Potential of Pyrolysis-CCS as Negative Emission Technology: Chances and Planetary Limits

The challenge and side effects of negative emissions for the 1.5° goal

Negative Emission Technologies (NETs) are needed to withdraw atmospheric CO_2 since decarbonization alone is not sufficient. A frequently discussed NET pathway is «bioenergy plus carbon capture and storage» (BECCS). This implies large industrial approaches and biomass plantations in concurrence to agricultural land use or natural conservation areas. Pyrolysis-CCS (PyCCS) technologies can offer soil fertility increases [1], reducing the pressure on land, and offer new economic opportunities. Here we assess the potential, impacts and limitations of three PyCCS technology approaches along cumulative mitigation and balancing scenarios up to 2100 to meet the 1.5° goal.

Methods for a Global Assessment

- Dynamic global vegetation model **LPJmL** (0.5°x0.5° grid) was used
- **Land surface**: Conservational & peat areas excluded (Fig. 1)
- **Negative Emissions up to 2100:** Mitigation 100, 200 or 300 GtC; plus Balancing of 200 and 700 GtC
- **C sequestration NETs**: **(1) basic**: biochar only, **(2) advanced**: biochar + bio-oil, **(3) ideal**: biochar + bio-oil + syngas-CO_2-CCS
- **Fraction** of biomass-C sequestered: **(1)** 0.47, **(2)** 0.77, **(3)** 0.86

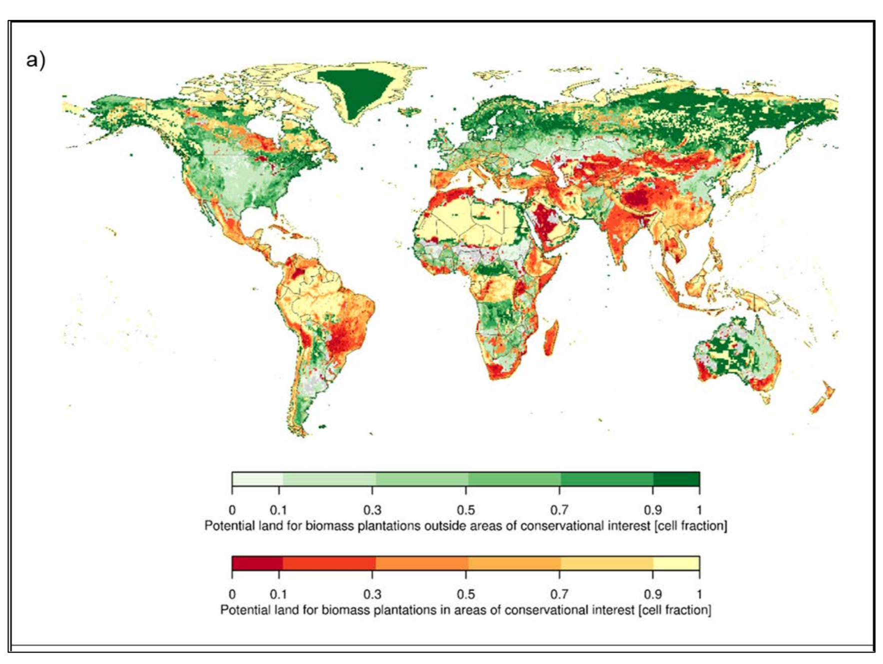

Fig. 1: Areas of conservational interest. These are: Legally protected areas, biodiversity hot spots, areas of endemic richness or with a high extinction rate / thread were all primarily excluded, but gradually included as Mitigation/balancing demands increased.

