NEGEM

Potential of Biomass-based NETPS within Planetary Boundaries

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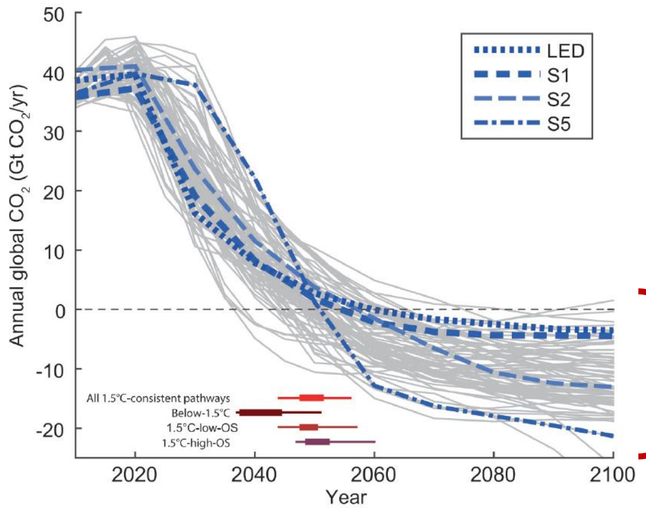
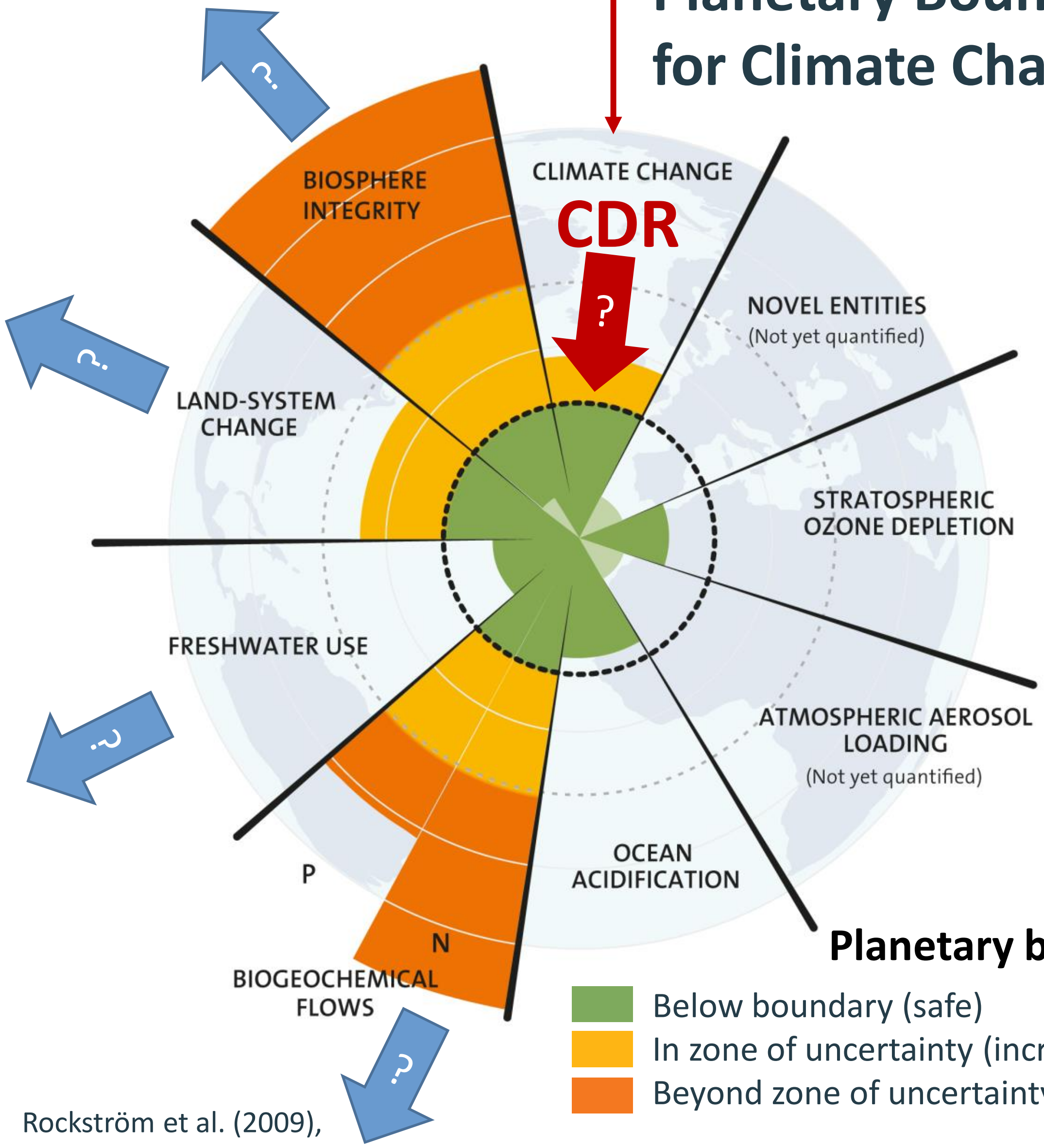
Beyond Climate Stabilization: Multi-Faceted Impacts of NETPs on Earth System Resilience



Planetary Boundary for Climate Change



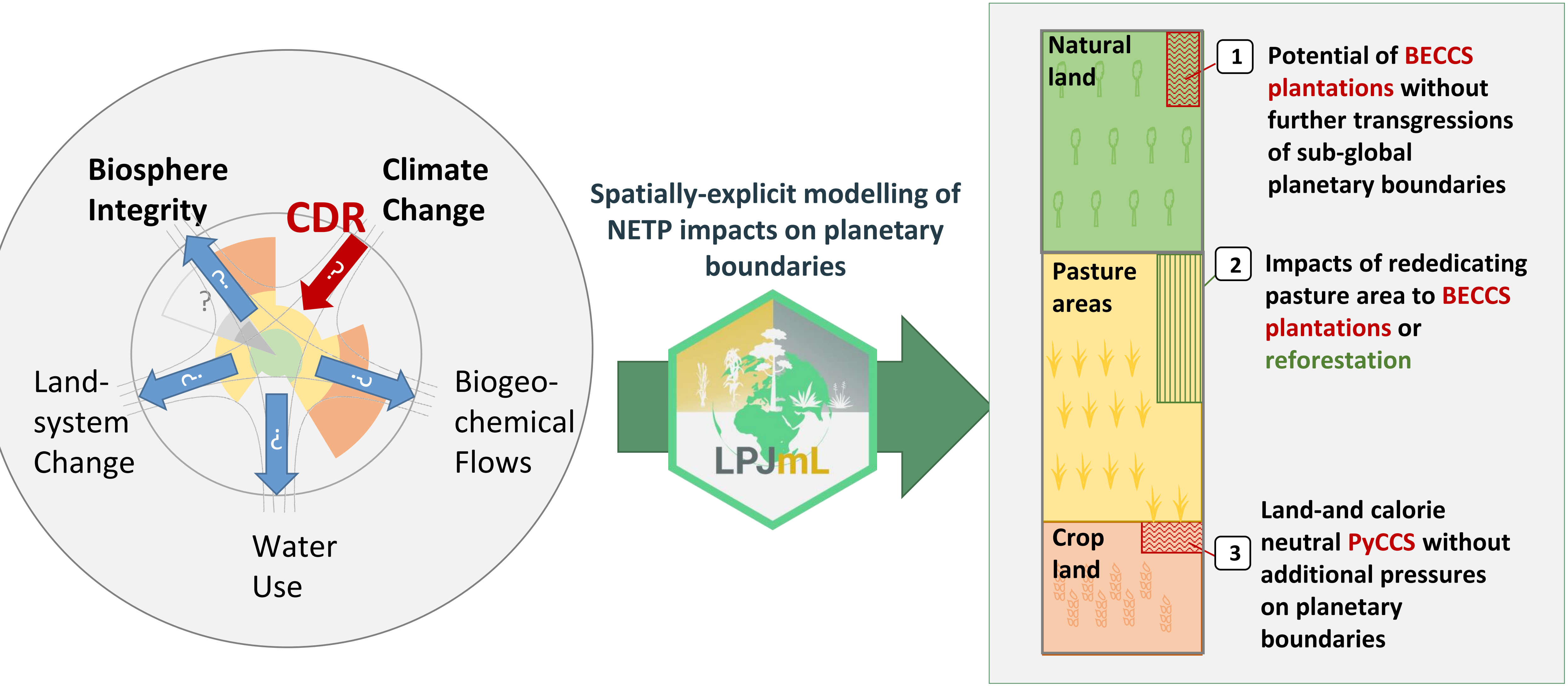
Planetary boundaries

- Below boundary (safe)
- In zone of uncertainty (increasing risk)
- Beyond zone of uncertainty (high risk)

Rationale of Earth system resilience
puts climate protection in the context of other planetary boundaries

Rockström et al. (2009), Steffen et al. (2015)

Impacts of land-based NETPs on four terrestrial planetary boundaries



Dynamic Vegetation Model LPJmL (Lund-Potsdam-Jena managed Land)

Carbon

GPP	gross primary production
Ra	autotrophic respiration
NPP	net primary production
Rh	heterotrophic respiration
Hc	harvest
Fc	fire carbon fluxes
Csom	soil organic matter

