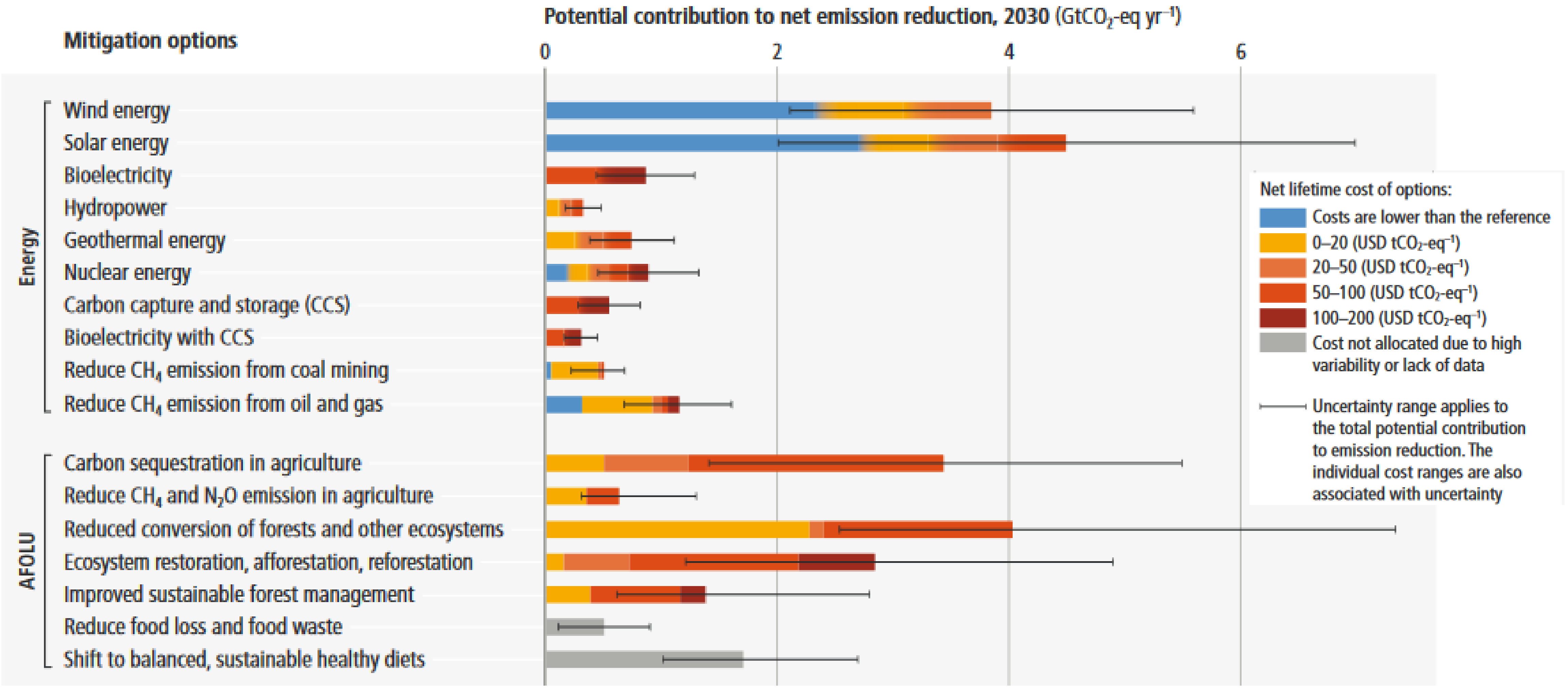


Note: EV = electric vehicle; LDV = light-duty vehicle. These labels include technologies that are directly tracked by our nine indicators that may follow an S-curve.

Source: Authors' judgment, based on Victor et al. (2019) and ETC (2020).

