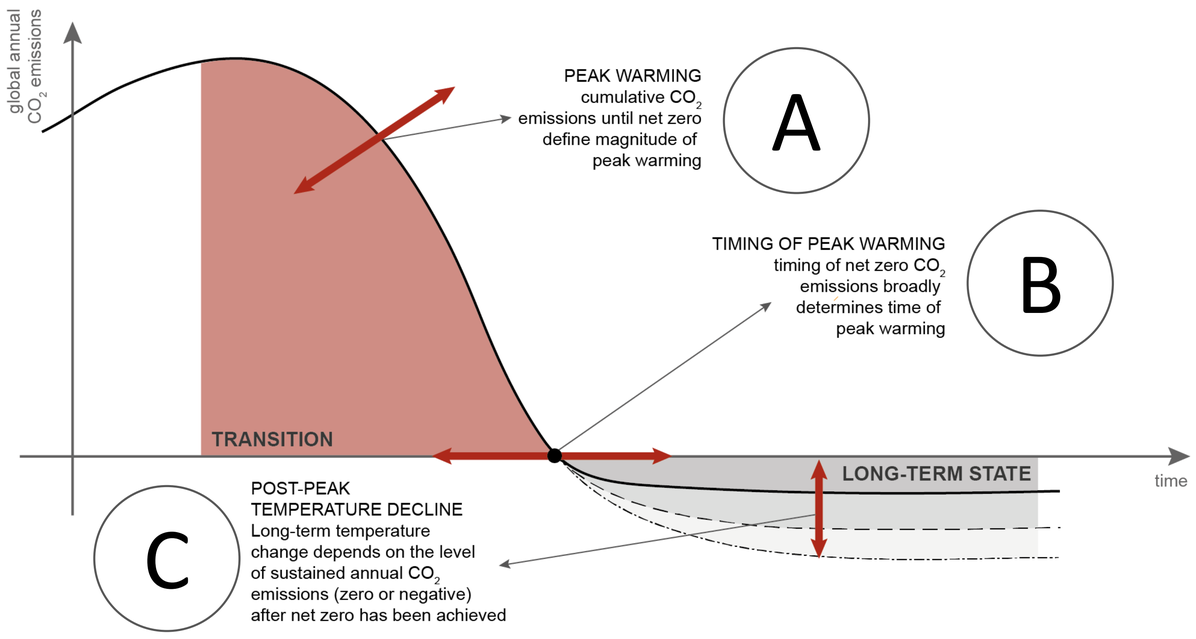
The importance of Carbon Dioxide Removal (CDR) for reaching Paris Climate Goals: Current research activities and new insights

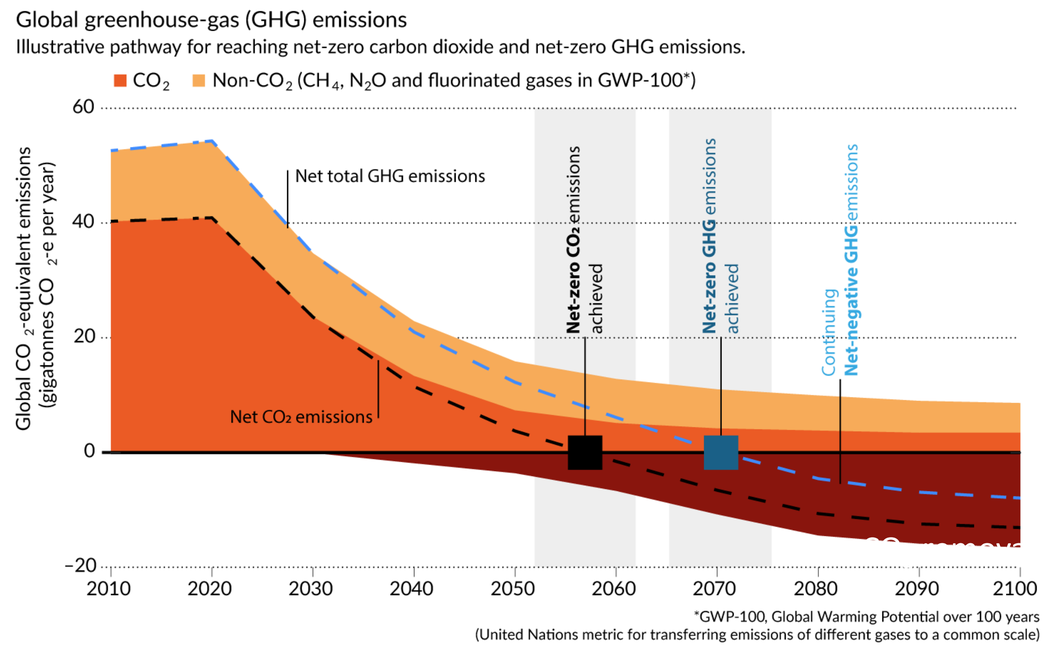
The global warming outcome of mitigation pathways is determined by three key elements



