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Policy Evaluation and Selection to Accelerate Geological Carbon Dioxide Removal Deployment

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Summary

- ***Geological carbon dioxide removal (CDR), which stores carbon permanently, is necessary to reach durable net zero.*** Bioenergy with carbon capture and storage (BECCS) and direct air carbon capture and storage (DACCS) are two prominent methods constituting geological CDR.
- ***CDR faces numerous scale-up challenges,*** including demand creation, supply promotion, and better regulatory frameworks. BECCS and DACCS developers and financiers prefer compliance markets (government-regulated carbon markets where they are legally required to reduce or offset emissions, e.g., integration into emissions trading systems (ETS)) to generate demand, while also supporting early-stage government support to dampen market risk.
- ***Mandatory compliance instruments are likely to be more effective at reaching net zero goals than voluntary markets.*** Voluntary markets align with the priorities of firms and investors, which may not necessarily align with regulatory targets.
- ***Balancing price stability with adaptability is key.*** Policies must provide stable investment conditions while remaining flexible enough to adjust as technology costs fall, helping to prevent large windfall gains for CDR technology owners**.** Instruments like carbon contracts for differences (CCfDs) can be designed to accommodate these changes.
- ***Policy incidence*** (who ultimately bears the cost of CDR policies) ***and market structure both influence policy feasibility.*** Large-scale CDR investments (e.g., BECCS or DACCS) risk market concentration, potentially leading to oligopolistic market structures.
- ***Effective policy combinations should target different technology readiness levels (TRLs) and market barriers and evolve as technologies mature.*** Tax breaks and direct grants are versatile, while public procurement schemes, advanced market commitments (AMCs), CCfDs, ETS integration and VCMs are more suitable for demonstrated technologies in the deployment/diffusion stages.
- ***The UK's consideration of ETS integration and CCfDs is a good starting point, but additional policies must be included for a well-rounded CDR policy portfolio.*** Given the nascency of the field, different means of support (such as supply-side support via grants) ought to be included for technologies at different TRLs (e.g. biochar and enhanced weathering).

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1 What do we need from a CDR market?

Carbon dioxide removal (CDR) is the 'net' in net zero, and is crucial to reaching net zero targets. Despite this need, the existing market for removals is thin. While there are a broad range of CDR techniques in development, differing across aspects ranging from their durability of storage to their technological readiness level, large-scale deployment has not occurred, primarily due to a lack of reliable demand. Policy intervention is necessary to enhance demand and subsequently accelerate the desired widespread deployment.

Since they can ensure durable net zero, this policy brief focuses on CDR technologies that are effectively permanent in terms of timescale of storage (Allen et al. 2025). Two of the most prominent CDR methods constituting "geological CDR" in terms of longevity of storage (in the order of thousands of years) include bioenergy with carbon capture and storage (BECCS) and direct air carbon capture and storage (DACCS). Early activity in the BECCS and DACCS spaces is driven largely by voluntary private purchases, and this volume is comparatively small, totalling less than two million tons of carbon dioxide to date (Smith et al. 2024). The challenges that developers and financiers within the BECCS and DACCS space face within this sector have been found to mainly be the inherent lack of reliable demand for removals and lack of long-term policy certainty (survey conducted in Yang et al. 2024). To address these issues, market participants in the BECCS and DACCS spaces would prefer the implementation of market-based instruments (such as the integration of removals into an emissions trading system (ETS)), supplemented with government support to reduce early market risks within the removal space, and stringent monitoring and regulation to ensure integrity.[1]

With these industry perceptions in mind, policymakers must carefully tailor policy design to effectively address five key challenges: reaching scale, ensuring emissions reductions are not undermined ("mitigation deterrence"), ensuring integrity within CDR through strict monitoring, ensuring fairness and accelerating the speed of deployment. The following sections draw on evidence from *Zhou et al. (2022)* and *Arlinghaus et al. (2025)*, which provide detailed assessments of CDR policy instruments and combinations across key criteria.

2 Evaluating CDR Policies

2.1 Policy instruments

This brief assesses the most commonly considered policies to support geological carbon removal, including integration into an ETS, tax breaks, voluntary carbon markets (VCMs), extended producer responsibility (EPR), public procurement schemes, advanced market commitments (AMCs), direct grants, and carbon contracts for difference (CCfDs).[2] We focus on how these instruments perform against key criteria such as effectiveness, efficiency, feasibility, and strategic fit, drawing on established economic principles and emerging best practices. Table 1 describes the theoretical benchmarks which CDR policies should be evaluated against and examples of enacted and proposed CDR policies.

1 For full details on the surveyed BECCS and DACCS participants' perceptions of challenges and policy preferences, see Yang et al. (2024).

2 Hickey et al. (2023) provide a comprehensive classification of these policy types in the CDR space.

Table 1: Selected CDR policies, definitions of benchmarks, and examples from policy practice