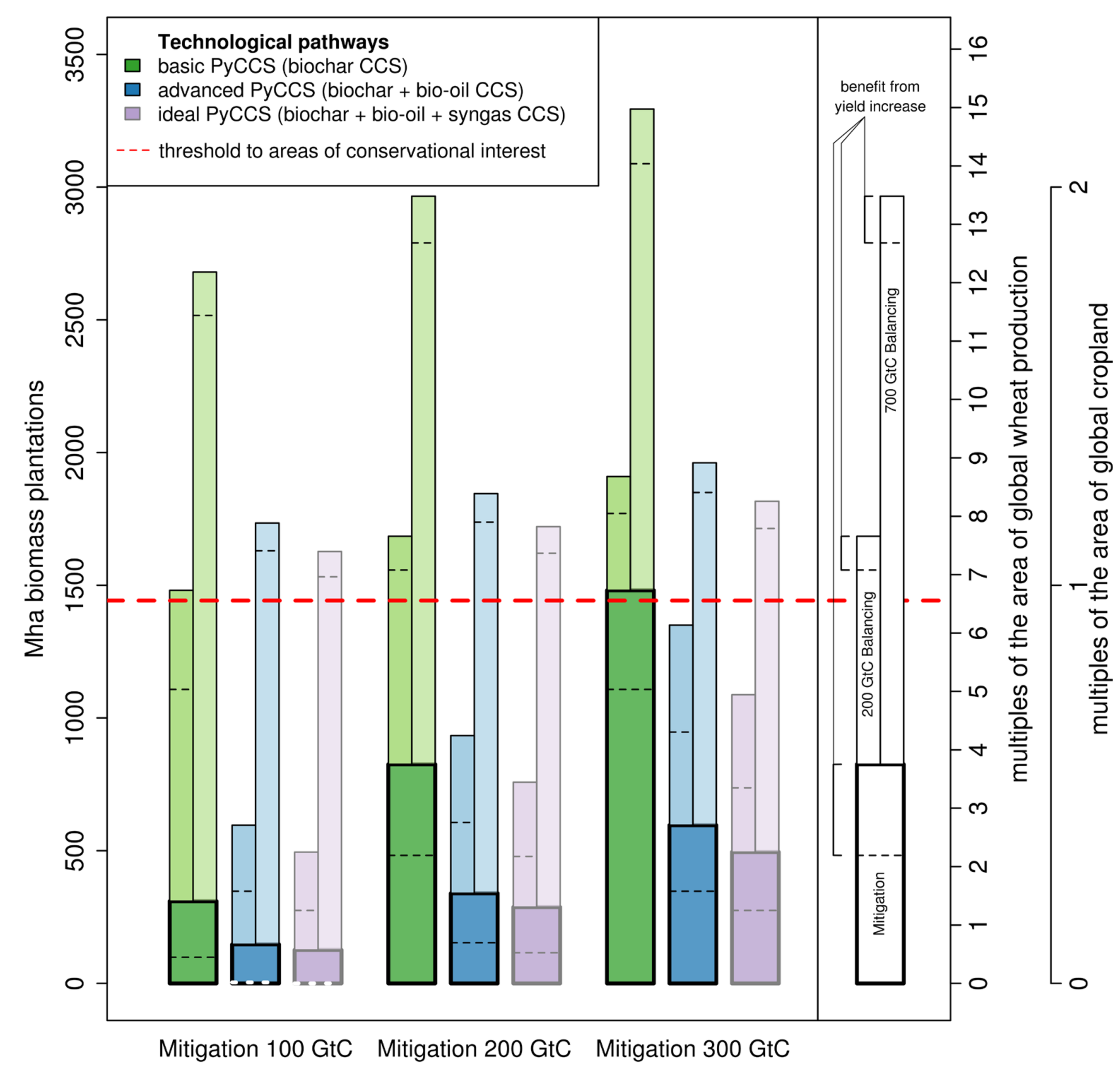

Fig. 2: Biomass plantation extent (Mha) on uncultivated land for the basic (1, green), advanced (2, blue) and ideal pyrolysis technology (PyCCS) (3, pale purple) under the three mitigation scenarios (bold blocks) plus additional carbon balancing of 200 GtC (darker stacked bars on the left) or 700 GtC (lighter stacked bars on the right). Reduced land requirements by biochar-mediated increases in agricultural yields are indicated by dashed lines. Red dashed line: Advancement into areas of conservational interest.

Results: Land Area Needs for PyCCS

Mitigation only: A low target of 100 GtC can be met by using the advanced NET (2) "biochar+bio-oil" for C sequestration. Biochar-mediated yield increases of 25%[1] in the (sub-)tropics reduce the land area needs considerably (4 Mha only). With a target of 300 GtC, however, biomass plantations consume 347 Mha, despite helpful biochar-induced yield increases: This area demand equals more than 1.5 times the global wheat production area!

Mitigation plus Balancing: The extension of land area increases exponentially with NE demands, invading areas of conservational interest (Fig. 2); e.g. 100 GtC Mitigation + 700 GtC Balancing will use more than the global cropland area, even with the most advanced PyCCS approach (NET 3: ideal, comparable to BECCS)

Table 1: Comparison of CO_2CCS (as in BECCS) versus PyCCS NET 2 (Biochar+Bio-oil): Technology readiness, opportunities, benefits and implementation restrictions

Parameter	(A) CO_2CCS	(B) PyCCS (advanced)
NET ready to employ?	No	Yes (mostly)
NET scales? (small-scale or large-industrial)	Large-scale only	Multiple scales possible (rural small to large scale)
NET acceptance of final C / CO_2 deposits?	Potentially problematic („nimby" effect)*	Easier to achieve (e.g. with yield increases)
Return of nutrients?	No or difficult	Yes, with biochar use
Soil prductivity increase?	may decline (nutrient removal)	+25% on average (sub)tropics
Economic C recycling? a) For heat production b) Carbon material use	a) Heat use only; b) C re-use: none	a) Heat use (less than A) b) C material use: yes, multipe options#

**nimby effect = „not in my backyard" = acceptance low*
#multiple options of non-oxidative C material use fertilizer carrier, cardboard/paper filler, building materials – sand replacement, manure management, animal fodder additive, air and soil decontamination, wastewater treatment etc.

[*] Jeffery, S., Abalos, D., Prodana, M., Bastos, A.C., van Groenigen, J.W., Hungate, B., A., Verheijen, F., 2017. Biochar boosts tropical but not temperate crop yields. *Environmental Research Letters* **12**, 053001.

Low negative emission demands can be achieved by plantation-based advanced pyrolysis technology.

For high mitigation + balancing demands, however, the pressure on land and biodiversity is extensive.

Increased soil fertility with biochar use are able to reduce land area demands considerably!

Contact

C. Werner[1], C. Kammann[2], H.-P. Schmidt[3], D. Gerten[1], W. Lucht[1]
[1]Potsdam Institute for Climate Change Research, Germany; [2]Hochschule Geisenheim University; Germany; [3] Ithaka Institute, Arbaz, Valais, Switzerland
Author's addresses: constanze.werner@pik-potsdam.de; Claudia.Kammann@hs-gm.de

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