Effectiveness of land-based natural climate solutions towards Net Zero plus goals

Julia Pongratz, Sabine Egerer, Stefanie Falk, Felix Havermann

Thanks for input to Dave Lawrence, Akihiko Ito, Philippe Peylin

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Outline

1. The need to comprehensively assess carbon dioxide removal
2. Potentials, risks and side-effects of land-based “natural climate solutions”
3. Land surface modeling of “natural climate solutions”

Outline

1. **The need to comprehensively assess carbon dioxide removal**

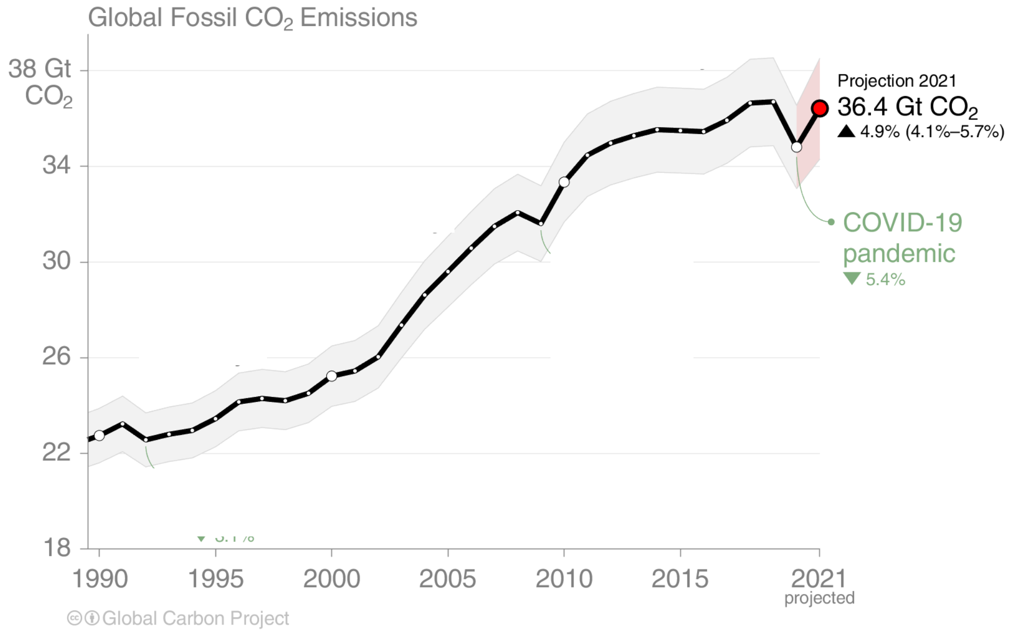
2. Potentials, risks and side-effects of land-based “natural climate solutions”

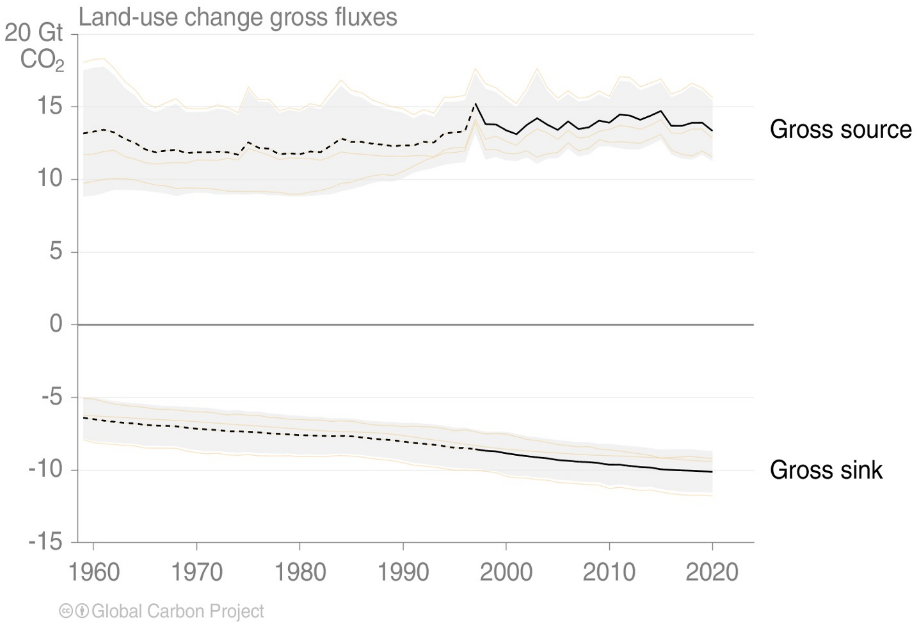
3. Land surface modeling of “natural climate solutions”

Current situation

- 7 years after the Paris Agreement, global emissions show no clear downward trend, leaving a large gap to emission trajectories compatible with <2℃ target

Global Carbon Budget 2021 (Friedlingstein et al., 2022)



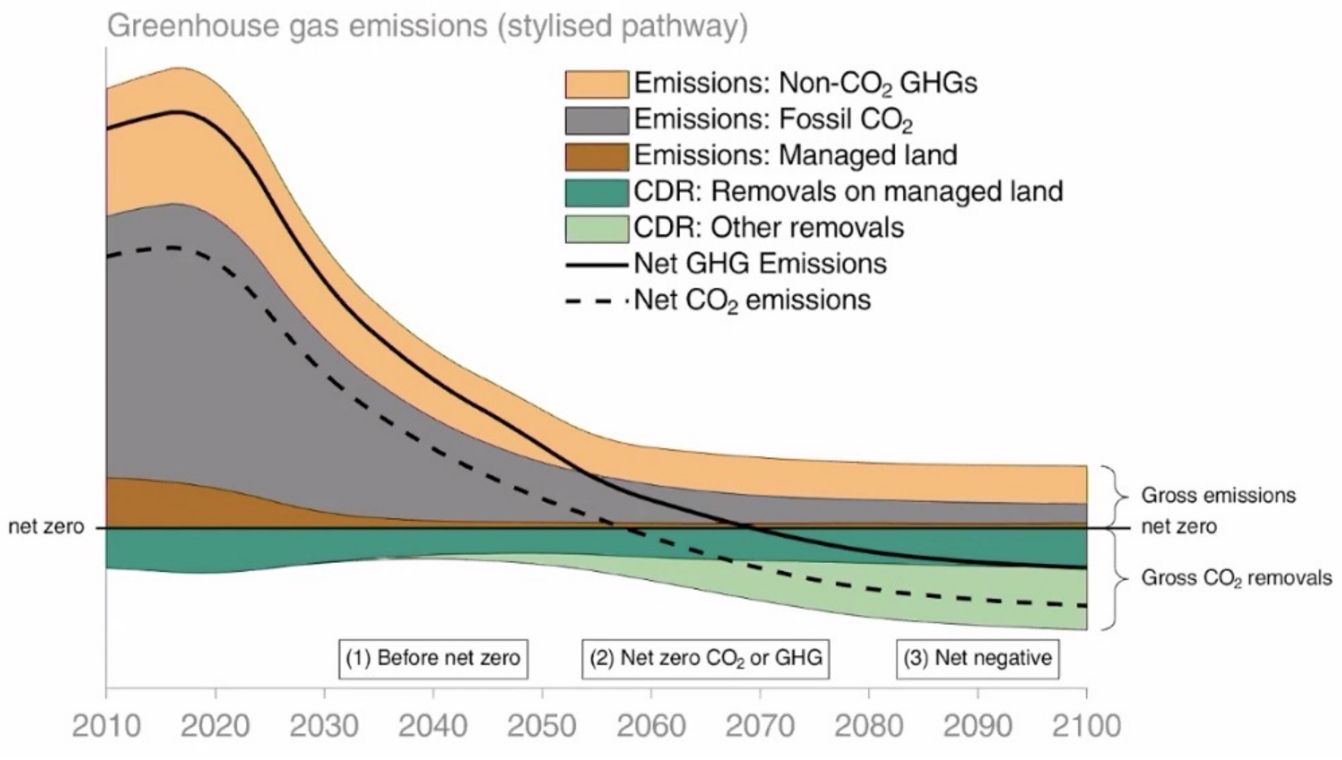


- “The deployment of CDR to counterbalance hard-to-abate residual emissions is unavoidable if net zero CO_2 or GHG emissions are to be achieved.” (AR6 WG3)

The need for Carbon Dioxide Removal (CDR)

- All 1.5℃ scenarios include some CDR
- Multiple roles of CDR (complementary to deep emissions reductions):

IPCC AR6 WG3 (Ch. 12)



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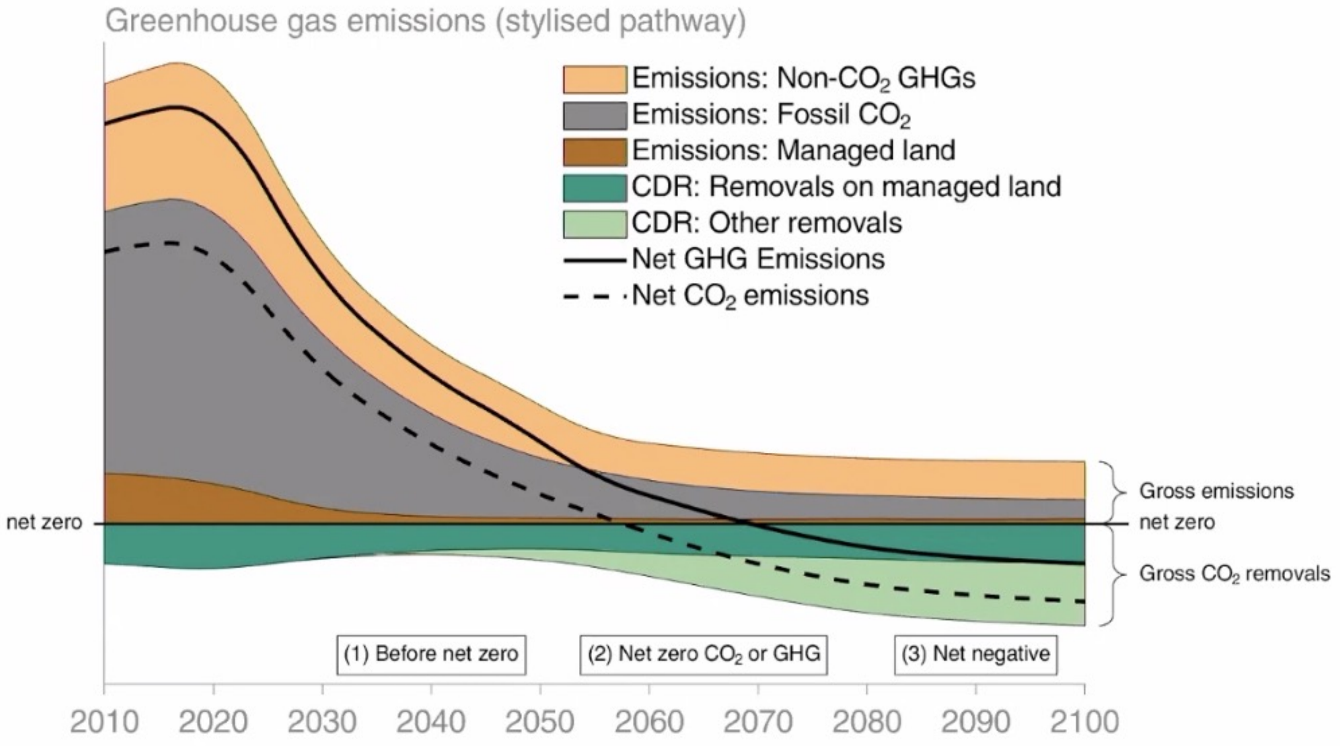

→ We no longer need to discuss *if* we do CDR – the Paris Agreement obliges us to do so – but *through which methods, by whom* and *where*!

