Project: **1241**

Project title: **Carbon Dioxide Removal**

Principal investigator: **Julia Pongratz**

Report period: **2022-11-01 to 2023-10-31**

CDRSynTra

1. We developed an algorithmic process that allows us to design ambitious Afforestation/Reforestation (AR) scenarios, by harnessing information available under the AR6 Scenarios database. This allows us to take into account technoeconomic, environmental, and societal considerations.
2. We developed an Ocean Alkalinity Enhancement (OAE) scenario, with deployment over coastlines globally.
3. Based on scenarios generated in (1) and (2), we performed 97 fully-coupled MPI-ESM simulations, 85 model-years each (from 2015 to 2100) including:
    1. 40 Reference simulations across 4 emission trajectories, where land-use is held constant and 10 ensemble members for each trajectory.
    2. 40 AR simulations across 4 emission trajectories with AR is appliedand 10 ensemble members for each trajectory.
    3. 8 OAE simulations under 1 emission trajectory, where OAE is applied (includes test-runs)
    4. 6 OAE+AR simulations under 1 emission trajectory, where OAE and AR are simultaneously applied
    5. 3 OAE simulations for the Carbon Dioxide Removal - Model Intercomparison Project (CDRMIP)

We have assessed the Earth System impacts, carbon cycle feedbacks, and efficiency of AR and OAE. The multitude of our experiments allows for a robust probabilistic treatment of the results, that can account for internal model variability. This process is still ongoing, and the following output is already produced or is expected:

1. One publication by Moustakis et al, (2023) entitled "Ambitious forestation can mitigate temperature overshoot" which has been submitted in the Nature Climate Change journal.
2. Provided useful material for the Master's Vorlesung "Boden-Pflanze-Atmosphäre Kontinuum".
3. Master thesis work started this semester on the following question: Even though we proved that AR mitigates global temperature, does it possibly increase adaptation needs locally/regionally?
4. A publication based on the CDRMIP simulations is currently under preparation led by our project partner Dr. Hao-Wei Wey, including Dr. Yiannis Moustakis as a co-author.
5. Based on the big ensemble of the 80 simulations, we are currently researching how and why temperature mitigation changes across different emission trajectories and prepare a publication on this issue led by Dr. Yiannis Moustakis, that will be submitted to the Environmental Research Letters Special Focus Issue on CDR.
6. Based on the OAE simulations we will be assessing how the Earth System responds when a CDR portfolio is applied, including both land- and ocean-based CDR methods.

Our results so far have proven the mitigation potential of large-scale AR, which is able to robustly mitigate temperature overshoot scenarios (Fig. 1). Mitigation can be observed also under different emission trajectories (Fig. 2).

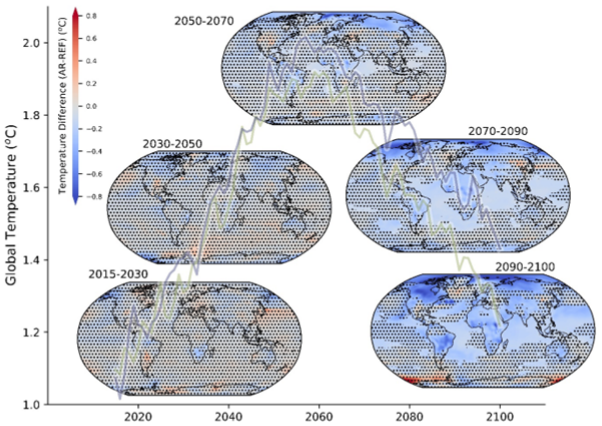

Figure 1: Spatiotemporal pattern of temperature change: The mean 2m temperature difference between AR and Reference simulations under an overshoot emission trajectory for the time periods 2015-2030, 2030-2050, 2050-2070, 2070-2090, and 2090-2100 are shown. A negative difference (blue color) indicates that temperature is lower in the AR scenario. To contextualize the maps within the responses of global average temperature overshoot through time, the average global temperature is also shown in the background. Dots indicate regions where the difference is statistically insignificant at the 5% level.

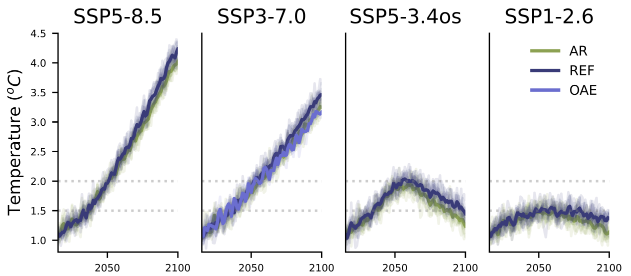

Figure 2: 2m Air Temperature for the different simulations (AR, OAE, and Reference (REF)), across different emission trajectories is shown.