Rogelj et al., A new scenario logic for the Paris Agreement long-term temperature goal Nature 10.1038/s41586-019-1541-4 (2019)

CO_2 removal (CDR) plays several important roles

1) Reaching **net zero CO2 emissions**
2) Reaching **net zero greenhouse gas (GHG) emissions**, which involves net negative CO2 emissions
3) Further reducing emissions to reach **net negative GHG emissions**



Rogelj et al., Net-zero emissions targets are vague: three ways to fix, Nature 10.1038/d41586-021-00662-3 (2021)

A + C Deeper emissions reductions until 2030 lower peak warming and reduce the reliance on CDR

- Weaker emissions reductions until 2030 result in higher transitional challenges in the next two decades and a higher reliance on CDR
- Strengthening the NDCs reduces costs as well as [illegible]cal and climate risks
- 1.5°C requires a combination of all three efforts: high near-term ambition, fast emission reduction 2030-2050, and a certain level of CDR.

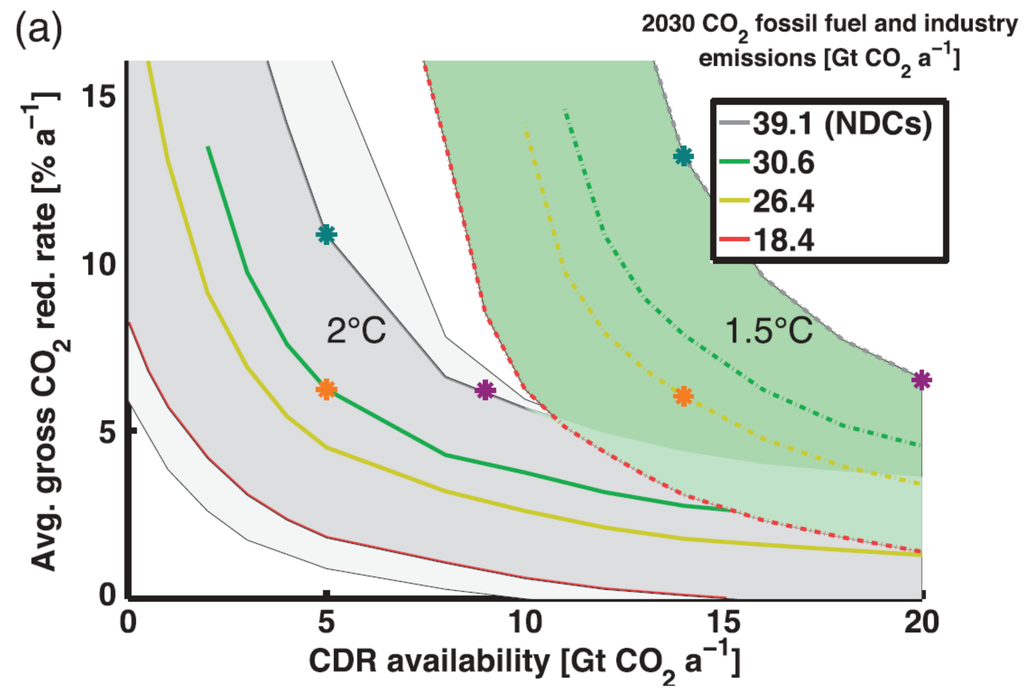


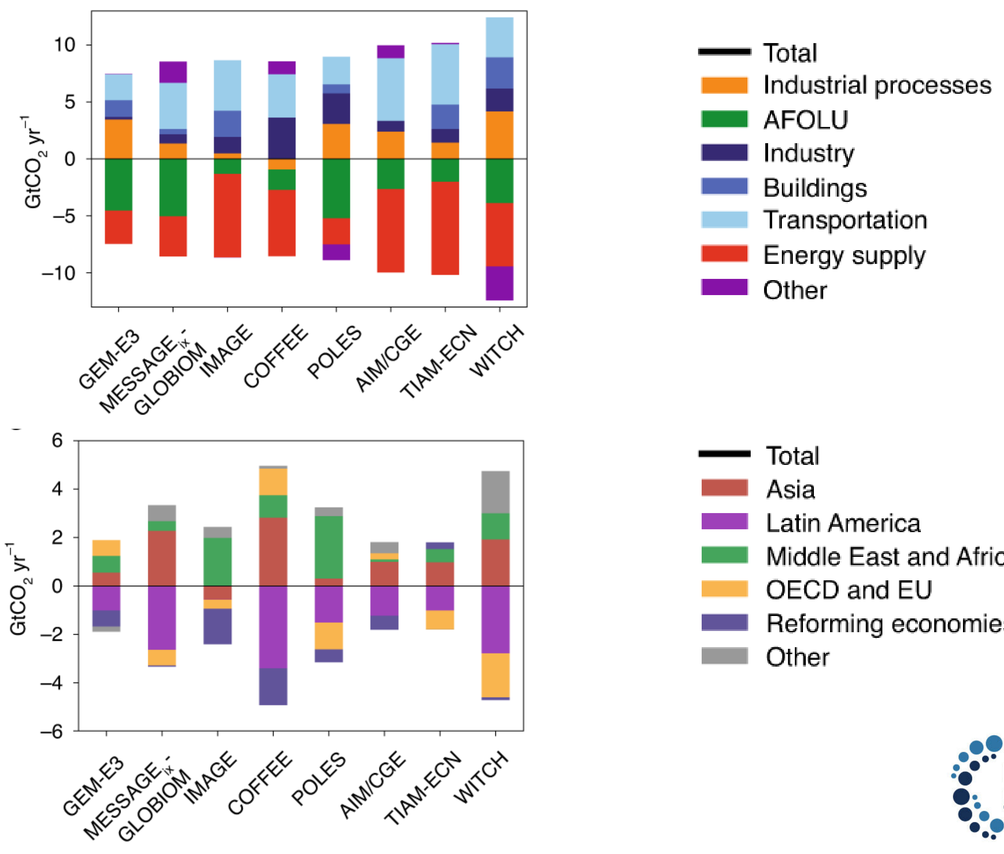
Figure: Trade-off between emissions reductions in 2030, transitional challenges in 2030-2050, and CDR availability for limiting warming to 2 °C (solid lines) or 1.5 °C (dashed lines).