Water

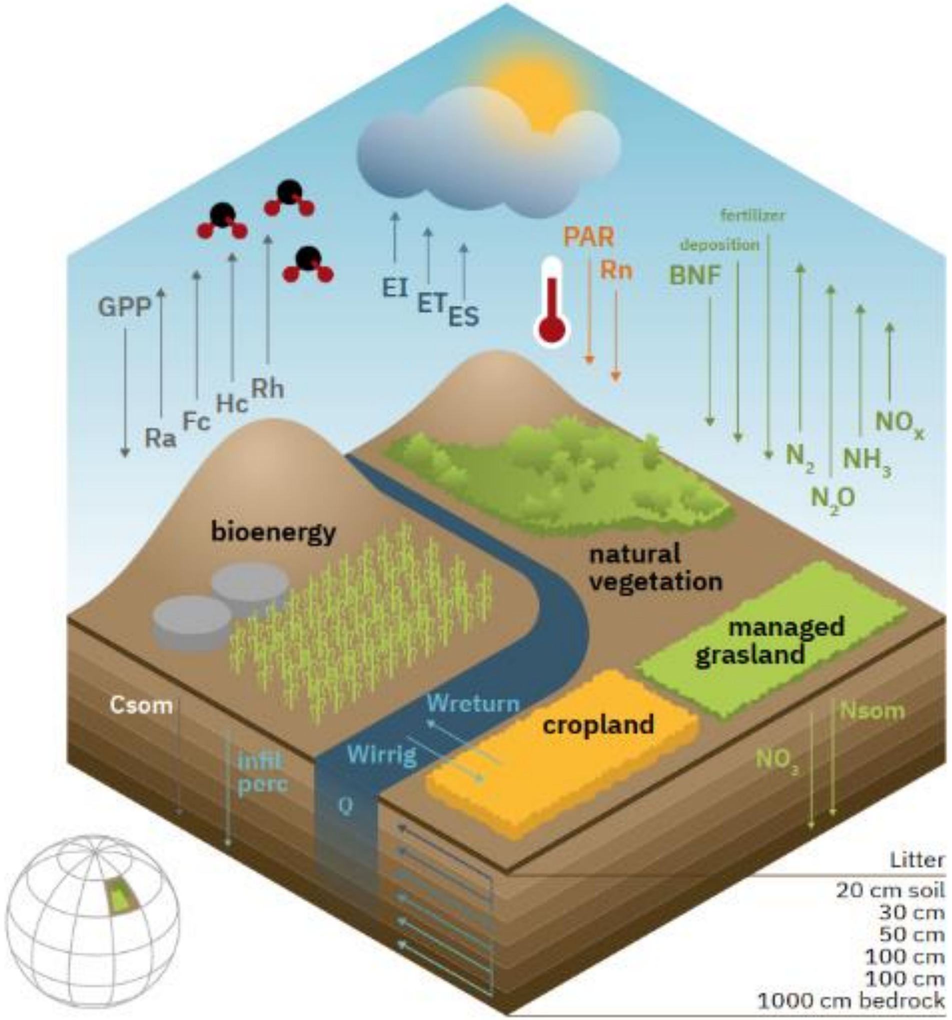
EI	interceprion
ET	transpiration
ES	evaporation
perc	percolation
infil	infiltration
R	runoff
Wreturn	return flow of irrigation
Wirrig	irrigation water
Q	dircharge

Energy

PAR	photosynthetic active radiation
Rn	net radiation

Nitrogen

BNF	biological nitrogen fixation
Nsom	nitrogen in soil organic matter



Spatial: 0.5° x 0.5°
Temporal: daily

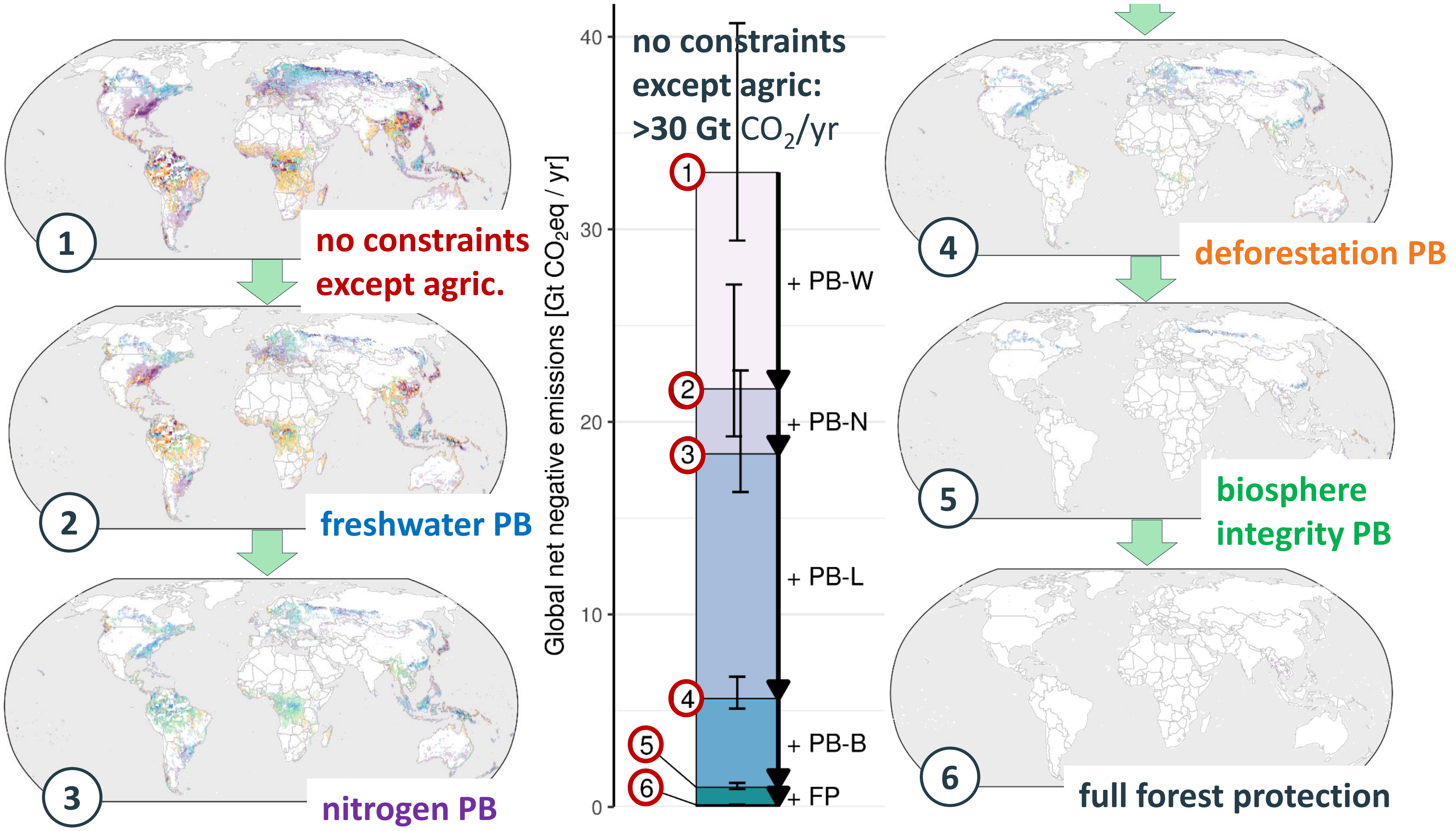
PFT
- Tropical broadleaved evergreen tree
- Tropical broadleaved raingreen tree
- Temperate needle-leaved evergreen tree
- Temperate broadleaved evergreen tree
- Temperate broadleaved summergreen tree
- Boreal needle-leaved evergreen tree
- Boreal broadleaved summergreen tree
- Boreal needle-leaved summergreen tree
- Tropical herbaceous
- Temperate herbaceous
- Polar herbaceous

CFT -- prescribed --
- Bioenergy tropical tree
- Bioenergy temperate tree
- Bioenergy C_4 grass
- Temperate cereals
- Rice
- Maize
- Tropical cereals
- Pulses
- Temperate roots
- Tropical roots
- Sunflower
- Soybean
- Groundnut
- Rapeseed
- Sugar cane

Schaphoff et al. (2018)

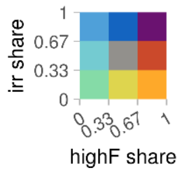
1

No potential of BECCS outside agricultural areas without further transgressions of planetary boundaries and full forest protection



Note:

- Study on energy crops, residual biomass potential not included
- Global, not local study
- Biomass plantations outside agricultural areas



highF = high fertilization
irr = irrigation

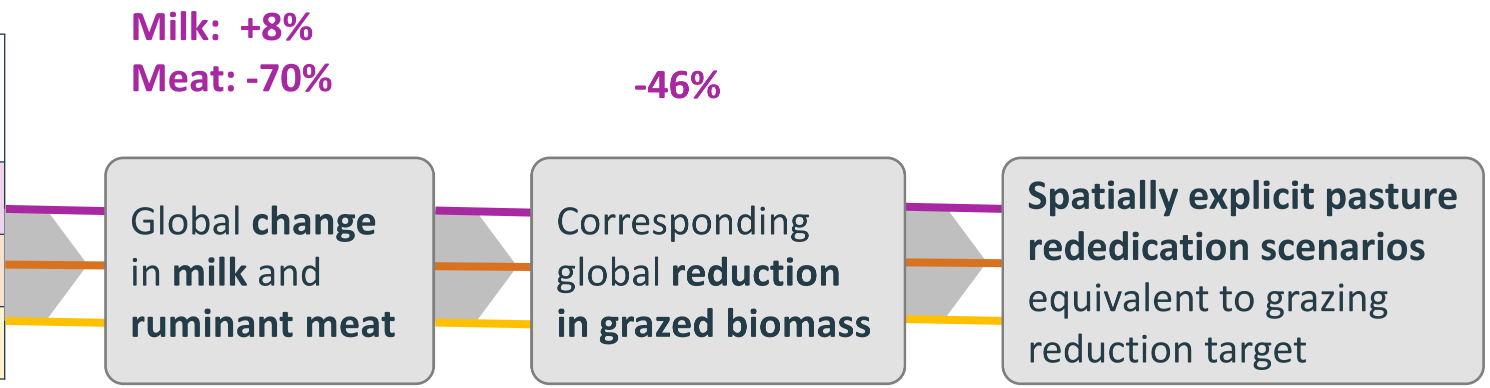
Plantation-based BECCS potentials constrained by planetary boundaries: <u>30 → 1 (→ 0) Gt CO_2/yr</u>

D3.2 on www.negemproject.eu

2 Unlocking Land for NETPs: Shifting Diets to Release Pastures and Preserve Natural Vegetation

- Future land availability for CDR thus depends on potential reduction in agricultural areas
- Pastures reductions are possible upon large-scale diet changes towards less livestock products, amongst others
- EAT-Lancet planetary health diet: contributing to both human and planetary health

EAT-Lancet target achievement	Scenario name
100%	DC100
50%	DC50
25%	DC25



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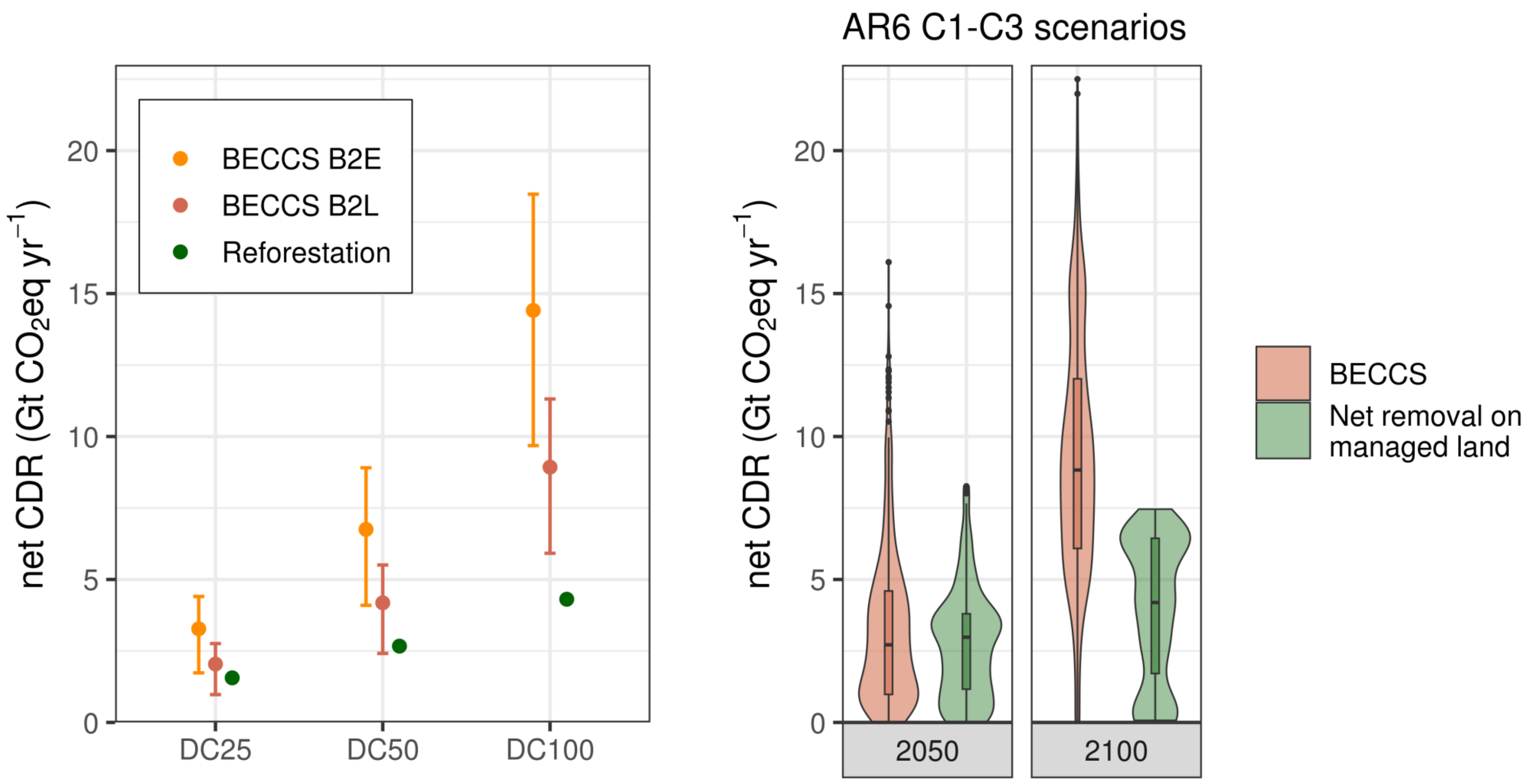
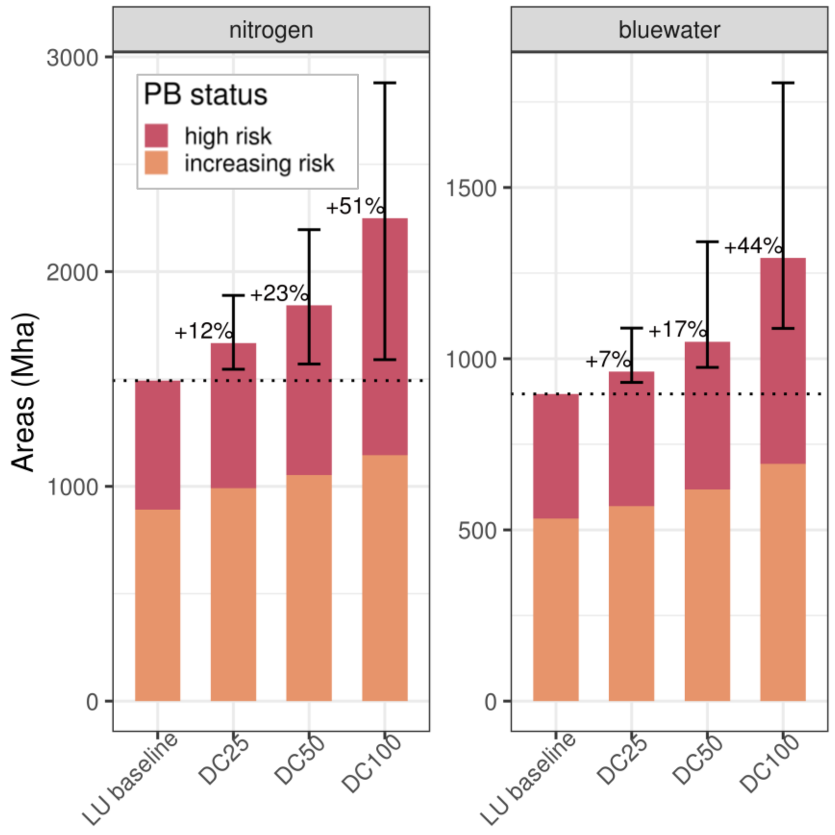
CDR potentials from rededicating pasture to biomass plantations for BECCS or reforestation



