Comparing the climate mitigation potential of afforestation/reforestation and bioenergy plants in CLM and JSBACH

Sabine Egerer[1],
Stefanie Falk[1], Dorothea Mayer[2], Tobias Nützel[1],
Wolfgang Obermeier[1], Julia Pongratz[1]
[1] University of Munich, Germany
[2] Board of Trustees for Forest Work and Forestry e.V., Groß-Umstadt, Germany

In cooperation with David Lawrence and Peter Lawrence
NCAR, Boulder

CESM Workshop 2023

Motivation

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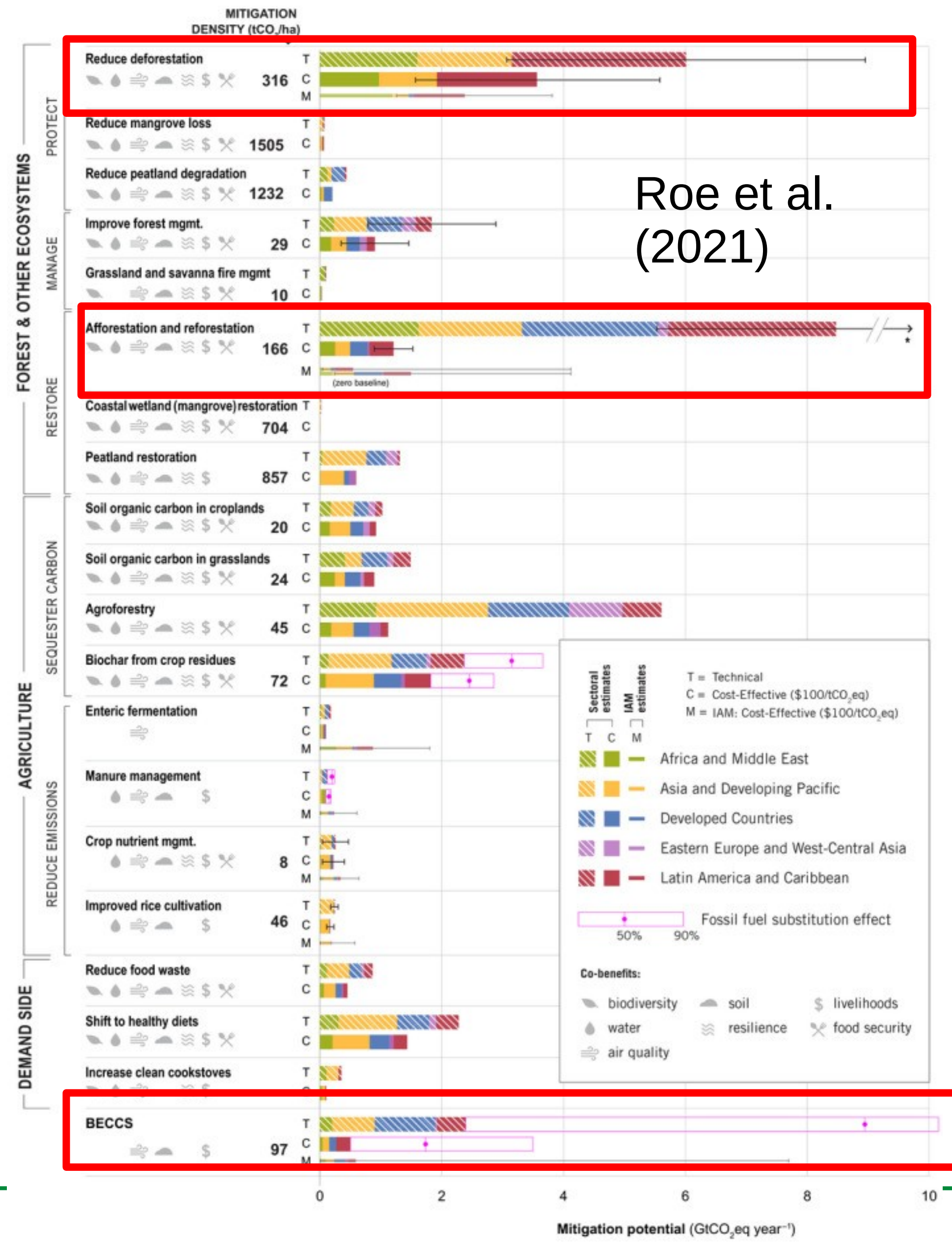
Land-based mitigation strategies included in nearly all **future IPCC scenarios** that limit climate change caused temperature increase to 2°C or below