- https://climateactiontracker.org/publications/state-of-climate-action-2021/

Mitigation potential and costs

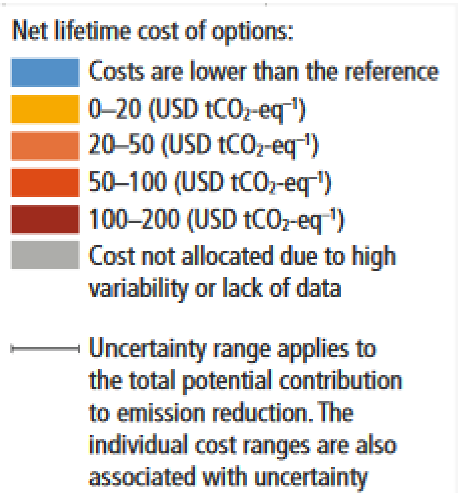


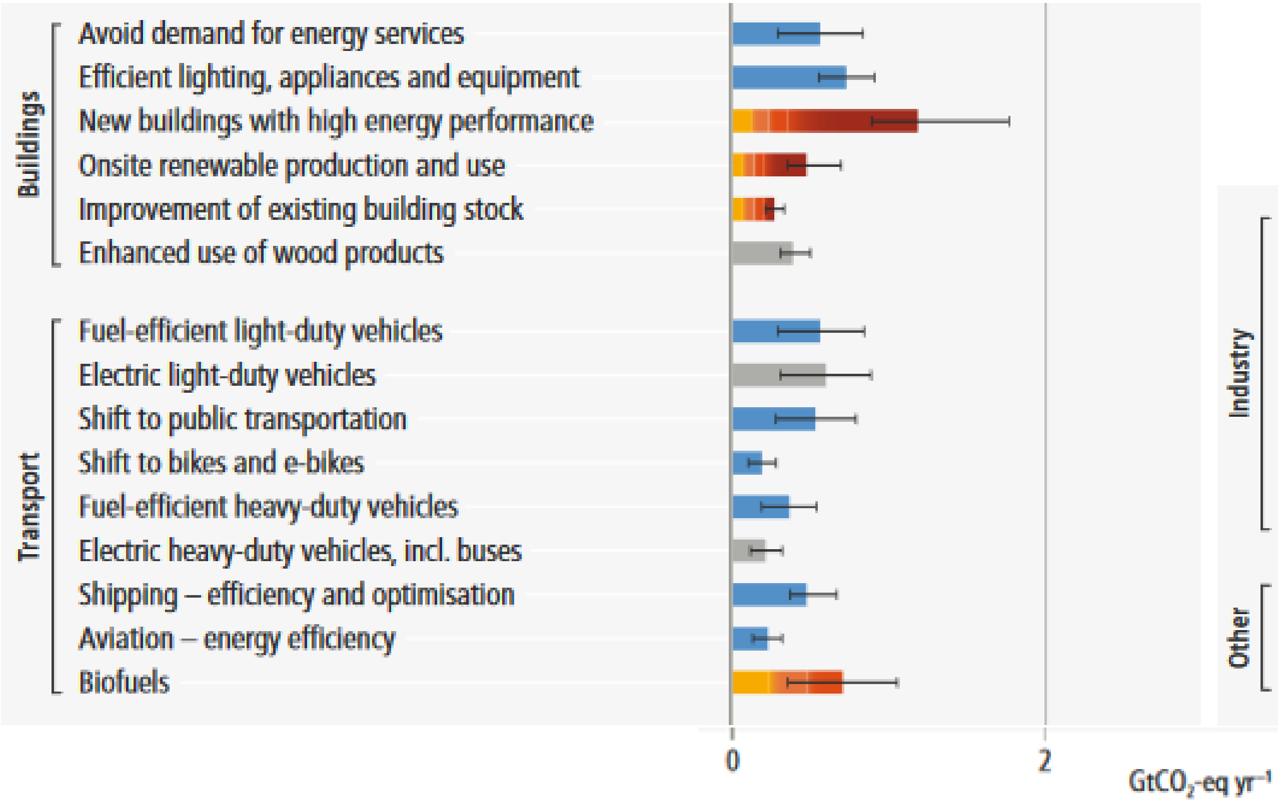
Sectors with largest potential

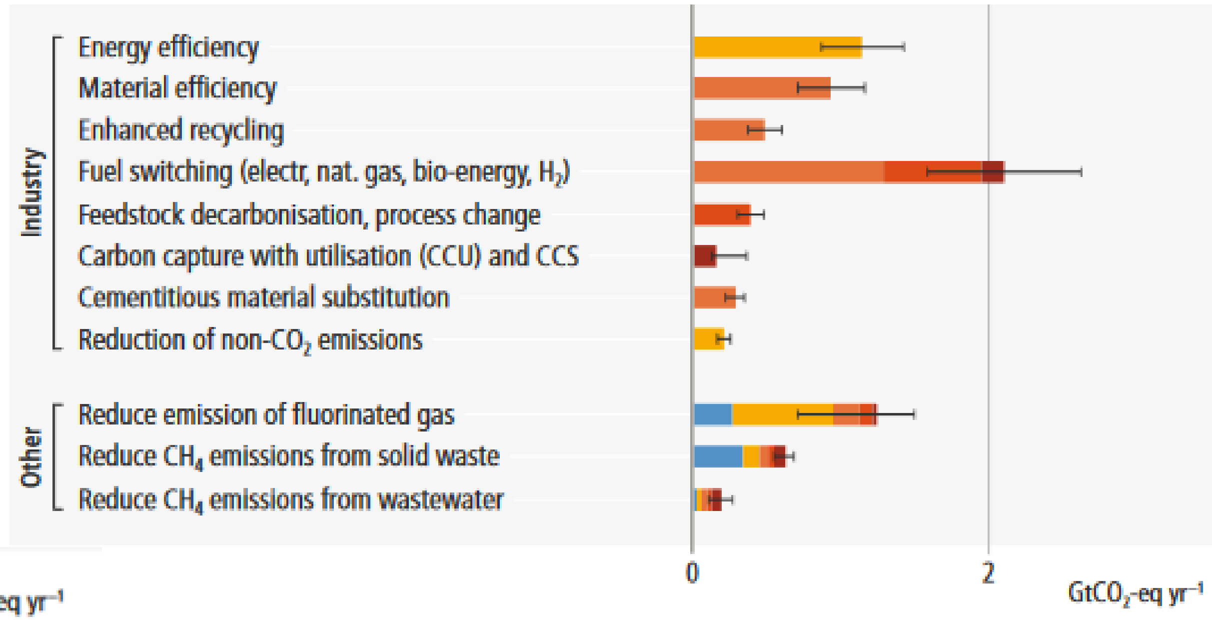
AR6, WGIII, SPM.7

Agriculture, Forestry, and Other Land Use - AFOLU

Mitigation potential and costs



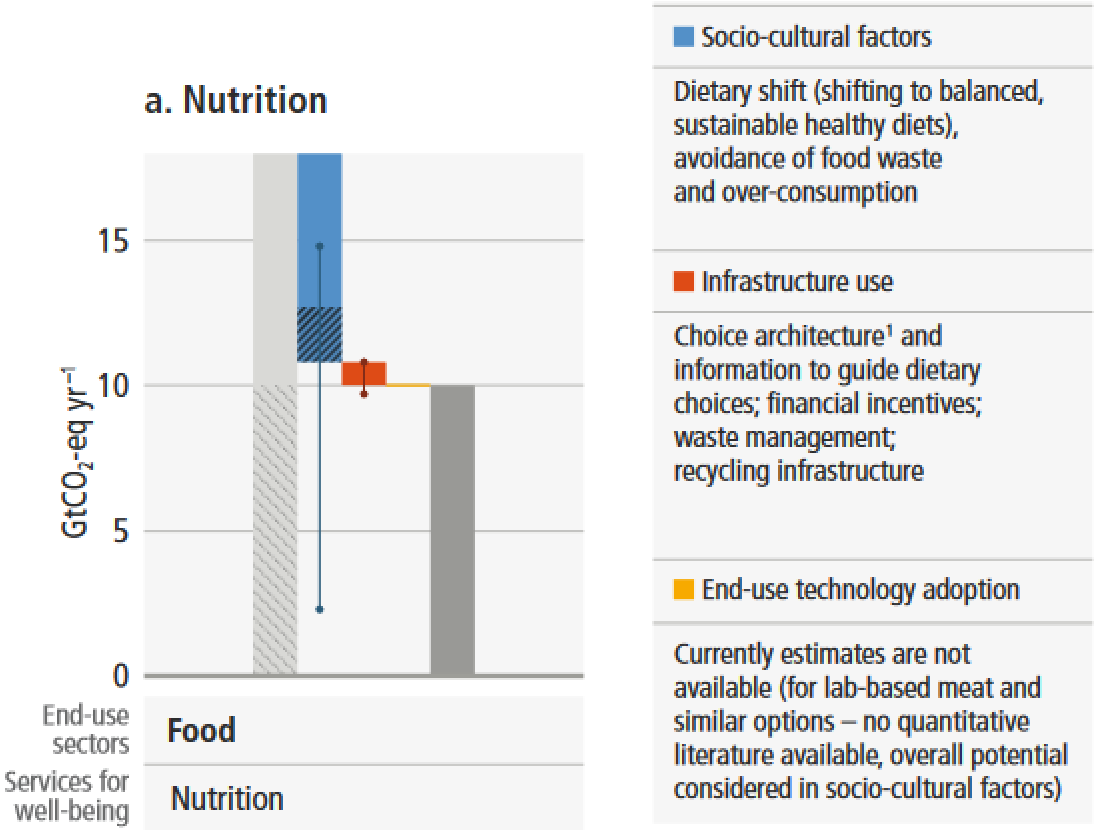




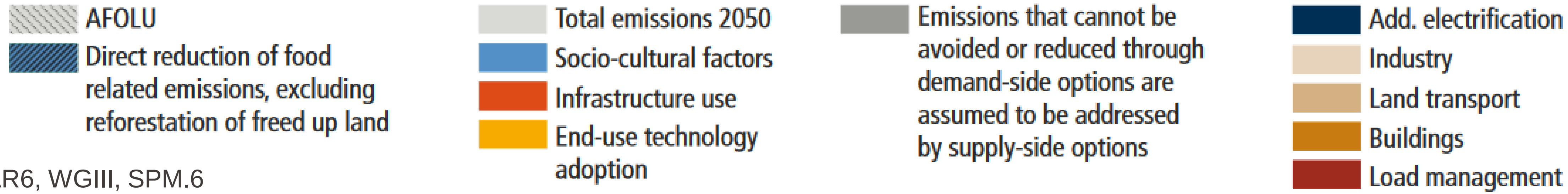
Sectors with smaller potentials

- AR6, WGIII, SPM.7

Demand side mitigation potentials



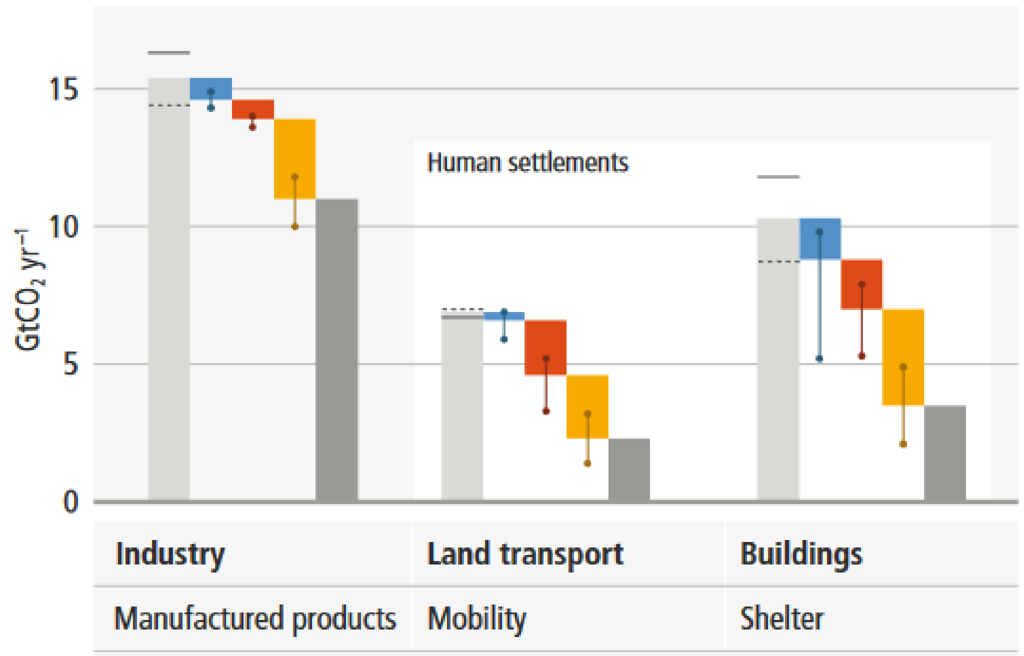
Largest potential on the demand side



- AR6, WGIII, SPM.6

Demand side mitigation potentials

b. Manufactured products, mobility, shelter



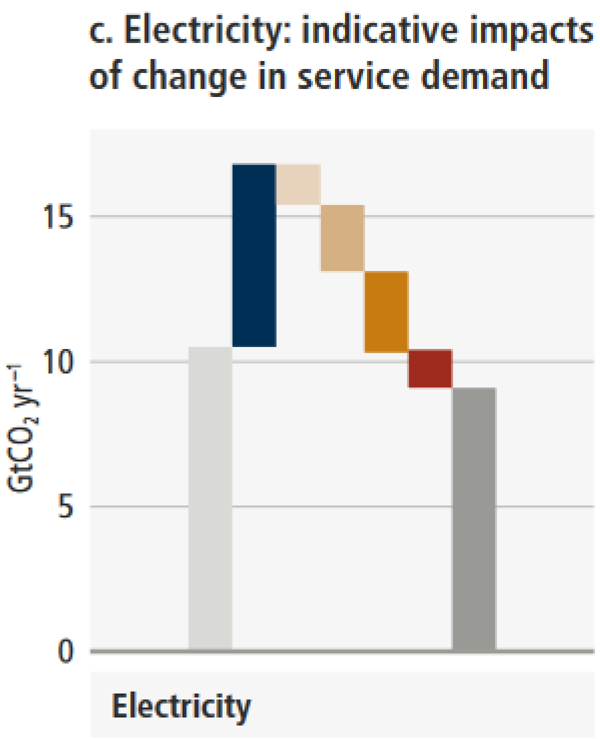
Socio-cultural factors		
Shift in demand towards sustainable consumption, such as intensive use of longer-lived repairable products	Teleworking or telecommuting; active mobility through walking and cycling	Social practices resulting in energy saving; lifestyle and behavioural changes
Infrastructure use		
Networks established for recycling, repurposing, remanufacturing and reuse of metals, plastics and glass; labelling low-emissions materials and products	Public transport; shared mobility; compact cities; spatial planning	Compact cities; rationalisation of living floor space; architectural design; urban planning (e.g., green roof, cool roof, urban green spaces etc.)
End-use technology adoption		
Green procurement to access material-efficient products and services; access to energy-efficient and CO_2 neutral materials	Electric vehicles; shift to more efficient vehicles	Energy efficient building envelopes and appliances; shift to renewables

- Total emissions 2050
- Socio-cultural factors
- Infrastructure use
- End-use technology adoption
- Emissions that cannot be avoided or reduced through demand-side options are assumed to be addressed by supply-side options

Transport and building sector have relatively high potential on the demand side

- AR6, WGIII, SPM.6

Demand side mitigation potentials



■ Additional electrification (+60%)

Additional emissions from increased electricity generation to enable the end-use sectors' substitution of electricity for fossil fuels, e.g. via heat pumps and electric cars {Table SM5.3; 6.6}

- Industry
- Land transport
- Buildings
- Load management[2]

Demand-side measures −73%

Reduced emissions through demand-side mitigation options (in end-use sectors: buildings, industry and land transport) which has potential to reduce electricity demand[3]

Emissions that cannot be avoided or reduced through demand-side options are assumed to be addressed by supply-side options

- Add. electrification
- Industry
- Land transport
- Buildings
- Load management

Currently small potential

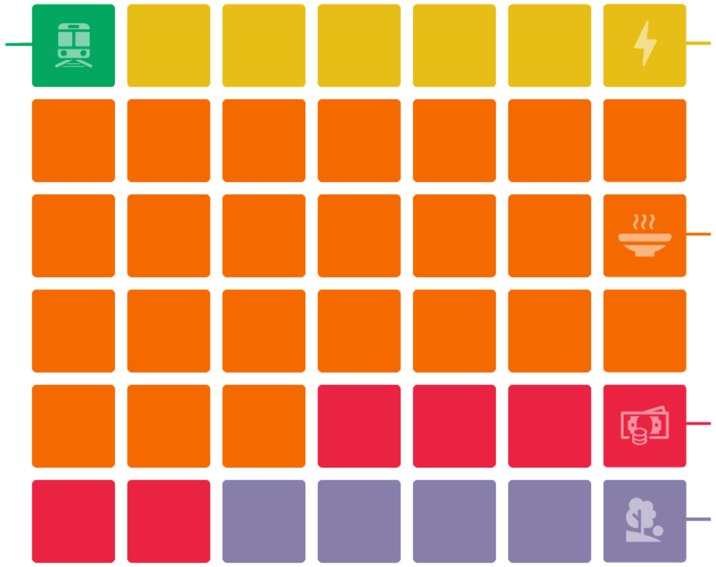
- AR6, WGIII, SPM.6

State of Climate Action

Global progress across sectors isn't happening at the pace and scale needed to limit warming to 1.5°C

Only one of 42 indicators is on track to reach its 2030 target

= 1 indicator | On Track | Off Track | Well Off Track | Wrong Direction | Insufficient Data



The **share of electric vehicles in passenger car sales** has more than tripled since 2020, and this exponential growth puts this indicator squarely on track for 2030.

The **share of solar and wind in electricity generation** has grown by an annual average of 14% in recent years, but this needs to reach 24% to help get the scale-up of zero-carbon power on track.

To sustainably feed a growing population and reduce GHG emissions, **increases in crop yields** must accelerate more than 10 times faster this decade.

Public financing for fossil fuels is now increasing, with government subsidies almost doubling since 2020 to reach the highest level in nearly a decade.

Available evidence in Russia, Germany and Indonesia suggests that **peatland restoration** is occurring but likely not at the pace and scale required globally.

Source: Boehm et al. 2023.

SYSTEMS CHANGE LAB

- https://climateactiontracker.org/publications/state-of-climate-action-2023/

EPFL

State of climate action

- **Still, an enormous acceleration in effort will be required across all sectors to get on track for 2030.** For example, the world needs to:
- Dramatically increase **growth in solar and wind power**. The share of these two technologies in electricity generation has grown by an annual average of 14 percent in recent years, but this needs to reach 24 percent to get on track for 2030.
- **Phase out coal in electricity generation** seven times faster than current rates. This is equivalent to retiring roughly 240 average-sized coal-fired power plants each year through 2030. Though continued build-out of coal-fired power will increase the number of plants that need to be shuttered in the coming years.
- Expand the coverage of **rapid transit infrastructure** six times faster. This is equivalent to constructing public transit systems roughly three times the size of New York City's network of subway rails, bus lanes and light-rail tracks each year throughout this decade.
- The annual **rate of deforestation** — equivalent to deforesting 15 football (soccer) fields per minute in 2022 — needs to be reduced four times faster over this decade.
- Shift to **healthier, more sustainable diets** eight times faster by lowering per capita consumption of meat from cows, goats and sheep to approximately two servings per week or less across high-consuming regions (the Americas, Europe and Oceania) by 2030. This shift does not require reducing consumption for populations who already consume below this target level, especially in low-income countries where modest increases in consumption can boost nutrition.

The report identifies targets and associated indicators for
- power,
- buildings,
- industry,
- transport,
- technological carbon removal,
- land and coastal zone management,
- agriculture,
- finance

that the literature suggests are the best available to monitor sectoral decarbonization pathways. Targets are designed to be compatible with limiting global warming to 1.5°C.

- https://climateactiontracker.org/publications/state-of-climate-action-2023/

EPFL

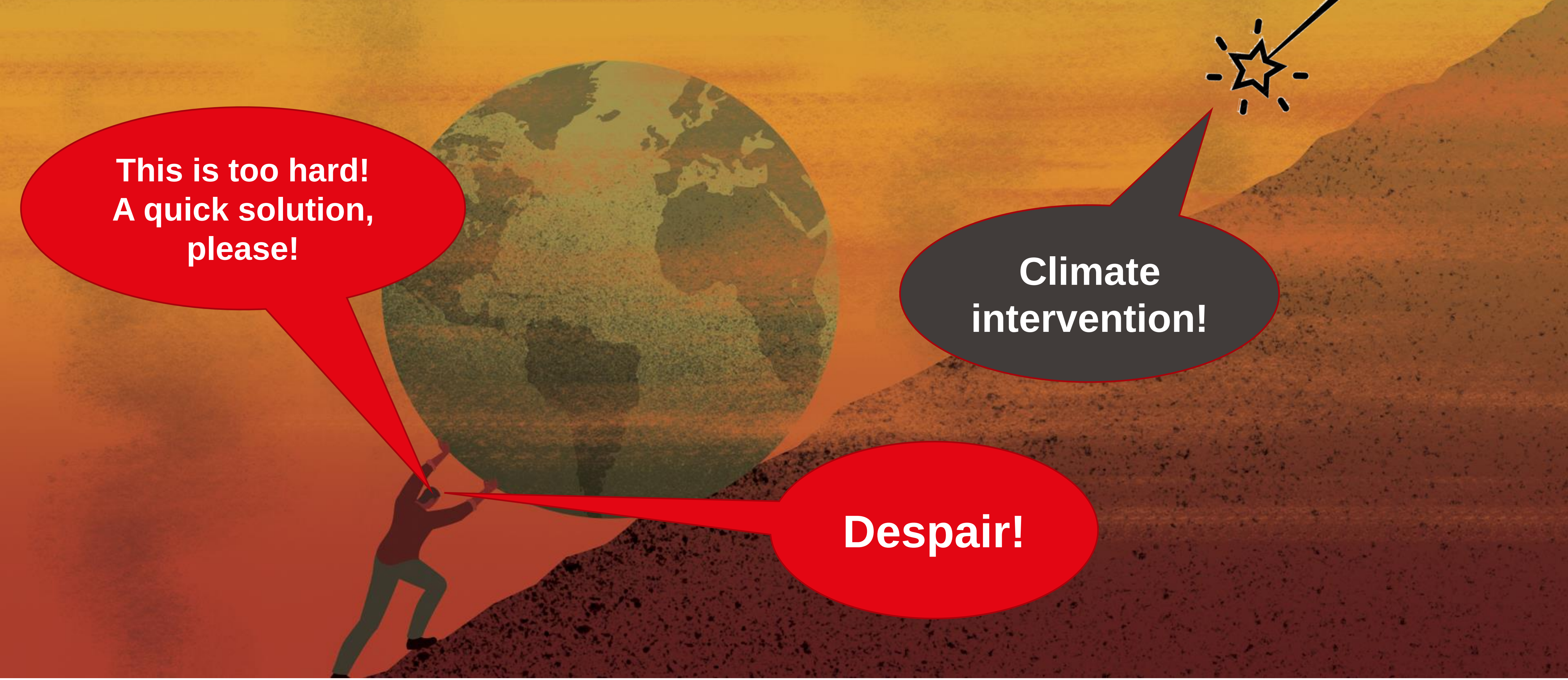
Climate Emergency in a nutshell

1. We are extremely close to our global temperature target of 1.5/2.0°C for 2100, with potentially severe consequences «now» in some regions.

2. Drastic emission reductions are needed now and net-zero needs to be achieved by 2050.

3. Humanity is faced with a technological, political, regulatory and behavioral challenge never encountered before.

How’s the mood?



