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Investigating potential climatic side-effects of a large-scale deployment of photoelectrochemical devices for carbon dioxide removal

Moritz Adam[1], Thomas Kleinen[2], Matthias M. May[3,4], Daniel Lörch[3], Arya Samanta[5], and Kira Rehfeld[1,5]
[1]Institute of Environmental Physics, Heidelberg University, Heidelberg, Germany (madam@iup.uni-heidelberg.de)
[2]Max-Planck-Institut für Meteorologie, Hamburg, Germany
[3]Institute of Physical and Theoretical Chemistry, University of Tübingen, Tübingen, Germany
[4]Institute of Theoretical Chemistry, Ulm University, Ulm, Germany
[5]Geo- und Umweltforschungszentrum (GUZ), University of Tübingen, Tübingen, Germany

Without substantial decarbonization of the global economy, rising atmospheric carbon dioxide (CO_2) levels are projected to lead to severe impacts on ecosystems and human livelihoods. Integrated assessments of economy and climate therefore favour large-scale CO_2 removal to reach ambitious temperature-stabilization targets. However, most of the proposed approaches to artificially remove CO_2 from the atmosphere are in conflict with planetary boundaries due to land-use needs and they may come with unintended climatic side-effects. Long-term draw-down of CO_2 by photoelectrochemical (PEC) reduction is a recent and promising approach that potentially entails a very low water footprint and could offer a variety of carbon sink products for safe geological storage. For renewable hydrogen fuel production, PEC devices have already been demonstrated to deliver high solar-to-fuel efficiencies. If such devices are adjusted to deliver high solar-to-carbon efficiencies for carbon dioxide removal, they would require comparably little land for achieving annual sequestration rates that are compatible with limiting global warming to 2°C or below. Yet, no production-scale prototype exists and the climatic side-effects of such an "artificial photosynthesis'' approach for negative emissions are unknown. Here, we discuss our work towards investigating potential impacts of PEC CO_2 removal on the climate and the carbon cycle in simulations with the comprehensive Earth System Model MPI-ESM. We designed a scheme to represent hypothetical PEC devices as a land surface type which is influencing land-atmosphere energy and moisture fluxes. We parameterize the irradiation-driven carbon sequestration of the devices and interactively couple their deployment area and location to a negative emission target. We plan to compare the potential side-effects between scenarios of dense, localized deployment and spread-out, decentralized application. These scenarios represent different guiding objectives for deploying hypothetical PEC systems such as maximizing the insolation per module area, or mitigating the overall impacts on climate and on carbon stocks. For the different scenarios, we intend to investigate changes in the surface balances, which could impact atmospheric circulations patterns. We further plan to quantify the amount of land-stored carbon that is relocated due to

land-use change, as this affects the amount of CO_2 that can effectively be withdrawn from the atmosphere. Finally, we relate theoretical expectations for area requirements and CO_2 withdrawal with results from the coupled simulations which could inform the technological development. While ambitious emission reductions remain the only appropriate measure for stabilizing anthropogenic warming, our work could advance the understanding of possible benefits and side-effects of hypothetical PEC CO_2 removal.

M. M. May & K. Rehfeld, *ESD Ideas: Photoelectrochemical carbon removal as negative emission technology*. Earth Syst. Dynam. 10, 1–7 (2019).