Potential to mitigate **10–15 GtCO2 eq/yr by 2050, about 20%–30%** of the mitigation needed to achieve the 1.5°C temperature target (Roe et al. 2019)

Afforestation/reforestation, BECCS and reduced deforestation have the highest potential to reduce carbon

Different implementation in different models (wide spread in CMIP6 models)



Roe et al. (2021)

Outline

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1) Terrestrial carbon dioxide removal (tCDR): Afforestation/reforestation (AR) and bioenergy plants (BE)

2) Implementation of the two methods in JSBACH and CLM

3) Previous tCDR studies with JSBACH and CLM

4) Current work with JSBACH/MPI-ESM

5) Planned intercomparison study

Terrestrial carbon dioxide removal

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Afforestation/ Reforestation

- Potential to mitigate about 2.98 (0.23–6.38) GtCO2 eq/yr
- Area needed: 322 (-67 to 890 Mha) in 2050
- Co-benfits: biodiversity, water recycling, air quality
- Side effects: biodiversity, food security

Bioenergy with Carbon capture and storage

- Potential to mitigate about 2.75 (0.52–9.45) GtCO2eq/yr
- Area needed around 199 (56 to 482) Mha in 2100
- Co-benefits: energy supply
- Side effects: biodiversity, food security

IPCC Working Group III, 2022

Implementation of tCDR

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<table>
<tr><th></th><th>JSBACH3.2</th><th>CLM</th></tr>
<tr><td rowspan="2">AR</td><td>- 4 tree PFTs
- no forest age classes</td><td>- 8 tree PFTs</td></tr>
<tr><td colspan="2">- no dedicated PFT, but rather scaling of (natural) forest types
- wood harvest from LUH2</td></tr>
<tr><td rowspan="2">BE</td><td>- PFT for Miscanthus and Panicum
- 70% of aboveground biomass harvested
- no fertilizer, no irrigation</td><td>- PFT for Miscanthus and switchgrass
- 59% - 71% of aboveground biomass harvested
- low fertilization for switchgrass, none for Miscanthus, no irrigation</td></tr>
<tr><td colspan="2">- fossil fuel subsitution and carbon capture and storage considered
- specific phenology, LAI, roughness length</td></tr>
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Open issues of implementation

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1) Land use transition

- Loss of information through translation of Integrated Assessment based scenarios (e.g LUH2) to land models (e.g. diVittorio et al. (2014) on afforestation)
- LUH2 based scenario used for CMIP6 → too little AR in the current data

2) Representation of afforestation through forest plantations

3) Forest management in JSBACH

- forest aging only included in JSBACH4
- wood harvest adapted to AR in JSBACH?

Previous studies

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CDRterra

JSBACH

1) Sonntag et al. (2016): Afforestation of abandoned agricultural areas, coupled model
extent of AR: ~800Mha, carbon captured: up to 220GtC, cooling effect relativley low (0.2K) in densly populated areas

2) Mayer (2017): Implementing herbaceous biomass plantations into JSBACH, extent of BE: ~550Mha, carbon captured: 255-333GtC (depending on harvest, FFS)

CLM

1) Cheng et al. (2020): AR vs BECCS, offline, focus on carbon sequestration potential and water stress in the US: 11.4 to 31.2 PgC, severe impacts of bioenergy plants to water stress over the US

Current work

Research question:

Which of the two tCDR methods, afforestation and bioenergy plant, sequesters carbon most effectively?

At which level of FFS do herbaceous biomass plantations become more effective than afforestation in sequestering carbon?

How does the effectiveness of the two tCDR methods change over time?