The need for Carbon Dioxide Removal (CDR)

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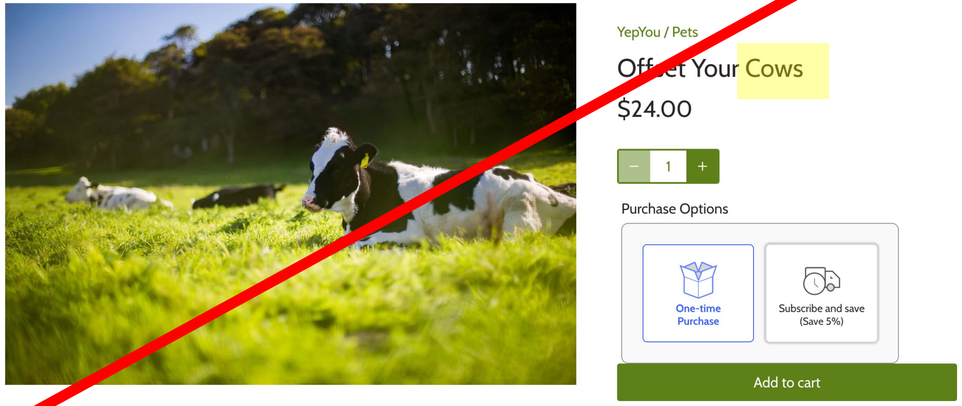

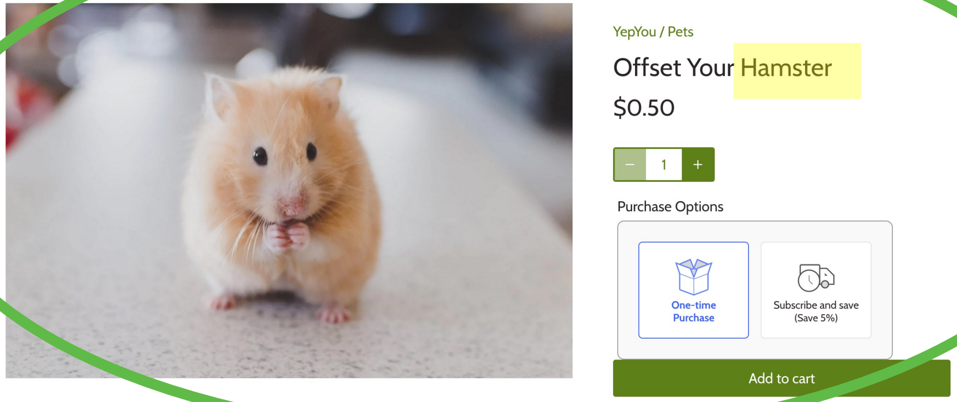

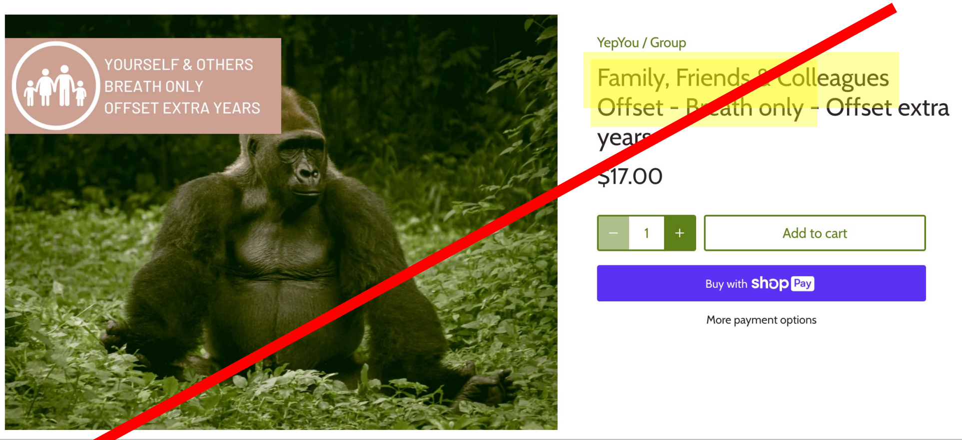

https://yepyou.com

A word on global scale (IPCC AR6 WG3)

- Amount of Carbon Dioxide Removal
  - Median value (5–95% range) across the scenarios likely limiting warming to 2°C or lower:

	BECCS	Net removal on managed land (incl. A/R)	DACCS
2020-2100, $GtCO_2$	328 (168–763)	252 (20–418)	29 (0–339)
2050, $GtCO_2$/year	2.75 (0.52–9.45)	2.98 (0.23–6.38)	0.02 (0–1.74)

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- Area
  - Pathways limiting warming to 1.5°C with no or limited overshoot:

	Bioenergy (incl.) BECCS	Increase in forest cover
million ha	199 (56-482) in 2100	322 (-67 to 890) in 2050

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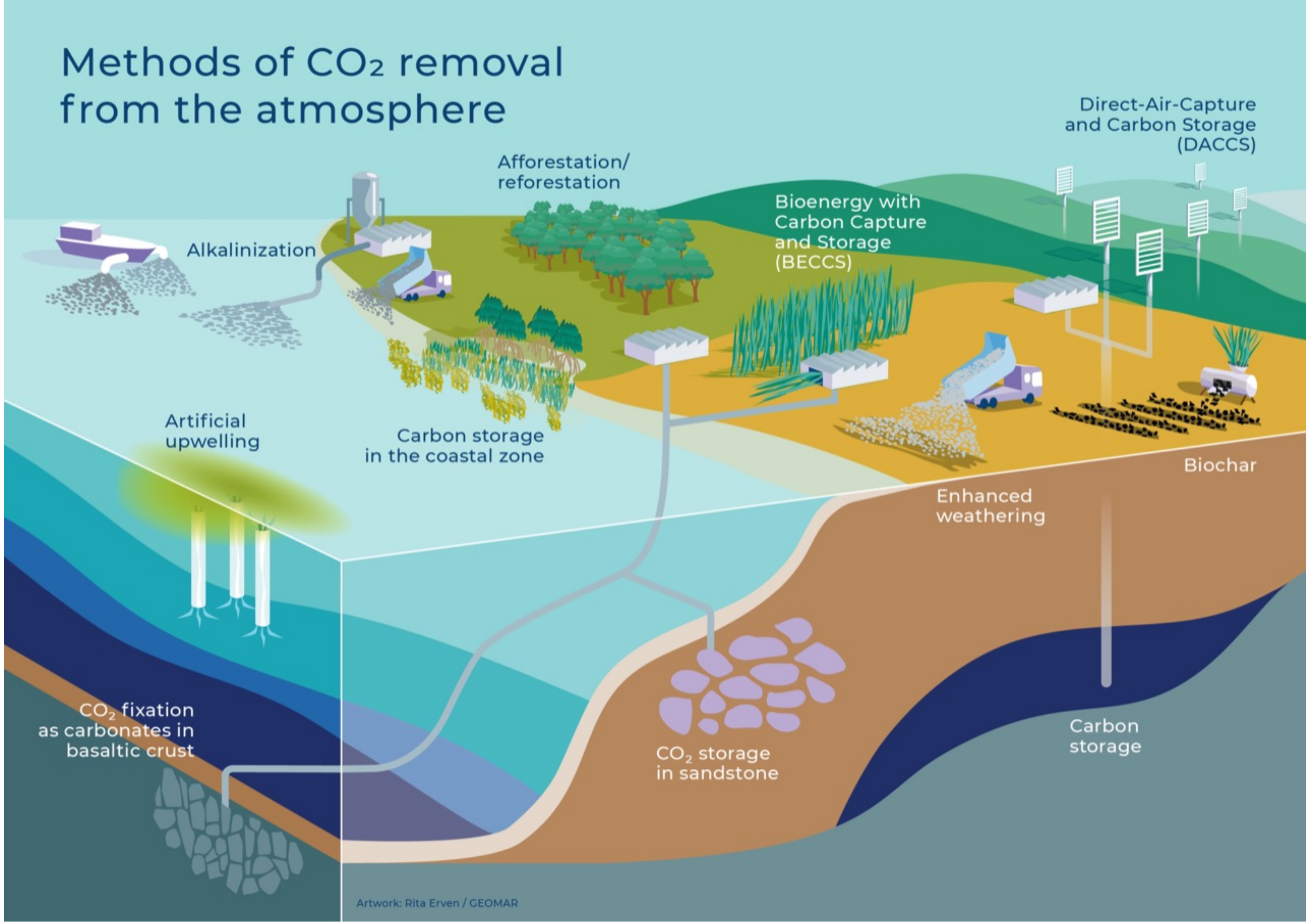
← Does not interfere with food security under high CO_2 price and/or dietary changes

Carbon Dioxide Removal methods

- Both land- and ocean-based approaches discussed and need to be evaluated against each other
- In CDRterra *realistic* potentials are assessed that account for conflicts over resources (water, land), societal processes, ecological sustainability and economical and political feasibility

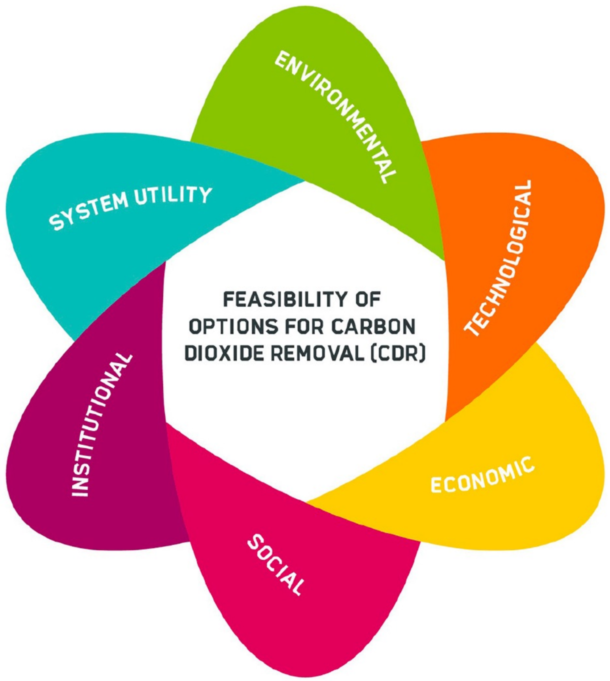


Common, comprehensive assessment framework

Assessment matrix across dimensions with quantitative/qualitative indicators

TABLE 1 | Overview of criteria and indicators included in the assessment framework, including the traffic light system.

Criteria	Indicator	Likely large hurdle to implementation	Uncertain, likely large hurdle to implementation	Likely medium hurdle	Uncertain, likely no hurdle to implementation	Likely no hurdle to implementation
Environmental dimension		(−−−)	(−−)	(−/+)	(++)	
A1 Impact on air/atmosphere	A1.1 Outdoor air quality (with an impact on human health)	Likely worsens	Uncertain, likely worsens	Likely no impact	Uncertain, likely improve	
	A1.2 GHG emissions related to land/sea use change	Likely increases	Uncertain, likely increases	Likely no emissions	Uncertain, likely reduces	
	A1.3 Net biophysical effect on local climate (different scales)	Likely negative	Uncertain, likely negative	Likely no impact	Uncertain, likely positive	
	A1.4 Net effects of audible noise on humans and ecosystems					
A2 Impact on land and sea area (from land-use/sea-use changes)	A2.1 Area demand and competition with other area use (land and/or sea)	Likely area demand + land under competition	Likely area demand + not under competition	Likely no area demand	Uncertain, likely reduces demand + reduces competition	
	A2.2 Biodiversity (ecosystems, species, genes)	Likely negative	Uncertain, likely negative	Likely no impact	Uncertain, likely positive	
	A2.3 Soils (chemical and physical quality)					



→ No ranking, but evaluation of (context-specific!) trade-offs and synergies

Förster et al., *Frontiers in Climate*, 2022

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What are “natural climate solutions”?

