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Mapping the Weather-Water Nexus: Comparing the Performance Weather Sensitivity and Water Consumption for Liquid-solvent Direct Air Capture

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Abstract

Carbon dioxide removal (CDR) is an essential technology for meeting climate goals and direct air capture (DAC) is a promising approach for CDR. DAC provides CDR through multiple steps: CO_2 from the air is absorbed into a liquid solvent or onto a solid sorbent; electricity and heat are used to regenerate the solvent or sorbent, releasing the captured CO_2; and the captured CO_2 is then compressed and sequestered underground. Depending on the cost and availability of other CDR approaches, recent research suggests that DAC deployment sufficient to provide gigatonne-levels of CDR may be required globally by 2050. Despite this, DAC facilities presently operate within annual capture rates ranging from tons to thousands of tons per year.

The pivotal shift toward scaling up DAC operations to the gigatonne-level faces nuanced challenges, particularly concerning two emerging factors related to the impact of weather on siting. Firstly, the consistent performance of DAC is heavily reliant on favorable and dependable weather conditions because the quantity of CO_2 removed from the atmosphere is a function of the temperature and relative humidity of the air. Secondly, water consumption presents a growing concern for solvent-based DAC, with projections indicating that each ton of CO_2 removed may require up to several tons of water. As the quantity of water consumed by solvent-based DAC is also intricately linked to the climate regime and its variability, it's overall environmental impact may be complex, especially in regions prone to aridity or unreliable rainfall. As such, the challenge lies in striking a balance: while analysis that predominantly considers CDR performance may steer siting decisions toward water-scarce areas, neglecting hydrological limitations could hinder project feasibility. Conversely, areas without water scarcity might compromise peak CDR performance. Investigating the interplay between these challenges for optimal CO_2 removal and sustainable water usage is a pivotal inquiry. Understanding where these factors converge and diverge spatially holds critical importance for strategic DAC deployment. This underscores the necessity of accounting for both environmental and operational facets for effective DAC technology implementation.

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To explore the trade-offs between DAC performance and water consumption, we developed a process-level model of a liquid-solvent DAC system. We coupled this model to a 20-year dataset of temperature and humidity conditions at a 9 km resolution across the contiguous US. This extensive spatial-temporal analysis enabled a comprehensive exploration from local to regional scales throughout the continental U.S., examining variations on an hourly basis. The outcome produced intricate maps delineating CO_2 capture potential ($MtCO_2$/year) and estimated water consumption (tons of H_2O). Through comparison of these comprehensive maps, we pinpointed areas characterized by high CDR efficiency and minimal water consumption, identifying compelling zones where optimal capture potential coincides with modest water demands. Moreover, our analyses uncovered regions exhibiting significant trade-offs between promising capture potential and substantial water requirements, shedding light on the intricate balance between DAC effectiveness and environmental resource use.

This study sets forth a data-driven set of results for minimizing the water-related economic burdens and environmental impacts associated with DAC deployment. By optimizing site selection based on the weather-water nexus, we provide a framework for reducing operational costs and enhancing the sustainability of DAC technology. This approach paves the way for economically viable and environmentally responsible large-scale carbon capture and storage solutions.

Keywords: Direct Air Capture, Liquid Solvent Absorption, Weather Sensitivity, Spatial Granularity, Siting Decisions, Performance Assessment, CO2 Capture, Climate Change Mitigation