STEPSEC

Wood harvest was extended from the transition to the state maps scheme in JSBACH3.2. This modification is used for all simulations in STEPSEC and CDRSynTra. The implementation of herbaceous biomass plantation (HBP) PFT representing 2nd generation bioenergy plants (Miscanthus, Switchgrass) by Mayer(2017) was improved by connecting it with the nitrogen cycle and the Yasso soil model in JSBACH3.2. Additionally, phenological parameters of the HBP PFT concerning leaf shedding were modified to better represent the response of the plant to adverse climatic conditions. This modified version of the HBP PFT will be published in Egerer et al. and serve as a basis for all future analyses of 2nd generation bioenergy plants with JSBACH3 / MPI-ESM, in STEPSEC, ESM2025, RESCUE and other projects. The HBP PFT will also be ported to JSBACH4 / ICON-ESM.

Performed simulations and analyses

(1) Spinup for (2) and (3)

- 3 x 5000-year spin-ups (three different climate forcings from ISIMIP3b - MPI-ESM 1.2 HR, UK-ESM, IPSL)
- 3 historical simulations 1700-2014 (three different climate forcings from ISIMIP3b

(2) Preparation of paper to compare the carbon sequestration potential of afforestation/reforestation (AR) and herbaceous biomass plantations (HBPs) on LUH2 prescribed areas for second order bioenergy crops: How to measure the effectiveness of terrestrial carbon dioxide removal methods? (Egerer et al., in prep.)

- 12 x 85 years (combination of 3 land use scenarios, 2 climate scenarios, with/without nitrogen, time span 2015-2100)

(3) Master thesis on the effect of avoided deforestation in the ssp370 scenario

- 4 x 85 years, future simulations 2015-2100 with modified LUH2 maps for ssp370 and present day climate

Simulations which still will be performed until end of the year

Due to the model development in JSBACH3.2, planned simulations for 2023 were postponed: This concerns simulations for global standalone idealized sensitivity study, where a fixed amount of agricultural land in every grid cell is replaced by CDR (HBPs or Forest) to compare the temporal dynamics of carbon storage effectiveness, our global AMIP simulations to quantify climate feedbacks and our high resolution, limited area simulations for the coupling with the agent-based model (ABM) CRAFTY-DE (KIT IMK-IFU). These simulations will be performed in Q4:

- 9 standalone JSBACH3.2 future simulations (Tier 1) for the sensitivity study
- 42 additional standalone JSBACH3.2 future simulations (Tier 2) for the sensitivity study
- 3 historical AMIP simulations to quantify climate feedbacks of CDR (= 3 members)
- 18 future AMIP simulations to quantify climate feedbacks of CDR
- 3 5000-year spin-ups, 3 historical (1700-2019) and 12 future (2020-2099) simulations for the coupling of JSBACH3.2 (at 0.5° resolution, European domain)

For the standalone idealized simulations, model output from two further models (LPJmL and LPJ-GUESS) will be stored on Levante since the analysis and intercomparison of model output in STEPSEC is lead by LMU-LUS.

Two sets of simulations requested for 2023 have to be postponed to 2024 because of delayed availability of the land use input (standalone simulations with CDR based on LUH2) from our project partners at PIK and delay in coupling with the ABM of our project partners at KIT IMK-IFU.

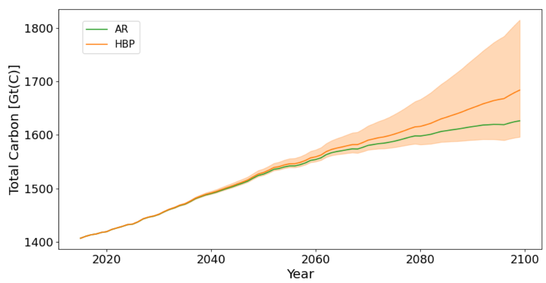

Figure 3: Cumulative land carbon of AR and HBP assuming 80% carbon capture and storages (CCS) and no fossil fuel substitution (FFS) from 2015 to 2100. The shaded area indicates the range of cumulative carbon without CCS and FFS to 100% CCS and 100% FFS.

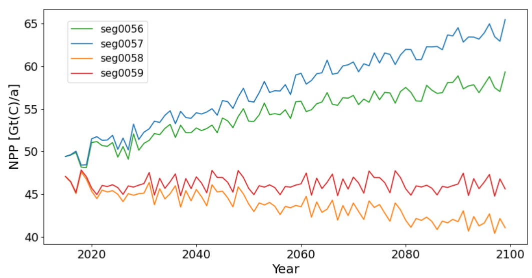

Figure 4: Global net plant productivity with SSP370 climate and land use (seg0056), SSP370 climate and avoided deforestation (seg0057), present-day climate and SSP370 land use (seg0058), and present-day climate and avoided deforestation (seg0059).