- → Protect, restore or sustainably manage ecosystems with the goal of mitigating climate change
- … while also addressing other societal challenges
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SEAN BAGSHAW/GETTY IMAGES in Rosen, *Science*, 2018

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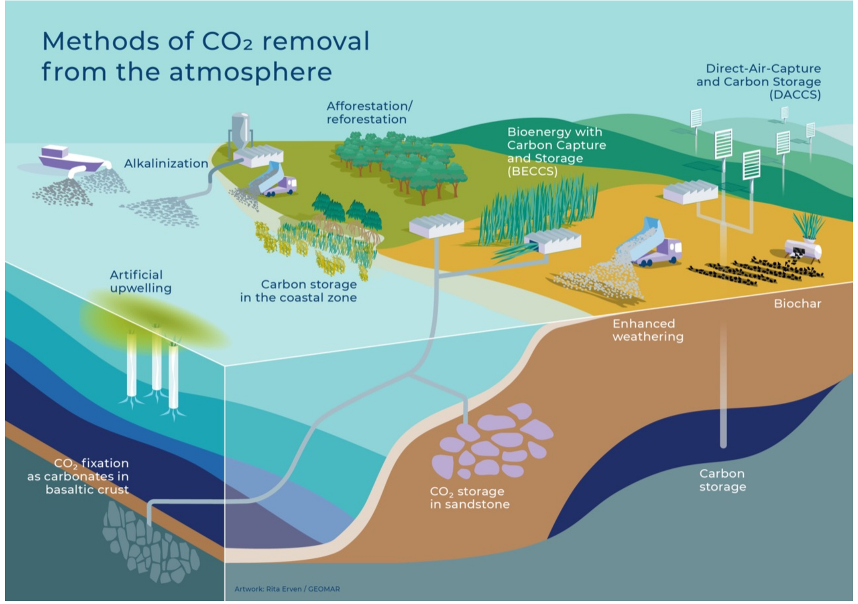
- Note: “NBS” or “NCS” may be misleading
- Note: the IPCC recommends to no longer distinguish nature-based and technological options



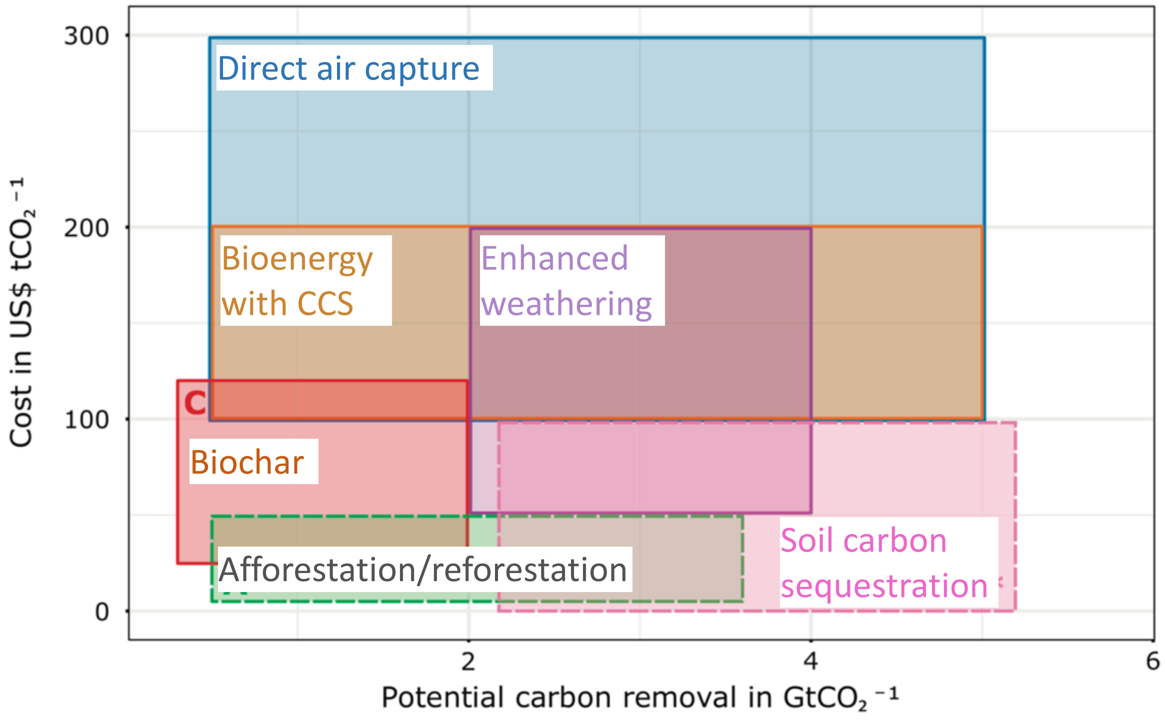
IPCC AR6 WG3

Tech. readiness level
Costs
Potential
Risks
Co-benefits
Trade-offs

CDR option	Status (TRL)	Cost (USD tCO_2^{-1})	Mitigation Potential ($GtCO_2$ yr^{-1})	Risk & Impacts	Co-benefits	Trade-offs and spill over effects	Role in modelled mitigation pathways	Section
DACCS	6	100–300 (84–386)	5–40	Increased energy and water use.	Water produced (solid sorbent DAC designs only).	Potentially increased emissions from water supply and energy generation.	In a few IAMs; DACCS complements other CDR methods.	{12.3.1.1}
Enhanced weathering	3–4	50–200 (24–578)	2–4 (<1–95)	Mining impacts; air quality impacts of rock dust when spreading on soil.	Enhanced plant growth, reduced erosion, enhanced soil carbon, reduced pH, soil water retention.	Potentially increased emissions from water supply and energy generation.	In a few IAMs; EW complements other CDR methods.	{12.3.1.2}
BECCS	5–6	15–400	0.5–11	Competition for land and water resources, to grow biomass feedstock. Biodiversity and carbon stock loss if from unsustainable biomass harvest.	Reduction of air pollutants; fuel security, optimal use of residues, additional income, health benefits and if implemented well can enhance biodiversity, soil health and land carbon	Competition for land with biodiversity conservation and food production	Substantial contribution in IAMs and bottom -up sectoral studies	Chapter 7, Section 7.4
Afforestation/Reforestation	8–9	0–240	0.5–10	Reversal of carbon removal through wildfire, disease, pests may occur. Reduced catchment water yield and lower groundwater level if species and biome are inappropriate.	Enhanced employment and local livelihoods, improved biodiversity, improved renewable wood products provision, soil carbon and nutrient cycling. Possibly less pressure on primary forest.	Inappropriate deployment at large scale can lead to competition for land with biodiversity conservation and food production.	Substantial contribution in IAMs and also in bottom-up sectoral studies.	Chapter 7, Section 7.4
Agroforestry	8–9	Insufficient data	0.3–9.4	Risk that some land area lost from food production; requires high skills.	Enhanced employment and local livelihoods, variety of products improved soil quality, more resilient systems.	Some trade-off with agricultural crop production, but enhanced biodiversity, and resilience of system.	No data from IAMs, but in bottom-up sectoral studies. with medium contribution.	Chapter 7, Section 7.4

Tab. 12.6 (small selection!)

Terrestrial CDR measures in comparison



Minx et al., *Environ. Res. Lett.,* 2018; Fuss et al., *Environ. Res. Lett.,* 2018

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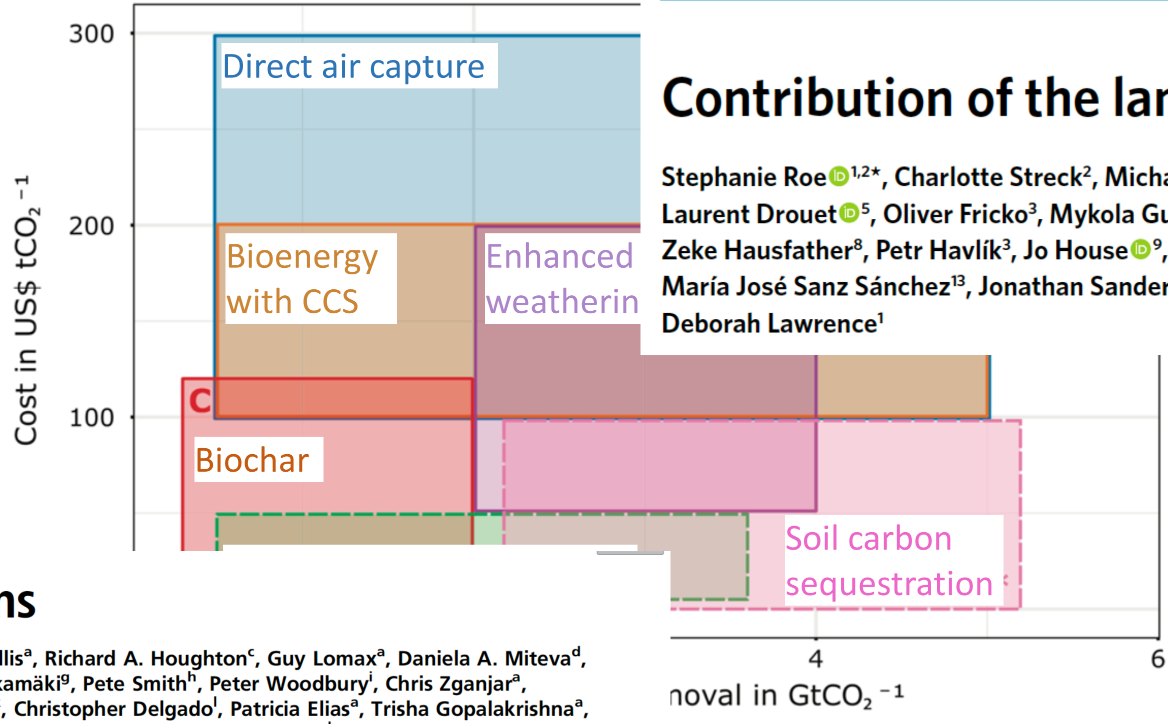

nature climate change

REVIEW ARTICLE

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Contribution of the land sector to a 1.5 °C world

Stephanie Roe[1,2*], Charlotte Streck[2], Michael Obersteiner[3], Stefan Frank[3], Bronson Griscom[4], Laurent Drouet[5], Oliver Fricko[3], Mykola Gusti[3], Nancy Harris[6], Tomoko Hasegawa[7], Zeke Hausfather[8], Petr Havlík[3], Jo House[9], Gert-Jan Nabuurs[10,11], Alexander Popp[12], María José Sanz Sánchez[13], Jonathan Sanderman[14], Pete Smith[15], Elke Stehfest[16] and Deborah Lawrence[1]

PNAS

Natural climate solutions

Bronson W. Griscom[a,b,1], Justin Adams[a], Peter W. Ellis[a], Richard A. Houghton[c], Guy Lomax[a], Daniela A. Miteva[d], William H. Schlesinger[e,1], David Shoch[f], Juha V. Siikamäki[g], Pete Smith[h], Peter Woodbury[i], Chris Zganjar[a], Allen Blackman[g], João Campari[j], Richard T. Conant[k], Christopher Delgado[l], Patricia Elias[a], Trisha Gopalakrishna[a], Marisa R. Hamsik[a], Mario Herrero[m], Joseph Kiesecker[a], Emily Landis[a], Lars Laestadius[l,n], Sara M. Leavitt[a], Susan Minnemeyer[l], Stephen Polasky[o], Peter Potapov[p], Francis E. Putz[q], Jonathan Sanderman[c], Marcel Silvius[r], Eva Wollenberg[s], and Joseph Fargione[a]

[a]The Nature Conservancy, Arlington, VA 22203; [b]Department of Biology, James Madison University, Harrisonburg, VA 22807; [c]Woods Hole Research Center, Falmouth, MA 02540; [d]Department of Agricultural, Environmental, and Development Economics, The Ohio State University, Columbus, OH 43210; [e]Cary Institute of Ecosystem Studies, Millbrook, NY 12545; [f]TerraCarbon LLC, Charlottesville, VA 22903; [g]Resources for the Future, Washington, DC 20036; [h]Institute of Biological and Environmental Sciences, University of Aberdeen, Aberdeen, AB24 3UU, Scotland, United Kingdom; [i]College of Agriculture and

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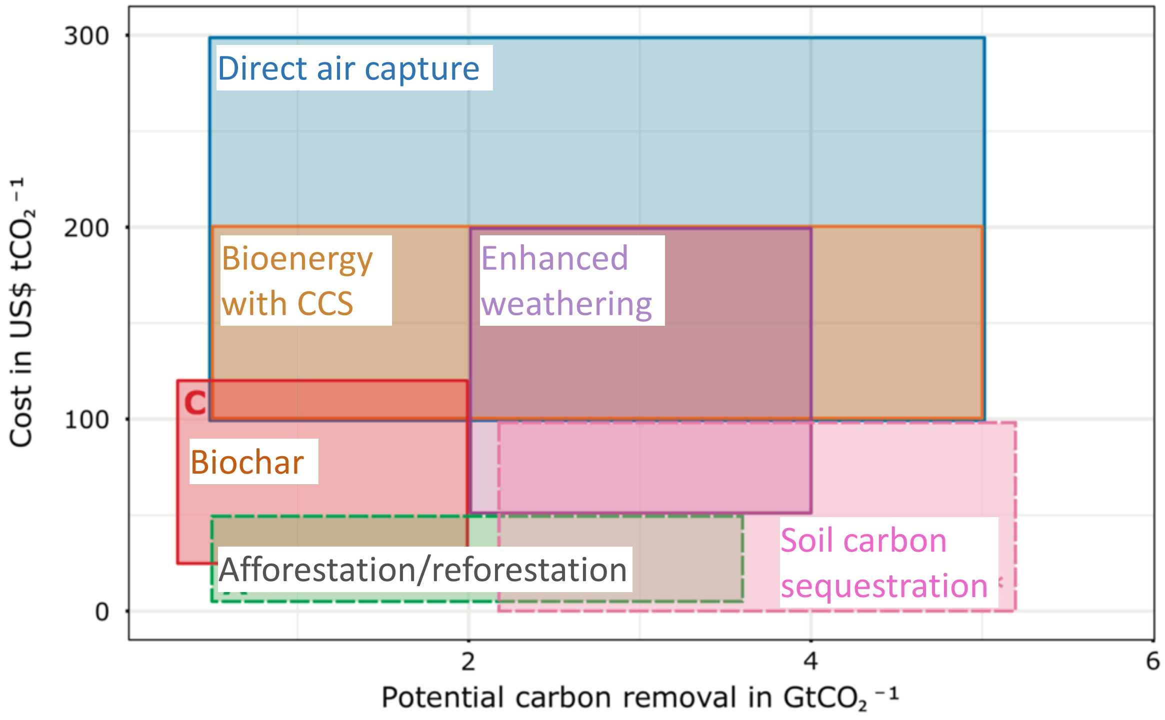

