# Life-Cycle Assessment Of An Industrial Direct Air Capture Process Based On Temperature–Vacuum Swing Adsorption


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## Abstract

Current climate targets require negative carbon dioxide ($CO_2$) emissions. Direct air capture is a promising negative emission technology, but energy and material demands lead to trade-offs with indirect emissions and other environmental impacts. Here, we show by life-cycle assessment that the commercial direct air capture plants in Hinwil and Hellisheiði operated by Climeworks can already achieve negative emissions today, with carbon capture efficiencies of 85.4% and 93.1%. The climate benefits of direct air capture, however, depend strongly on the energy source. When using low-carbon energy, as in Hellisheiði, adsorbent choice and plant construction become more important, inducing up to 45 and 15 g$CO_2$e per kilogram $CO_2$ captured, respectively. Large-scale deployment of direct air capture for 1% of the global annual $CO_2$ emissions would not be limited by material and energy availability. However, the current small-scale production of amines for the adsorbent would need to be scaled up by more than an order of magnitude. Other environmental impacts would increase by less than 0.057% when using wind power and by up to 0.30% for the global electricity mix forecasted for 2050. Energy source and efficiency are essential for direct air capture to enable both negative emissions and low-carbon fuels.

## Data availability

Data on the LCI, the studied scenarios and the resulting environmental impacts are available within this paper and the Supplementary Information. More details on the datasets generated and/or analysed during the current study are not publicly available since they contain commercially relevant information from Climeworks, but are available from the corresponding author on reasonable request and with permission of Climeworks.

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