Barriers and enablers of two development pathways for Direct Air Capture

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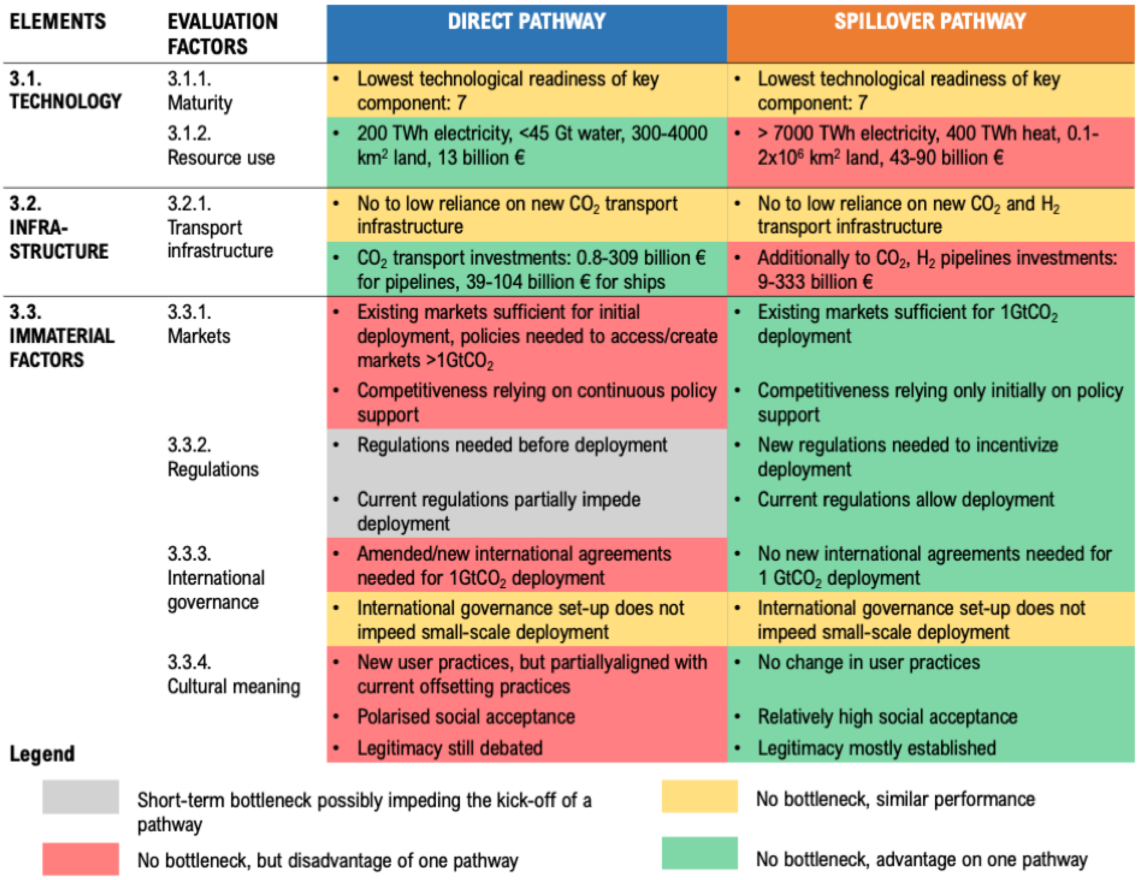
Abstract

Carbon dioxide removal is likely to be unavoidable to achieve ambitious climate goals. Deploying Direct Air Capture (DAC) might be necessary, in the long-term, to avoid conflicts for land-surface, biomass, and water usage [1–6]. Currently, only a handful of commercial-scale DAC plants exist, with costs ranging from at least 600 to 1000 USD/tCO_2 removed [7–9]. To reduce theses costs through technological learning and economies of scale[10], governments will need to adopt policies encouraging the development and deployment of DAC plants. Using the multi-level perspective on technological transition as theoretical framework[11,12], we investigate two possible development pathways for DAC: its explicit deployment for carbon removal (the *DAC Direct* pathway), or its deployment for CO_2 utilization e.g., for synthetic fuels, chemicals, and plastics (the *DAC Spillover* pathway). In particular, we assess the differences between these pathways in terms of what they require to deploy the first gigaton of air-captured CO_2. We thereby identify barriers and opportunities for the creation of new socio-technical regimes along three dimensions: (1) technology, (2) infrastructure, and (3) immaterial factors and institutions.



