Report on previous allocation period

Project: **1241**
Project title: **Carbon Dioxide Removal**
Principal investigator: **Julia Pongratz**
Report period: **2025-11-01 to 2026-10-31**
Maximum of 2 pages including figures. 9 pt minimum font size.

During the 2025-2026 reporting period significant progress was made and DKRZ tools and resources have been crucial in this regard.

CDRSynTra Phase 2

- **New forest Plant Functional Types**: We have developed four new forest PFTs in MPI-ESM to distinguish newly established from pre-existing forest. This enables their carbon stocks, productivity, albedo, and water and energy fluxes to be modelled and analyzed separately. Model preparation and testing have been completed. Test simulations confirmed that the implementation is successful, and the new PFTs provide the diagnostics required for the planned attribution. The updated configuration is therefore ready for the simulations proposed for 2027.
- **Overshoot reversibility:** Building on our existing SSP5-3.4overshoot MPI-ESM simulations performed during the previous allocation periods, we have expanded our setup with simulations featuring: (a) dynamic vegetation biogeographical changes enabled, and (b) fixed aerosol forcing. This allows us to study the (ir)reversibility of the Earth system following overshoot, while isolating the effects of vegetation biogeographical changes and aerosols, which we have identified as potential sources of irreversibility.
- **Reforestation impacts**: We have expanded our analysis of our existing MPI-ESM ensemble featuring >120 simulations that was performed during previous allocation rounds. The relevant paper is close to acceptance in Nature Climate Change, following revisions. We have concluded our analysis on the impacts of reforestation on heat extremes (manuscript in preparation), and further investigated reforestation impacts on heat-mortality with collaborators at Imperial College London (manuscript in preparation).

WIEMIP

Our group joined the Warming-Induced Greenhouse Gas Emissions Model Intercomparison Project (WIEMIP), coordinated by Spark Climate Solutions (Dr. Ben Poulter), as a contributing modelling group with JSBACH3 standalone. All protocol simulations were completed, comprising the four 1pctCO2 simulations (spin-up, control, biogeochemically and fully coupled; 150 years each) for three different climate forcings (UKESM1-0-LL, IPSL-CM6A-LR, GFDL-ESM4), used to diagnose the carbon–concentration (β) and carbon–climate (γ) feedback parameters, and the climate overshoot simulations. The output has been submitted to WIEMIP for the multi-model synthesis informing IPCC AR7.

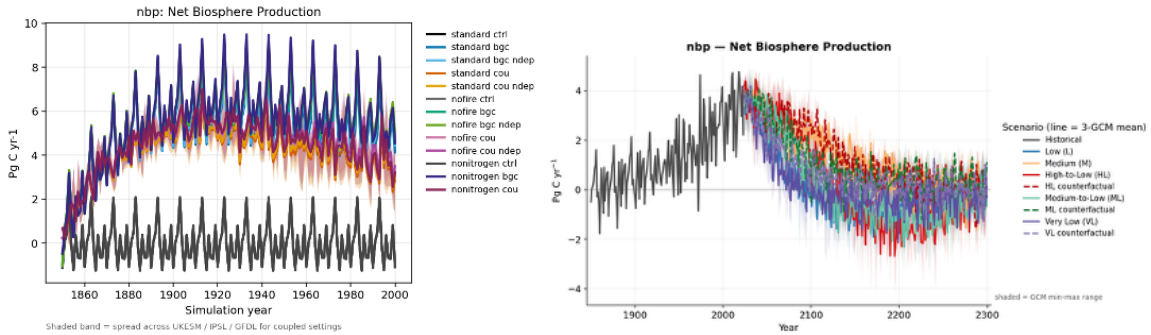


Figure 1. Net biome productivity (NBP) simulated by three general circulation models (GCMs) participating in WIEMIP, including the 1pctCO2 experiments and the overshoot experiments.

STEPSEC project

(1) Standalone land surface model-intercomparison for re-/afforestation (A/R) and bioenergy with carbon capture and storage (BECCS) (Nützel et al. in prep.)

