Consequences of the spatial configuration of Carbon Dioxide Removal for its withdrawal potential

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1 | Motivation

The projected need of large-scale carbon dioxide removal (CDR) for limiting global warming[1] raises hopes for technology-based solutions to defossilization[2]. Focussing on hoped-for technological development could easily blind out potential climatic and societal risks in case of CDR not meeting expectations on resource efficiency, land use constraints[Fig.1], and up-scaling[3,4]. Future projections with Earth system models (ESMs) implicitly account for CDR through forced greenhouse gas pathways, but do not simulate its deployment and feedbacks interactively in space and time[5,6]. Enlarging the option space that projections are able to illustrate[7], we represent solar energy-based CDR[8] in an ESM ("artificial photosynthesis", AP). Initial results for an efficient parameter set show little Earth system side effects but highlight the importance of the technology's spatial configuration for its land footprint. Sampling of uncertain technology parameters and scenarios constitutes the next stage of this analysis.

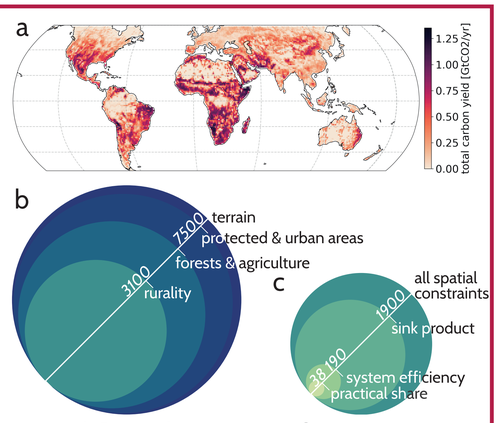
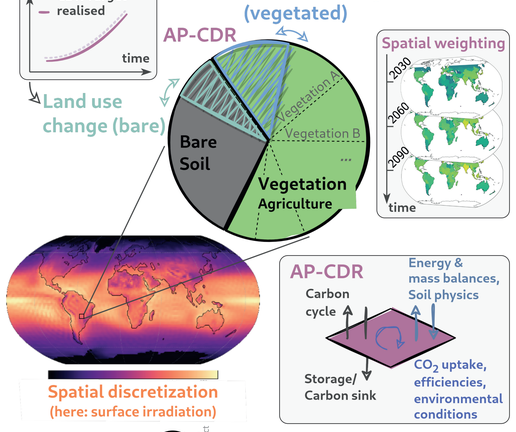


Fig.1: a) Spatial constraints[9] and b) total AP-CDR yield [$GtCO_2$/yr] at hoped-for[8] and c) less ambitious system parameters

2 | Carbon Dioxide Removal in an Earth System Model[Fig.2]

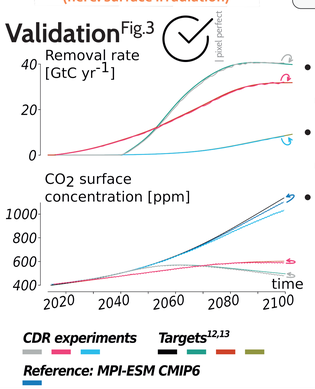


Concept

- MPI-ESM1.2/JSBACH[10,11], expanded land surface
- CDR surface type couples to energy & mass balances
- Model deploys CDR interactively in response to global target & spatial weights

Fig.2: Interactive AP-CDR land cover in JSBACH/MPI-ESM

Validation[Fig.3]



- Deployment as expected
- Mass & energy conserved
- Footprint tuned precisely

Fig.3: Test runs: model meets targets accurately

Scenario design

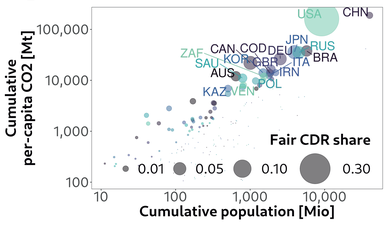
Emission forcing (corresponding global CDR target)