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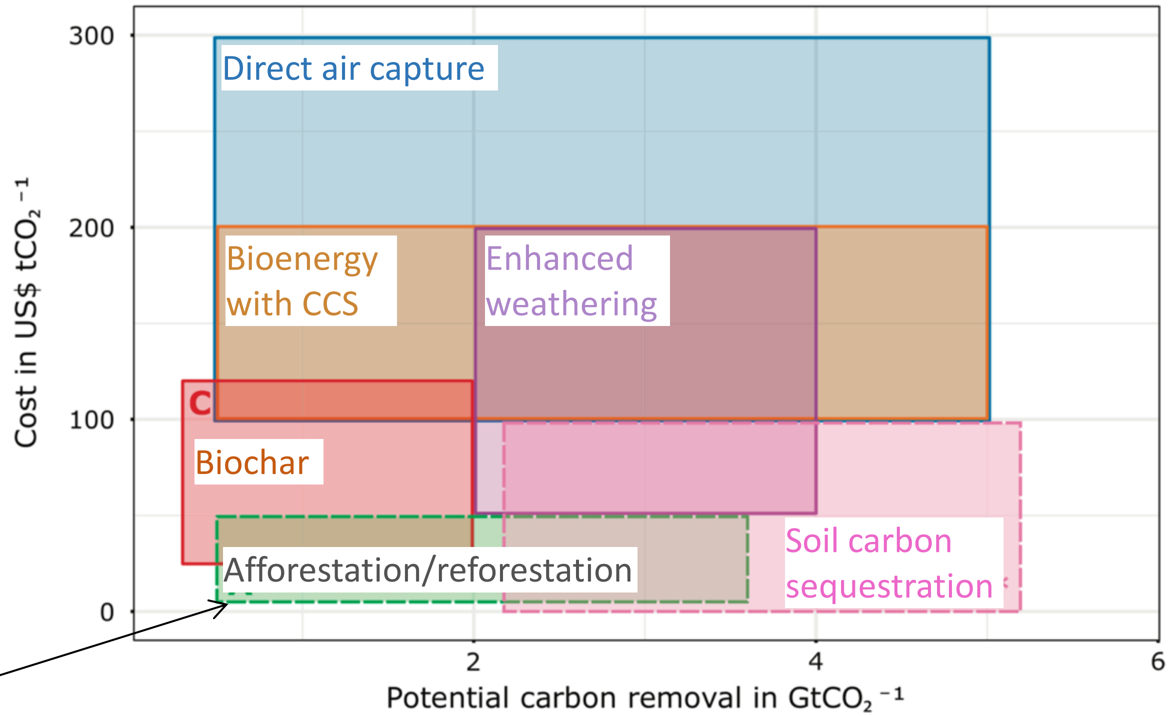

cheap & ready!

but alters water and energy fluxes

Permanence!

Minx et al., *Environ. Res. Lett.*, 2018; Fuss et al., *Environ. Res. Lett.*, 2018

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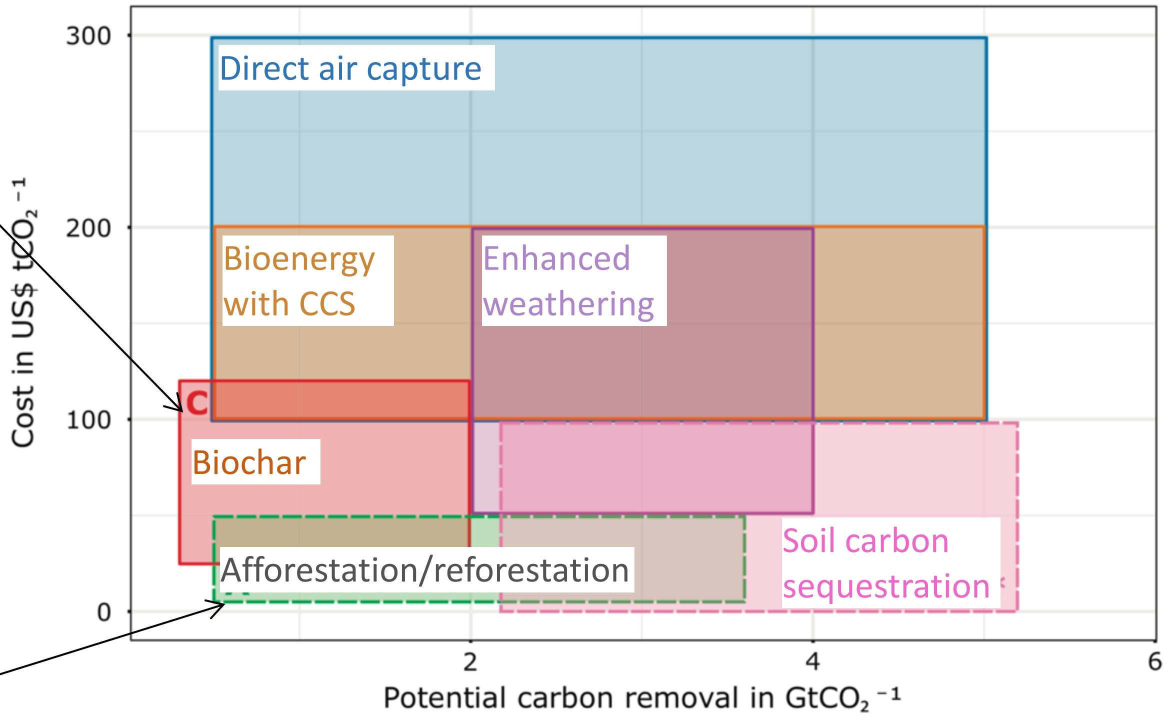
Terrestrial CDR measures in comparison

may increase soil fertility
limited potential



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cheap & ready
other ecosystem
services

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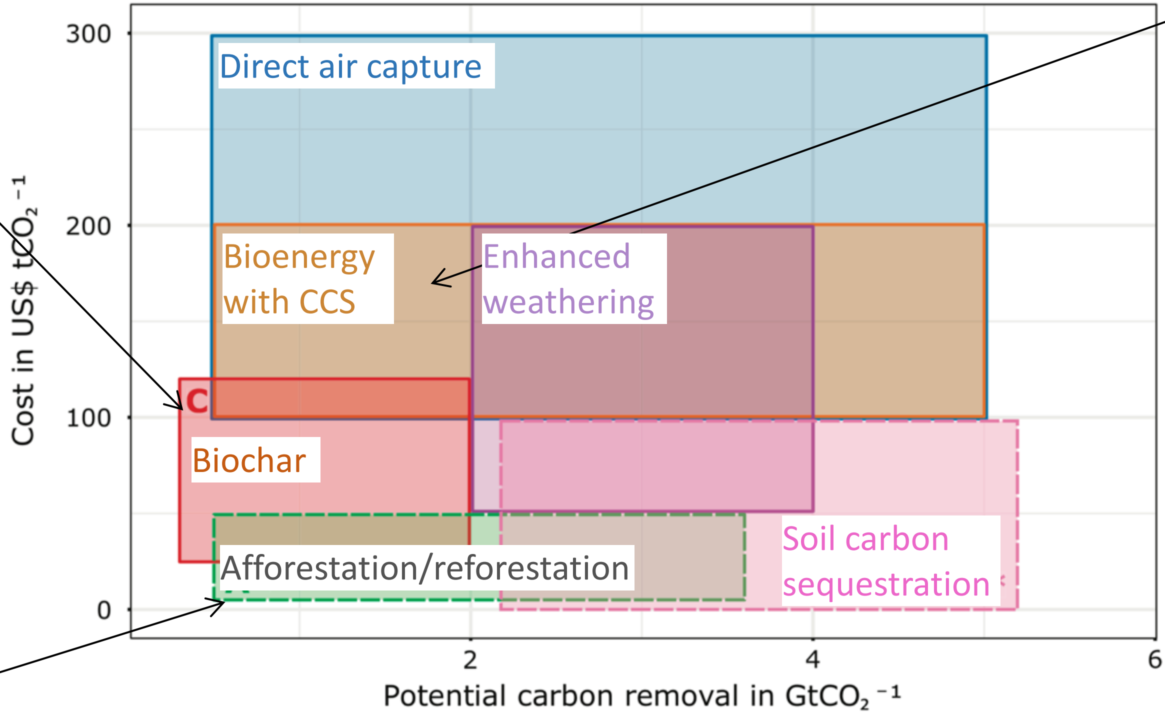
limited potential



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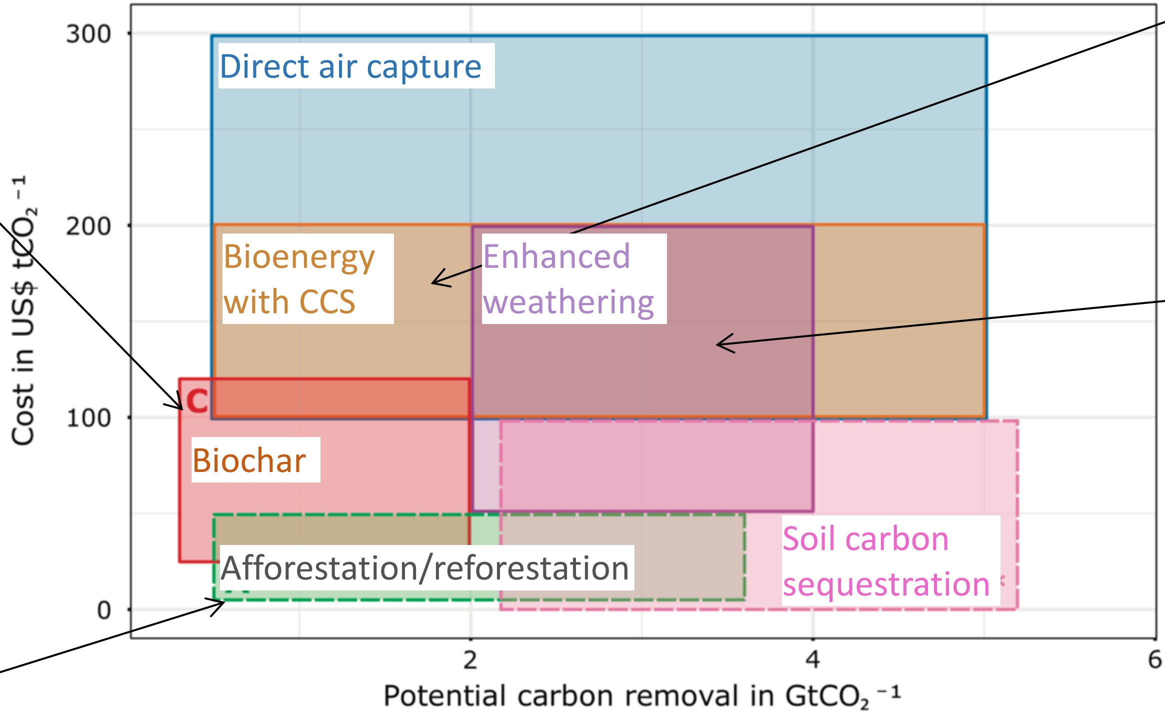

increased soil fertility
ecological impacts of mineral extraction and transport

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Permanence!

