180 kWh environmental protection

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In the SSP2-RCP1.9 w/ DACCS scenario, the US electricity sector achieves a full decarbonization by 2035 (Fig, 2d), which is in-line with current targets and an economy-wide decarbonization by 205039. The scenario features an earlier phase-out of coal and natural gas (by 2050) and higher renewable energy penetration (81%) by 2100 (Fig. 2c). In this scenario, the climate change impact of DACCS exhibits more rapid reductions before 2050 and reaches levels of -0.91 to -1.25 t CO2-eq by 2100 (Fig. 1a).

Stacked bars show the change of annual generation by technology when DACCS is a carbon dioxide removal option in the same mitigation scenario. The red line represents the net difference in annual power generation subtracting the SSP2-RCP1.9 w/o DACCS from the w/ DACCS scenario (primary y-axis). The black line represents the annual DACCS operational capacity (secondary y-axis).

Impact categories include (a) climate change impact, (b) human toxicity impact, (c) freshwater eutrophication impact, (d) freshwater ecotoxicity impact, (e) terrestrial acidification impact, (f) terrestrial ecotoxicity impact, (g) metal depletion, (h) water depletion. The bar in each subplot represents the absolute change (per 1 kWh generation) of each impact subtracting the SSP2-RCP1.9 w/o DACCS from the w/ DACCS scenario from 2020 to 2100 (primary y-axis). The lines in each subplot represent the relative change (percentage) per impact compared to its 2020 reference level (secondary y-axis) under an RCP1.9 w/ (blue) and w/o DACCS scenario (orange).

As more IAM scenarios start to include DACCS as a critical CDR technology for meeting stringent climate targets, the performance of DACCS should be evaluated in the context of those targets to better guide policy decision and deployment of DACCS in the future. As our LCA shows, a rapid decarbonization of the power and energy demand sectors that is consistent with the 1.5 ?C climate target can increase the net sequestration efficiency of DACCS and facilitate its climate change mitigation potential, suggesting DACCS deployment and electricity system decarbonization should act synergistically in climate change mitigation efforts.

Electricity consumption is a major contributor to the terrestrial ecotoxicity and metal depletion levels of DACCS, which are mainly driven by the solar and wind penetration levels in the background electricity system in our scenarios. Therefore, as the decarbonization of the electricity system progresses with expanding renewable energy generation and storage capacities, additional efforts are needed to facilitate sustainable mining, manufacturing, and expanding the circular economy of energy materials used in those technologies, which will reduce these impact levels.

The prospective LCA framework presented herein can inform policy discussions around research and development prioritization for emerging technologies that support energy sector decarbonization and long-term climate change mitigation targets. By incorporating regionally and temporally explicit electricity sector scenarios and technology projections for grid-connected DACCS, it captures the complex non-linear relationships between a CDR technology and its environmental impacts, caused by either changes in the broader energy system44,45,46 or its specific technology context29,47. Future capability extensions of this framework will model material circularity and capture the technological changes in broader energy and industrial sectors.

Brightway2 is an open-source framework for LCA calculations in Python48. It consists of several modules that handle data import, managing and accessing data, calculating, and analyzing LCA results. The combination of a modular structure, the interactivity of Python, and tunable calculation pathways allows for flexibility and user-defined functionalities in conducting LCA studies and offers new possibilities compared to existing LCA tools.

Wurst is also a Python-based software that enables the systematic modification of LCI databases with external scenario data37. Wurst supports several generic modification types, including changing material efficiency, emissions, relative shares of markets inputs, and separating a global dataset into multiple regions. The current version of Wurst focuses on modifying the ecoinvent LCI database using IMAGE scenario data. More detailed information regarding modification steps of Wurst are discussed in the "LCI database modifications with climate scenario data" section.

We focus on two types of DACCS technologies: a solvent-based and a sorbent-based DACCS, which rely on different capture and release mechanisms to remove CO2 from the atmosphere.