- https://www.thenewatlantis.com/publications/after-climate-despair

Types of interventions

Carbon dioxide removal (CDR)

- Biochar
- Bioenergy with carbon capture and storage (BECCS)
- Blue carbon management
- Direct air carbon capture and storage (DACCS)
- Enhanced rock weathering
- Large scale afforestation and reforestation
- Peatland and wetland restoration
- Soil carbon sequestration

Solar radiation modification (SRM)

- Cirrus cloud thinning*
- Ground-based albedo modification**
- Marine cloud brightening
- Space sunshades and reflectors
- Stratospheric aerosol injection

Emerging technology and research

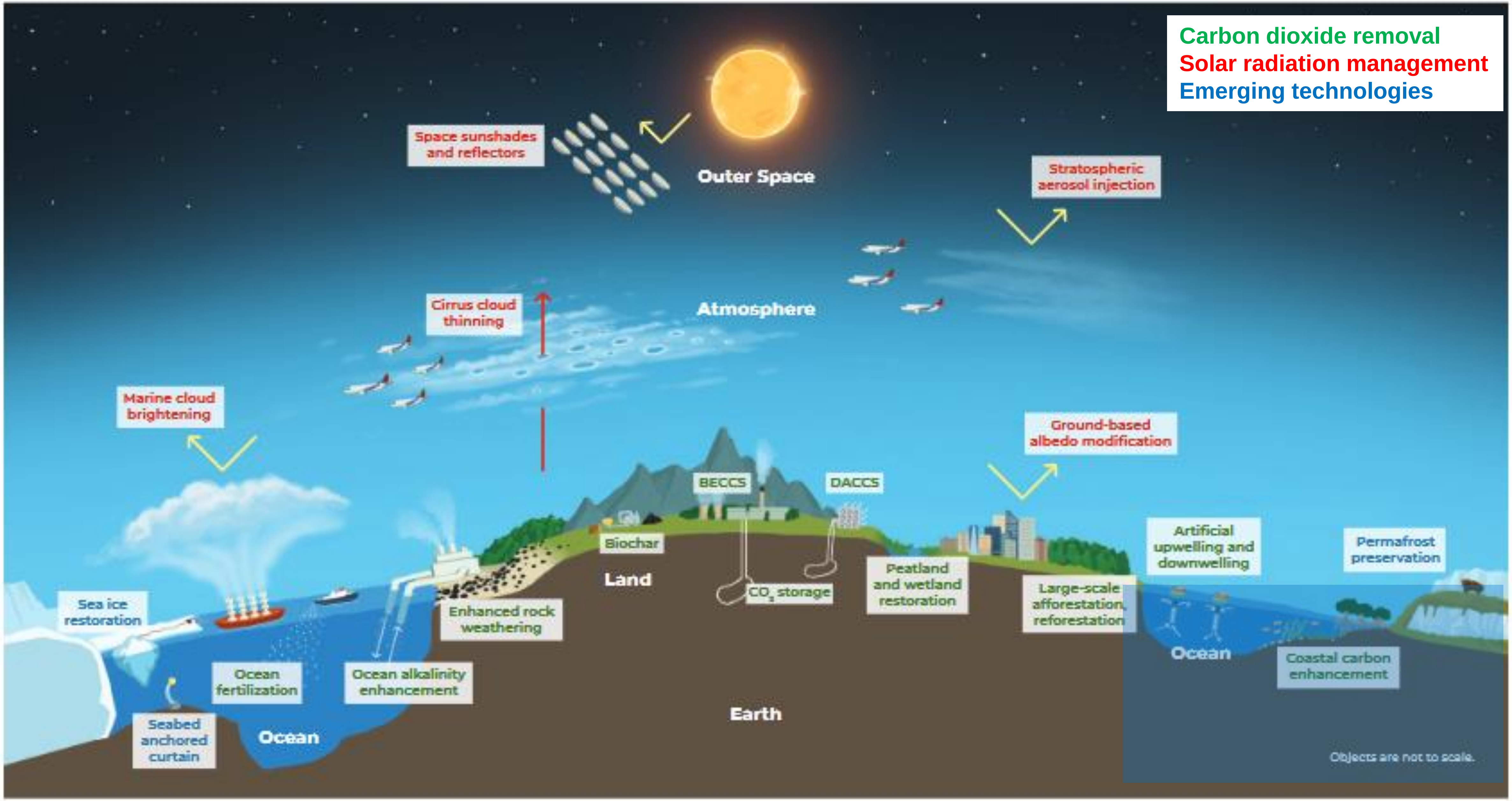
- Glacial climate intervention and ice sheet restoration
- Sea ice restoration
- Permafrost preservation

* Related to SRM but does not reflect sunlight; instead, it intervenes in long wave radiation

** Includes making human infrastructures, crops, desert areas, glaciers, and the ocean more reflective.

FIGURE 2: Types of climate intervention technologies and methods.

- https://www.agu.org/learn-about-agu/about-agu/ethics/ethical-framework-for-climate-intervention



https://agu.mediavalet.com/portals/ethicalframework

Science-based Ethical Framework just published

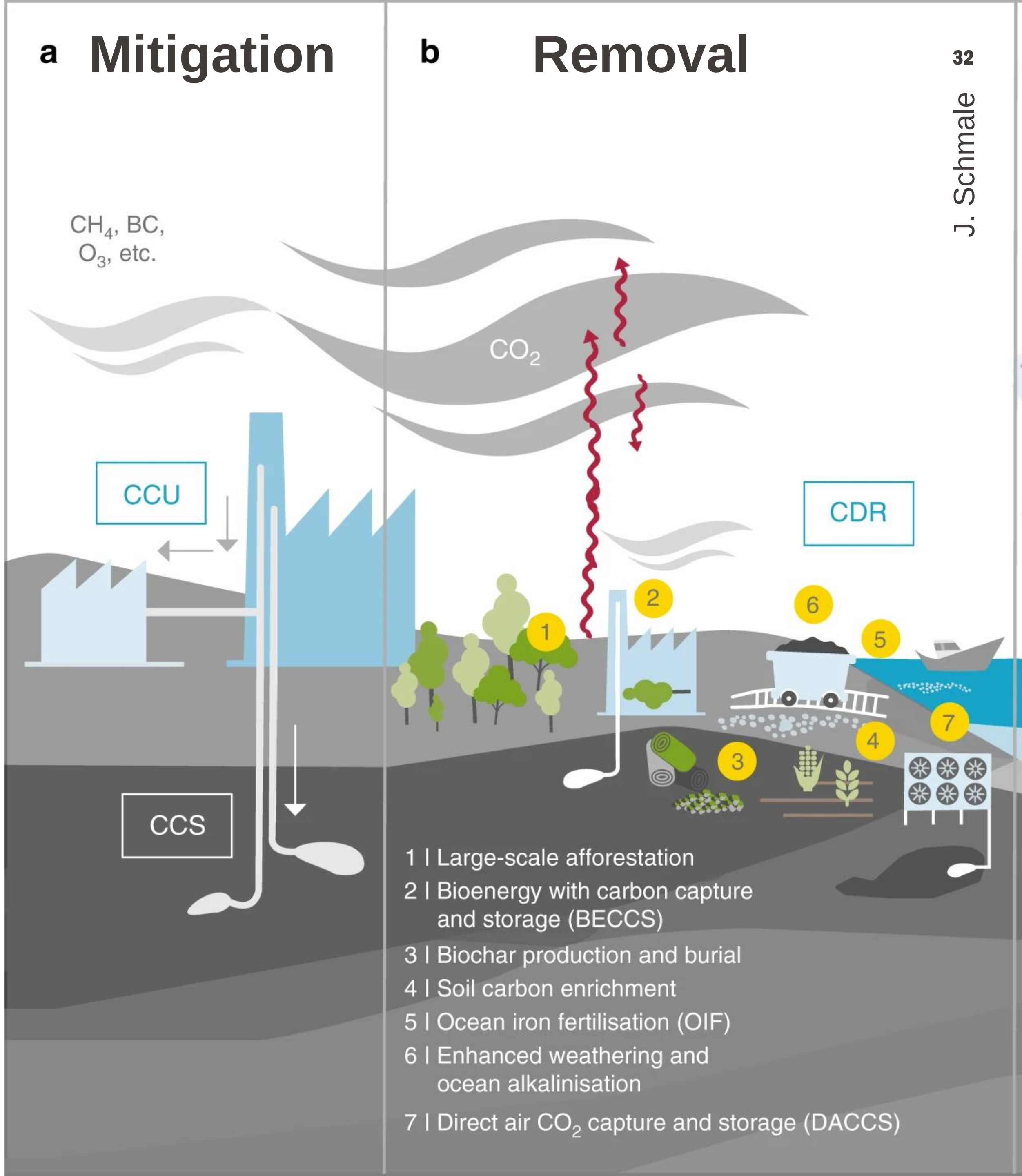
- https://www.agu.org/learn-about-agu/about-agu/ethics/ethical-framework-for-climate-intervention

EPFL

Carbon mitigation and removal

- **Mitigation**
  avoid emission of greenhouse gases through **carbon capture** and usage (CCU) and carbon capture and storage (CCS)

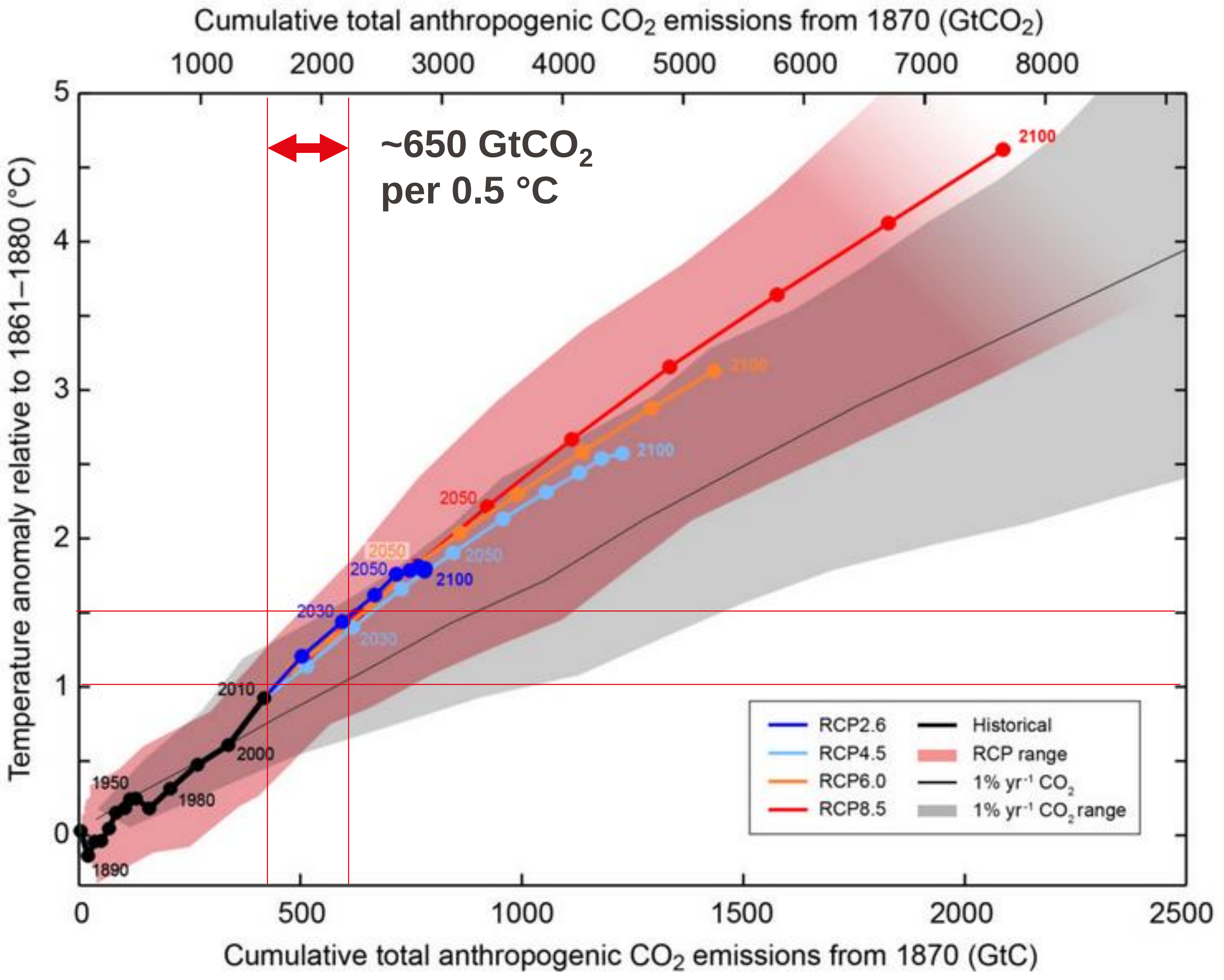
- **Carbon Dioxide Removal (CDR)**
  removes CO_2 **after** it has been emitted



J. Schmale

- Lawrence et al. (2018);
  terminology: climate geoengineering techniques

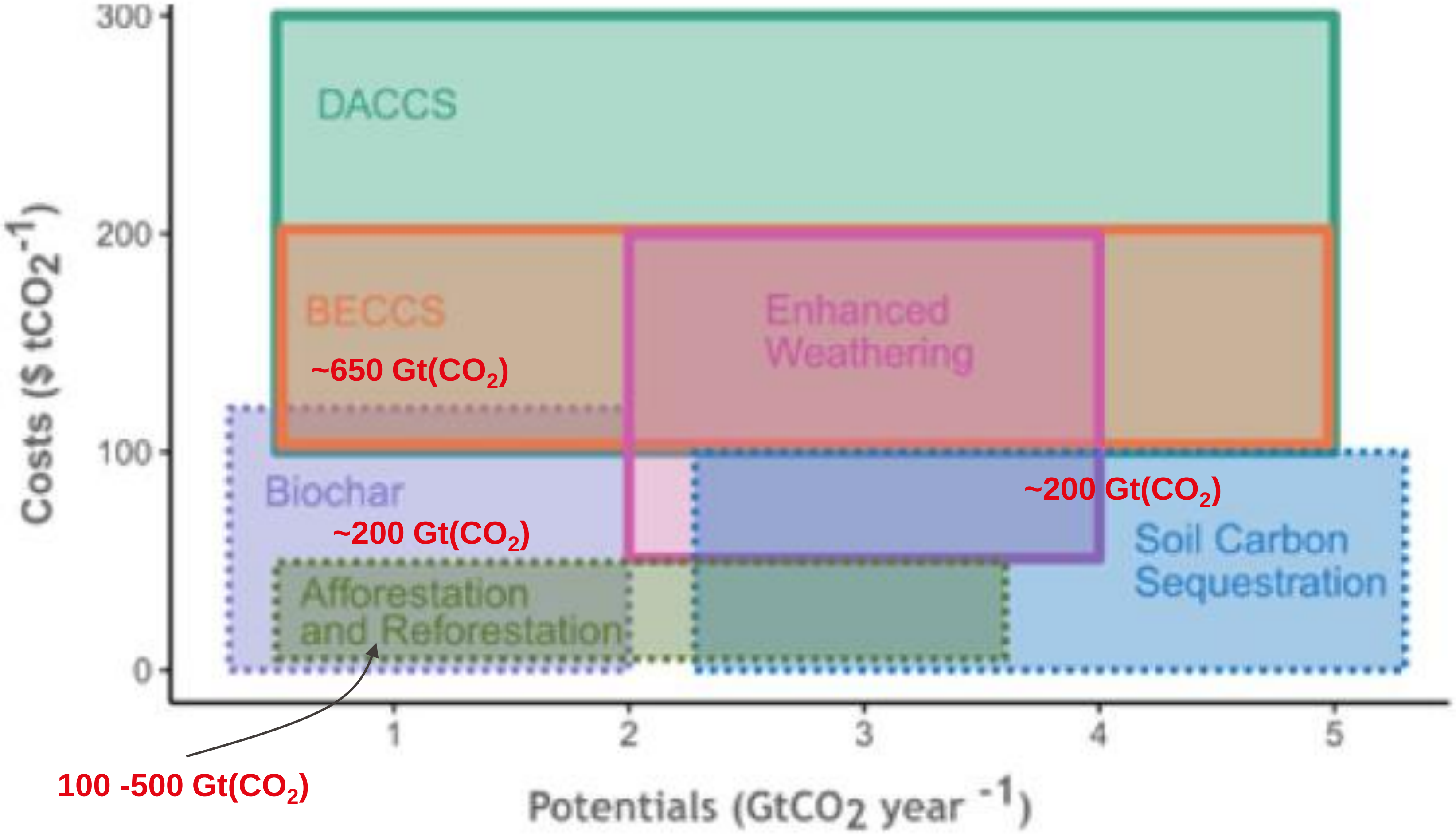
What would carbon avoidance or removal need to deliver?