Method:

JSBACH3.2 offline with MPI-ESM ssp126 climate forcing

LUH2 ssp126 bioenergy areas, comparing BE and A/R on these areas

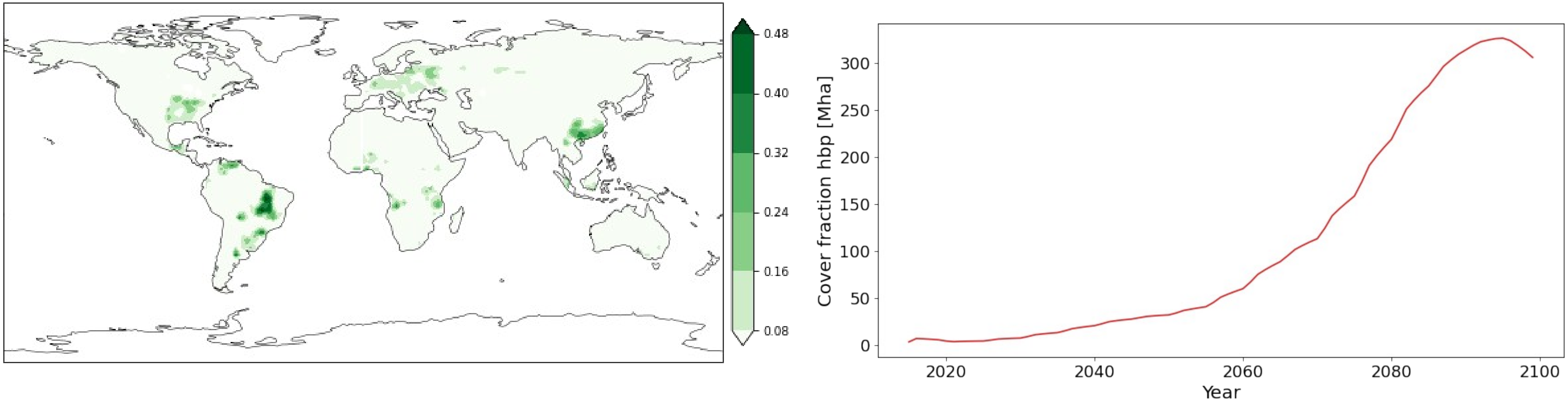

Fig.: Cover fraction in 2100 and total area over time of bioenergy plants in LUH2 ssp126.

Results

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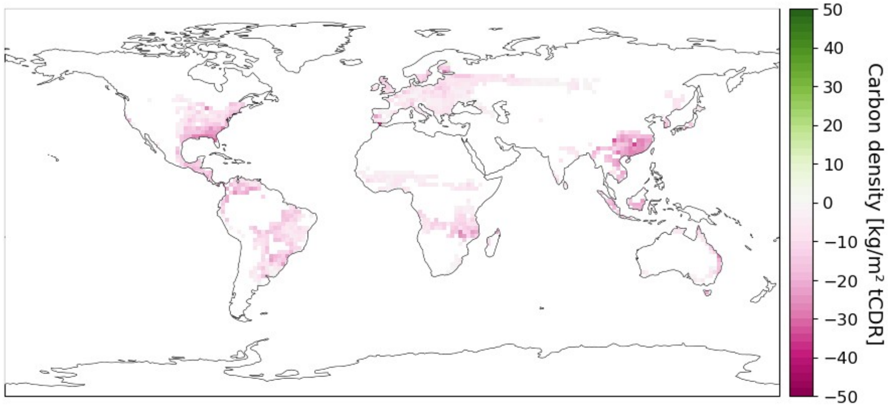
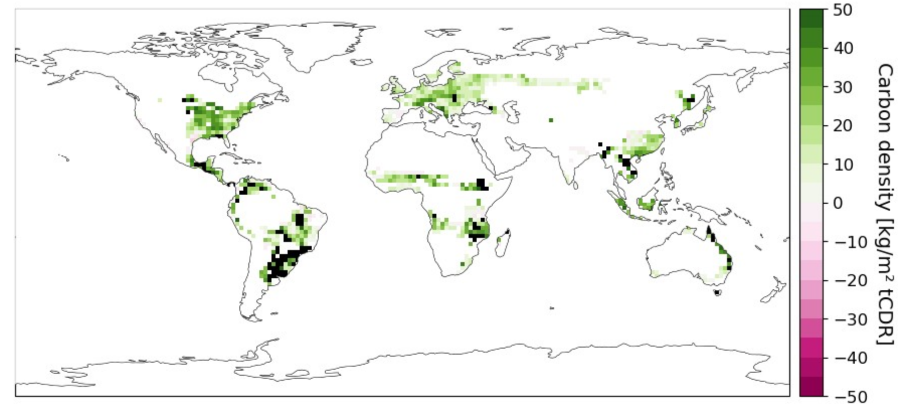
Difference in carbon sequestration in 2100

