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Significant land-sparing potentials from implementing carbon capture and utilization for the Brazilian sugarcane ethanol industry

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Brazil is the global frontrunner in the production of sugarcane ethanol. Strong national biofuels policies, a consolidated internal demand for ethanol for transportation purposes, and a global growing demand for sugar and ethanol have supported this development. The sugarcane ethanol industry has contributed to economic growth, technological progress, job creation and is among the key strategies for mitigating CO_2 emissions in Brazil. However, the industry is also responsible for a wide range of undesirable impacts on land. Biodiversity loss, structural soil degradation, pollution, and depletion of water sources can result from the associated direct and indirect land-use change. We therefore assess the potential of a carbon capture and utilization pathway to increase the fuel production of this industry in a land-neutral way.

The pathway combines the almost clear surplus CO_2-stream from the ethanol fermentation process with H_2 produced using wind and solar power to synthesize methanol. The change of use of land from sugarcane production to renewable electricity generation is an intensification step which allows to spare significant amounts of land.

To understand the implications of this pathway in terms of land-use and cost, we develop a spatio-temporal model to determine the cost-optimal system configuration, the resulting land effciency, and consequently the land sparing potential. The core of the model consists of a techno-economic optimization model that minimizes cost for a system that includes variable renewable electricity generation (wind and solar power), storage (electricity, CO_2 and H_2), electrolyzers and methanol synthesis installations for each one of the sugarcane ethanol production plants in the country. The optimization model relies crucially on two time-series which we derived specifically for each Brazilian ethanol plant based on a consolidated spatially explicit data set of sugarcane ethanol installations: first, individual time series of the CO_2-streams from ethanol fermentation, and second multi-year time series of wind and solar power in hourly temporal resolution using ERA5

and ERA5-land reanalysis data. Furthermore, we extensively review costs of individual system components and derive footprints of Brazilian solar and wind power plants from satellite imagery.

The proposed pathway leads to a combined amount of ethanol and methanol that represents an increase of 43%-49% compared to the current output of the ethanol industry in energetic terms. This amounts to around 100 TWh of methanol that would be sufficient to cover the projected growth in Brazil biofuel demand until 2030. In contrast, if the same amount of energy would be provided by sugarcane ethanol, produced at the current average Brazilian sugarcane-to-ethanol land-use efficiency, an additional 23,000 km^2 - 27,000 km^2 of land would be required. This underlines the significant land sparing potential of the proposed pathway.