Policy Brief

New scenarios shed light on the role of carbon dioxide removal

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RESCUE

Summary

New scenarios shed further light on the role of carbon dioxide removal in 1.5°C scenarios with and without overshoot to support ambitious policy making

Carbon dioxide removal (CDR) has an important role to play in keeping 1.5°C within reach. It is therefore important to deepen the understanding of CDR: the total deployment, the timing and scale-up speed of the deployment, and the CDR portfolio and its feasibility, to to limit warming to certain levels with and without a temporary exceedance ("overshoot"), and the associated climate impacts and risks, to support effective policy making.

Based on newly developed scenarios from the European project RESCUE, we find that:

- While CDR deployment is necessary, **stringent emissions reductions from fossil fuels and deforestation** account for the largest share in emissions reductions to limit warming to 1.5°C.
- Limiting warming to 1.5°C with **no or low overshoot requires an early CDR ramp up**, while a high overshoot would require significantly more CDR, especially towards the end of the century, to draw temperatures back down.
- **Limiting overshoot can limit overall reliance on CDR**, while a high overshoot would entail significantly higher CDR deployment. Scaling up CDR comes with sustainability and feasibility constraints.
- **High overshoot pathways come with much higher climate risks and impacts** compared to pathways with lower overshoot.
- CDR would need to be **ramped up in countries' NDCs**, as part of more ambitious 2030 and new and ambitious 2035 targets, which separate out CDR.

New scenarios to study CDR portfolios for 1.5°C

RESCUE develops new CDR scenarios that look at a core portfolio of four CDR options: **Afforestation/reforestation**, **Bioenergy with carbon capture and storage (BECCS)**, **Direct air carbon capture and storage (DACCS)**, and **ocean alkalinity enhancement**. Since ocean alkalinity enhancement is a particularly uncertain CDR option, we test having it available or not. Due to the uncertainty of ocean alkalinity enhancement, more research can shed light on whether it should be considered as part of a broader CDR portfolio [1].

Figure 1 shows the annual and cumulative emissions, temperature, and the emissions and removals from different sources, for each of the scenarios.