BE 0% FFS - AR



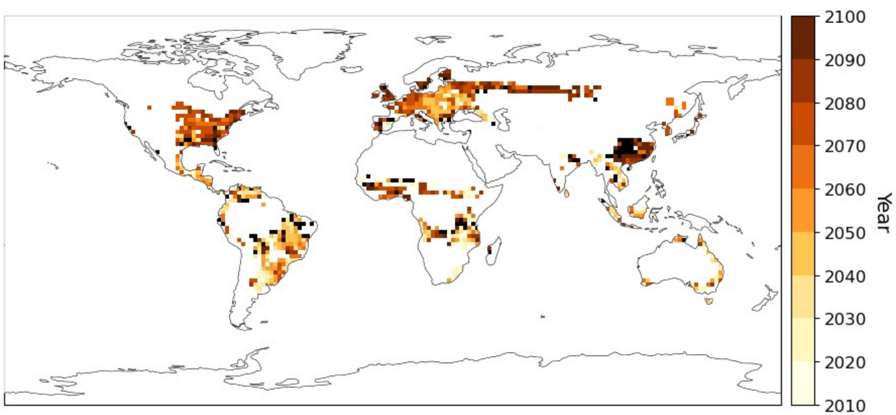
BE 100% FFS - AR



BE

AR

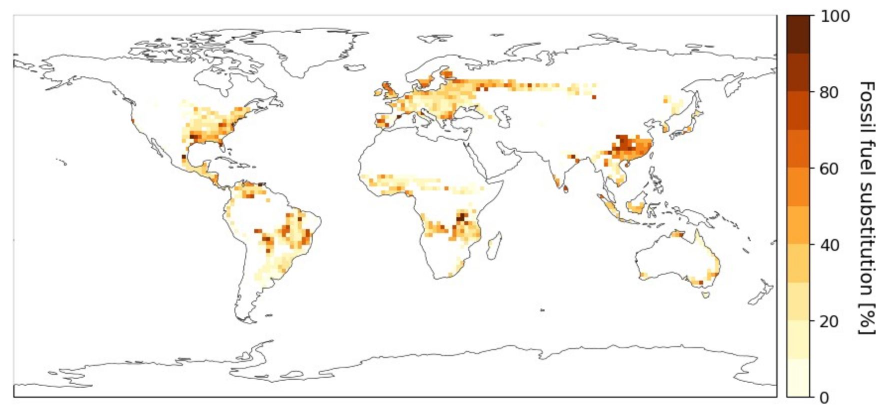
Year in which BE at 70% FFS become more effective than AR



AR

BE

Level of fossil fuel substitution for BE to become more effective than AR in 2100