B2E = Biomass-to-Electricity
B2L = Biomass-to-Liquid

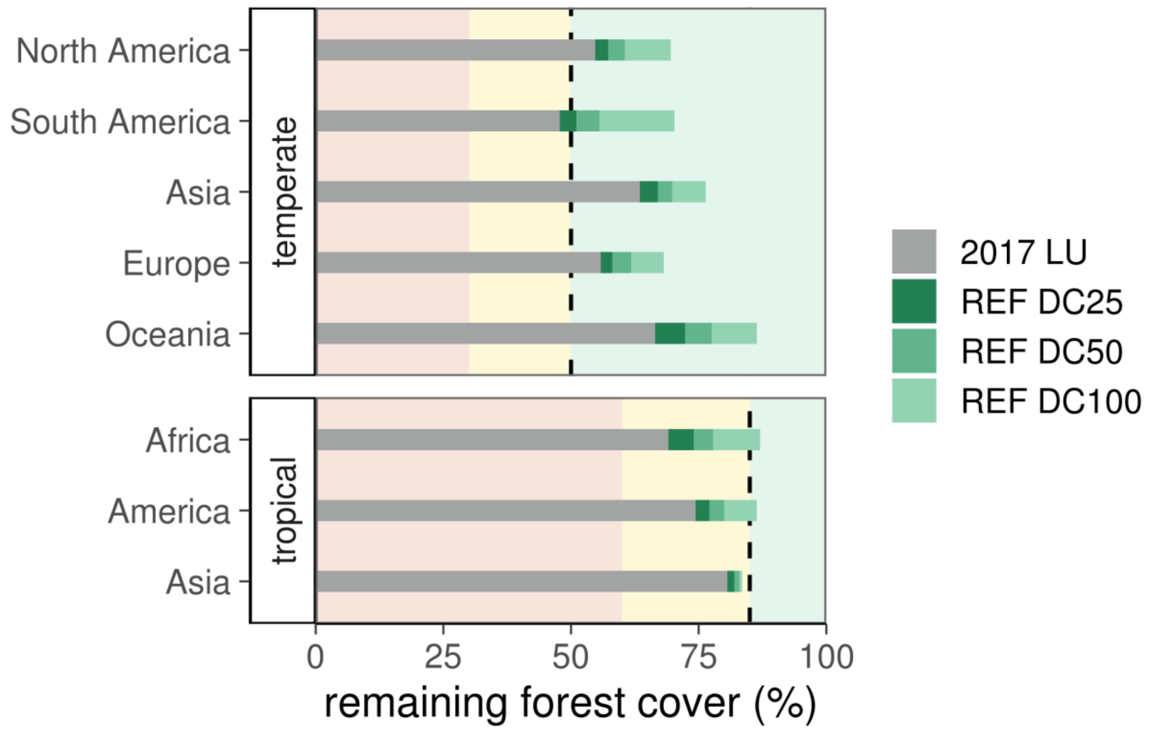
2 Impacts on freshwater, nitrogen and land-system change boundaries

BECCS



Reforestation

Land-system change



- BECCS DC100 scenario under moderate management implies ~50% increase in areas with transgressions of environmental boundaries for nitrogen and water
- In contrast, reforestation scenarios would slightly improve the water and nitrogen status, and significantly improve the status of the land-system change boundary, especially in the tropics

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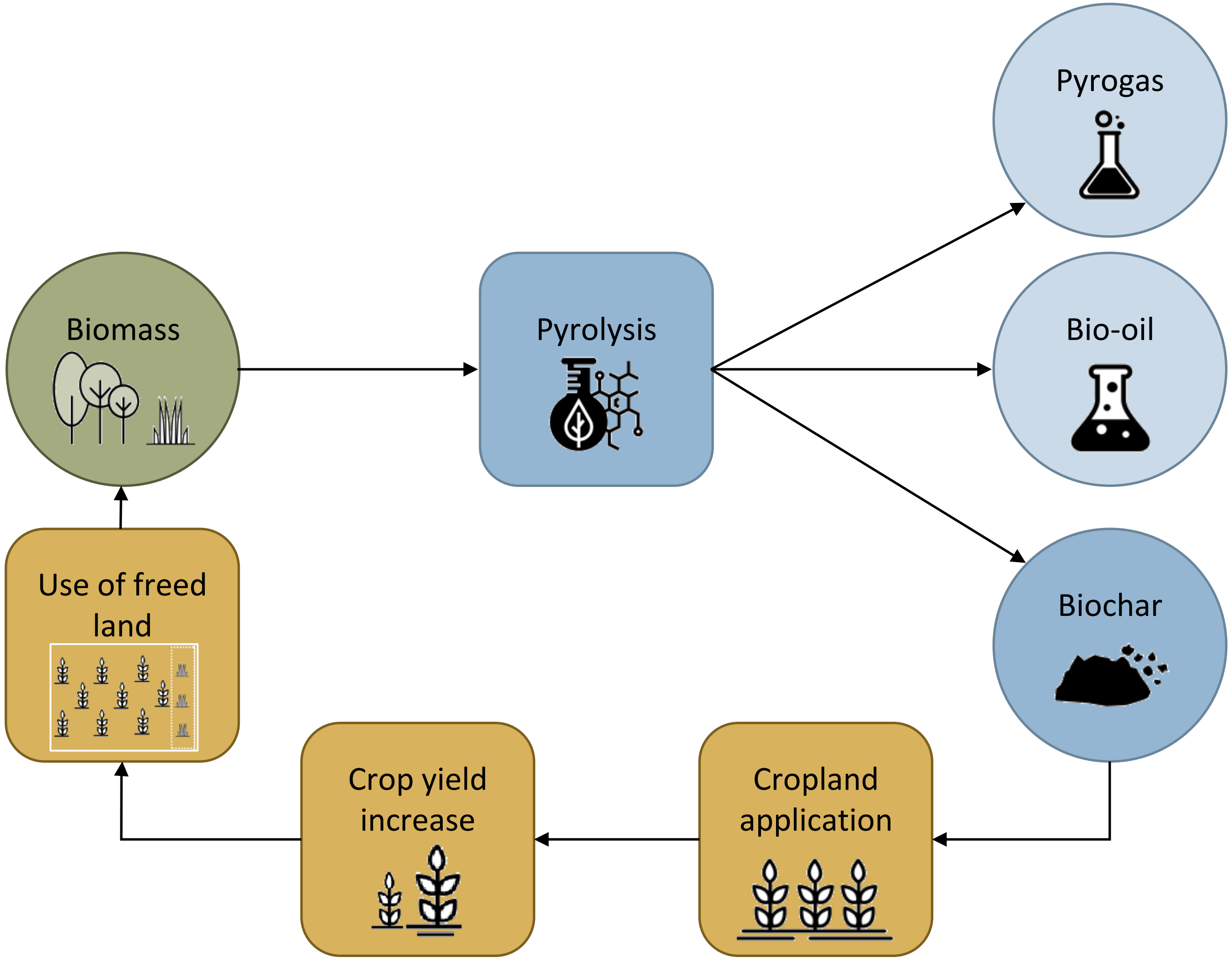
2

Biomass plantations for BECCS on pasture area increasing the pressure on PBs – reforestation alleviating it

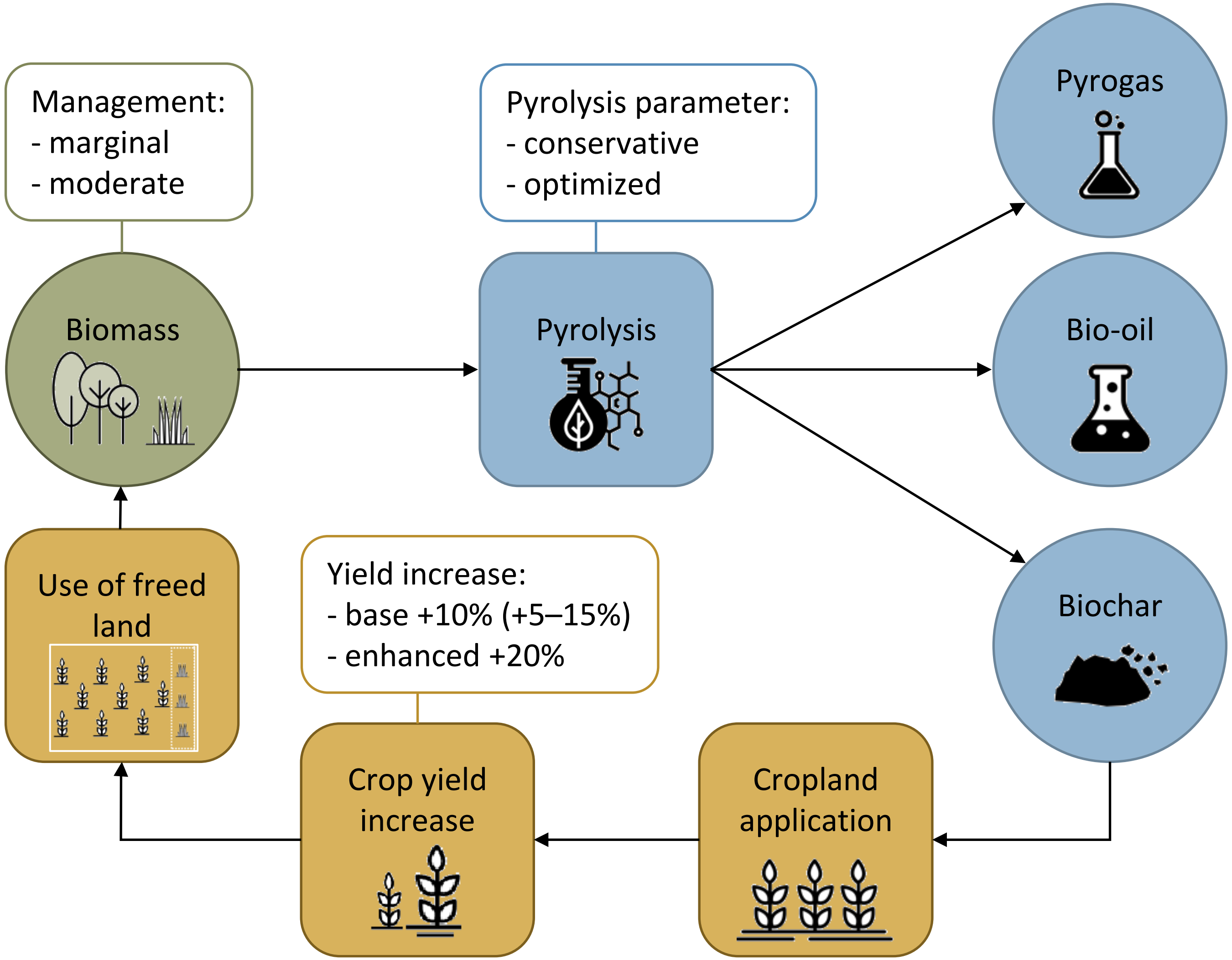
- Any **conversion of (semi-)natural land** for CDR would **further undermine** terrestrial **planetary boundaries** and other environmental targets
- Future **land availability for CDR** thus depends on a **potential reduction in pasture area**, which is amongst others possible upon **diet changes** towards less livestock products (e.g. a transition to the EAT-Lancet planetary health diet)
- Rededicating pastures to **biomass plantations for BECCS** would allow for **more CDR** (with a higher level of permanence) than reforestation, but could come at the cost of **drastic trade-offs with terrestrial PBs,** if sustainable management on biomass plantations cannot be ensured globally.
- CDR from **reforestation** on pastures is reversible, saturates over time and **is less efficient per area**, thus requiring more ambitious diet changes to reach similar CDR rates as BECCS. It would however allow to achieve **multiple sustainability targets**, by simultaneously contributing to both **climate stabilization and nature restoration**.

