Chapter 8

Technical Annex

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A8.1 *The State of CDR* 3rd Edition Scenario Protocol

The purpose of this scenario protocol is to facilitate a coordinated model intercomparison assessment of the role of CDR strategies in achieving the Paris Agreement temperature goal. Developed within the framework of the *State of CDR* project, this protocol aims to inform the scientific community, policymakers, industry, and the private sector about the status, feasible potential, and systemic implications of deploying various CDR methods under alternative climate policy pathways.

Our goal is to assess modelled scenarios with broadly harmonized scenario inputs and modelling assumptions across integrated assessment modelling (IAM) teams globally, ensuring transparency and comparability in exploring critical sensitivities beyond CDR methods, including their feasibility, sustainability, and interactions with energy, land, and broader Agenda 2030 goals.

In this context, we aim to assess the role of CDR approaches across three distinct scenarios:

1. **Targets & Pledges:** A pathway consistent with currently implemented policies and nationally determined contributions (NDCs) and long-term low greenhouse gas emission development strategies (LT-LEDS) submitted under the Paris Agreement (excluding the United States, in line with estimates from the 2025 UNEP Emissions Gap Report). Policy effort beyond stated targets should be maintained at equivalent levels (e.g. constant carbon prices).

2. **Highest Ambition:** A pathway reflecting the highest feasible level of near-term mitigation ambition, consistent with achieving net-zero greenhouse gas emissions before 2100[i] and limiting peak warming to well below 2°C, with efforts towards 1.5°C.

3. **Delayed Ambition:** A transition pathway in which mitigation follows *Targets & Pledges* in the near term and shifts to *Highest Ambition* after a delay of approximately 10 years (from around 2035). The pathway should explicitly reflect the consequences of postponed mitigation, including increased dependence on CDR.

For each of the scenarios, modelling teams are asked to include all CDR approaches that can be presented in their model, consistent with the taxonomy proposed in the 3rd Edition of *The State of CDR* report (see below).

[i] Regional net zero timings should not be later than those adopted in LTSs (scenario 1).