Results

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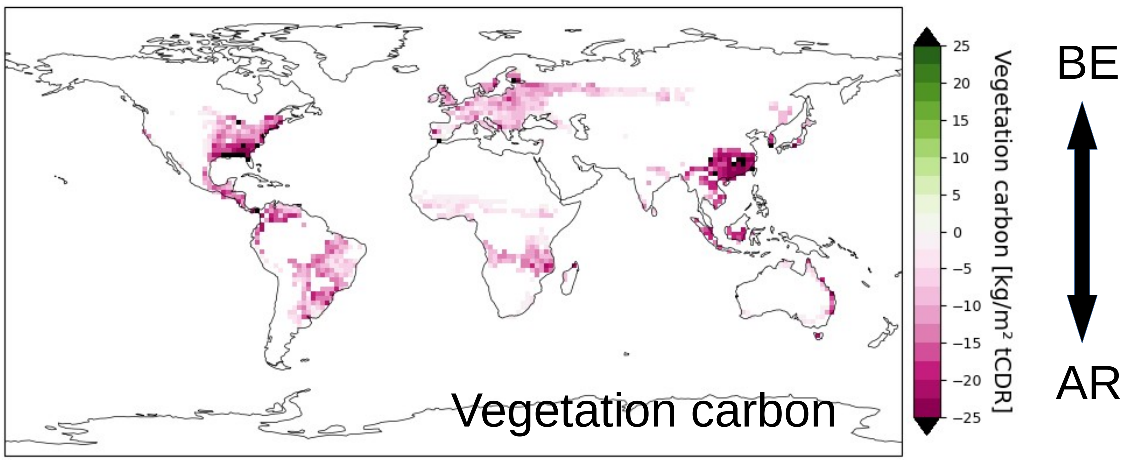
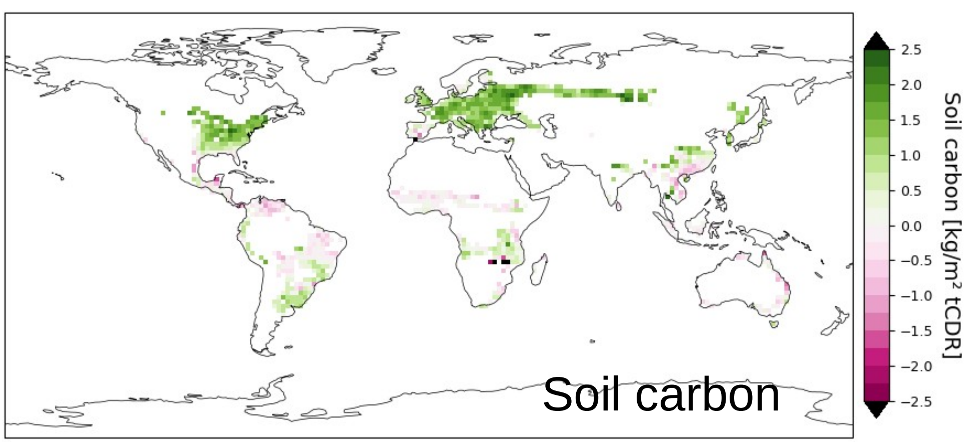
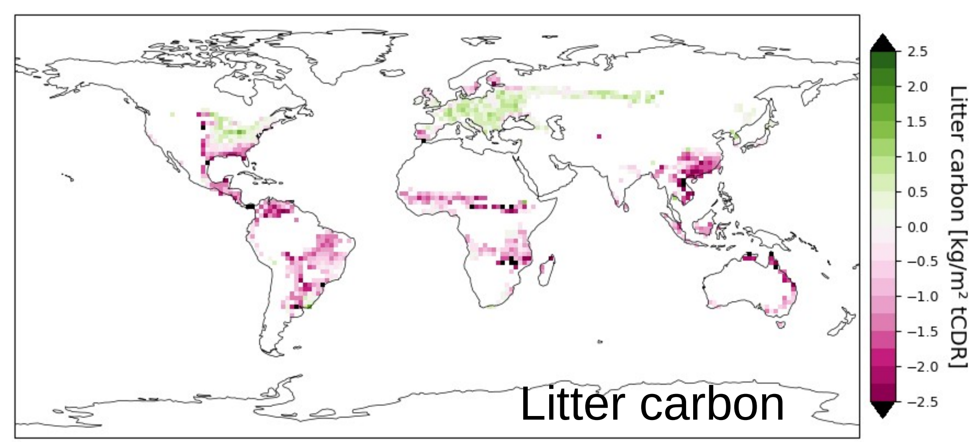
Difference in vegetation and soil carbon sequestration between BE and AR in 2100