Our model-intercomparison of future global standalone simulations, where a fixed amount of agricultural land in every grid cell is replaced by A/R or BECCS and is kept constant afterwards, is ongoing. This effort is led by Tobias Nützel and therefore post-processed output data of all involved land surface models is stored, processed and analyzed on Levante. Focus of this allocation period was to add data from two more

collaborating models (CLM, ORCHIDEE) to the already existing four models (JSBACH, JULES, LPJmL, LPJ-GUESS), resulting in a multi-model ensemble of 24 (CLM) to more than 100 simulations (JSBACH) per model on Levante. Additionally, a new routine was developed using DKRZ resources to post-process and compress the full output of LPJmL. Thereafter, output of all six models was regridded and harmonized for comparative analysis. Currently, two manuscripts, one focusing on across-model differences regarding A/R and one regarding BECCS, are in preparation.

(2) Implementation of improved representation of the fate of harvested wood in the bookkeeping model BLUE (Nützel et al. in prep.)

Our improved representation of the fate of harvested wood was implemented into the most recent version of the bookkeeping model BLUE. A set of simulations with historical global land use change were run to assess the impact of our improved scheme on global and regional land use CO_2 emission estimates and assess sensitivities to individual changes such as the treatmeant of slash, different product pools or product decay curves (manuscript in preparation).

(3) Machine learning modeling of socioeconomic constraints on afforestation and reforestation (A/R)-based carbon dioxide removal and future A/R projection (Bao et al., 2026; Bao et al. in prep.)

We have developed over 100 machine learning models through thousands of iterations of testing, training and validation, using multi-source high-resolution planted forest datasets and socioeconomic datasets to investigate the relations between current global A/R efforts and their socioeconomic constraints. One paper is published in One Earth led by Wenkai Bao, with Dr. Yiannis Moustakis and Prof. Julia Pongratz. This study finds that poverty, food insecurity, insecure land tenure, and weak governance emerge globally as the most important constraints. Around 73% of the estimated forest-based carbon removal potential lies in countries facing medium-to-high socioeconomic constraints (Fig. 2).

Besides, to robustly project future A/R trends, we expand our evaluation to more than 300 machine learning models by exploring various algorithms and variable combinations. We employed these models to project country-level A/R areas under different Shared Socioeconomic Pathways (SSPs), explicitly incorporating SSP-specific socioeconomic constraints that are often underrepresented in existing assessments. We show that the projected A/R expansion is more conservative than current widely-used A/R potential maps and scenarios, and more than half of the countries will be unable to meet their A/R pledges by 2060 in SSP2 current-policy scenario.

Utilization in teaching: research conducted using DKRZ resources has provided useful material for the Master's course "Land use seminar", at LMU's Department of Geography.

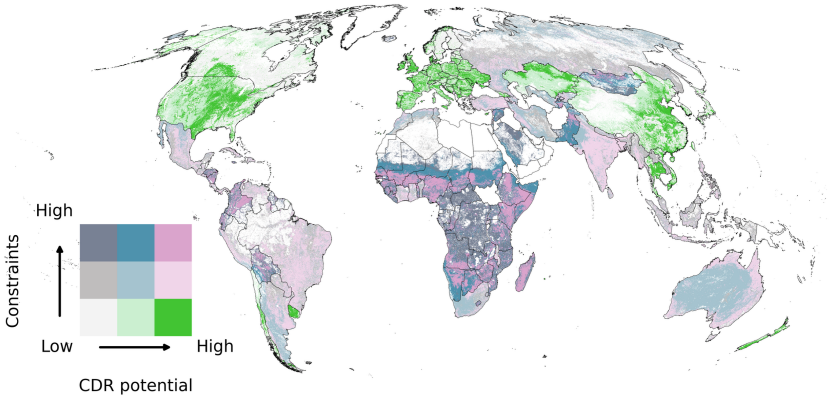


Figure 2. Literature-based and machine learning derived relative importance of socioeconomic constraints on A/R (upper panel). Arrow width indicates the importance of constraints. Global patterns of socioeconomic constraints and biophysical A/R-based CDR potential (lower panel), resulting from the overlay of model-derived socioeconomic risks with existing estimates of biophysical CDR potential.