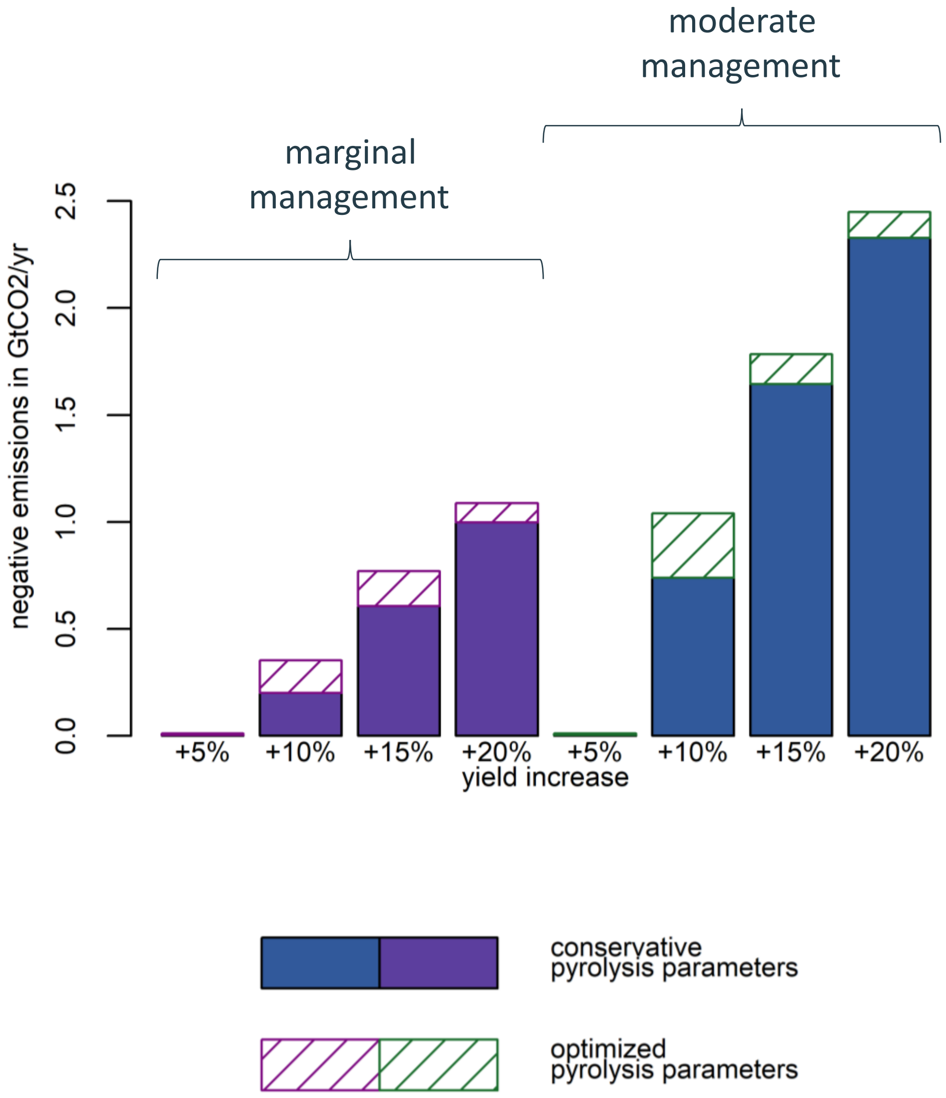
3 Land-and calorie neutral PyCCS without additional pressures on planetary boundaries



PyCCS =
pyrogenic carbon capture and storage

3 Exploring the operation space for land- and calorie-neutral PyCCS





Werner et al. (2023) in review

3 Exploring the operation space for land- and calorie-neutral PyCCS

- LCN-PyCCS may contribute to climate stabilization without further pressures on land resources and food security.
- NETP co-benefits (i.e. yield increases in LCN-PyCCS) are worth considering for the assessment of land-constrained NETP deployment
- Research and practice should aim for developing the best biochar application achievable under field-specific conditions to maximize the potential.
- The assessment of biomass-based NETPs requires elaborate models/databases on residue and waste use – large-scale deployment of PyCCS should not rely on purpose-grown biomass (especially as it is the advantage of PyCCS that it can be adapted to diverse systems)

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Thank you!

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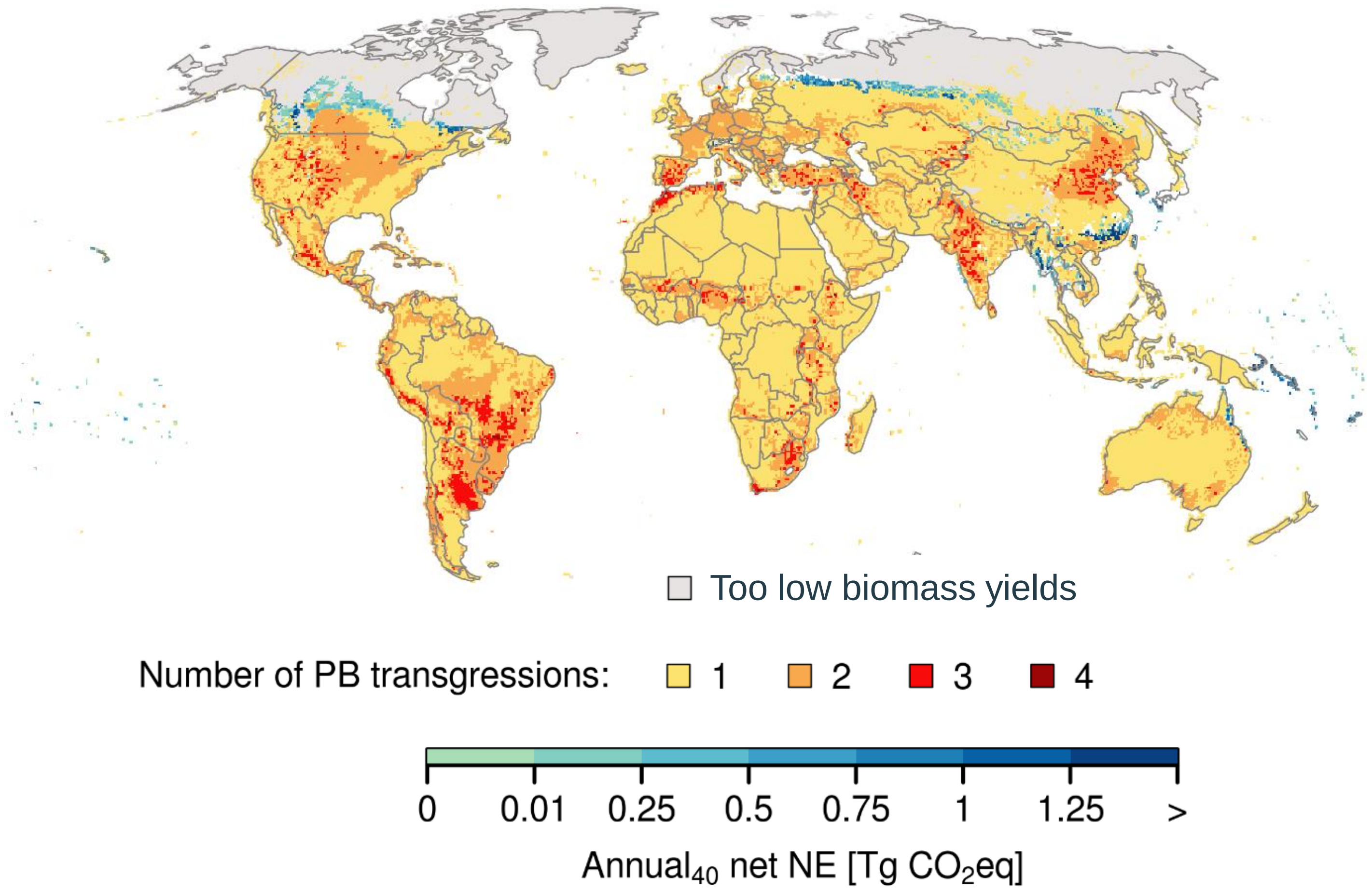
Appendix