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Results

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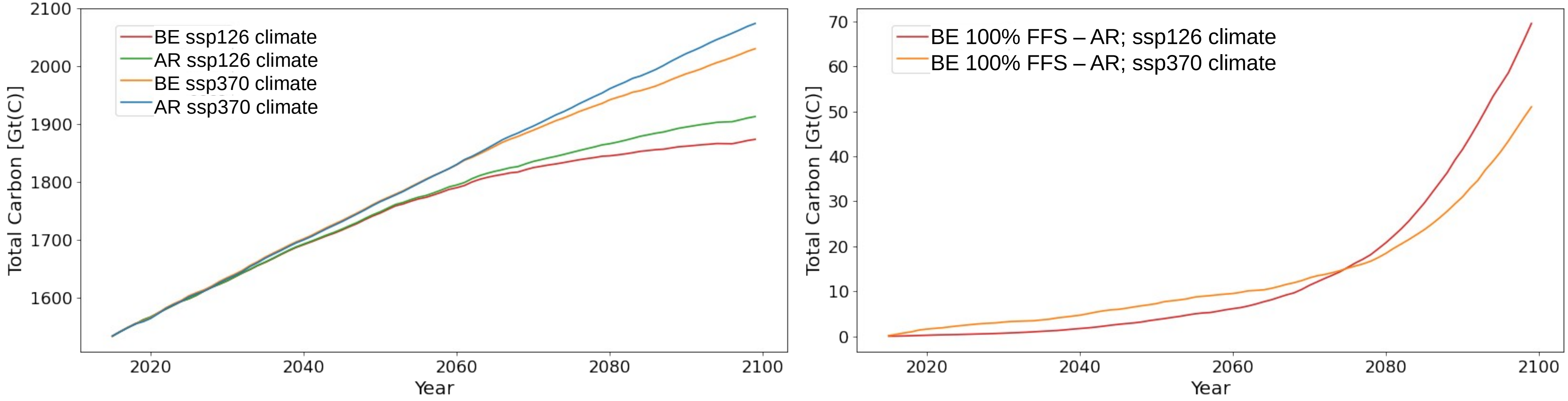
Total carbon (left) and accumulated carbon from harvest (right) for ssp126 and ssp370 climate.



- Strong increase in wood carbon in trees for ssp370 climate due to CO2 fertilization
- BE plants less productive in ssp370 climate → barely increased CO2 fertilization for C4 plants
- HBPs more productive for 100% FFS

Results

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Take home messages:

1. Effectiveness depends very much on FFS (and CCS).
2. Carbon sequestration driven by vegetation carbon in trees
3. AR higher potential in ssp370 due to CO_2 fertilization
4. Same areas more beneficial for AR, some more for BE
   → caused by water availability, temperatures, soils?

Missing: wood harvest → any ideas how to include?

Planned model intercomparison

Multi-model analysis of sensitivity of land surface **biogeochemical and biogeophysical effects of AR/BE based on LUH2 spatial distribution**

1) How large / important is the **model structural and parametric uncertainty in future land carbon uptake** from AR/BE?

2) How do both methods differ regarding **climate feedbacks and biogeophysical effects**?

3) **Evaluate spatial distribution of AR and BE measures in LUH2**
   → **new harmonized data from IAMs with enhanced AR available end of June**
   → **give recommendations for CMIP7/LUH3**

Further ideas and suggestions?

Thank you for your attention!