- *CTRL*: SSP[12]1-2.6 CO_2, SSP3-7.0 land use & GHGs
- *126ccs*: CTRL+CDR implicit in SSP1-2.6
- *370-126f2*: CTRL+1/2(CO_2 gap SSP3-7.0 <-> 1-2.6)

Spatial weights

- *weql*: equal weight
- *wcpe*: "fair share"[Fig.4]

Fig.4: Fair CDR share[13] in 2100[12] from past emission burden[14,15,16]



3 | Results

Withdrawal/Footprint[Fig.5]

- Withdrawal seasonality depends on global target and spatial configuration
- Seasonality opposed to that of CO_2 concentration

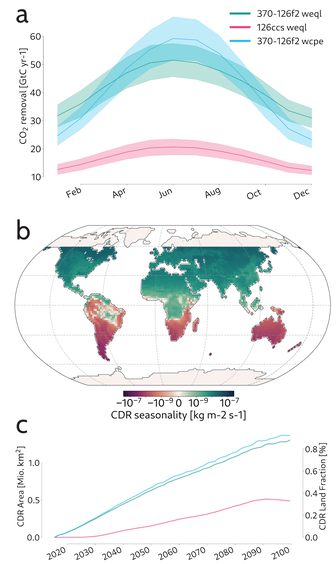


Fig.5: a) Multi-annual mean CDR seasonality, b) difference at global maximum (May) and minimum (December) withdrawal (370-126f2 weql), c) global land footprint

Surface climate[Fig.6]

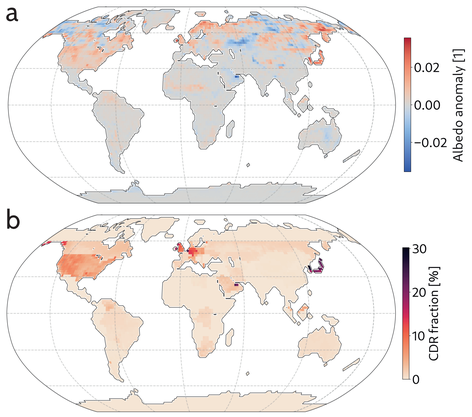


Fig.6: a) Small albedo shifts compared to CTRL in regions with b) large CDR cover fraction (wcpe) do not propagate into significant climate anomalies

Land carbon stock[Fig.7]

- High-CDR experiment with reduced land carbon uptake
- Mechanism: Land use?

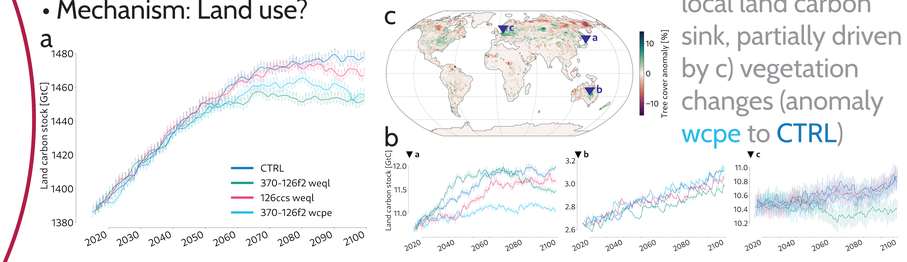


Fig.7: a) Global & b) local land carbon sink, partially driven by c) vegetation changes (anomaly wcpe to CTRL)

4 | Conclusions & Roadmap

- [x] Interactive CDR cover and deployment in an ESM?
  - Spatio-temporal CDR target validated
  - Dynamic vegetation and land use transitions available
- [x] CDR at hoped-for land use efficiency?
  - Climatic side effects small
  - Carbon stocks demand investigation
  - Spatial configuration determines footprint
- [ ] Consequences at present-day technology parameters?
- [ ] Effects of cooling through chemical fixation of CO_2?
- [ ] CDR portfolios in ESM projections?

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