ELEMENTS	EVALUATION FACTORS	DIRECT PATHWAY	SPILLOVER PATHWAY
3.1. TECHNOLOGY	3.1.1. Maturity	• Lowest technological readiness of key component: 7	• Lowest technological readiness of key component: 7
	3.1.2. Resource use	• 200 TWh electricity, <45 Gt water, 300-4000 km^2 land, 13 billion €	• > 7000 TWh electricity, 400 TWh heat, 0.1-2x10^6 km^2 land, 43-90 billion €
3.2. INFRA-STRUCTURE	3.2.1. Transport infrastructure	• No to low reliance on new CO_2 transport infrastructure	• No to low reliance on new CO_2 and H_2 transport infrastructure
		• CO_2 transport investments: 0.8-309 billion € for pipelines, 39-104 billion € for ships	• Additionally to CO_2, H_2 pipelines investments: 9-333 billion €
3.3. IMMATERIAL FACTORS	3.3.1. Markets	• Existing markets sufficient for initial deployment, policies needed to access/create markets >1GtCO_2	• Existing markets sufficient for 1GtCO_2 deployment
		• Competitiveness relying on continuous policy support	• Competitiveness relying only initially on policy support
	3.3.2. Regulations	• Regulations needed before deployment	• New regulations needed to incentivize deployment
		• Current regulations partially impede deployment	• Current regulations allow deployment
	3.3.3. International governance	• Amended/new international agreements needed for 1GtCO_2 deployment	• No new international agreements needed for 1 GtCO_2 deployment
		• International governance set-up does not impeed small-scale deployment	• International governance set-up does not impeed small-scale deployment
	3.3.4. Cultural meaning	• New user practices, but partiallyaligned with current offsetting practices	• No change in user practices
		• Polarised social acceptance	• Relatively high social acceptance
		• Legitimacy still debated	• Legitimacy mostly established

Legend

⬜	Short-term bottleneck possibly impeding the kick-off of a pathway	🟨	No bottleneck, similar performance
🟥	No bottleneck, but disadvantage of one pathway	🟩	No bottleneck, advantage on one pathway

Our results concerning the different needs along the two development pathways are summarized in Figure 1. We find that the use of DAC-based CO_2 fuels and chemicals in the *Spillover* pathway requires more resources, and larger infrastructural investments than simply storing the captured CO_2 underground. However, the institutional framework needed to govern the production of CO_2-based fuels and chemicals largely overlaps with the existing set-up, highlighting the lower societal barriers to their adoption. The *Direct* pathway, conversely, relies on less energy and capital, yet it faces the challenge of having to set up a whole new industry with new markets, user practices, and socio-cultural meanings.

We conclude that initially supporting spillover-technologies i.e., CO_2-based fuels and chemicals, could face less short-term barriers than directly scaling up DAC for CO_2 storage (DACCS) while having co-benefits for the decarbonization of different sectors of the economy. Yet, due to this pathway's higher costs and energy use, this is only true as long as volumes of CO_2-based fuels and chemicals are small. On the longer-term, however, as the institutional framework enabling carbon removal starts materializing, DACCS-supporting policies could become more politically feasible. Yet, since the advantages of each pathway are counterbalanced by trade-offs that might affect the local deployment differently, the suitability of each pathway is heavily context-dependent.

References

1. Fuhrman, J. *et al.* Food–energy–water implications of negative emissions technologies in a +1.5 °C future. *Nat. Clim. Chang.* **10**, 920–927 (2020).
2. Nolan, C. J., Field, C. B. & Mach, K. J. Constraints and enablers for increasing carbon storage in the terrestrial biosphere. *Nat Rev Earth Environ* **2**, 436–446 (2021).
3. Smith, P. *et al.* Biophysical and economic limits to negative CO2 emissions. *Nature Clim Change* **6**, 42–50 (2016).
4. Strefler, J. *et al.* Carbon dioxide removal technologies are not born equal. *Environ. Res. Lett.* **16**, 074021 (2021).
5. Low, S. & Schäfer, S. Is bio-energy carbon capture and storage (BECCS) feasible? The contested authority of integrated assessment modeling. *Energy Research & Social Science* **60**, 101326 (2020).
6. Dooley, K., Christoff, P. & Nicholas, K. A. Co-producing climate policy and negative emissions: trade-offs for sustainable land-use. *Global Sustainability* **1**, (2018).
7. Ishimoto, Y. *et al.* Putting Costs of Direct Air Capture in Context. *SSRN Journal* (2017) doi:10.2139/ssrn.2982422.
8. Lackner, K. S. & Azarabadi, H. Buying down the Cost of Direct Air Capture. *Ind. Eng. Chem. Res.* (2021) doi:10.1021/acs.iecr.0c04839.
9. Young, R., Yu, L. & Li, J. Cost Assessment of Direct Air Capture: Based on Learning Curve and Net Present Value. SSRN Scholarly Paper at https://doi.org/10.2139/ssrn.4108848 (2022).
10. Nemet, G. F. *et al.* Negative emissions—Part 3: Innovation and upscaling. *Environmental Research Letters* **13**, 063003 (2018).
11. Geels, F. W. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy* **31**, 1257–1274 (2002).
12. Geels, F. W. & Kemp, R. Dynamics in socio-technical systems: Typology of change processes and contrasting case studies. *Technology in Society* **29**, 441–455 (2007).