Characteristics of CDR methods

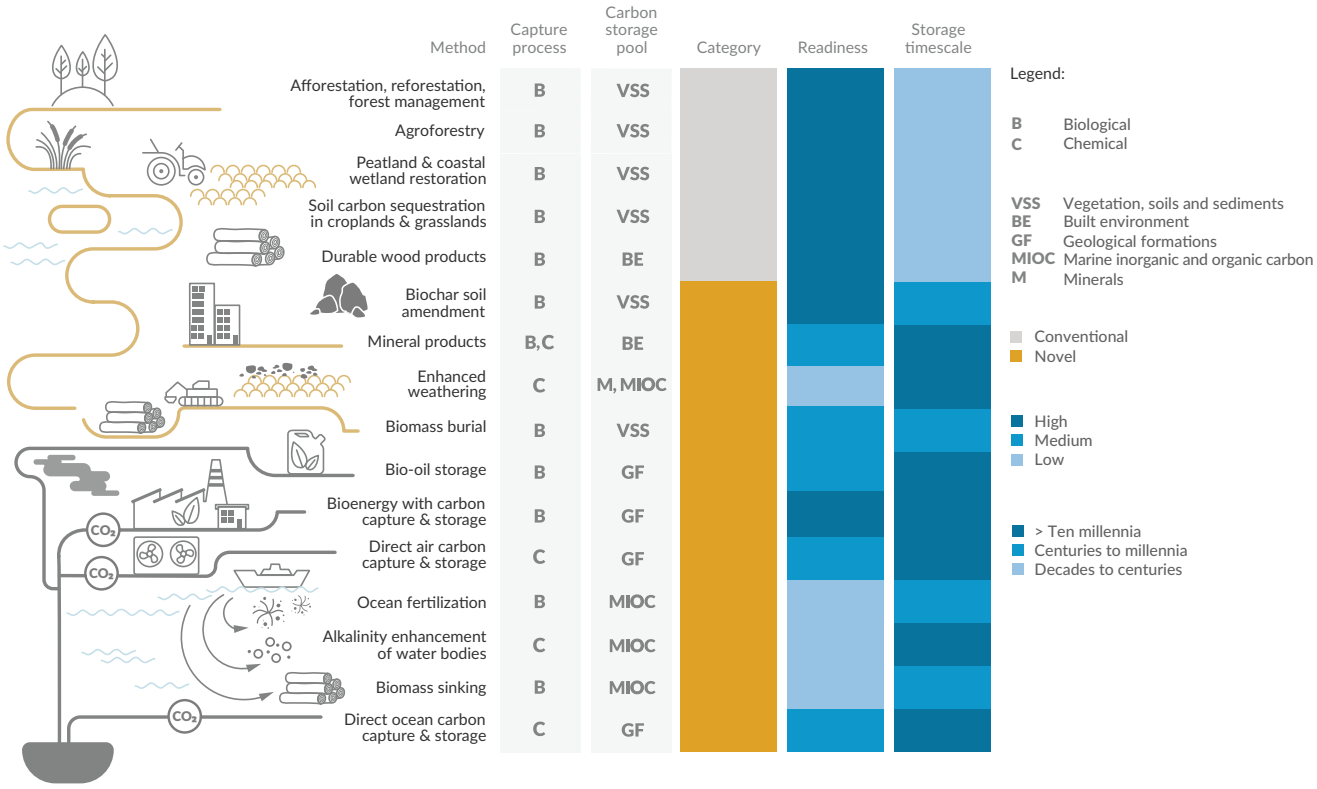

Figure 1.3 *Summary of CDR methods, noting their respective capture process and storage carbon pool, categorizations as "conventional" or "novel", and characteristic storage timescale. Mineral products here include aggregates, asphalt, cement and concrete as well as biogenic CO_2 from BECCS or biochar applied in building materials.*

Socioeconomics

To enable full comparability across scenarios, modelling teams are asked to prioritize submissions using the latest SSP2 socioeconomic projections (population, GDP, urbanization, inequality, etc.). If teams have the capability for further sensitivities, we ask that they prioritize SSP1 assumptions of technoeconomic and other parameters, ensuring alignment with the three scenario definitions, and consistency with overall SSP narrative assumptions. The main goal is to harmonize socioeconomics and maximize comparability across model frameworks.

Sustainability

We ask teams to apply, to the extent possible, their interpretation of the sustainability considerations as outlined in the SDG, especially related to land-use and forestry for the *Highest Ambition* scenario. This should include considerations of increasing energy efficiency, minimizing or eliminating population at risk of hunger, returning to levels of biodiversity similar to pre-industrial, and minimizing residual emissions from fossil and non-CO_2 GHG sources.

To the extent possible, we ask teams to follow assumptions of the SDP-EI pathway from Soergel et al. 2024[1] for the Highest Ambition scenario and request that key sustainability indicators are of similar magnitudes by at least 2100 in the *Delayed Ambition* scenario. Where teams decide to deviate from these, we request that they explicitly document how and why deviations occur.

In order to assess comparability between model results we request that teams:

1. **Provide explicit documentation of sustainability assumptions:** Teams are required to clearly state the sustainability assumptions applied in their scenario narratives and quantifications, at a minimum at the global level. These assumptions should include, but are not limited to, land-use practices, dietary shifts, energy access, poverty alleviation, biodiversity conservation, and GHG emissions trajectories. Where relevant, regional-level assumptions may also be included.

2. **Minimum sustainability criteria:** The following basic sustainability conditions should be met in scenarios *Highest Ambition* (as soon as possible) and *Delayed Ambition* (in the second half of the century):

   — Global population at risk of hunger is reduced to near-zero levels

   — Final energy per capita improves (decreases) continuously and reaches at least 40-60% reduction by 2100 relative to 2020.