Strefler et al., Between Scylla and Charybdis: Delayed mitigation narrows the passage between large-scale CDR and high costs, Env. Res. Letters 13(4)

B Not all net zero worlds are created equal

Reaching net zero CO2 emissions globally can be achieved in a variety of ways that differ in:

- Their residual gross CO2 and required CDR contributions
- The relative and absolute contributions of different sectors
- The regional distribution of residual gross CO2 emissions and CDR contributions



Riahi et al., Cost and attainability of meeting stringent climate targets without overshoot, Nature Climate Change 10.1038/s41558-021-01215-2 (2021)

B + C CDR potentials are distributed unevenly across the globe raising important technical and equity issues

- Most Integrated Assessment Models (IAMs) include only a limited number of CDR options, such as BECCS and/or re- and afforestation (AR)
- Regional potentials of CDR options differ widely and can lead to imbalances and strong differences in regional strategies (see figure), e.g. Enhanced Weathering of rocks (EW) and AR.
- Development of a CDR portfolio can balance regional deployment and reduce risks.

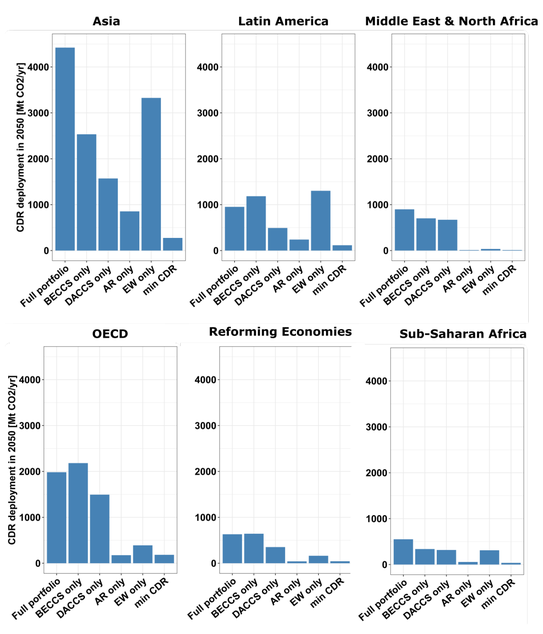


Figure: Regional CDR deployment in 2050 for scenarios with availability of either only BECCS, DACCS, Enhanced Weathering of rocks (EW), or re- and afforestation (AR), all options (full portfolio), or minimal amounts of CDR from current policies and industry BECCS (min CDR).

Strefler et al., Carbon dioxide removal technologies are not born equal, ERL, 2021.

Outlook: current and future research activities

Several research projects just started:

- **CDRterra (BMBF) - investigation of CDR options** such as agroforestry, soil carbon sequestration, biochar, and also innovative technologies like photoelectrochemical carbon capture or long-lived materials, including an evaluation framework and sustainable CDR roadmaps for Germany and Europe.
- **CDRmare (BMBF) – investigation of ocean CDR options** such as ocean alkalinity enhancement, artificial upwelling, and also offshore carbon storage.
- **ERC Project: GENIE** (environmental, technical, social, legal, ethical and policy dimensions of CDR)
- **EU horizon projects**: NEGEM (Quantifying and Deploying Responsible Negative Emissions in Climate Resilient Pathways), LANDMARC (Land Use Based Mitigation for Resilient Climate Pathways), OceanNETs (ocean-based CDR technologies), ESM2025 (understanding resilience of land-based CDR approaches), PROVIDE (assessing the risk of CDR and overshoot)

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