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LUH2 data

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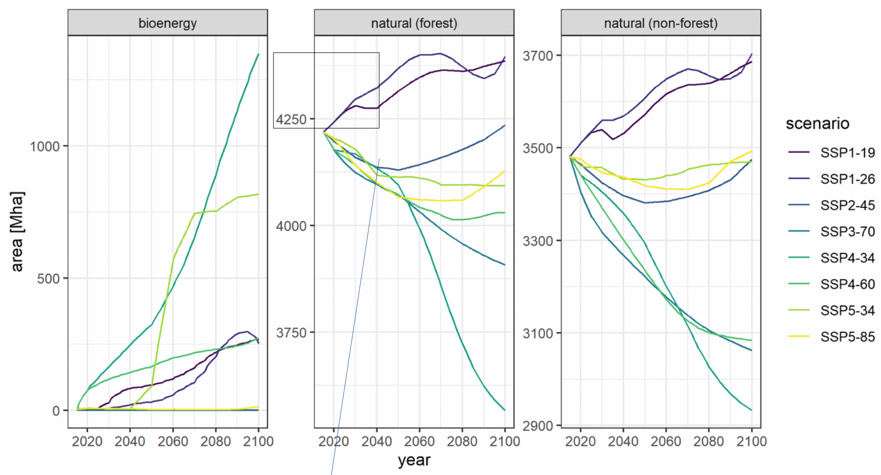
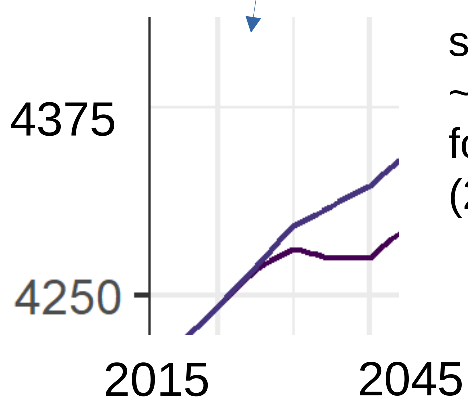
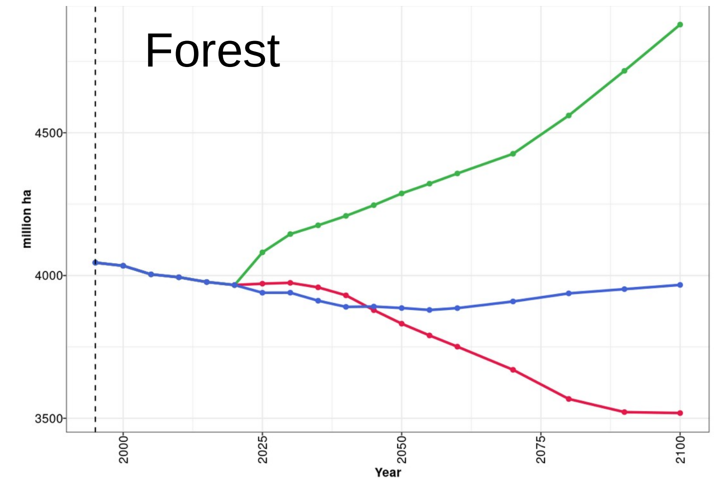




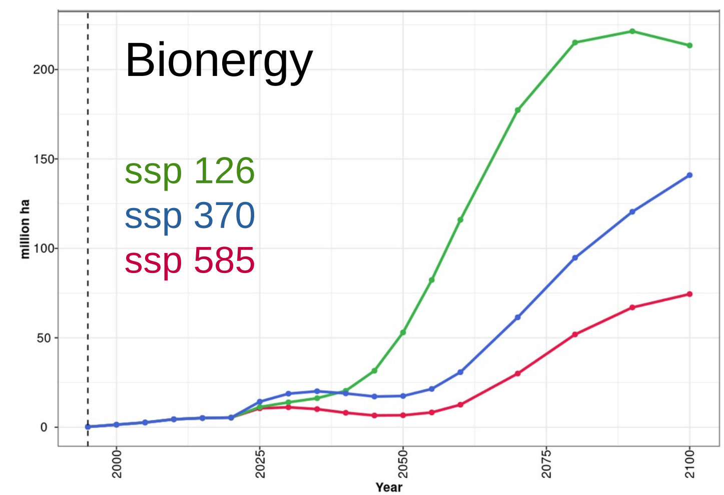
ssp126:
~ 100Mha (~0.5%)
forest area increase
(2015-2045)

New MagPIE simulation output:

ssp126:
~ 750 Mha
forest area
increase



ssp126:
~ 220Mha
bioenergy
area increase



MAgPIE raw data

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ssp 126
ssp 370
ssp 585