   — Deforestation halts, net forest area is at least maintained globally, and there are strongly positive trends in biodiversity restoration, aiming for species abundance and ecosystem services.

   — Dependence on biomass for energy services is limited in line with above considerations.

   — Residual GHG emissions from fossil fuel use and agricultural non-CO_2 sources are constrained in line with sustainability-compatible levels (as in SDP-EI).

- Equitable access to modern energy services and basic infrastructure is ensured for all regions by mid-century.

3. **Default sustainability assumptions:** For modelling groups that do not adopt or specify alternative sustainability narratives, we suggest adopting the SDP-EI pathway assumptions from Soergel et al. 2024 as the default. These include ambitious but achievable levels of international cooperation, global convergence of living standards, moderate dietary changes (e.g. reduced ruminant meat consumption), stringent land-use safeguards, and a coordinated global effort to meet sustainability targets across multiple sectors.

Feasibility

All scenarios should explicitly account for the feasibility of CDR and related carbon management deployment, guided by available scientific literature. Specifically:

- **CCS Scale-Up:** Teams are requested to include realistic assumptions regarding the scale-up of carbon capture and storage (CCS), based on current literature (see *CCS Feasibility Limits* for some examples)

- **Carbon Storage Limits:** Cumulative geological CO_2 storage should not exceed approximately 1,460 $GtCO_2$ this century, following estimates from Gidden et al. 2025[2]. We ask teams to apply region-specific "Planetary Limit" values as provided in the "country" sheet of *Geologic Carbon Storage*. Scenarios with lower ambition or slower action (e.g. *Delayed Ambition*) should assume significantly lower utilization of this storage potential. If teams choose to exceed these limits, we ask them to explicitly document how and why they choose to do so.

- **Land-Based Approaches:** The application of material on agricultural fields (e.g. biochar and enhanced weathering) should be limited to land biomes with no or minimal tillage, in order to enable maximum CO_2 uptake and ensure long-term carbon retention in soils. Additionally, other aspects related to buffering capacity, pH levels, and adequate precipitation and temperature conditions to support geochemical reactions that promote CO_2 removal should be considered.

- **Ocean-Based Approaches:** Deployment of ocean-based CDR methods should be limited to interventions within Exclusive Economic Zones with known and measurable carbon uptake above natural background fluxes, to ensure scientifically grounded accounting.

Permanence & Durability

We encourage teams to include non-permanent CDR if that is explicitly part of modelled mitigation strategies (especially, e.g., the built environment and other harvested wood products). We ask that teams do not model stochastic risk of release.

Sensitivity and Robustness Analysis

For teams who are interested, we will further explore scenario variants of scenario (2) along key dimensions:

1. Value of verification and permanence (reducing value of low-MRV approaches).

2. Importance of sustainability (how CDR portfolios change when multiple sustainability considerations are applied).

3. Reversibility (how CDR methods respond to environmental hazards including stochastic risk of release).

4. Regional differentiation in mitigation outcomes by running sensitivity cases where one model region at a time follows scenario 1 and all other regions contribute to a globally cost-effective solution.

5. Impact of socioeconomic assumptions (applying SSP1 socioeconomic assumptions).

Reporting Variables

In the provided variable templates, we provide variables in Tiers (1-3). We require variables in Tier 1 to be provided in scenario submissions (and should be set to 0 if teams do not explicitly consider that variable). We prefer teams to provide variables in Tier 2 if possible. Tier 3 variables are useful to have but not required. In general, we strongly recommend teams to provide as many variables as possible, consistent with their reporting in other scenario intercomparisons.

References

1. Soergel, B. *et al.* 2024 *Environ. Res. Lett.* **19** 124009. **DOI** 10.1088/1748-9326/ad80af.

2. Gidden, M.J., Joshi, S., Armitage, J.J. et al. A prudent planetary limit for geologic carbon storage. *Nature* **645**, 124–132 (2025). https://doi.org/10.1038/s41586-025-09423-y.