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FROM FOAK TO NOAK: THE DYNAMIC EVOLUTION OF DIRECT AIR CAPTURE FINANCING STRUCTURES AND CARBON CAPTURE COSTS

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Extended Abstract

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Abstract Summary

We examine how financing affects the scale-up of direct air capture (DAC), a carbon dioxide removal technology that is still expensive and largely limited to early demonstration plants. Current DAC carbon removal costs range from 600 to 2400 USD/tCO2, which makes it accessible only to a small number of buyers. We argue that moving from first-of-a-kind (FOAK) to nth-of-a-kind (NOAK) plants will require major capital mobilization and strong policy support, and that financing costs must be treated as a central variable in DAC cost projections.

Using a mixed-methods approach, we combine interviews with 24 DAC startups and venture capital investors, financing cost calculations, and a global cost optimization model. We assess three DAC types: solid sorbent, liquid solvent, and electrochemical DAC. We derive FOAK and NOAK costs of capital (CoC) by estimating financing structures and expected returns from different capital sources, then combine DAC-specific risk premiums with country-level risk rates. These assumptions are integrated into a model that optimizes DAC deployment based on renewable energy availability and DAC performance.

Our results show that financing structures are expected to change significantly as DAC matures. FOAK projects rely mainly on venture capital and grants, while NOAK projects are expected to shift toward infrastructure equity and project finance debt, lowering the CoC. However, regional risk remains highly important. Even in 2050, DAC costs may stay high in risky countries such as Yemen, while they could be much lower in stable markets such as Japan.

We conclude that DAC policy must evolve with technology maturity. Early-stage DAC benefits most from tax credits and investment grants, while later-stage scale-up will depend on compliance markets and long-term carbon purchase agreements that stabilize revenues and attract low-cost debt.

Presenting Author Biography

Mak joined Forschungszentrum Jülich in July 2025 as Scientific Lead of the DACStorE project, a major Helmholtz-funded initiative on scaling Direct Air Capture and Storage (DACS). He also leads DACStorE's techno-economic assessment work as Principal Investigator, focusing on DACS siting, financing, risk, and cost analysis. Previously, he was a Postdoc at ETH Zurich's Climate Finance & Policy group, researching financing for renewable and decentralized energy technologies in Switzerland. He completed his PhD in Energy Economics at the Technical University of Denmark, studying how renewable energy auctions affect financing conditions. Earlier, he worked across development, policy advice and consultancy in renewable energy.