- IPCC AR5, Fig. SPM10

EPFL

Carbon dioxide removal methods



SCS - soil carbon sequestration;
OA - ocean alkalinization;
EW- enhanced weathering;
DACCS - direct air carbon dioxide capture and storage;
BECCS - bioenergy with carbon capture and storage;
AR - afforestation

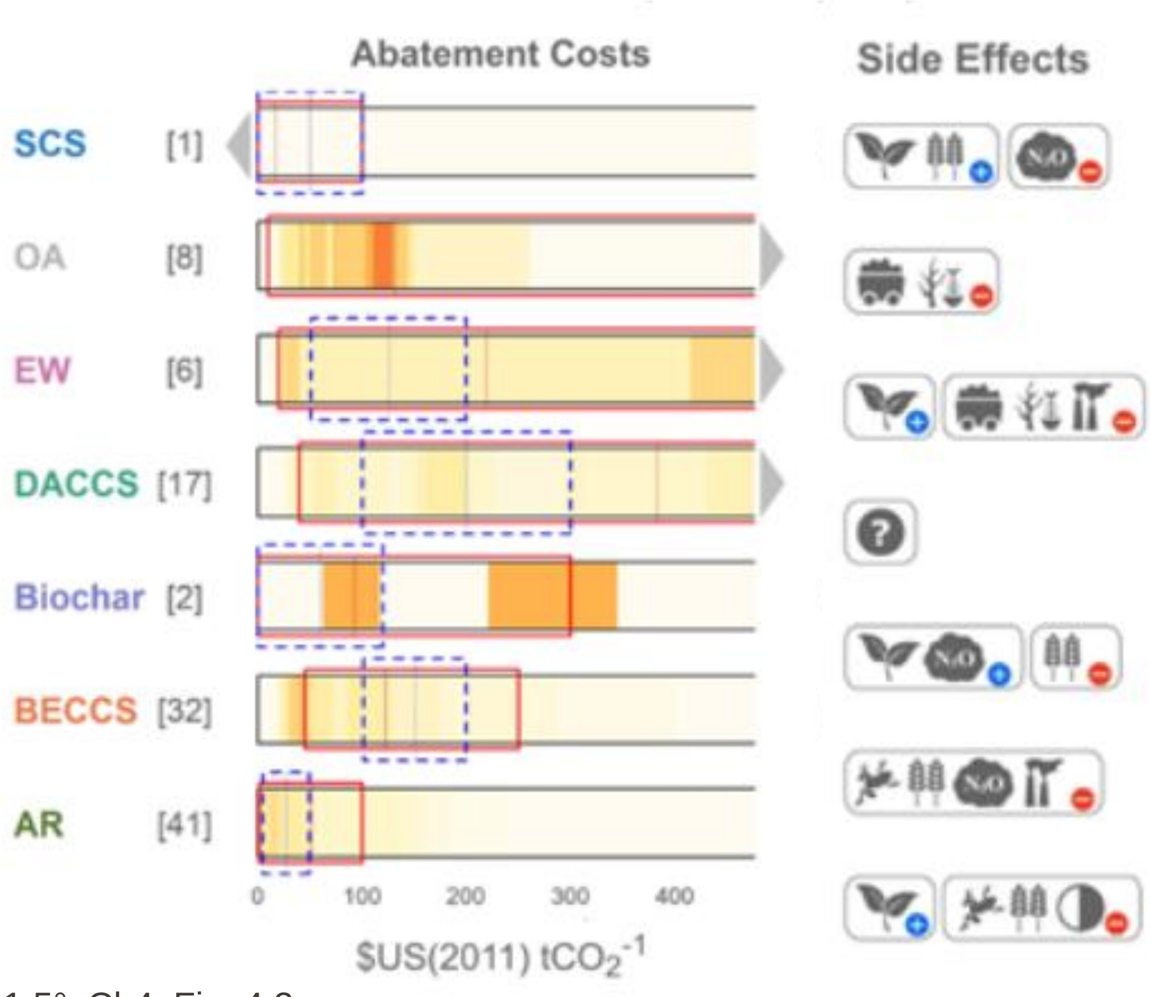
Terrestrial biomass techniques:

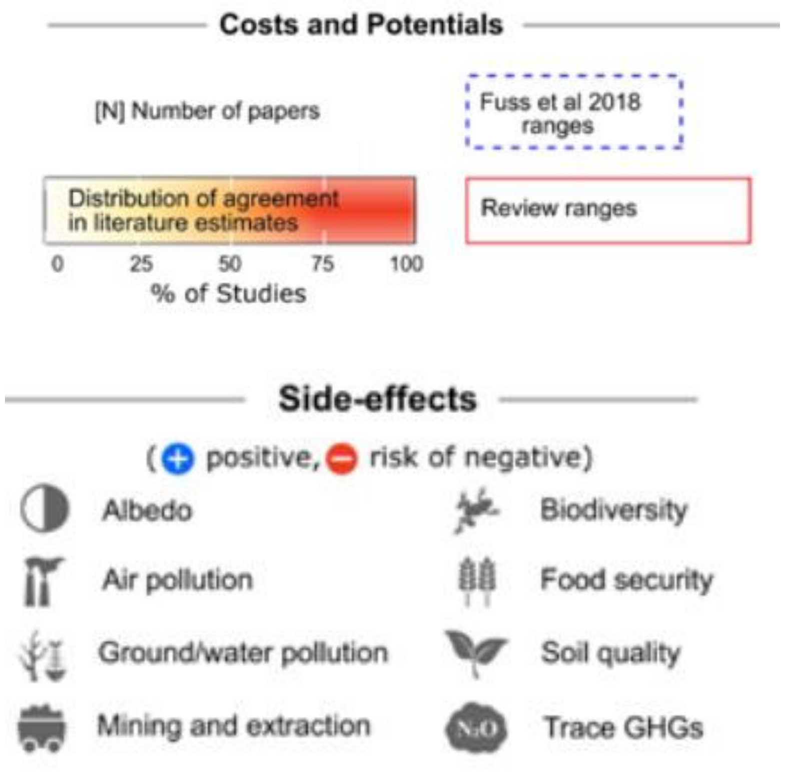
CDR potentials based on literature and until 2100
Lawrence et al. (2018)

- SR 1.5°, Ch4, Fig. 4.2

EPFL

CDR abatement costs and side effects

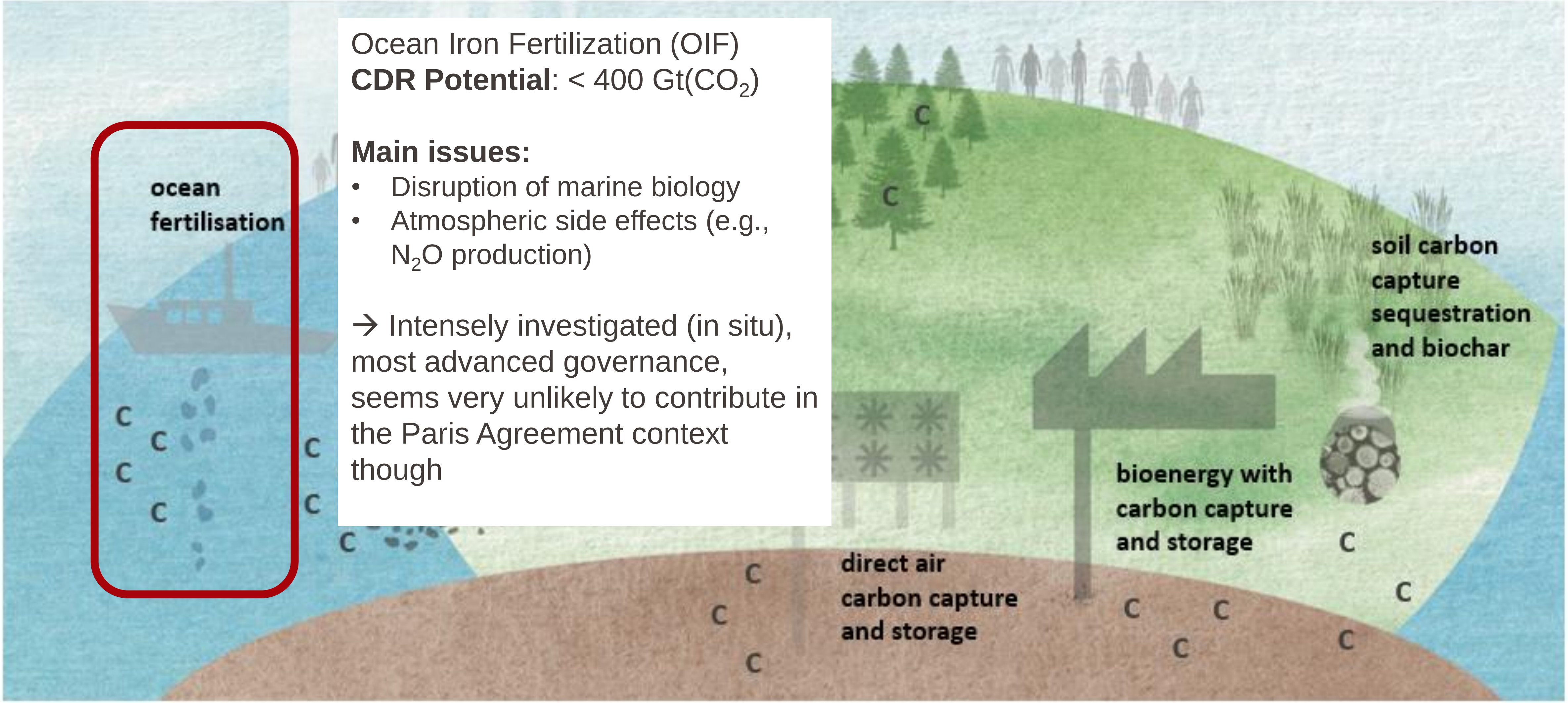




SCS - soil carbon sequestration;
OA - ocean alkalinization;
EW- enhanced weathering;
DACCS - direct air carbon dioxide capture and storage;
BECCS - bioenergy with carbon capture and storage;
AR - afforestation

- SR 1.5°, Ch4, Fig. 4.2

Carbon Dioxide Removal



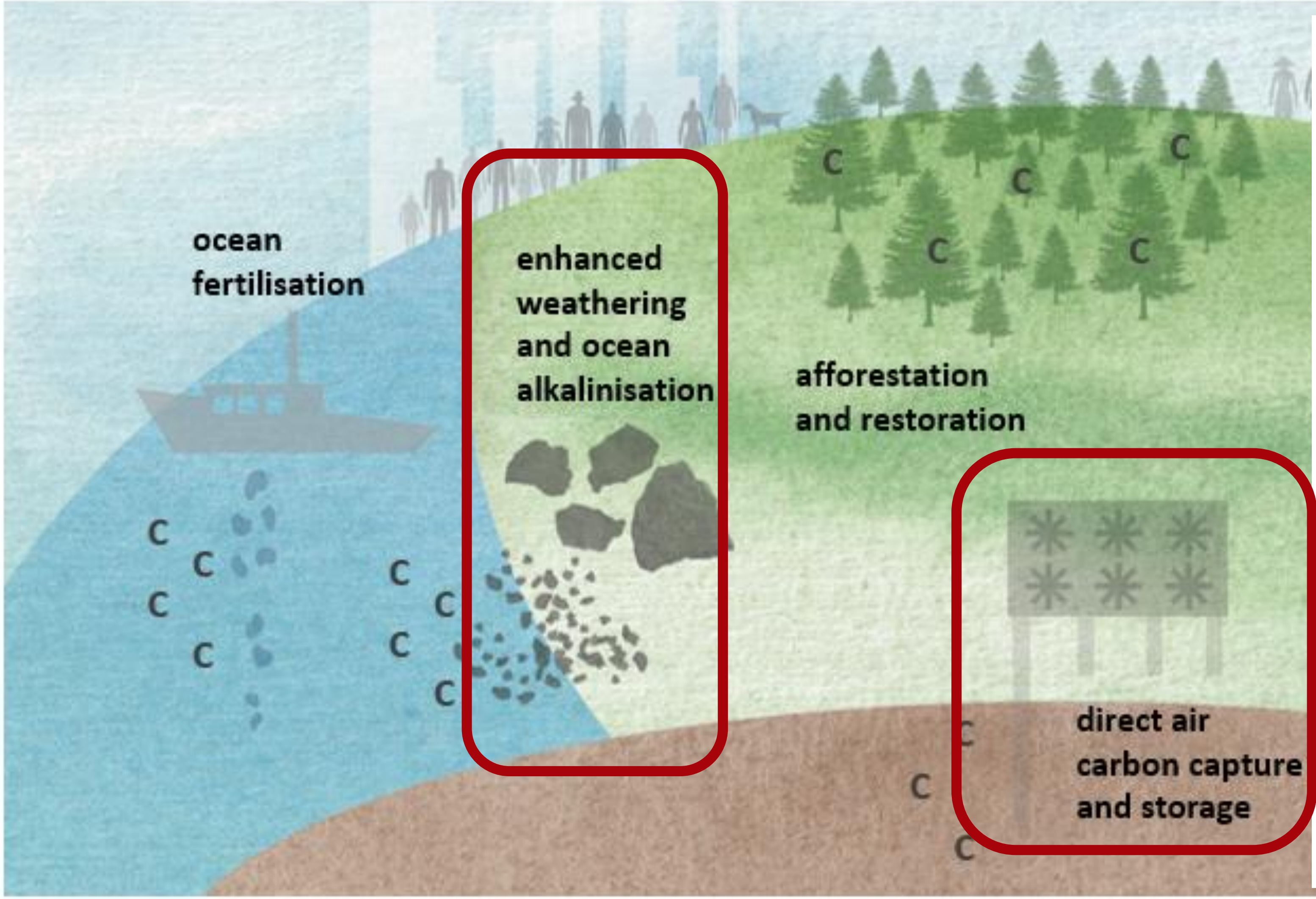
Ocean Iron Fertilization (OIF)
CDR Potential: < 400 Gt(CO_2)

Main issues:

- Disruption of marine biology
- Atmospheric side effects (e.g., N_2O production)

→ Intensely investigated (in situ), most advanced governance, seems very unlikely to contribute in the Paris Agreement context though

Carbon Dioxide Removal



<u>Abiotic (Chemical) Techniques</u>

CDR Potential: >> 650 Gt(CO_2)

Main Issues:

Enhanced weathering and ocean alkalinisation

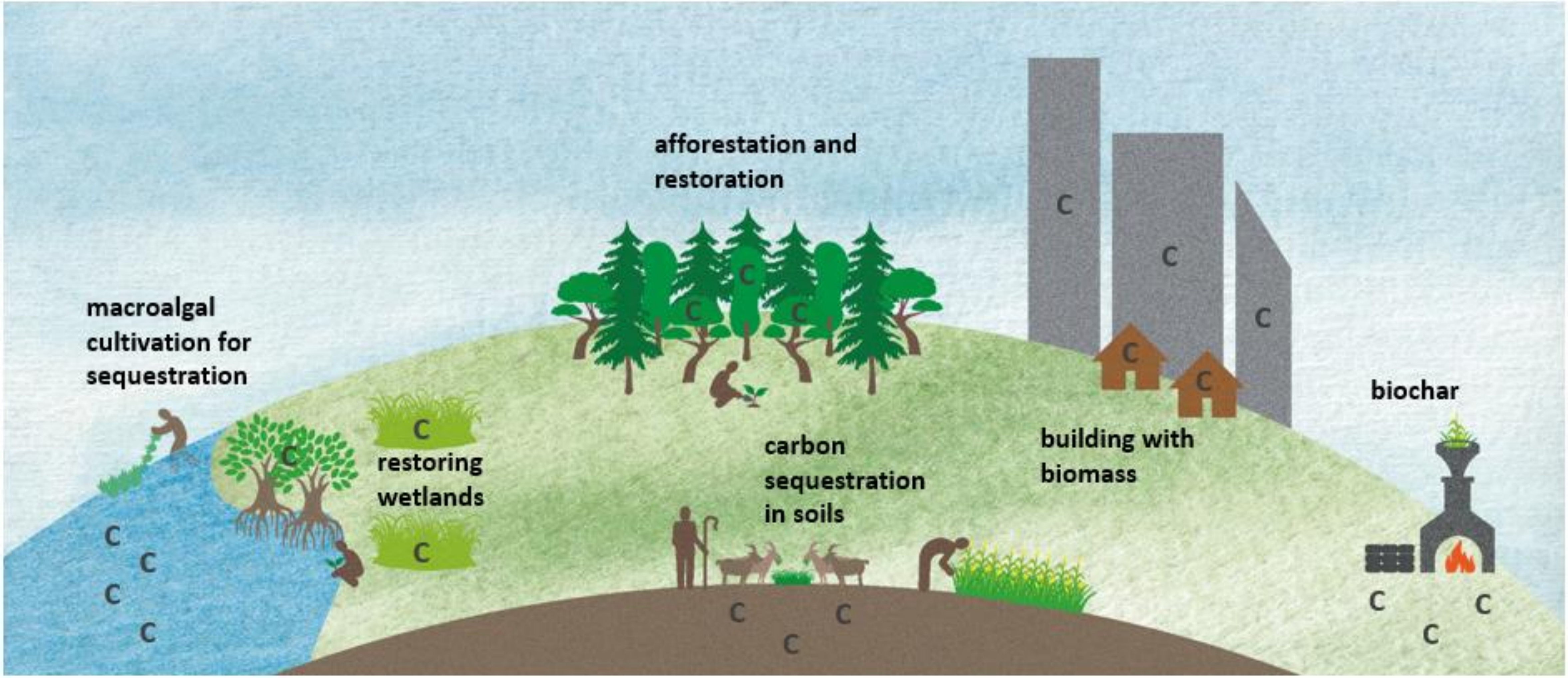
- Resource requirements (comparable to current mining)
- Safe disposal / storage of weathering products
- Impacts on terrestrial and marine biospheres

Direct air capture and carbon storage (DACCS)

- Technology development
- Energy requirements
- Economic competition with CCS or CCU at point sources

C2G

Nature-Based Approaches to Carbon Dioxide Removal



Summary of Carbon Dioxide Removal (CDR)

- Several proposed techniques could remove several hundred Gt(CO_2) by 2100, but…
- Costly (likely ca. \$100/ton CO_2), plus extensive infrastructure and energy requirements
- Climate-relevant CO_2 removal likely not until after ~2050
- Significant uncertainties and likely side effects (environmental and social) of most techniques

- Lawrence et al. (2018)

Solar Radiation Management

General idea

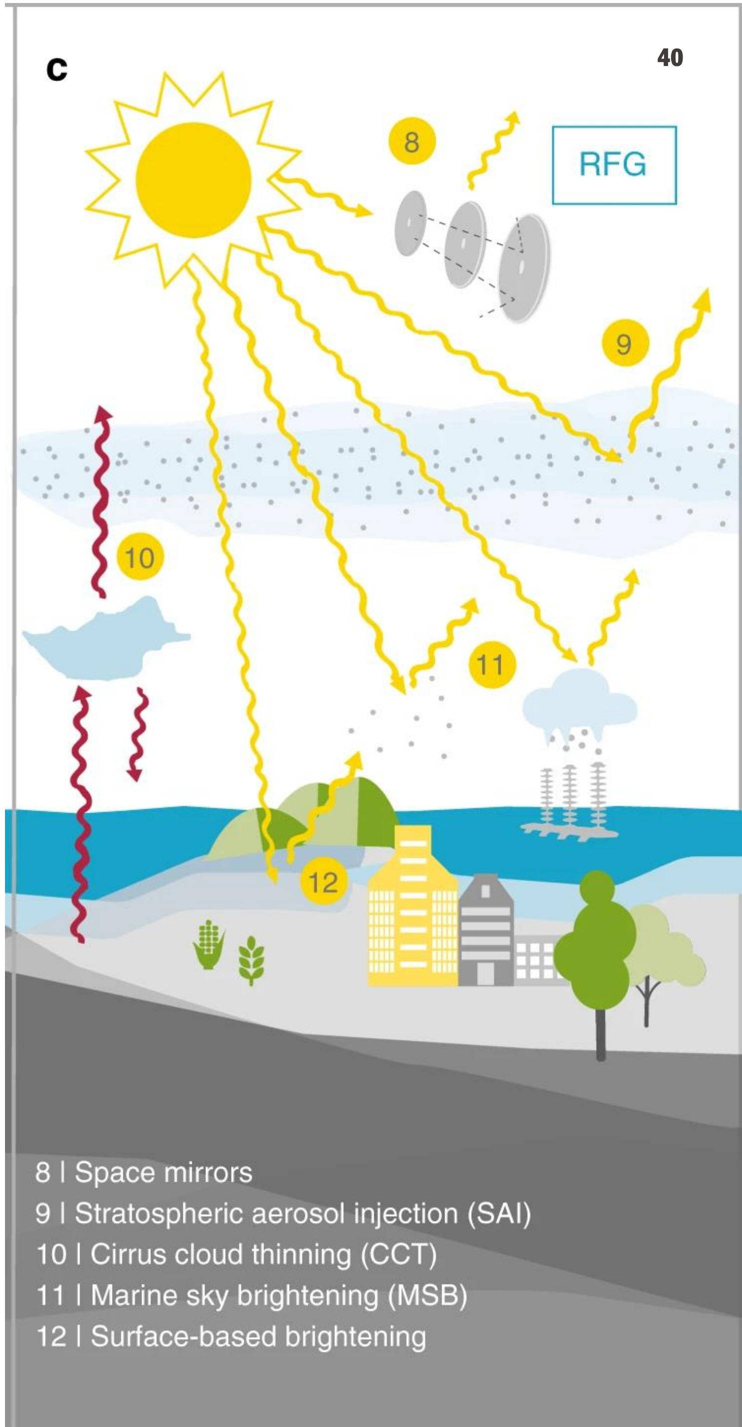
- keep solar radiation from being absorbed on Earth
- → reflect it to space

Options

- Space mirrors
- Stratospheric aerosol injection (mimicking a volcano)
- Cirrus cloud thining
- Marine sky brightening
- Surface-based brightening

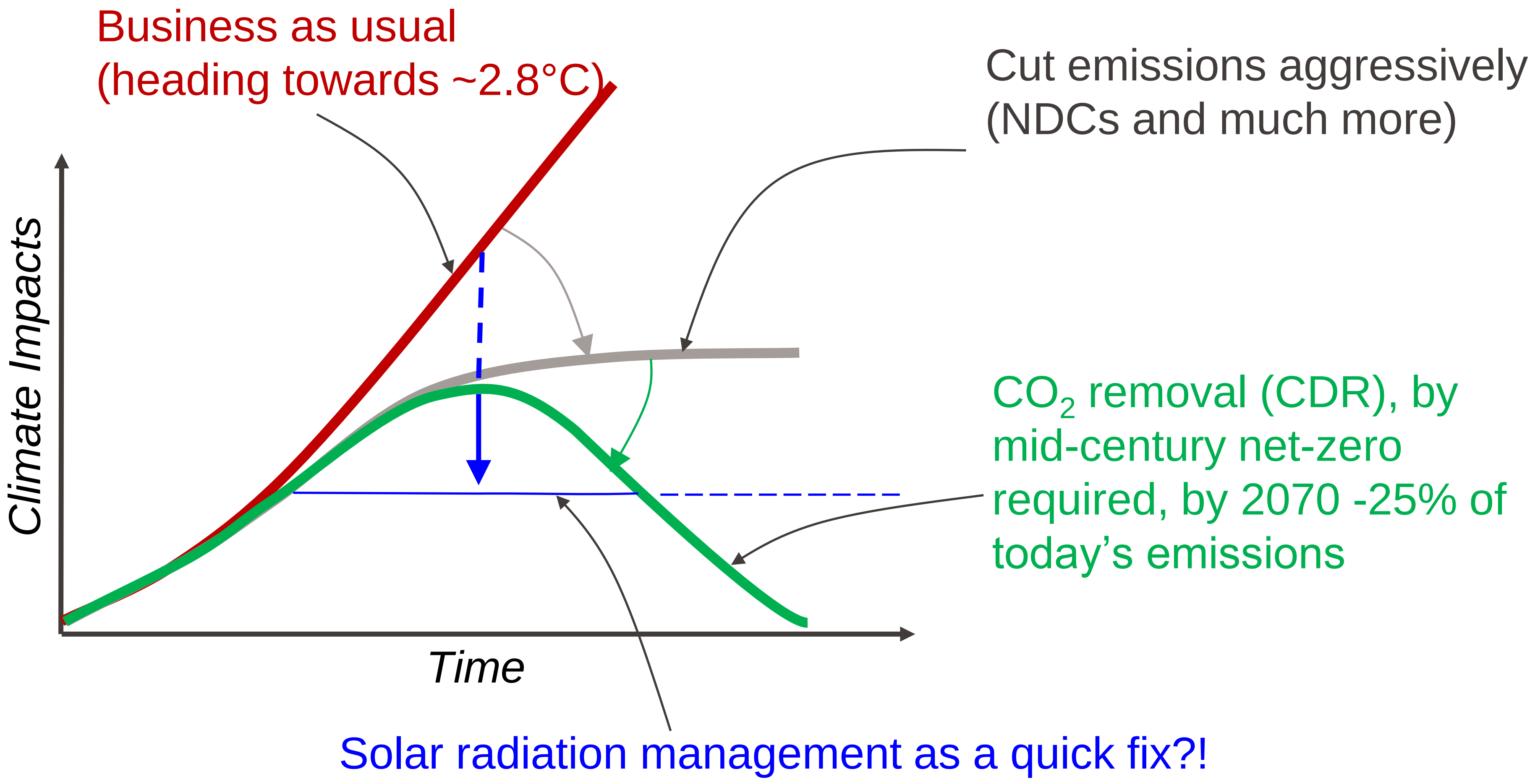
Concerns

- Adverse effects not fully known
- No governance, no legal framework → Who decides?
- Many other…



- Lawrence et al. (2018)

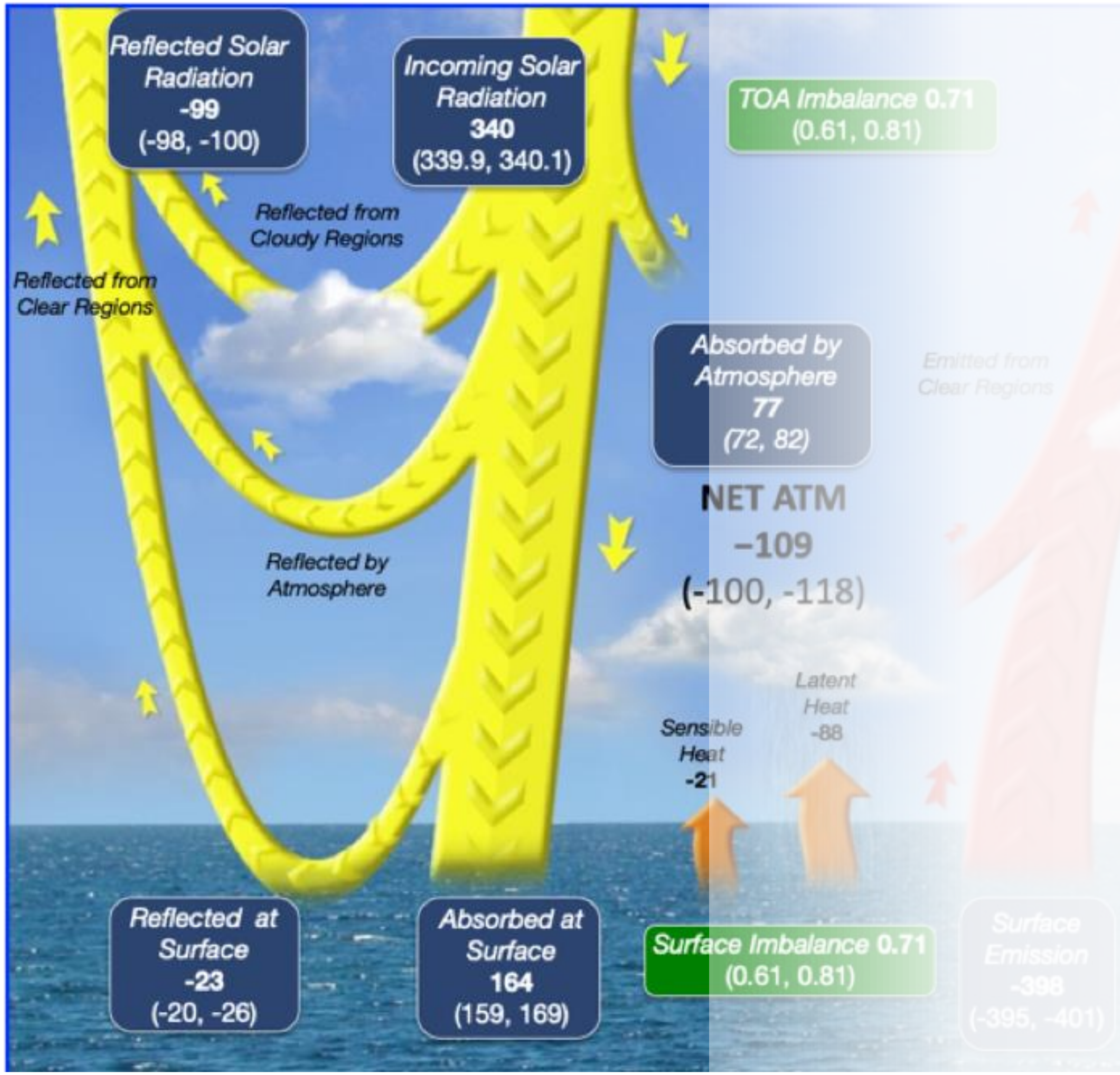
Solar radiation management



- **SHEPHERD, J 2010 The 'napkin diagram' of multiple responses to climate change** http://jgshepherd.com/wp-content/uploads/2011/01/Napkin-diagram.pdf

NDCs … nationally determined contributions

What would solar radiation management have to deliver?