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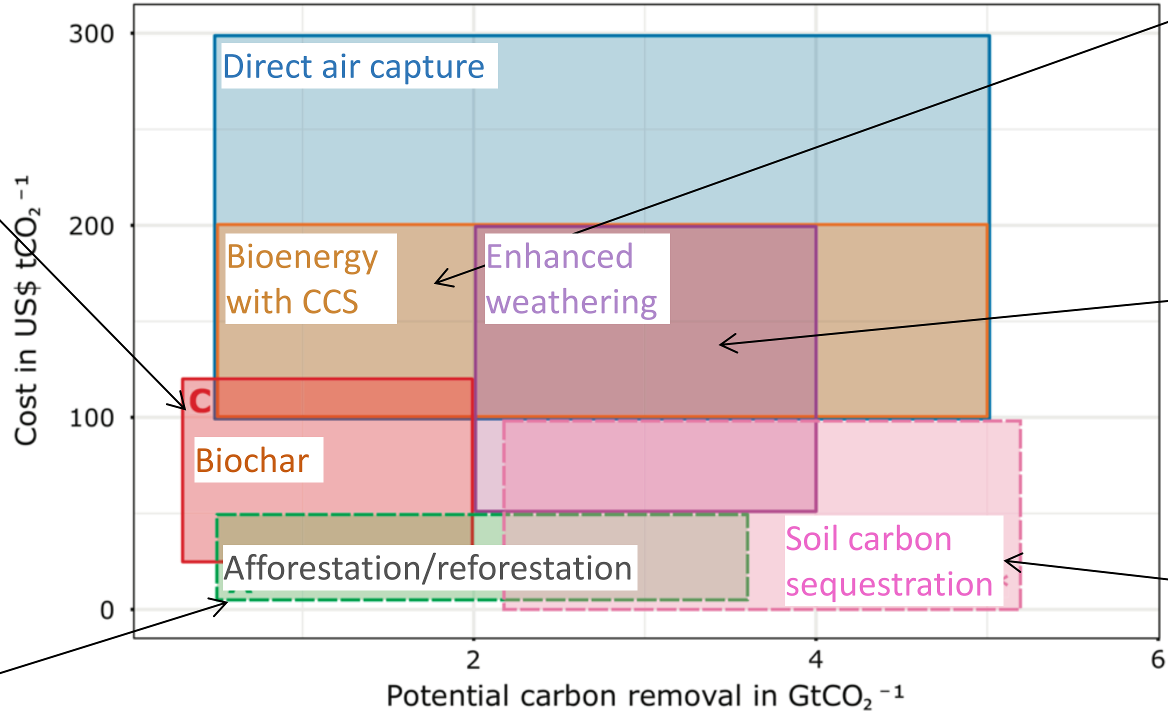

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Terrestrial CDR measures in comparison

small land demand
high costs and energy demand

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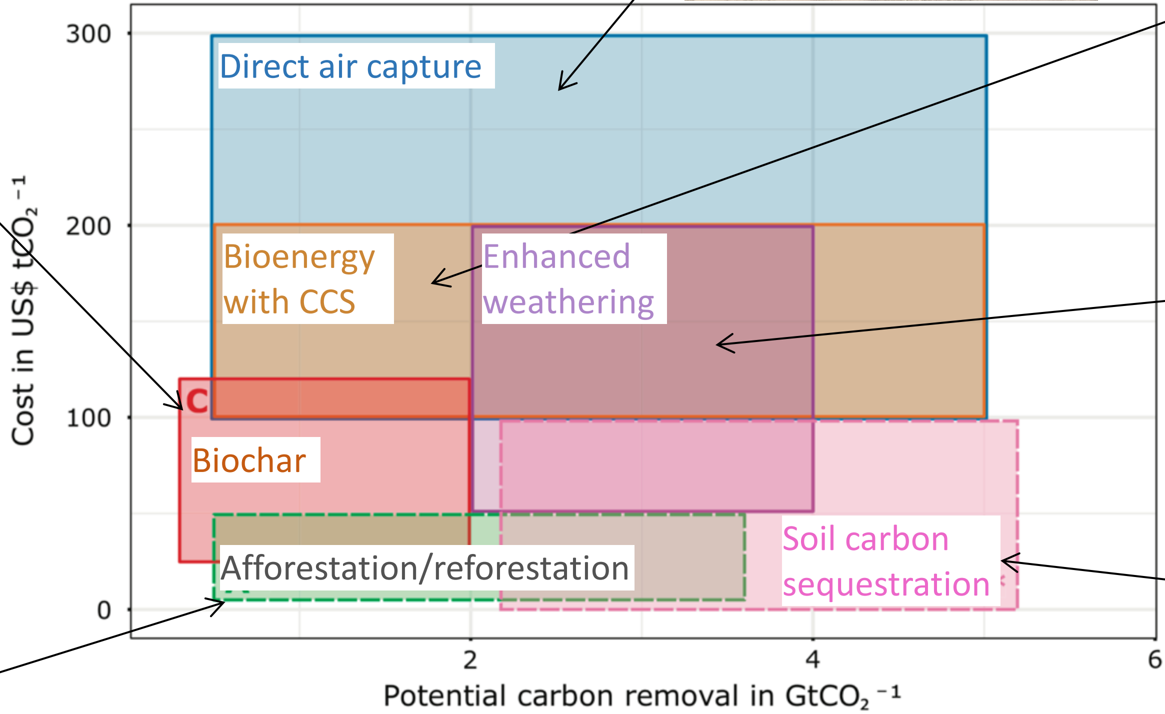
cheap & ready
other ecosystem services

may increase soil fertility
limited potential



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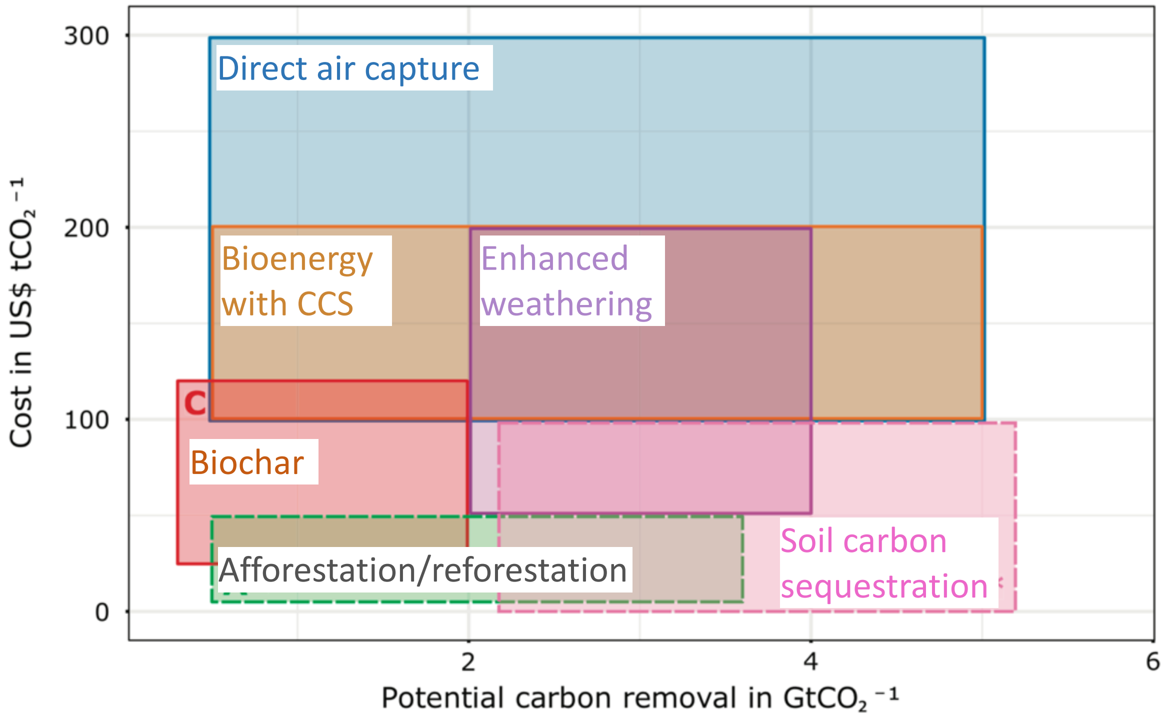

All potentials are limited

All methods have risks and side-effects

→ **Portfolio** of options needed

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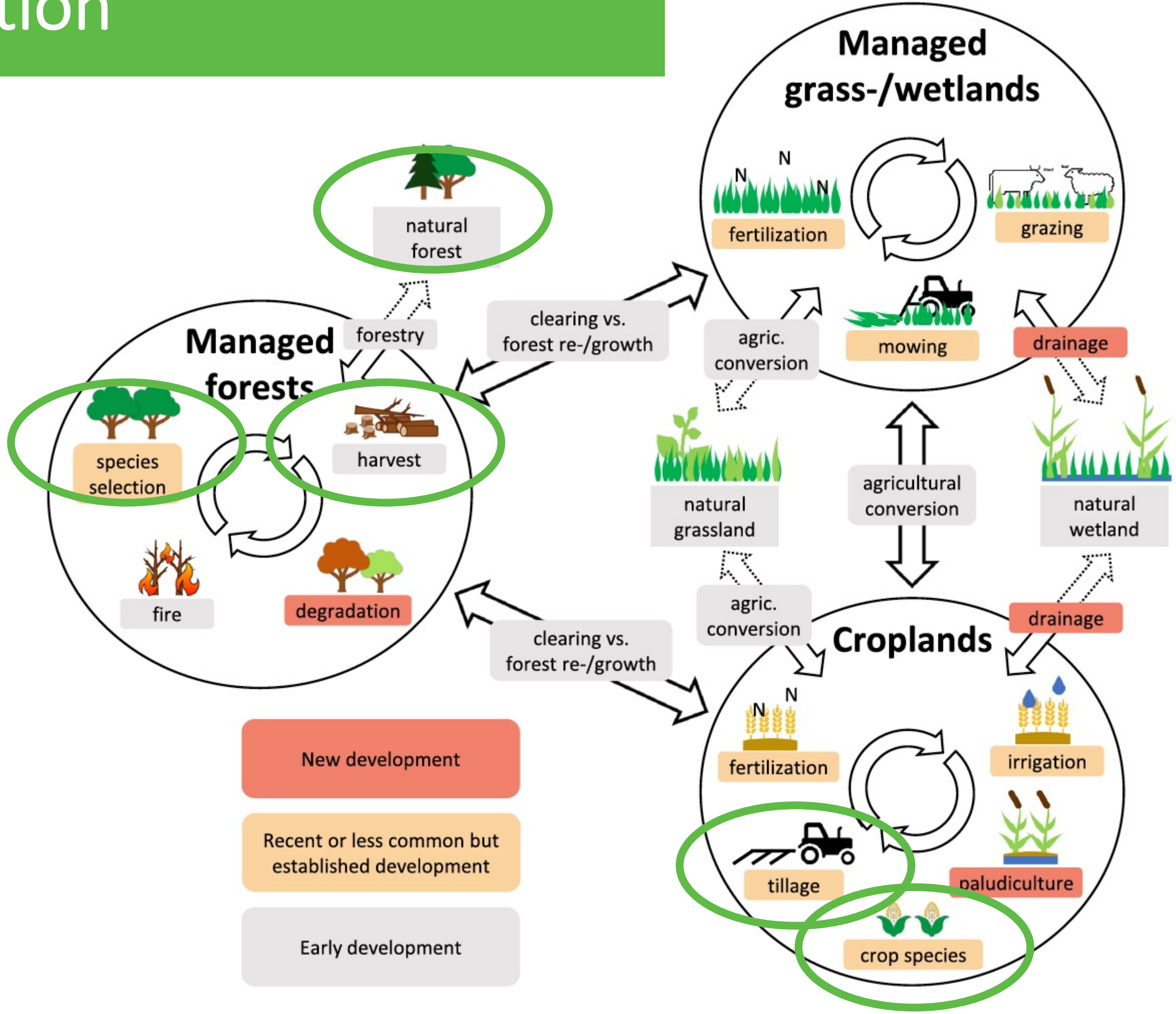
Status of model implementation

- BECCS, A/R, forestry (, soil C sequestration) included in several LSMs (with varying detail)
  - Note: problems exists for A/R that the *area* the IAMs assume is not realized in the LSMs (Di Vittorio et al., *BG,* 2014)