D3.2: NETP potentials without further transgressing planetary boundaries

1 BECCS potentials constrained by planetary boundaries

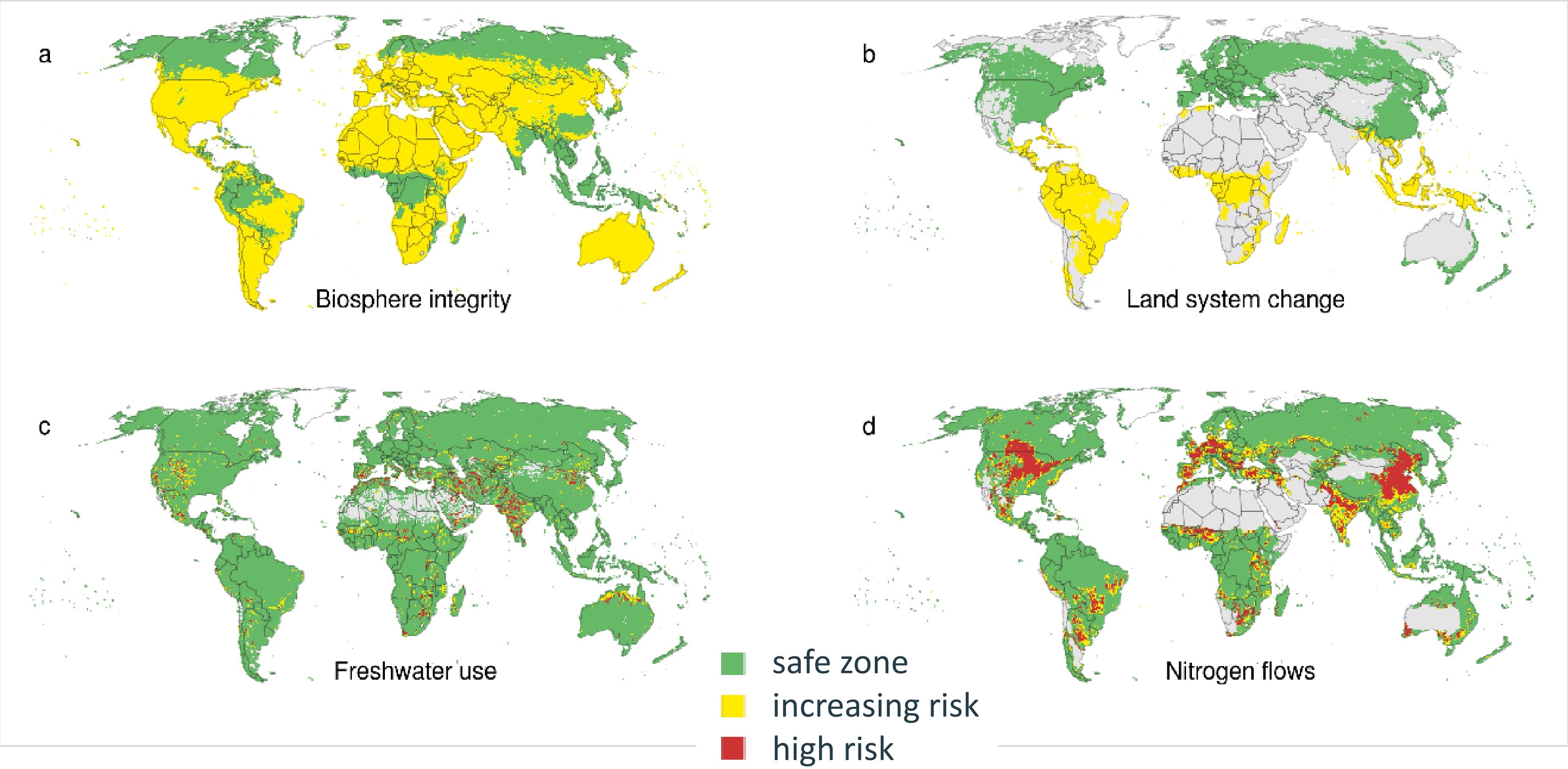


PB definitions

Earth System Process	Control Variable	Planetary Boundary and sub-global assessment unit	Constraint for biomass plantations	References for control variables and thresholds
Change in biosphere Integrity	Biodiversity Intactness Index (BII)	90%, assessed by continental biomes	BII reductions by biomass plantations only up to a BII of 90% (in areas where BII is already <90% in the agricultural baseline, no more biomass plantations may be added)	Steffen et al. 2015, Newbold et al. 2016
Biogeochemical Flows (N cycle)	N in runoff to surface water as proxy for dissolved inorganic N concentrations in surface water	1 mgN l^{-1}, assessed at the grid cell level (0.5°x0.5°)	N in runoff from biomass plantations may not lead to additional transgressions of the nitrogen threshold in runoff . In cells where the N threshold is already transgressed in the agricultural baseline, no more biomass plantations may be added .	De Vries et al. 2013, 2021
Land-System Change	Area of forested land as % of potential forest for each biome	Tropical: 85% Temperate: 50% Boreal: 85% Assessed for each continent and biome	Forest may only be converted to biomass plantations as long as PB thresholds are not transgressed	Steffen et al. 2015
Freshwater Use	River flow reduction as % of potential mean monthly river flow (MMF)	low-flow months: 25%; intermediate-flow months: 40% high-flow months: 55%,assessed at the grid cell level taking into account upstream-downstream effects	River flow alterations by biomass plantations (from irrigation or changes in runoff) may not lead to additional PB transgressions in any month of the year.	Steffen et al. 2015, Pastor et al. 2014

D3.2: 1) BECCS potentials constrained by sub-global planetary boundaries

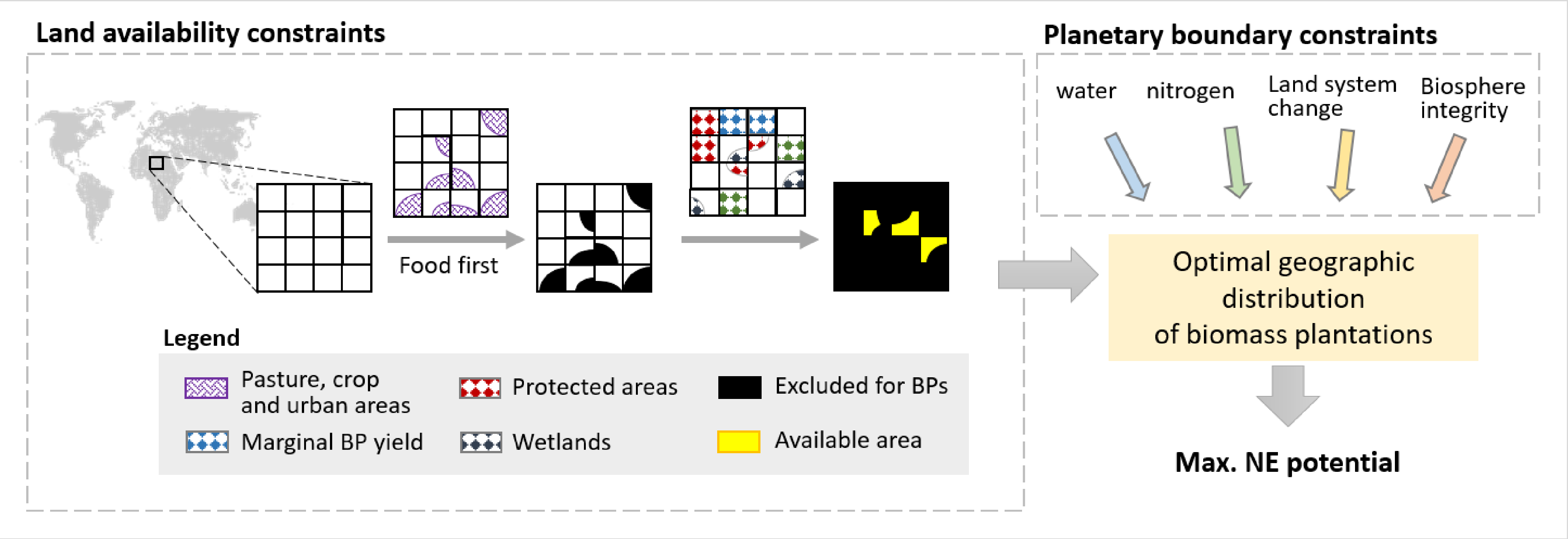
Planetary boundary constraints based on 2015 land use input (averaged for 1986-2015 climate)