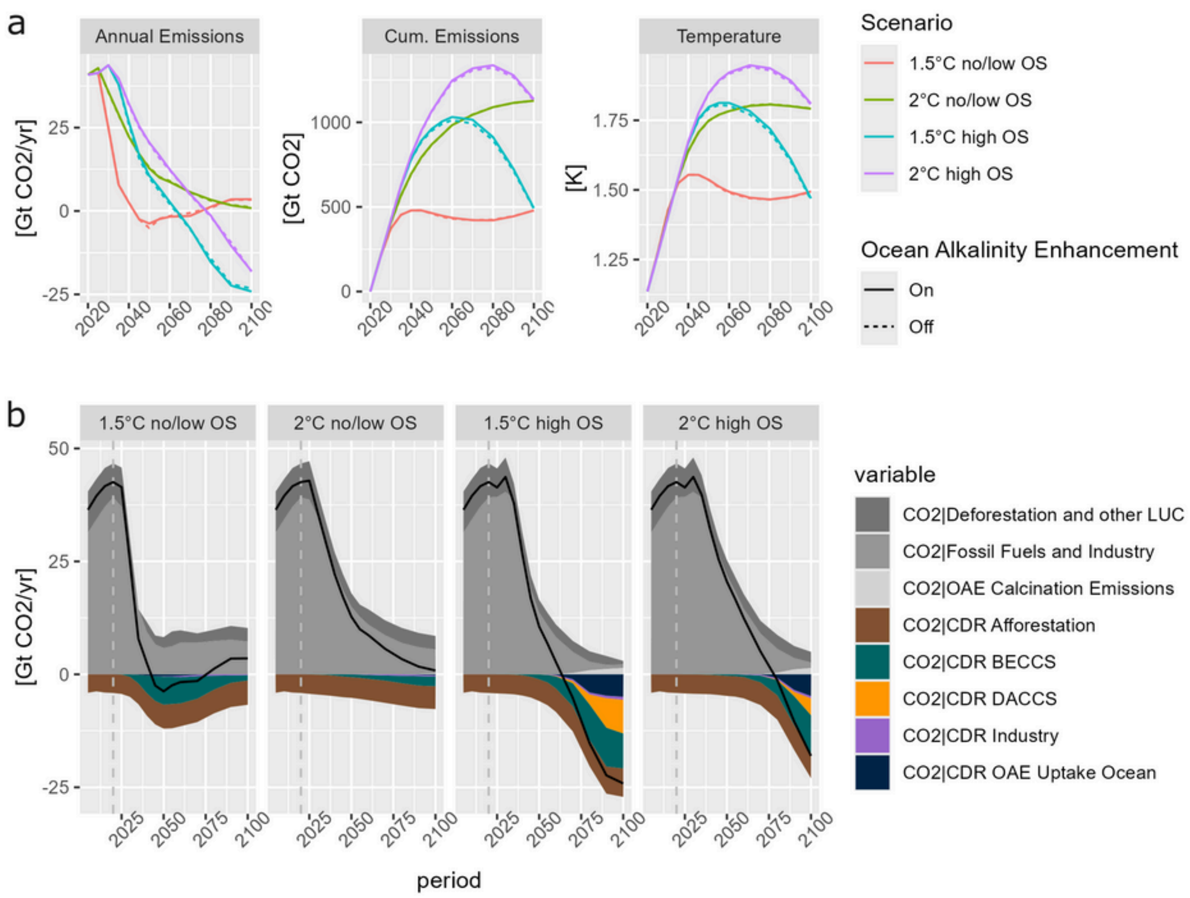

Figure 1. a) Annual and cumulative (from 2020) anthropogenic CO_2 emissions and temperature response for the eight different scenarios: 1.5°C with no/low overshoot, 2°C with no/low overshoot, 1.5°C with high overshoot, 2°C with high overshoot, each with ('on') / without ('off') ocean alkalinity enhancement (OAE) available. b) Emission profiles of the scenarios with OAE available, from different sources, as well as removals. Black lines denote net CO_2 emissions.

CDR options

Afforestation/reforestation is considered a conventional CDR method, while BECCS, DACCS, and ocean alkalinity enhancement are considered novel. They vary with regards to the capture process, where the carbon is stored, the maturity of the method and its costs, the mitigation potential, and the timescale of storage [2]. There is uncertainty around how much CDR is currently taking place but estimates put it at around 2 gigatonnes of CO_2 (Gt CO_2) per year, almost exclusively from the conventional methods from land use, land use change and forestry. Novel methods make up less than 0.1% of total CDR but are growing more rapidly [2-4].

See our Climate Classroom for an introduction to the CDR options.

As Figure 1 shows, in terms of **total CDR deployment**, limiting warming to 1.5°C with no or low overshoot requires an early CDR ramp up: Already in 2040, 5.5 and 5.7 Gt CO_2 per year are being stored in underground geological formations, without and with ocean alkalinity enhancement available, respectively. To achieve that, very high storage scale-up rates are necessary, with capacity additions of up to 500 megatonnes of CO_2 (Mt CO_2) every year between 2030 and 2050, given that the annual capacities used for novel CDR are virtually zero at the moment [2]. While 1.5°C no/low overshoot would require around 500 Gt CO_2 of cumulative CDR this century, a high overshoot of 1.5°C would require significantly more CDR (around 750 Gt CO_2), especially towards the end of the century, to draw temperatures back down. High overshoot would also mean a higher energy demand for CDR (DACCS and ocean alkalinity enhancement), and also the economic conse-quences are drastic as high scale-up rates would need to be maintained for a long time.

A low overshoot of 1.5°C requires very quick scale-up of CDR in the near term to reduce net CO_2 emissions sufficiently fast. Without the CDR necessary, emission reductions would not be enough to limit the overshoot. The required CDR deployment comes with considerable feasibility concerns. Returning to 1.5°C after a high overshoot of about 0.3°C would entail less near-term CDR deployment, but much larger removals in the second half of the century. Such large-scale CDR after 2050, especially at the magnitudes in high overshoot pathways, also comes with limitations in terms of feasibility, considering current levels of deployment, and sustainability [5].

Importantly, there are **climate impacts and risks associated with the magnitude and duration of overshoot**. It is important to not just consider the destination (the warming limit) and when it will be achieved, but also the journey there. Overshoot has impacts on humans and ecosystems, which can be long-lasting or even irreversible, including for sea level rise, and critical thresholds in the Earth system ("tipping points") can be reached for example in the cryosphere or for biodiversity [6,7].