Back of the envelope estimation

Incoming solar radiation: $\mathbf{S_0}$~340 W/m^2
Earth's average albedo: **α** ~0.3
→ 70 % of S_0 are absorbed → $\mathbf{S_e}$~240 W/m^2

If we increased **α** by 1% (absolute)
→ 69 % of S_0 are absorbed → $\mathbf{S_e}$~235 W/m^2

With the Stefan-Bolzmann law we can derive Earth's equivalent black body temperature T_E
→ T_E ~255 K @ 240 W/m^2 *
→ T_E ~254 K @ 235 W/m^2 *

Increasing Earth's albedo by 1 % would result in ~1 °C cooling.

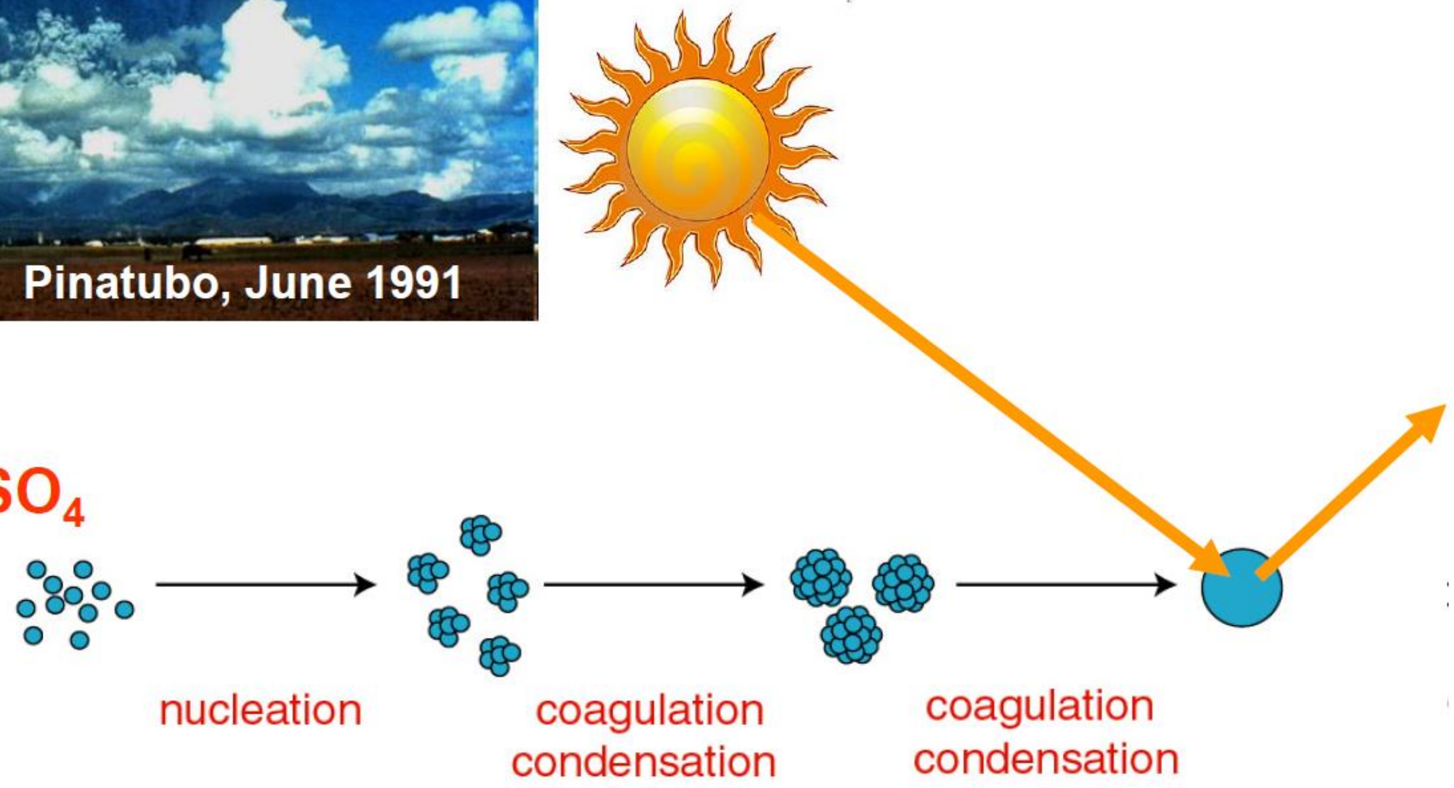
Real-world reference: The Mt. Pinatubo eruption injected 20 Tg SO_2 into the stratosphere. One year later ~0.3 °C [0.1 – 0.5°C] cooling were observed.

https://ceres.larc.nasa.gov/science/

* Not accounting for the natural greenhouse effect.

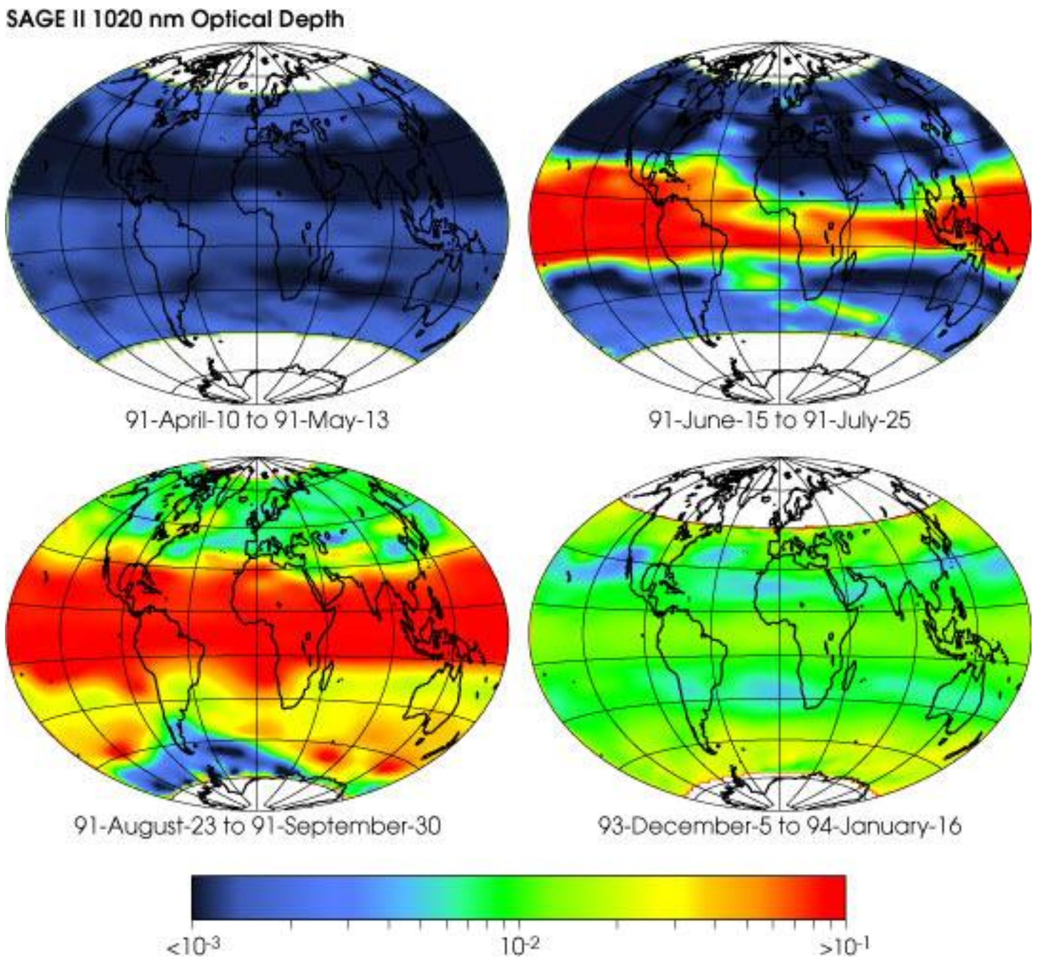
Stratospheric Aerosol Injections

Mimicking volcanoes:
About 20 Million tons of SO_2 injected into the stratosphere.

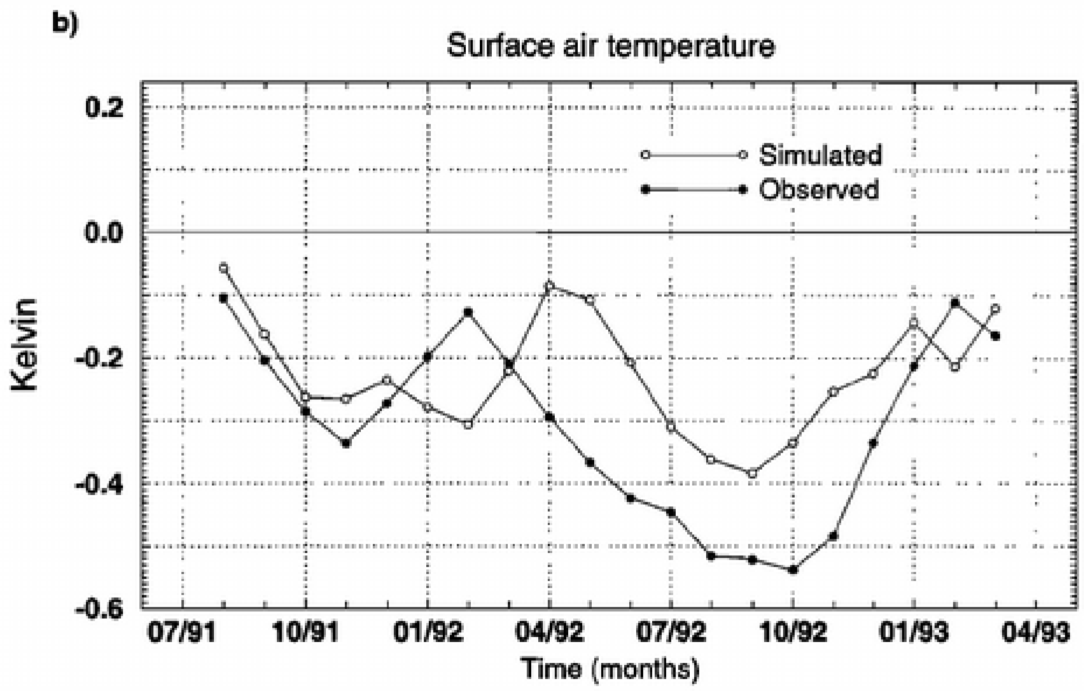


Temperature effect of Mt. Pinatubo eruption

15 June 1991

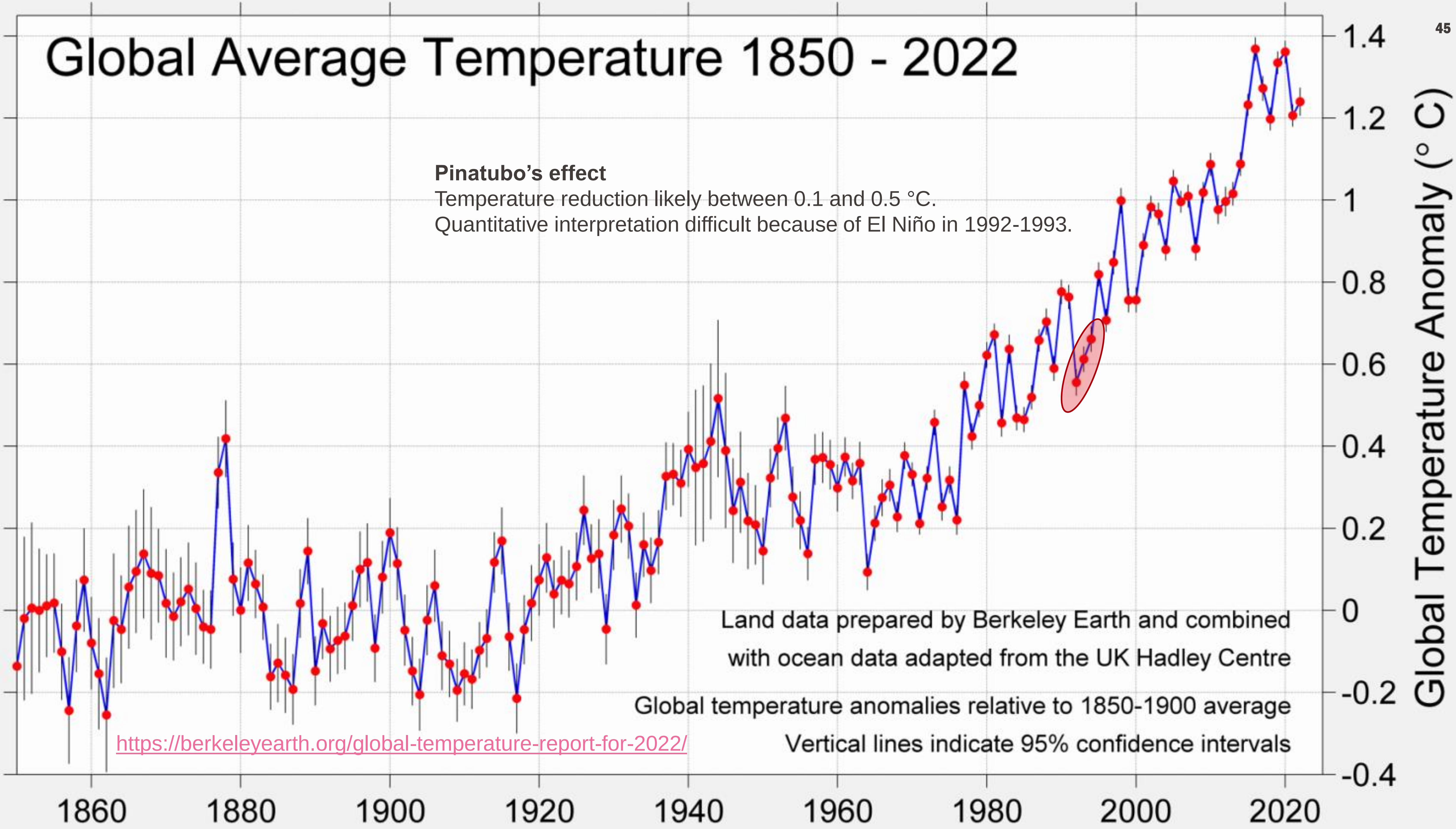


Global cooling 1 year later.