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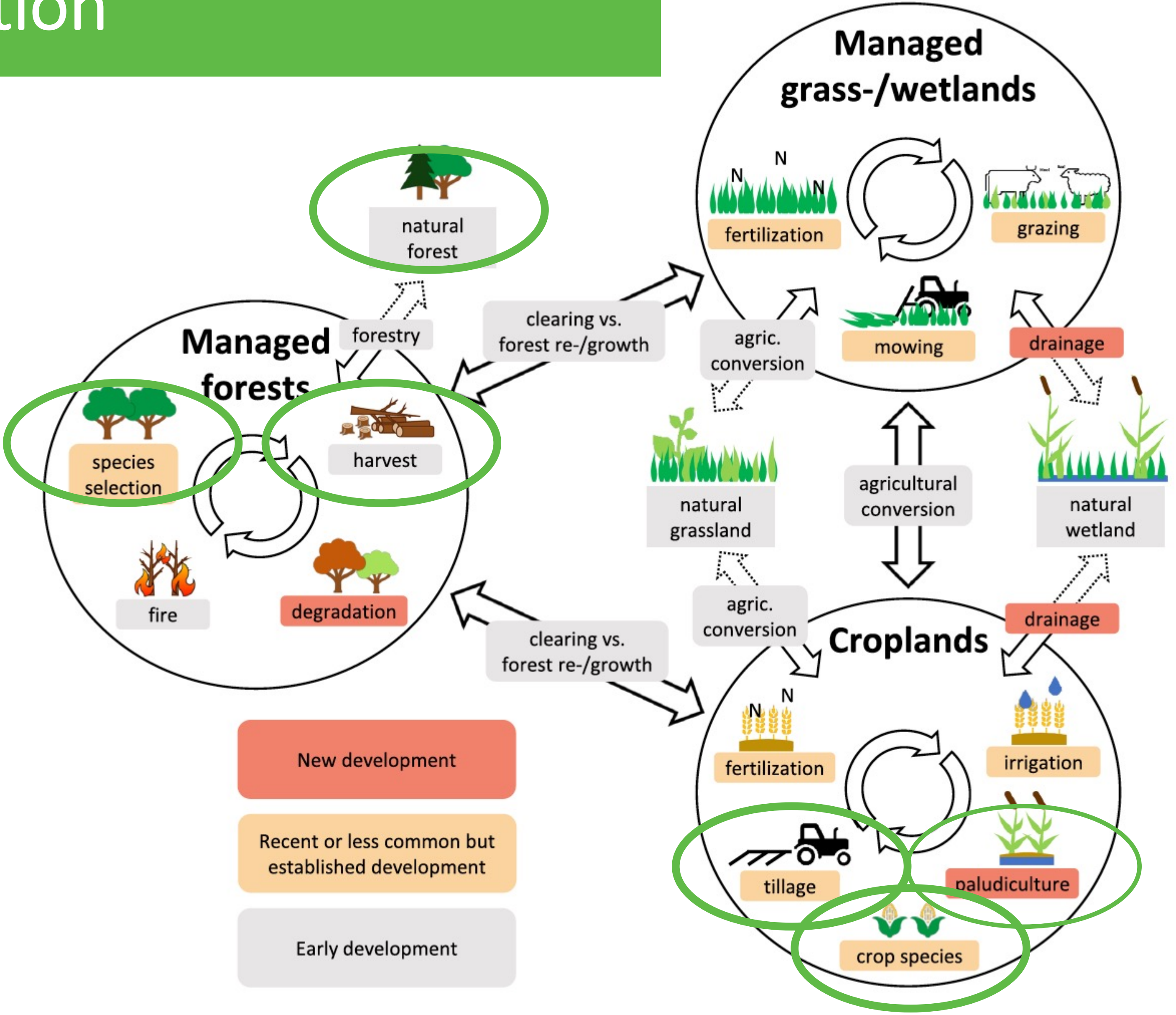
- Agroforestry, biochar, enhanced weathering (, paludiculture) largely missing

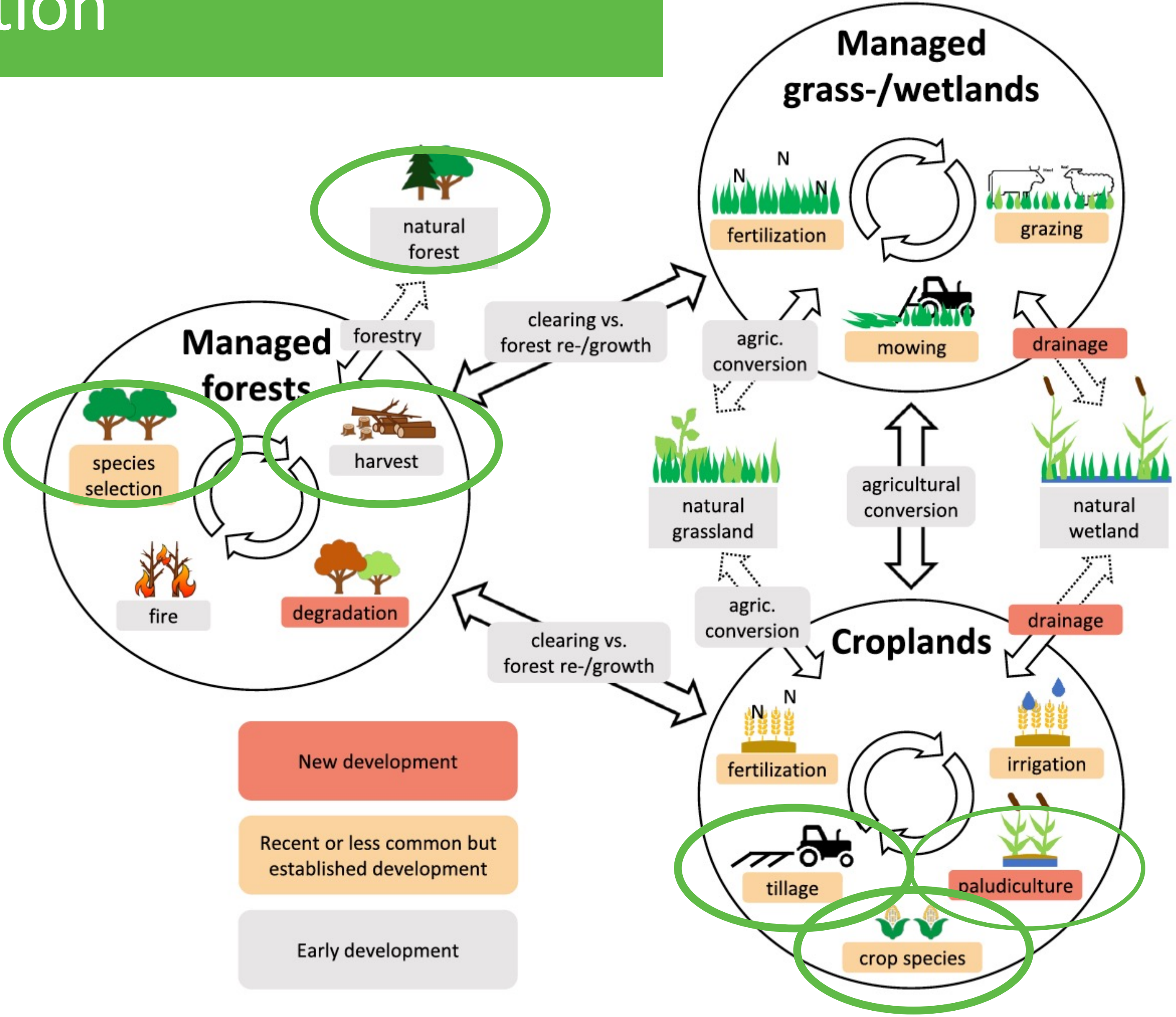


Status of model implementation

- BECCS, A/R, forestry (, soil C sequestration) included in several LSMs (with varying detail)
  - Note: problems exists for A/R that the *area* the IAMs assume is not realized in the LSMs (Di Vittorio et al., *BG,* 2014)

- Agroforestry, biochar, enhanced weathering (, paludiculture) largely missing

- Blyth et al., *CCCR,* 2021: future direction is link to models for food and water use



Examples of implementation of BECCS in 3 LSMs

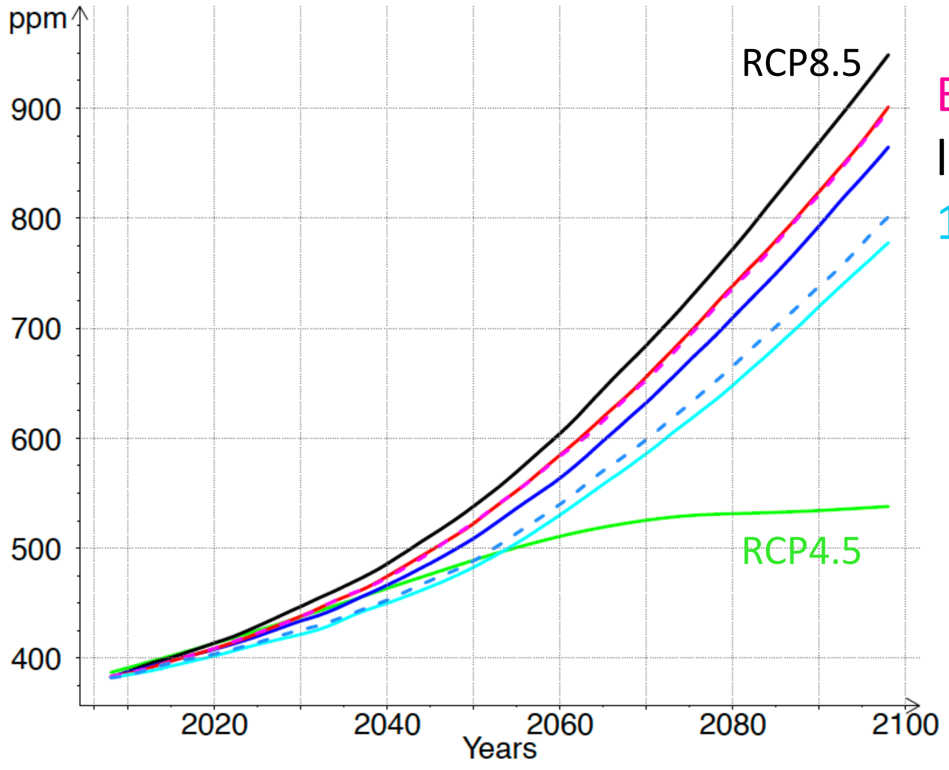
	Type	Representation	Bioenergy use	reference
JSBACH3	Miscanthus	1 new PFT (specific parameters, phenology and harvesting)	Substitution levels from 0-100%	Mayer, *Reports on Earth System Science*, 2017
ORCHIDEE-MICT-BIOENERGY	Miscanthus, switchgrass, poplar/willow, eucalypt	4 new PFTs (specific parameters and harvesting)	Separate bioenergy harvest pool that is released to atmosphere immediately	Li et al., *GMD*, 2018
CLM5	Miscanthus, switchgrass	2 new CFTs (specific parameters, planting & harvesting, fertilization, irrigation)	Bioenergy harvest released to atmosphere immediately	Cheng et al., *JAMES*, 2019




Example: Comparing A/R to BECCS in JSBACH

- Using plausible land-use scenario (RCP4.5), letting forests regrow or use the same area for BECCS (~6 mio km^2) → How much C do we sequester? Which method is better?

