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Reassessing Carbon Dioxide Removal Pathways System Consistency Between Electricity-Driven DAC and CO_2 Handling

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Overview
Integrated assessment models (IAMs) increasingly rely on large-scale carbon dioxide removal (CDR) and carbon capture, transport and storage (CCTS) to achieve net-zero and net-negative emission pathways. However, empirical evidence from operational projects reveals a persistent gap between modelled deployment assumptions and realised capacities. Despite rapidly increasing announcements of DAC and CCTS projects, actual capture volumes and system integration remain limited, raising concerns about the feasibility of assumed capture trajectories (Schmidt et al. 2025).

Recent research shows that DAC deployment is constrained not only by scale-up challenges, but also by technology-inherent characteristics that shape cost trajectories and limit convergence toward low marginal costs (Sievert, Schmidt, and Steffen 2024). In parallel, DAC is increasingly conceptualised as an electricity-driven or electrochemical process that can act as a flexible consumer of renewable electricity, introducing strong dependencies on electricity price distributions and grid carbon intensity that are rarely represented explicitly in energy system models. European evidence further suggests that CO_2 transport and storage infrastructure does not scale automatically with capture deployment, creating additional timing and capacity constraints along the CDR chain (Tumara et al. 2024).

While modelling and policy discussions continue to emphasise geological storage as the dominant downstream option, recent analysis highlight as a scarce system resource shaped by policy, infrastructure availability, and competition with other strategic energy uses rather than an unconstrained sink (Patonia et al. 2025). Where utilisation pathways are considered, sustainability literature stresses that CO_2-based polymer and biopolymer applications are not automatically climate-beneficial, as outcomes depend on market scale, end-of-life handling, and time dynamics rather than capture alone (Sovacool et al. 2023).
Methods
We develop a system-good consistency analysis that evaluates whether CO_2 capture deployment can be reconciled with realistic system constraints. The analysis focuses on collective feasibility and system closure across three elements: (i) conditional availability of DAC and CCTS, (ii) electricity-system dependence of electricity-driven DAC, and (iii) capacity- and timing-constrained transport and downstream handling of captured CO_2.

DAC is represented as a price-responsive, electricity-coupled activity whose utilisation depends on electricity prices and grid carbon intensity, rather than baseload operation. Downstream handling is modelled through constrained sink categories, including permanent geological storage and utilisation routes, with storage treated as a capacity- and policy-constrained system resource. Polymer- and biopolymer-based utilisation is represented as a bounded option limited by market uptake and end-of-life dynamics (Sovacool et al. 2023).

These elements are additionally combined in a reduced-form economic model, linking electricity prices, CO_2 incentives, capture operation, transport constraints, and sink capacities through explicit mass-balance and capacity conditions. The model generates additional system-level indicators such as achievable capture volumes, downstream allocations, and a system-closure ratio indicating gaps between captured and effectively handled CO_2. Building on this formulation, further analysis can explore how changes in electricity-system conditions, policy incentives, and downstream capacities affect system consistency
Preliminary Results
Initial results indicate that the CDR chain performance is governed by interactions between electricity-driven capture and downstream handling, rather than by capture availability alone. Electricity-driven DAC enters

the system as a conditional, price-responsive activity, with realised capture volumes determined by electricity prices and grid carbon intensity. Downstream handling emerges as a binding constraint: limited transport infrastructure and constrained storage capacity restrict access to both geological storage and utilisation pathways, and generating gaps between captured and effectively handled CO_2 even when capture is economically viable. Polymer and biopolymer utilisation functions as a limited bridge option but cannot substitute for large-scale permanent storage due to market and end-of-life constraints.
Preliminary Conclusions
Starting from a system-good perspective highlights that the contribution of DAC and CCTS to decarbonisation is constrained not only by capture performance, but by electricity-system interaction, transport availability, storage capacity, and downstream utilisation. Treating these elements as independent risks overstating the role of carbon capture in mitigation pathways.

The proposed CDR-chain framework provides a transparent basis for bridging the gap between IAM assumptions and real-world feasibility by explicitly testing system closure prior to optimisation, techno-economic assessment, or life-cycle analysis. Recent evidence on underground storage for decarbonisation underscores that CO_2 storage competes with other strategic energy uses and requires coordinated planning, reinforcing the need for chain-level consistency analysis in the design of robust decarbonisation strategies (Patonia et al. 2025).

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