To hedge against the possibility of the climate system warming more than expected, there might also be the need for additional, **preventive CDR** capacity of several hundred gigatonnes of net removals, which could be of a similar order of magnitude as the capacity already deployed in these 1.5°C pathways with no or low overshoot [7].

As for the **timing of CDR deployment and reaching net zero CO_2**, the 1.5°C no/low overshoot scenarios with ocean alkalinity enhancement reach net zero CO_2 around 2043. This is broadly in line with previous benchmarks from the IPCC, which put the year of net zero CO_2 emissions around mid-century for 1.5°C pathways [8]. A high overshoot above 1.5°C would shift the year of net zero CO_2 by 20 years to around 2063. Delaying emissions mitigation does not necessarily enable a slower CDR ramp-up, but only shifts years of strong growth to the future.

The **CDR portfolio** shows that afforestation/reforestation plays a critical role for near-term mitigation in the current decade to limit warming to 1.5°C, while novel methods scale until mid-century and beyond – but this also differs substantially depending on whether there is an overshoot or not. To achieve 1.5°C with no or limited overshoot, an immediate and steep reduction in emissions from fossil fuels and industry is required. There is a fast switch to bioenergy crops in the next few decades. In case of a high overshoot above 1.5°C, a broad technical CDR portfolio is required, that includes the more speculative options of DACCS and ocean alkalinity enhancement next to afforestation/reforestation and BECCS. With a high 1.5°C overshoot, there would be a lot (500 Mha) of additional forest until 2100. If ocean alkalinity enhancement is available, this technology is used as a substitute for DACCS, because these two technologies have similar systemic properties, including similar amounts of energy required.

CDR to be ramped up in countries' NDCs

The predominant role of afforestation/reforestation in (especially near-term) deployment in our scenarios is also reflected in countries' climate plans: afforestation/reforestation and revegetation were among the most frequently indicated options in countries' **Nationally Determined Contributions (NDCs)** as of 2023 [9]. While many countries proposed expanding land-based removals, in what can be considered an over-reliance on land, none had yet committed to scaling novel CDR methods. Recent research found that the CDR in almost all of the different kinds of scenarios that limit warming to 1.5°C is higher than the CDR efforts proposed by countries [10]. There has been an increase in the share of countries mentioning ecosystem restoration and afforestation/reforestation in NDCs as of 2024 compared to previous years [11].

This further underscores the need for CDR to be ramped up in national policies and NDCs. For the next round of NDCs to be submitted, with more ambitious 2030 targets and new and ambitious 2035 targets, there continues to be the need for sectoral plans and targets, and separating out land use and forestry as well as other CDR by type [12].

At the same time, it is important to keep in mind that the land-based carbon sink cannot compensate for CO_2 emissions from fossil fuel use, especially considering the declining forest carbon sink due to unsustainable forest management and climate impacts. Reducing fossil fuel and deforestation emissions accounts for the largest share in gross GHG emissions reductions until global net zero CO_2, regardless of the warming level to be achieved. Phasing out fossil fuels, alongside ending deforestation, must therefore remain the priority, in order to **keep pathways to 1.5°C open** [13-16].

Scenarios

In RESCUE, scenarios that limit warming to 1.5°C with a likelihood of 50% have a remaining carbon budget of 500 Gt CO_2 from the beginning of 2020, while scenarios that limit warming to 2°C with a likelihood of 67% have a remaining carbon budget of 1150 Gt CO_2 from the beginning of 2020. Note that continuing emissions since 2020 have further shrunk the budgets. Scenarios with no or low overshoot are not allowed to exceed the prescribed carbon budget; implementation of climate policies starts immediately. High overshoot scenarios temporarily exceed the carbon budget and return to the budget by the end of the century via large-scale CDR; mitigation starts later, only around 2035. This allows comparing the reversibility of climate impacts between scenarios with no/low overshoot and high overshoot. All greenhouse gas (GHG) emissions are covered by a comprehensive pricing policy. For instance, the policy covers emissions and removals from the energy and industry, as well as the land-use sector [17].

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