Atmospheric CO_2 concentration under RCP8.5 fossil forcing (RCP4.5 for comparison)



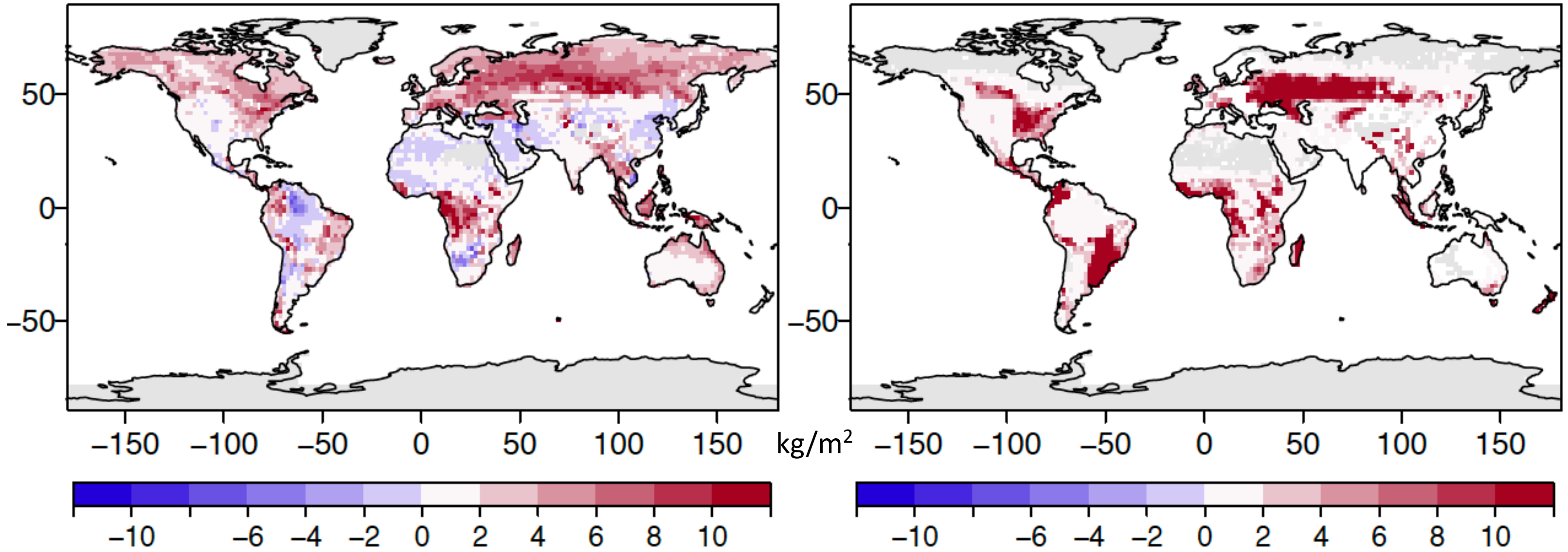
BECCS with 0% fossil-fuel substitution is less efficient than A/R, but BECCS with 100% substitution is much more efficient

Example: Comparing A/R to BECCS in JSBACH

Total carbon uptake 2006-2100

… for A/R

… for BECCS (100% substitution)

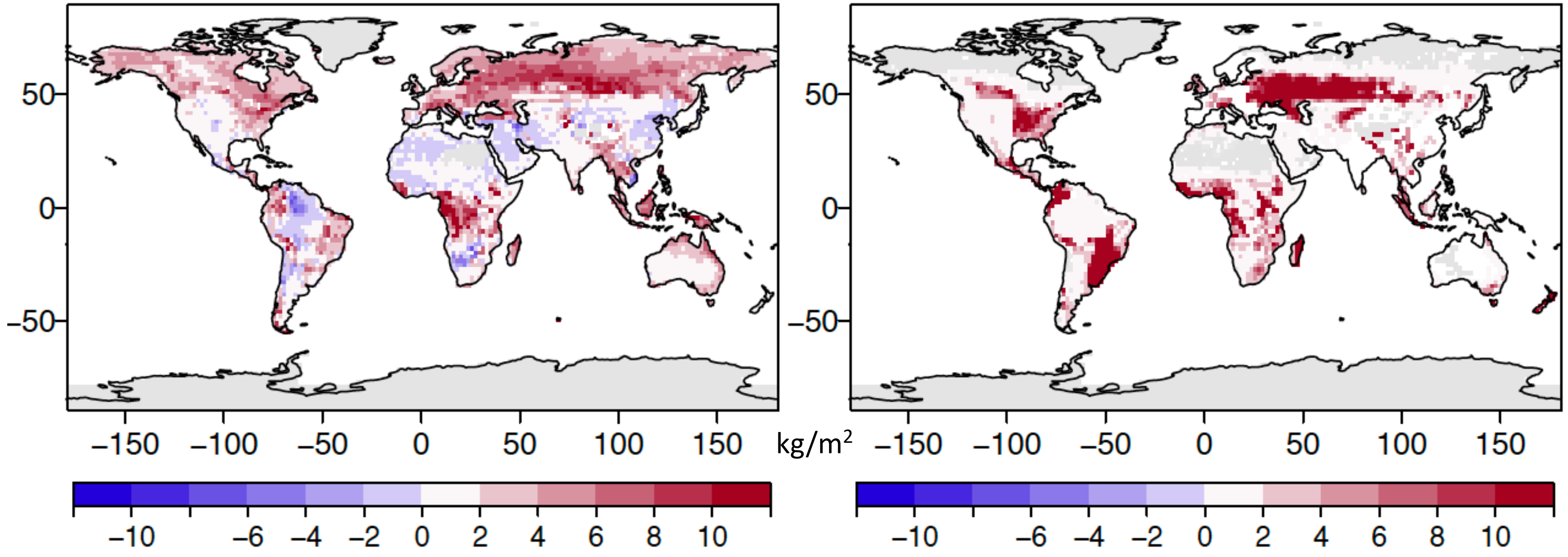


Example: Comparing A/R to BECCS in JSBACH

Total carbon uptake 2006-2100

… for A/R

… for BECCS (100% substitution)



↑

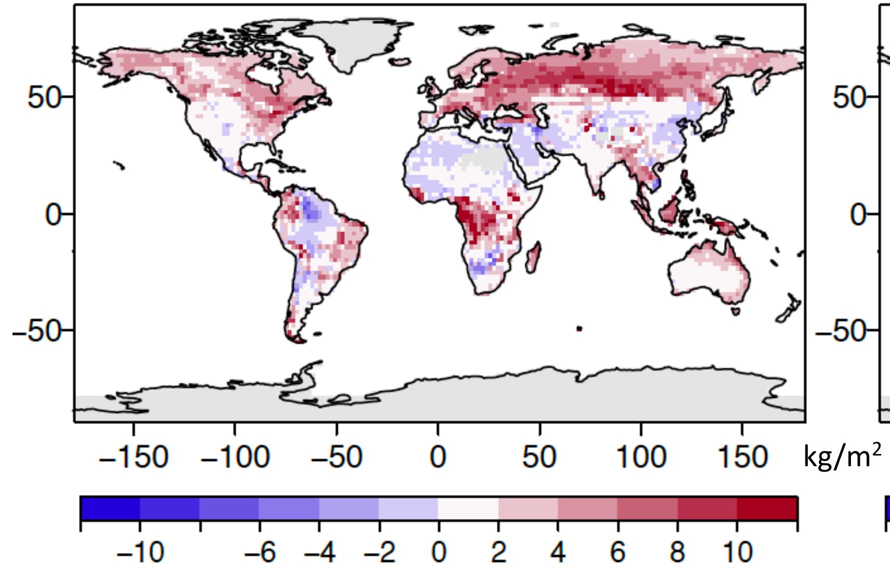
Note: Includes a lot of soil C sequestration!

See Ito et al., *ERL*, 2020 for analysis of soil C in LUMIP simulations

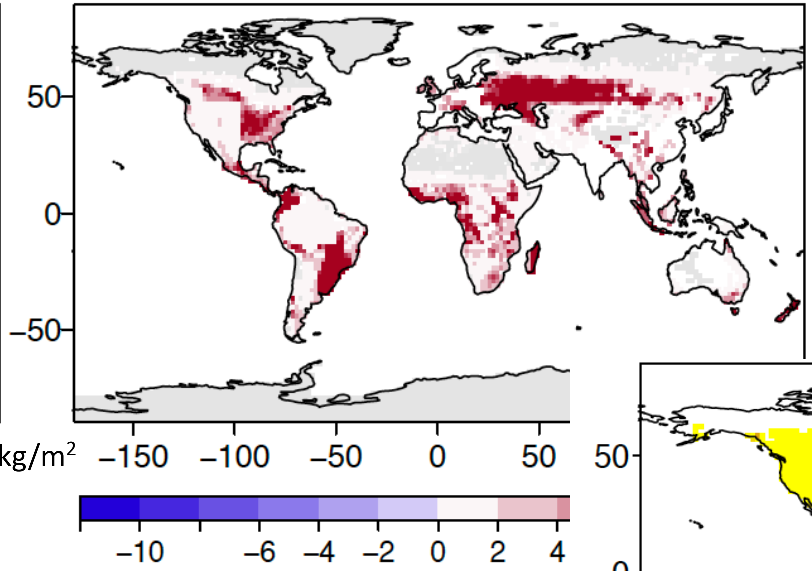
Example: Comparing A/R to BECCS in JSBACH

Total carbon uptake 2006-2100

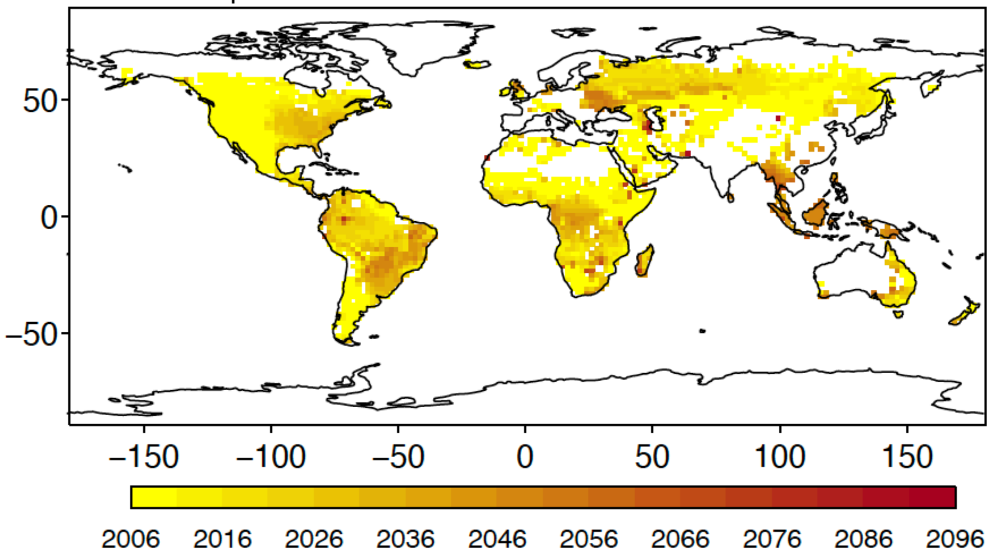
… for A/R



… for BECCS (100% substitution)

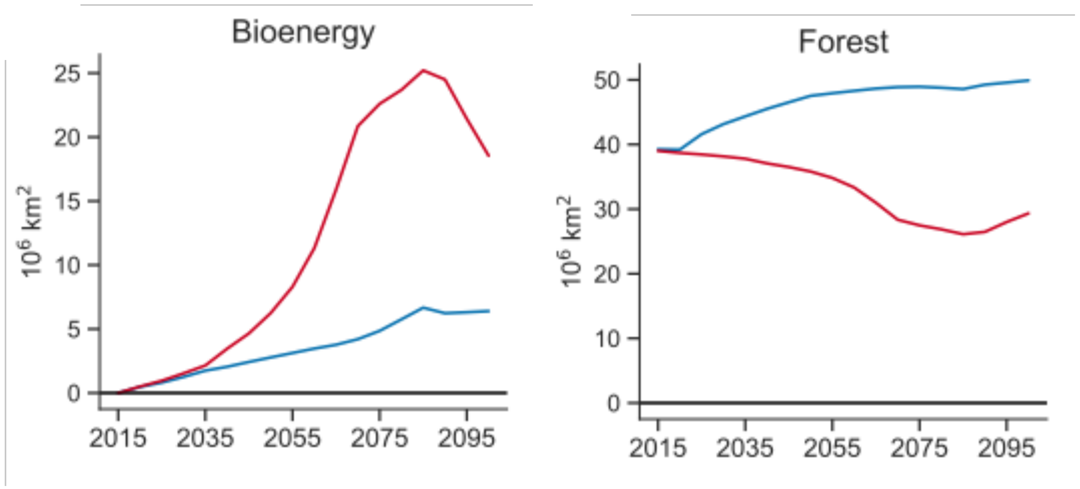


In this year, BECCS become more efficient in sequestering CO_2 than A/R:



Example: Comparing A/R to BECCS scenarios in CLM5

Radiative forcing / CO_2	Land Use	Name
SSP1-2.6	SSP1-2.6Lu	REFOREST
SSP1-2.6	SSP2-2.6Lu	BIOCROP



→ see Poster by Dave Lawrence!