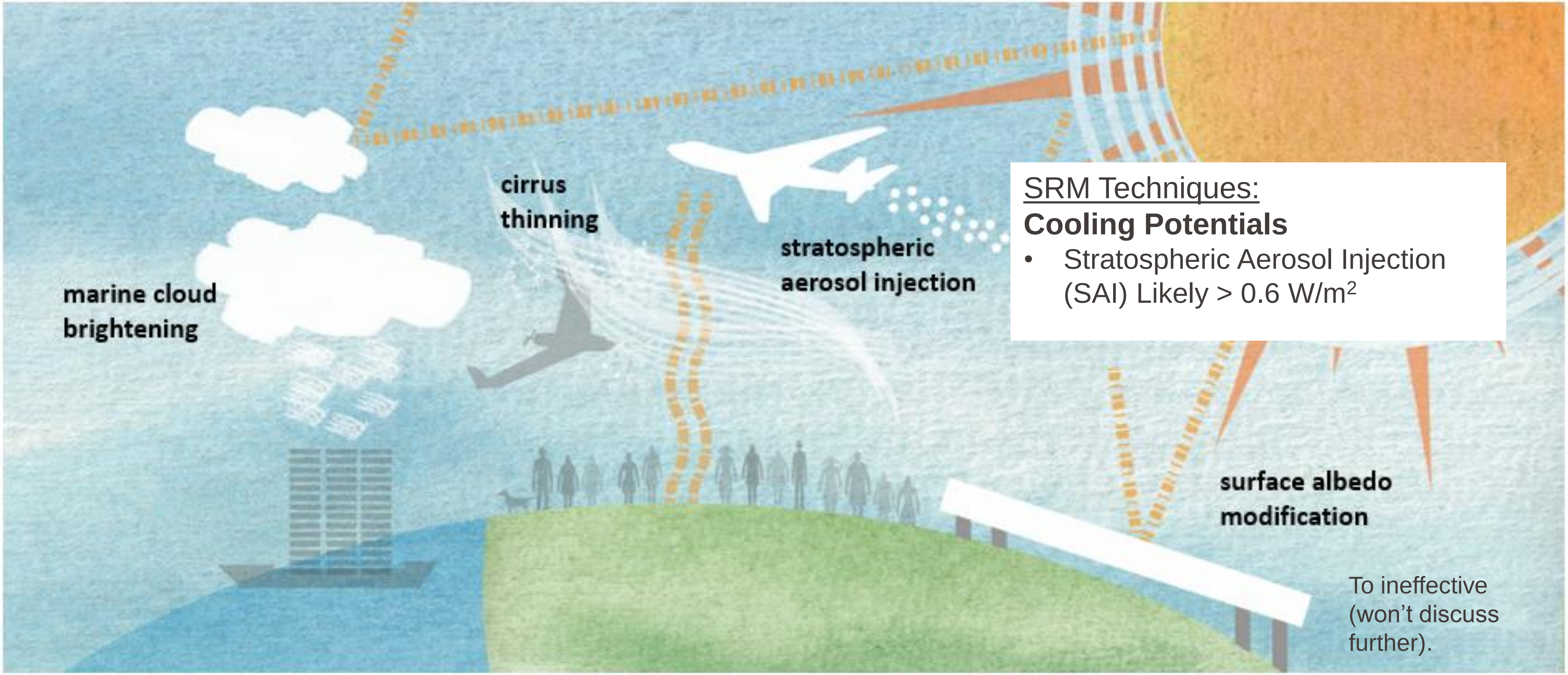


https://earthobservatory.nasa.gov/images/1510/global-effects-of-mount-pinatubo

https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/1999JD900213, Kirchner et al., 1999, JGR


Global Average Temperature 1850 - 2022
Pinatubo's effect
Temperature reduction likely between 0.1 and 0.5 °C.
Quantitative interpretation difficult because of El Niño in 1992-1993.
Land data prepared by Berkeley Earth and combined
with ocean data adapted from the UK Hadley Centre
Global temperature anomalies relative to 1850-1900 average
Vertical lines indicate 95% confidence intervals
https://berkeleyearth.org/global-temperature-report-for-2022/
Global Temperature Anomaly (° C)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
1860
1880
1900
1920
1940
1960
1980
2000
2020

Solar Radiation Modification (SRM) concepts



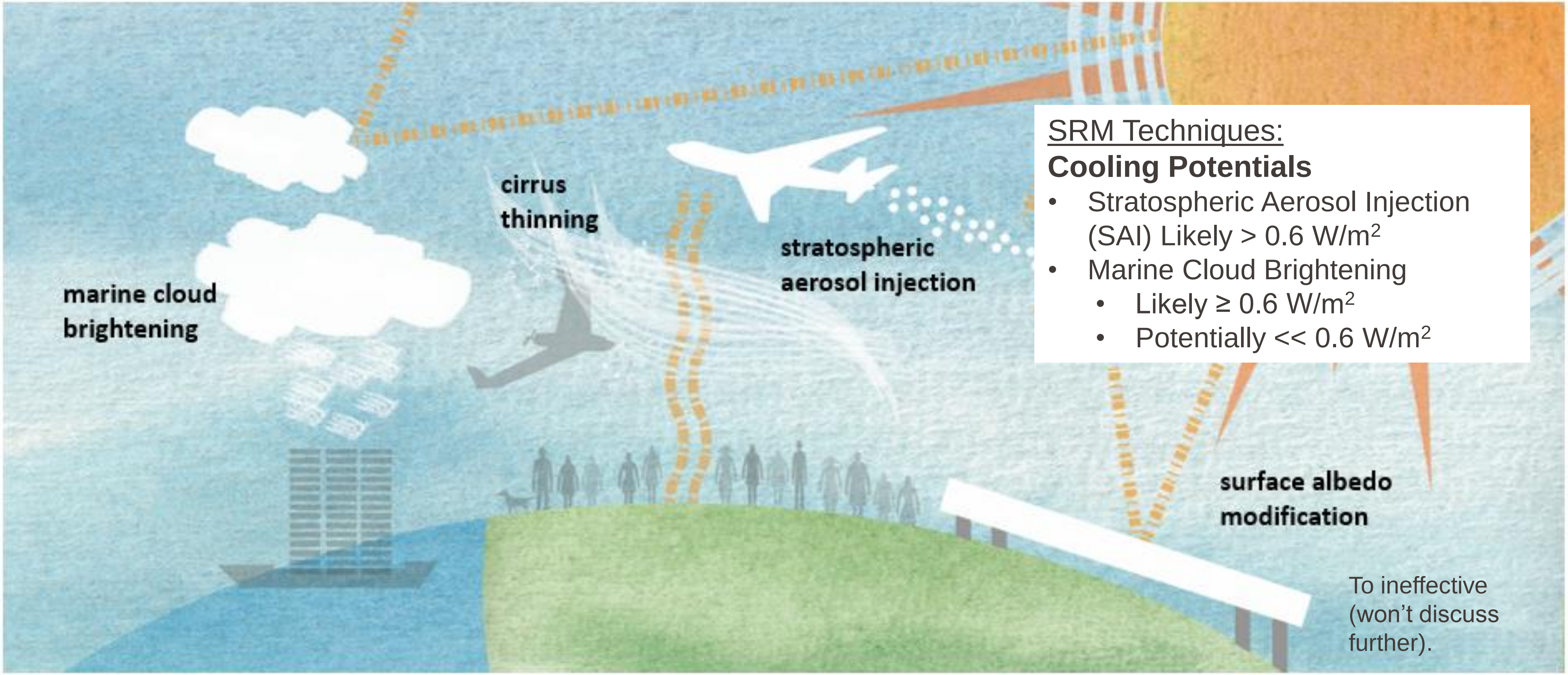
SRM Techniques:

Cooling Potentials

- Stratospheric Aerosol Injection (SAI) Likely > 0.6 W/m^2

To ineffective (won't discuss further).

C2G Solar Radiation Modification (SRM) concepts

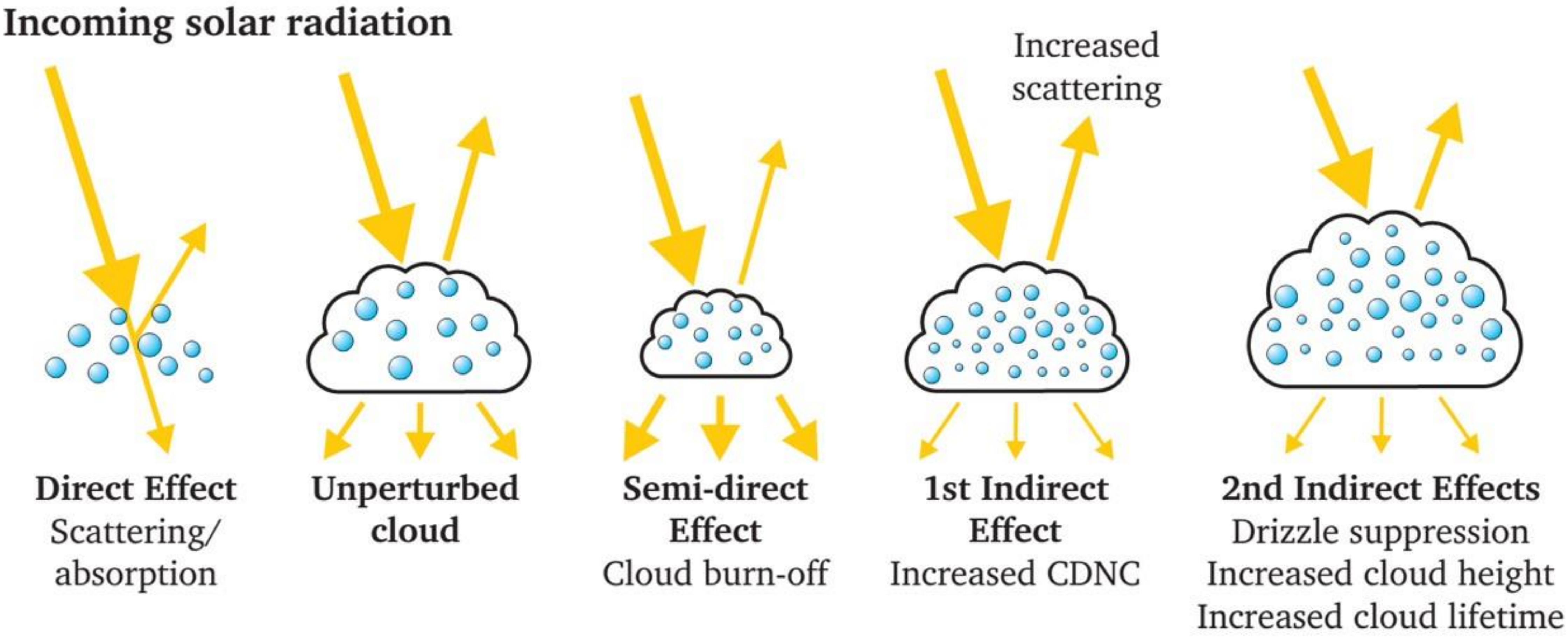


<u>SRM Techniques:</u>
Cooling Potentials

- Stratospheric Aerosol Injection (SAI) Likely > 0.6 W/m^2
- Marine Cloud Brightening
  - Likely ≥ 0.6 W/m^2
  - Potentially << 0.6 W/m^2

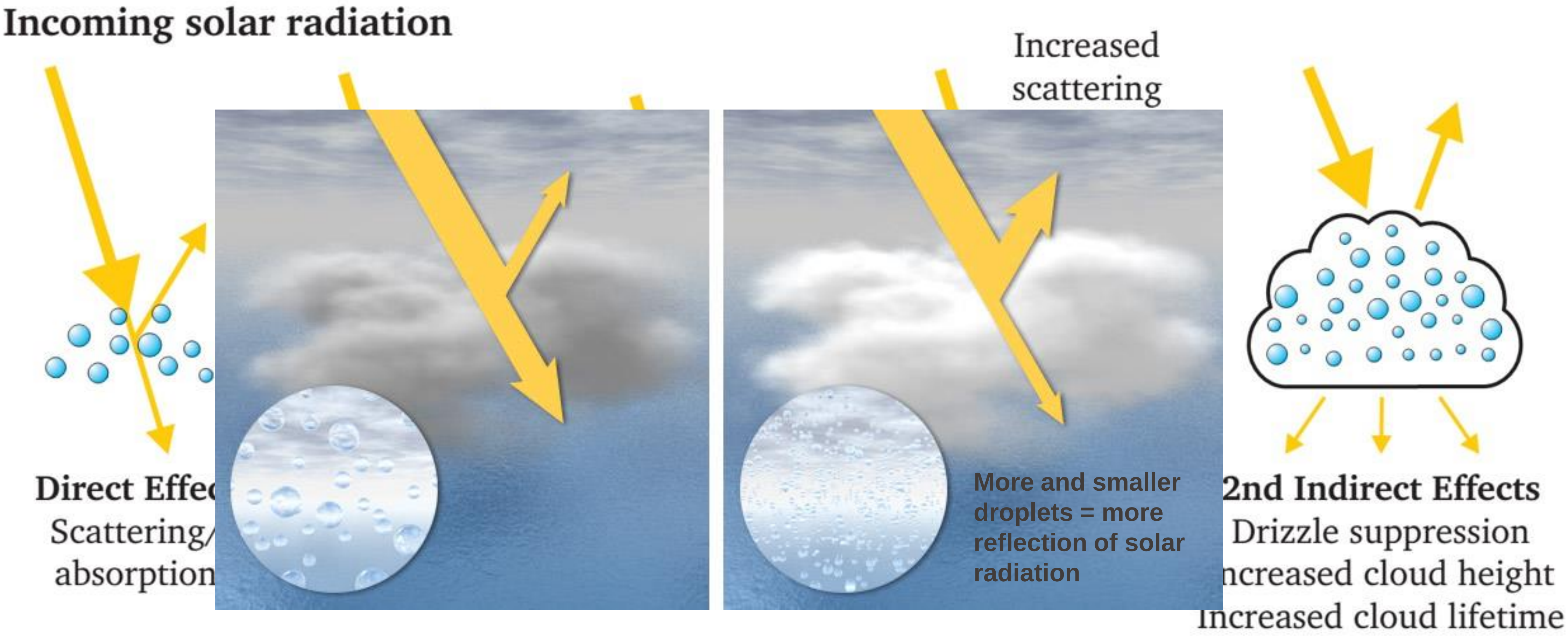
To ineffective (won’t discuss further).