D3.2: NETP potentials without further transgressing planetary boundaries

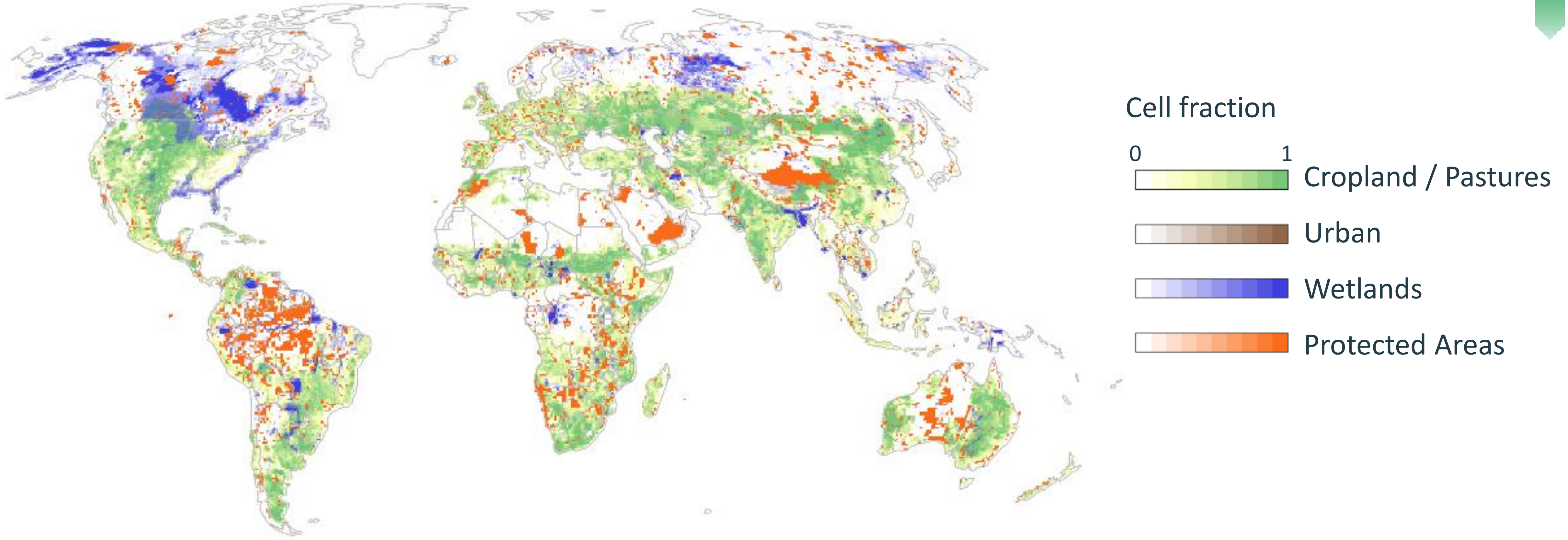
1 BECCS potentials constrained by planetary boundaries

General approach



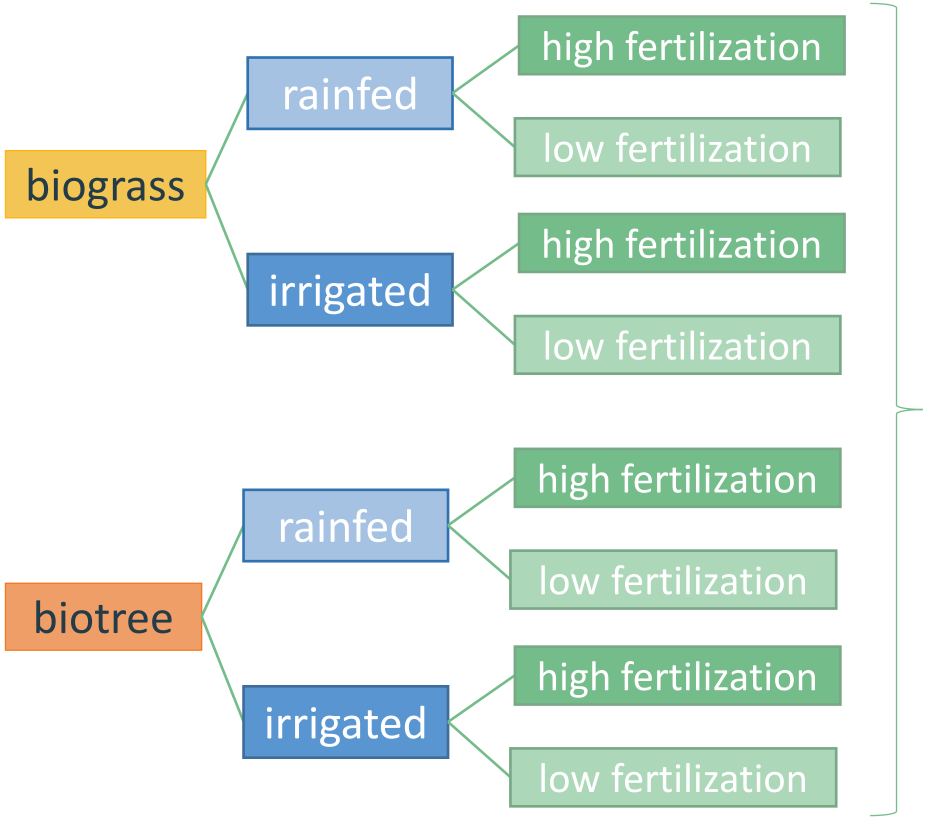
D3.2: 1) BECCS potentials constrained by sub-global planetary boundaries

a) Constraints for the land availability for biomass plantations



D3.2: 1) BECCS potentials constrained by sub-global planetary boundaries

b) Optimized distribution of biomass plantations under planetary boundary constraints



Maximise net NEs under the constraint that further transgressions of regional planetary boundaries (N, W, BI, LSC) are excluded:

$$netNE_j^p = H_j^p * CEff^p - LUC_j^p - N20_j^p$$

$$\max_{f_j \in C_{PB}^{reg}} \left(\sum_{j=1}^{n} \sum_{p} f_j^p \cdot netNE_j^p \right)$$

H_j^p: harvest of biomass plantations j = 1…n (grid cells)

$CEff^p$: carbon removal efficiency

LUC_j^p: land use change emissionsand

$N20_j^p$: additional N_2O emissions (in CO_2-eq)

C_{PB}^{reg}: fixed regional boundary constraints

f_j^p: cell fractions

$p \in \{bg_{rf_{hF}}, bg_{rf_{lF}}, bg_{irr_{hF}}, bg_{irr_{lF}}, bt_{rf_{hF}}, bt_{rf_{lF}}, bt_{irr_{hF}}, bt_{irr_{lF}}\}$

Simulation of pasture rededication scenarios in LPJmL

In cooperation with ICL (MONET)

Pasture rededication scenarios

Biomass plantations for BECCS

3 DC scenarios à
3 management scenarios

Reforestation

3 DC scenarios

management scenario	irrigation	fertilization	CO_2 removal efficiency B2E	CO_2 removal efficiency B2L
intensive	irrigation share as for crops, but min. 30% of rededicated cell area	2 x N harvest under unlimited N conditions	0.923	0.669
moderate	irrigation share as for crops, but max. 30% of rededicated cell area	1 x N harvest under unlimited N conditions	0.836	0.603
minimal	0	0	0.795	0.583