Example: Comparing A/R to BECCS scenarios in CLM5

Radiative forcing / CO_2	Land Use	Name
SSP1-2.6	SSP1-2.6Lu	REFOREST
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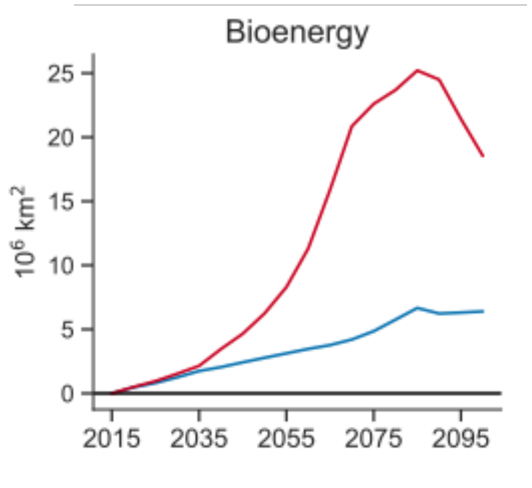
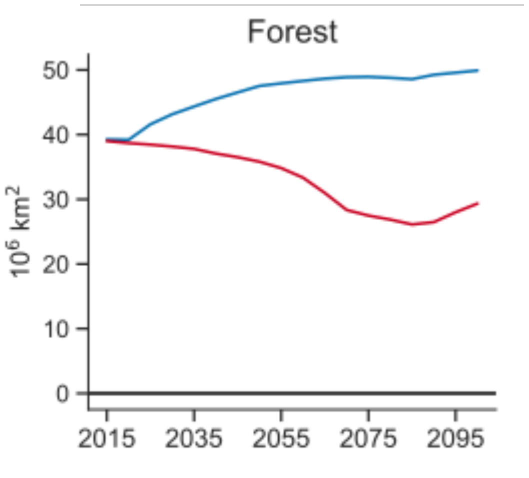
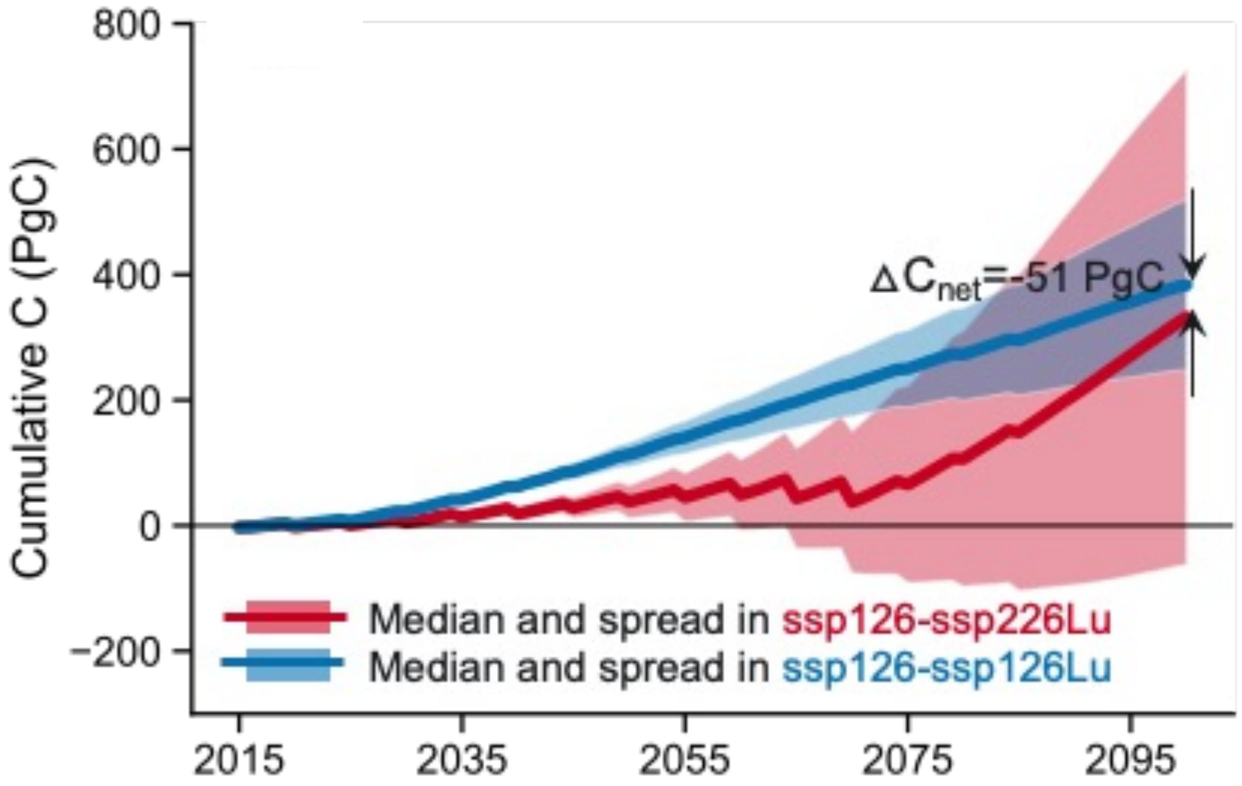


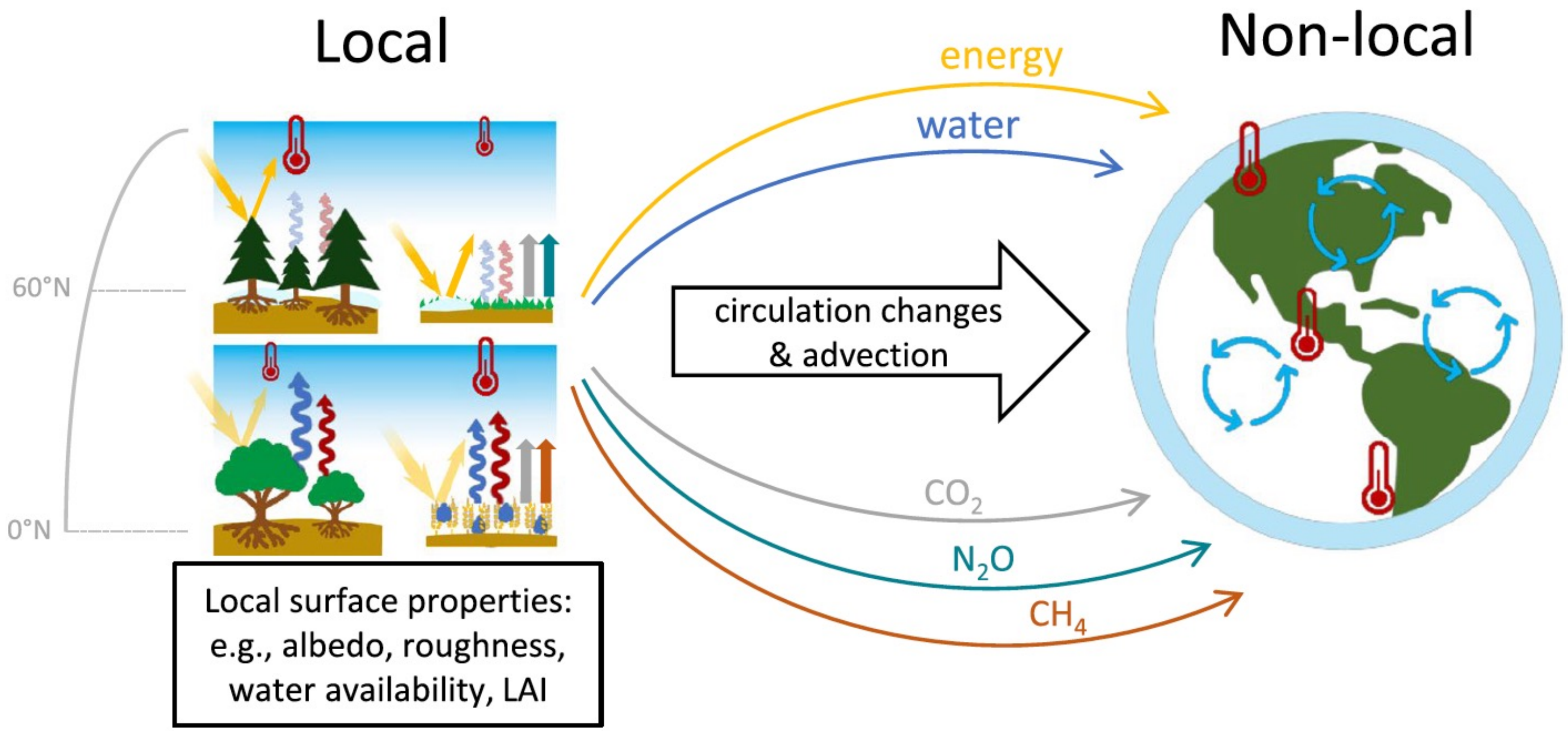


Net carbon uptake in the two scenarios



→ see Poster by Dave Lawrence!

+ side-effects on climate…



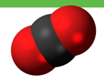
Pongratz et al, *Curr. Clim. Ch. Rep.,* 2021

Further research and transfer needs

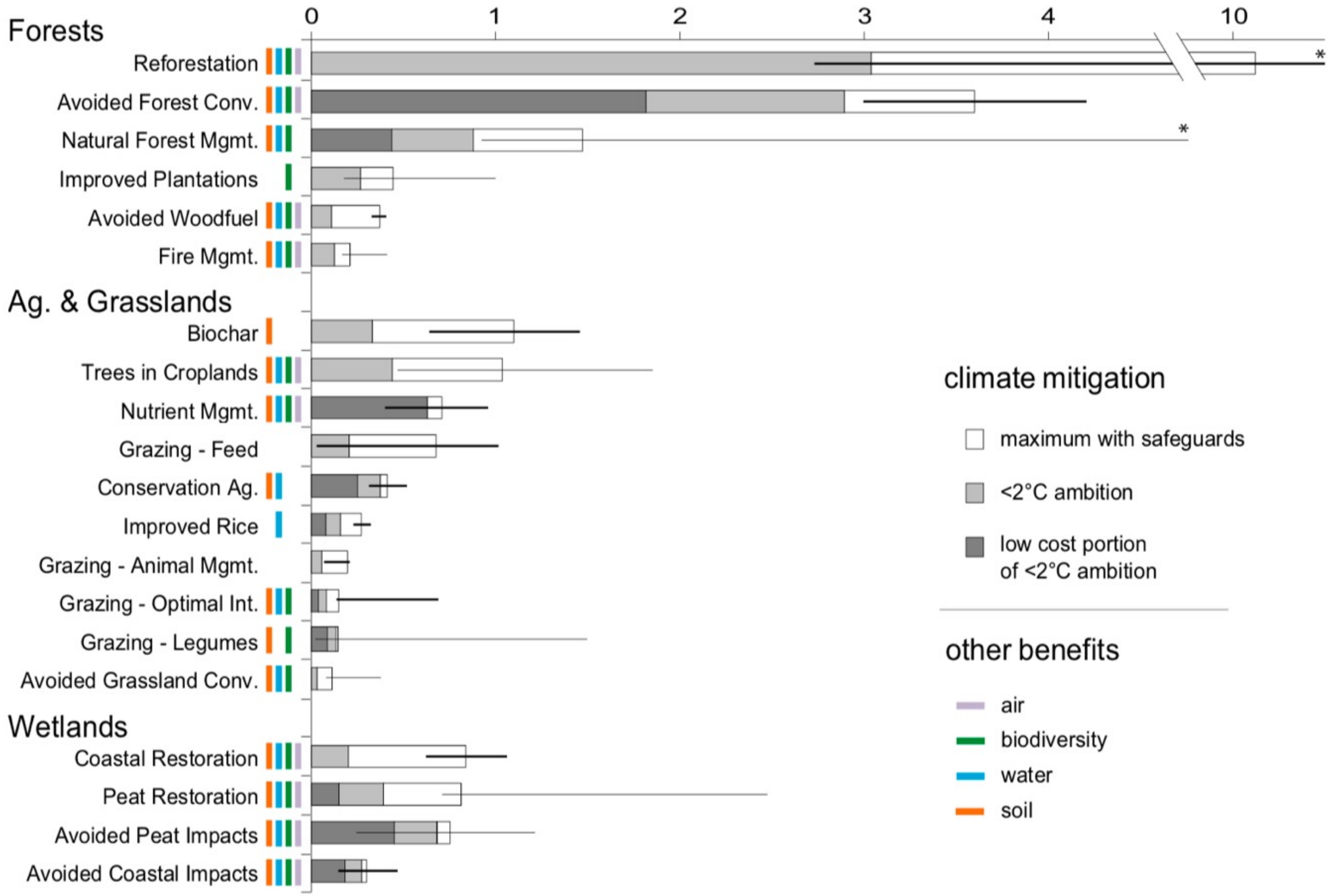
- Development and implementation of Monitoring, Reporting and Verification of CDR (MRV) → e.g. EU certification
- Improvement and operationalization of model und Earth observations systems
- Research at the interface of science and policy to create incentive and governance structures
- Demonstration projects of untested CDR methods, closely accompanied by research
- Transparent dialogue between science, politics, and public to create broad acceptance

Most prominent examples of "natural climate solutions"

1 $PgCO_2$ = 0.27 PgC



Global climate mitigation potential in 2030 ($PgCO_2e$/year)



Griscom et al, *PNAS*, 2017