Marine Cloud Brightening



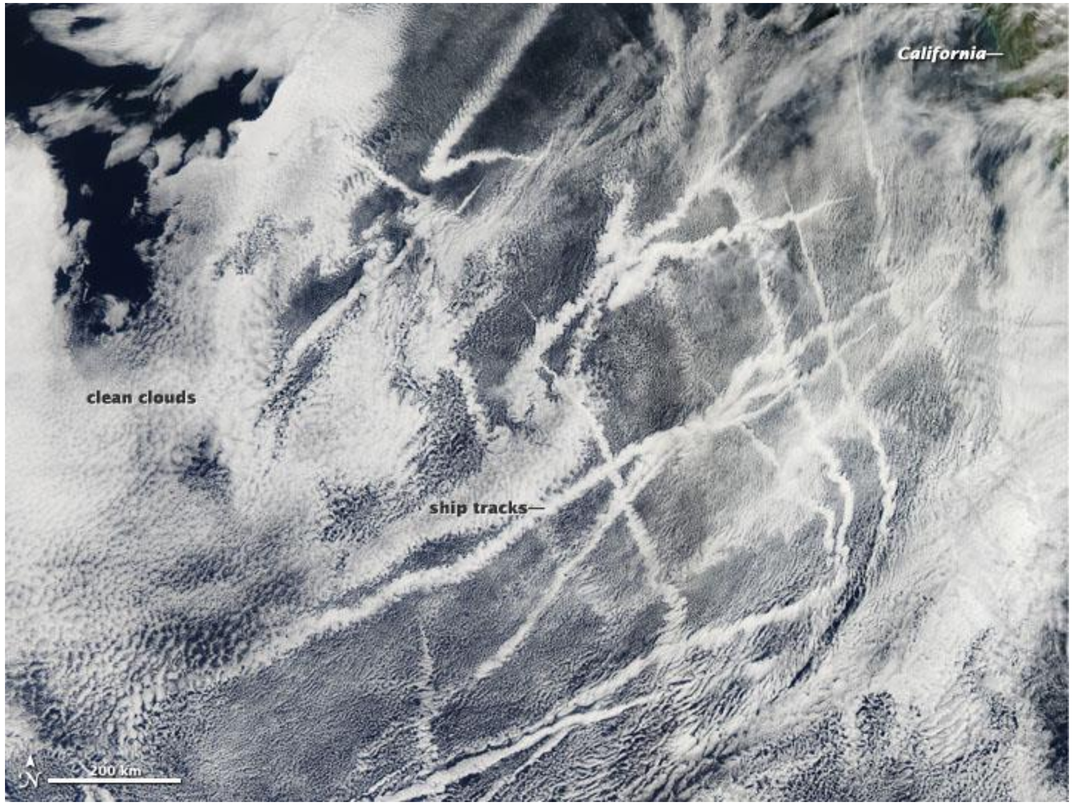
- https://earthobservatory.nasa.gov/features/Aerosols/page4.php

Marine Cloud Brightening



- https://earthobservatory.nasa.gov/features/Aerosols/page4.php

Marine Cloud Brightening



- First proposed by Latham (Nature, 1990)
- Twomey effect: more cloud condensation nuclei (CCN) → smaller droplets → brighter clouds
- Observed extensively with ship tracks…
- …also possible using sea salt spray?

- Ca. 40% of Oceans already covered by marine stratus clouds
- Many uncertainties: Effectiveness? Side Effects?

- https://earthobservatory.nasa.gov/images/77345/ship-tracks-off-the-california-coast, https://royalsocietypublishing.org/doi/10.1098/rsta.2012.0086

Solar Radiation Modification (SRM) concepts

<u>SRM Techniques:</u>

Cooling Potentials

- Stratospheric Aerosol Injection (SAI) Likely > 0.6 W/m^2
- Marine Cloud Brightening
  - Likely ≥ 0.6 W/m^2
  - Potentially << 0.6 W/m^2
- Cirrus Cloud Thinning (CCT)
  - Potentially ≥ 0.6 W/m^2
  - Potentially << 0.6 W/m^2
  - Potentially negative (i.e., warming)

Main issues:

- Geographically differing temperature and precipitation responses
- Detailed scientific understanding lacking
- Implementation challenges
- Governance & societal challenges

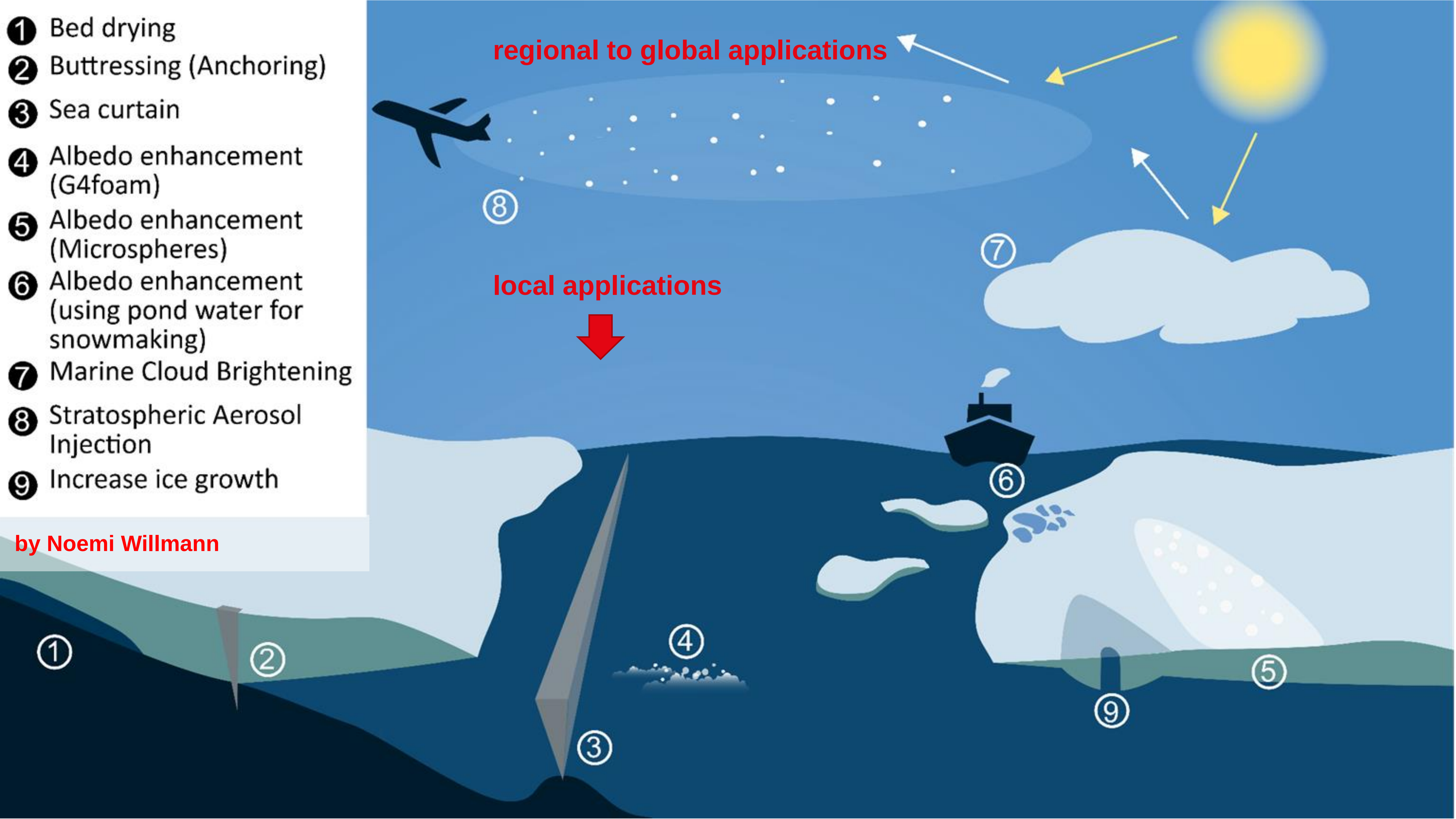
Summary for solar radiation management (SRM)

- Some techniques might be able to cool the planet quickly, possibly at relatively low implementation costs (< 100 Bn €/yr), but…:
  - Many uncertainties: technology, effectiveness, side effects
  - Uneven regional impacts on temperature and precipitation
  - May detract from addressing other impacts of increasing CO_2 (esp. ocean acidification)
  - Numerous ethical concerns regarding a “just” or “sustainable” implementation, making governance very difficult
  - SRM also cannot be relied on to contribute significantly to staying below 2°C before the second half of the century (i.e., likely too late for achieving the Paris Agreement)

Emerging technologies

- This is an artistic illustration, not reality

Image: Faris Rajak Kotahatuhaha, https://edition.cnn.com/style/article/refreeze-arctic-design-scn/index.html



1 Bed drying
2 Buttressing (Anchoring)
3 Sea curtain
4 Albedo enhancement (G4foam)
5 Albedo enhancement (Microspheres)
6 Albedo enhancement (using pond water for snowmaking)
7 Marine Cloud Brightening
8 Stratospheric Aerosol Injection
9 Increase ice growth
by Noemi Willmann
regional to global applications
local applications
8
7
6
4
5
9
1
2
3

EPFL

Why we seriously need to pay attention to Polar climate intervention

- Recent panel discussions at GESDA and Arctic Circle have shown **increasing pressure to find intervention solutions** to the climate crisis, fueled by potentially large investments
- Strong **positive attitude by some industry representatives. Start-ups** are forming to implement climate intervention
- **Strong push from NGOs**, e.g. Operation Arctic in Finland, **young generation**
- **Scientists publish proposal for non-use agreement** (Biermann et al. 2022 https://doi.org/10.1002/wcc.754)
- **Scientists publish a Glacial Climate Intervention research vision:** https://climateengineering.uchicago.edu/wp-content/uploads/2024/05/Glacial-Climate-Intervention_A-Research-Vision.pdf

There is not much regulation.
Action could happen suddenly.
The scientific community cannot ignore the topic.

gesda

geneva science and diplomacy anticipator

ARCTIC CIRCLE

Arctic science-policy-business conference

make sunsets

https://makesunsets.com/

CLIMATE REPAIR CAN STILL SAVE OUR GENERATION

Example: Albedo modification of sea ice

- Covering key areas with **Hollow Glass Microspheres (HGM)** to **enhance albedo** of young ice.
- Initial small-scale field tests in 2014-2017
  - Higher albedo for treated area, delay in ice melting
- To cover 25,000 km^2 in a monolayer 300,000 t/year needed → 12 g / m^2 / year

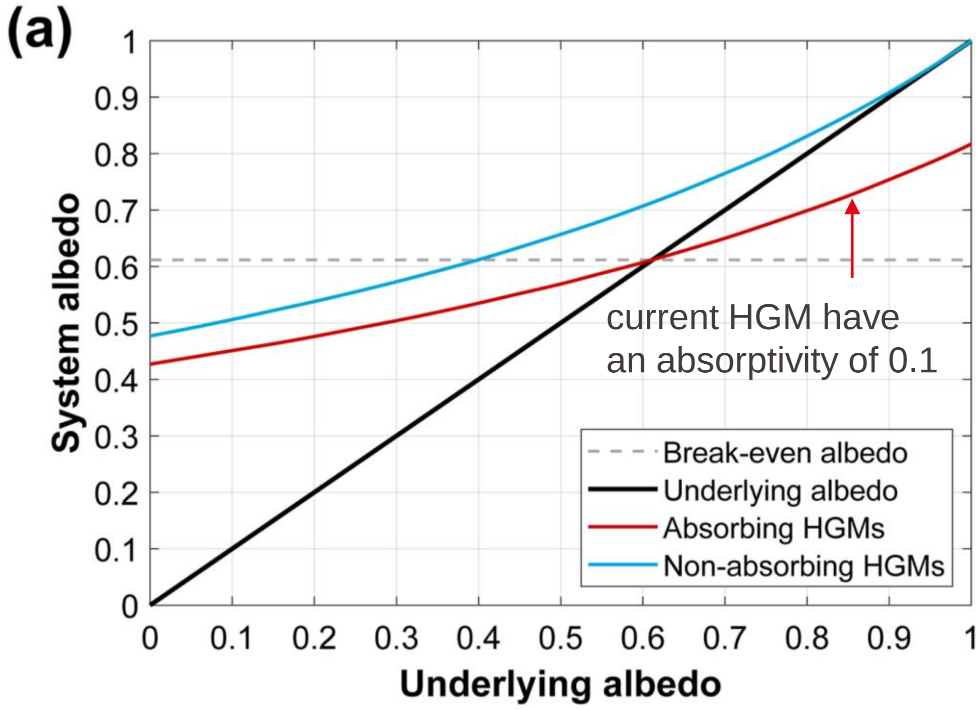
ARCTIC ICE PROJECT

Field et al. (2018), www.arcticiceproject.org

© Ned Rozell, 2019, https://www.gi.alaska.edu/alaska-science-forum/powdery-idea-reduce-sea-ice-loss

© Kathryn Hansen, 2011, NASA Goddard Space Flight Center, https://www.flickr.com/photos/gsfc/6151061591/in/album-72157626302085681/

Example: Albedo modification of sea ice



Webster and Warren (2022)

- Model simulations by a “response” study show that HGM would darken surfaces with albedo > 0.61.
- HGMs would be most efficient on melt ponds during summer
  - Dark water
  - Intense sunlight
- HGMs get blown to pond edge
  - Melting of snow covered ice
  - Would lead to net warming
- “real-world” effect could be “warming” rather than “cooling”.

Example: Albedo modification of sea ice

- **Criticized** that Indigenous Peoples were not consulted enough. Twelve tribes and >25 organizations signed a letter against the project.

- **Scientific concerns:**
  - Leaching of Silica observed → Potential dissolution of HGMs in seawater over time
  - Changes in biogeochemistry
  - Influence on light below ice
  - Aerosol exchange into atmosphere
  - Impact on the blooming of algae
  - Fate of the HGMs after deployment unknown
  - …

- Project is **back in the lab** after initial field tests. Field studies to resume once HGM methodology is deemed "scientifically sound"

- Needs better integration of Indigenous Peoples
- No response to the criticism on the method.
- **At least there was one scientific "response-study"!**

General Considerations on mitigation

- Effective mitigation will **not be achieved if individual agents advance their own interests independently**.
- There **are issues of equity, justice, and fairness** that arise with respect to mitigation and adaptation.
    - Countries' past and future contributions to the accumulation of GHGs in the atmosphere are different, and countries also face varying challenges and circumstances, and have different capacities to address mitigation and adaptation. The evidence suggests that outcomes seen as equitable can lead to more effective cooperation.
- Many areas of climate policy-making **involve value judgements and ethical considerations**.
    - These areas range from the question of how much mitigation is needed to prevent dangerous interference with the climate system to choices among specific policies for mitigation or adaptation. Social, economic and ethical analyses may be used to inform value judgements and may take into account values of various sorts, including human wellbeing, cultural values and non-human values.
- Climate policy may be informed by a consideration of a **diverse array of risks and uncertainties**, some of which are difficult to measure, notably events that are of low probability but which would have a significant impact if they occur.
- The design of climate policy is influenced by **how individuals and organizations perceive risks and uncertainties and take them into account**.