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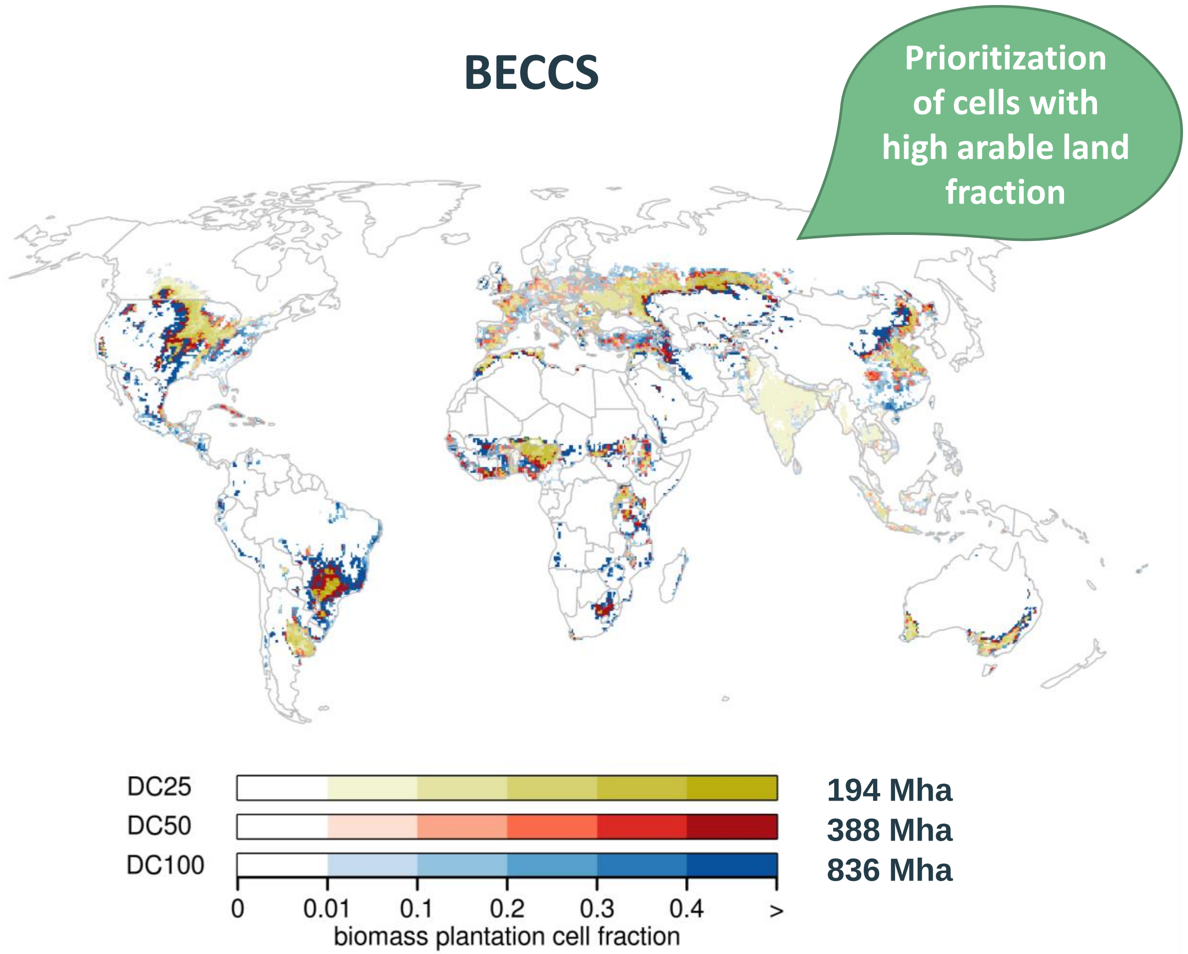
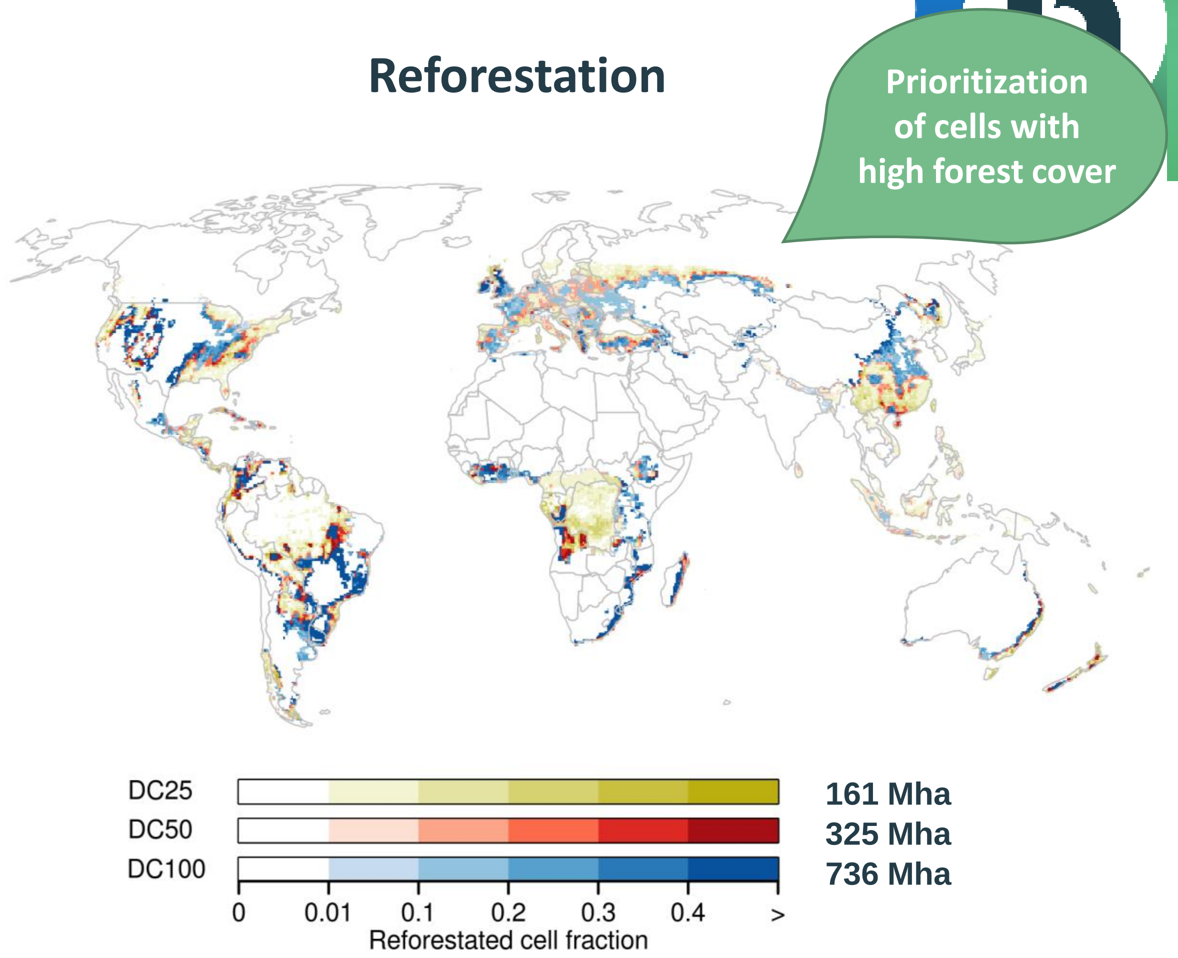
Spatially explicit pasture rededication scenarios to biomass plantations for BECCS or reforestation





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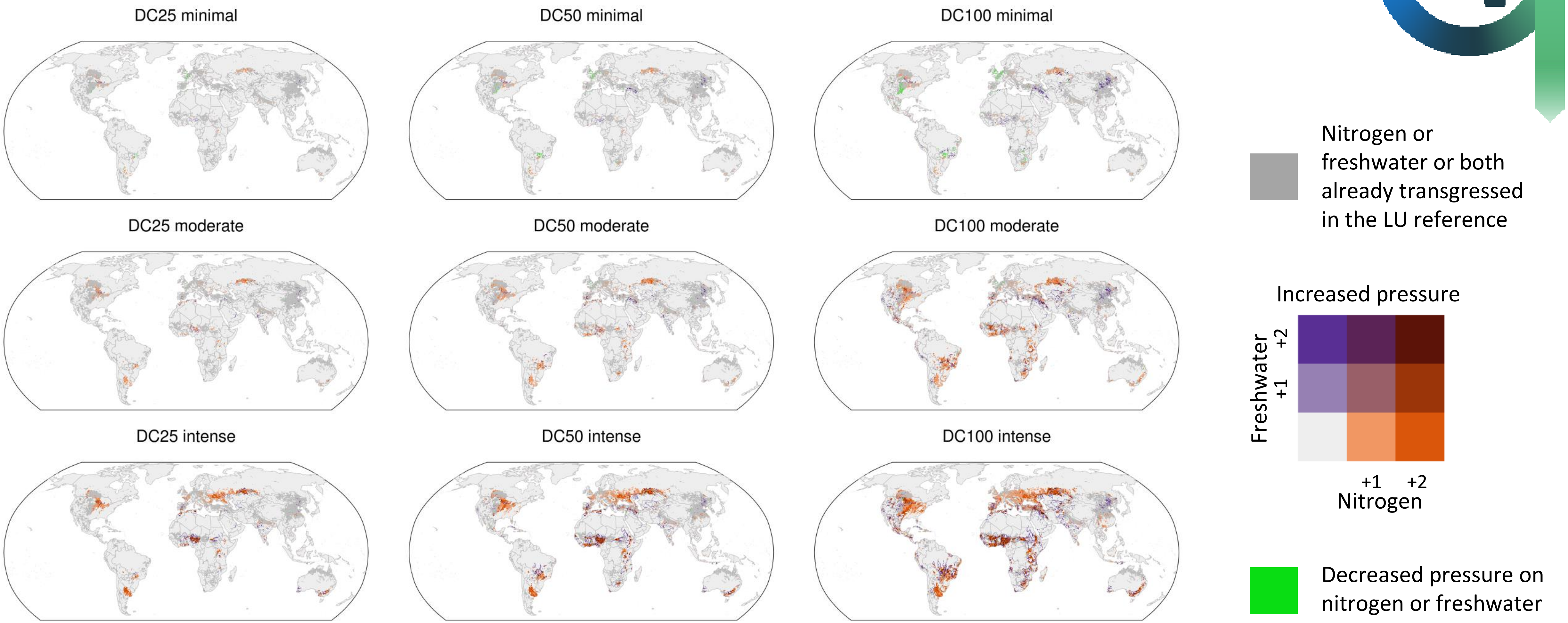
Impacts on freshwater, nitrogen and land-system change boundaries

BECCS



Parameter ranges LCN-PyCCS

Table S 1. Ranges of the operation space of LCN-PyCCS assessed in this study.

Ranges	Feautures		References
Management of biomass production			
marginal	LPJmL-simulated yields under rainfed conditions		--
moderate	Mid-range between LPJmL-simulated yields under rainfed and irrigated conditions		--
Pyrolysis paramters			
conservative	Herbaceous:	biochar yield = 23% ash-free DM biomass C in biochar = 39%	Woolf et al. (2021)
	Woody:	biochar yield = 27% ash-free DM biomass C in biochar = 43%	
optimized	Herbaceous:	biochar yield = 31% ash-free DM biomass C in biochar = 53%	Schmidt et al. (2019), Grafmüller et al. (2022)
	Woody:	biochar yield = 35% ash-free DM biomass C in biochar = 61%	
Biochar-mediated yield increases			
base	+10% yield increase (+5–15%)		grand mean and confidence interval of yield responses reported in Melo et al. (2022)
enhanced	+20% yield increase		within confidence interval for biochar with a carbon content >30% in Melo et al. (2022)