Policy	**Benchmark**[3]	**CDR Example (selection)**[4]
Integration in ETS	Stricter cap to accommodate removals, sufficiently high carbon price for removals.	Japanese ETS accepts permanent removal credits; EU and UK ETSs consider integration of negative emissions; several ETSs worldwide accept carbon offsets (e.g., New Zealand ETS, California ETS) to fulfil compliance obligations.
Tax Breaks	Per-ton of credit for social value of ton of carbon removed (adjusted for impermanence), additional tax breaks for upfront infrastructure capital.	Internal Revenue Code §45Q offers 180 USD per-ton of carbon removed by DACCS and 85 USD per-ton removed by BECCS.
VCMs	High degree of participation from high-impact firms, purchasing (voluntary) carbon credits on the VCM at a price reflecting the social value of im/permanent removal. Stringent monitoring, reporting, and verification.	Project Hummingbird in Kenya, a DACCS project joint venture between Climeworks and Great Carbon Valley; Varaha, a start-up exploring enhanced rock weathering in India.
Extended Producer Responsibility & Product Standards	Firms removing the decreed amount of carbon proportional to their produced carbon emissions.	Carbon Take-Back Obligation (CTBO, proposed).
Public Procurement & AMCs	Firms credibly commit to a carbon market with a promised price reflecting both the dynamic cost of removal, and the social value of removals.	Frontier pledged over 1 billion USD for permanent carbon removal between 2022 and 2030.
Direct Grants & Subsidies	Targeted to technologies with maximal expected removals per pound sterling invested, sufficient de-risking.	UK Research and Innovation's five Demonstrators; Swiss grants under the Climate and Innovation Act (to kick off in 2025).
CCfDs	Sound, stable reference price corresponding to the shadow price of carbon. Strike price schedule set high enough to cover removal cost to minimise expenditure, decreasing over time for learning.	Stimulation of sustainable energy production and climate transition (SDE++, Netherlands), UK Low Carbon Dispatchable Contract for Difference with Drax Power Ltd.
Source: Arlinghaus et al. (2025)		

3 Unlike in the case of emissions reductions, well-defined theoretical benchmarks for evaluating CDR policies are not as established. These proposed benchmarks are drawn where possible on reasoning inherent in microeconomic theory.
4 Policy examples are as of March 2025.

2.2 Evaluation of individual CDR policies

We assess policies using criteria adapted from established frameworks in pollution control and CDR policy evaluation, including Goulder and Parry (2008), Vivid Economics (2019), and Zhou et al. (2022). The full assessment can be found in Arlinghaus et al. (2025).

2.2.1 Effectiveness

Does the policy provide sufficient incentive to encourage carbon removals?

Compliance-based instruments, such as integration into an ETS, CCfDs, or tax breaks tend to be more effective at generating the demand needed to scale CDR to net zero levels. While VCMs have supported some deployment to date, they offer limited potential for scaling carbon removals at the level required for net zero. Policies that offer a high and targeted price, such as the U.S. §45Q tax credits for BECCS and DACCS, or direct grants, offer strong incentives but may entail high fiscal costs. More complex instruments like ETS integration and CCfDs can be effective but require careful design to ensure that prices are high enough to stimulate removals without undermining abatement or overspending.

Does the policy provide sufficient legal certainty to attract private investment?

Policy reversals due to shifts in government priorities pose a significant risk to investors, potentially deterring or delaying investment in CDR. This risk is higher for policies like tax breaks, which can be changed annually, while instruments such as CCfDs and AMCs offer greater stability through long-term contracts. When implemented by credible non-governmental organisations, VCMs and AMCs may further reduce legal and political risk by insulating contracts from government turnover.

Does the policy provide sufficient certainty on prices, risks, and return profiles to attract private investment?

Market-led instruments like ETS integration can expose CDR to significant long-term price volatility, increasing market risks. Policies such as AMCs and CCfDs can reduce investment risks by offering guaranteed prices and predictable revenue streams for CDR firms.

2.2.2 Efficiency

Does the policy encourage market players to deploy the most fiscally efficient CDR technology?

Government-funded policies like tax breaks, public procurement and grants tend to be more expensive, while voluntary policy interventions require no public spending. However, high cost-effectiveness may come at the expense of broader social efficiency, as participation is often limited to low-cost suppliers (e.g., the very limited and highly selective sample of suppliers on VCMs). In contrast, public procurement ensures broader access but may overlook differences in environmental performance.

Does the policy lead to the desired balance between removal and abatement across both negative emissions and emissions abatement?

While most CDR policies do not directly undermine abatement, limited public resources and overlapping mechanisms—such as ETS integration—may inadvertently shift focus toward removals and introduce possibilities to weaken the cap. High-cost policies like grants and public procurement can also strain government budgets, potentially crowding out support for emissions reductions.

2.2.3 Feasibility

Where is the main incidence of policy costs?

The distribution of CDR policy costs depends on how they are passed through to the buyers of removal credits, which varies based on market structure and pricing dynamics (Pless and van Benthem, 2019). In the context of CDR, however, technologies are often privately owned and markets are concentrated, and large-scale subsidies could primarily benefit firms, potentially amplifying inequality. Andreoni et al. (2024) highlight this risk, suggesting that financing DACCS under current market structures could increase within-country inequality.

How difficult is the policy to administer and monitor?

Monitoring, reporting, and verification (MRV) systems are more established for conventional technologies, while those for newer approaches like BECCS and DACCS remain underdeveloped (Smith et al. 2024). A key distinction exists between mandatory and voluntary markets: in VCMs, limited oversight and financial incentives can lead to inflated claims and poor-quality offsets (Battocletti et al., 2023). These concerns are less pronounced in regulated compliance markets, where MRV is typically more robust despite associated transaction costs.

2.2.4 Strategic Fit

At which stage of technology readiness level is the policy most effective?

While some policies—such as tax breaks or direct grants—can support both early and late-stage technologies, many principally target more mature solutions in the deployment phase. We discuss this both for our individual policies and policy combinations further in Section 3.

Is the policy technologically neutral? Is price differentiation by technology possible?

Differentiating support can improve efficiency and reduce windfall profits, but requires detailed information and increases administrative complexity. While many policies are flexible enough to accommodate cost differences, implementing technology-specific pricing under instruments like ETS integration can be challenging. In contrast, CCfDs allow for tailored contract terms, making it easier to reflect varying costs across technologies.

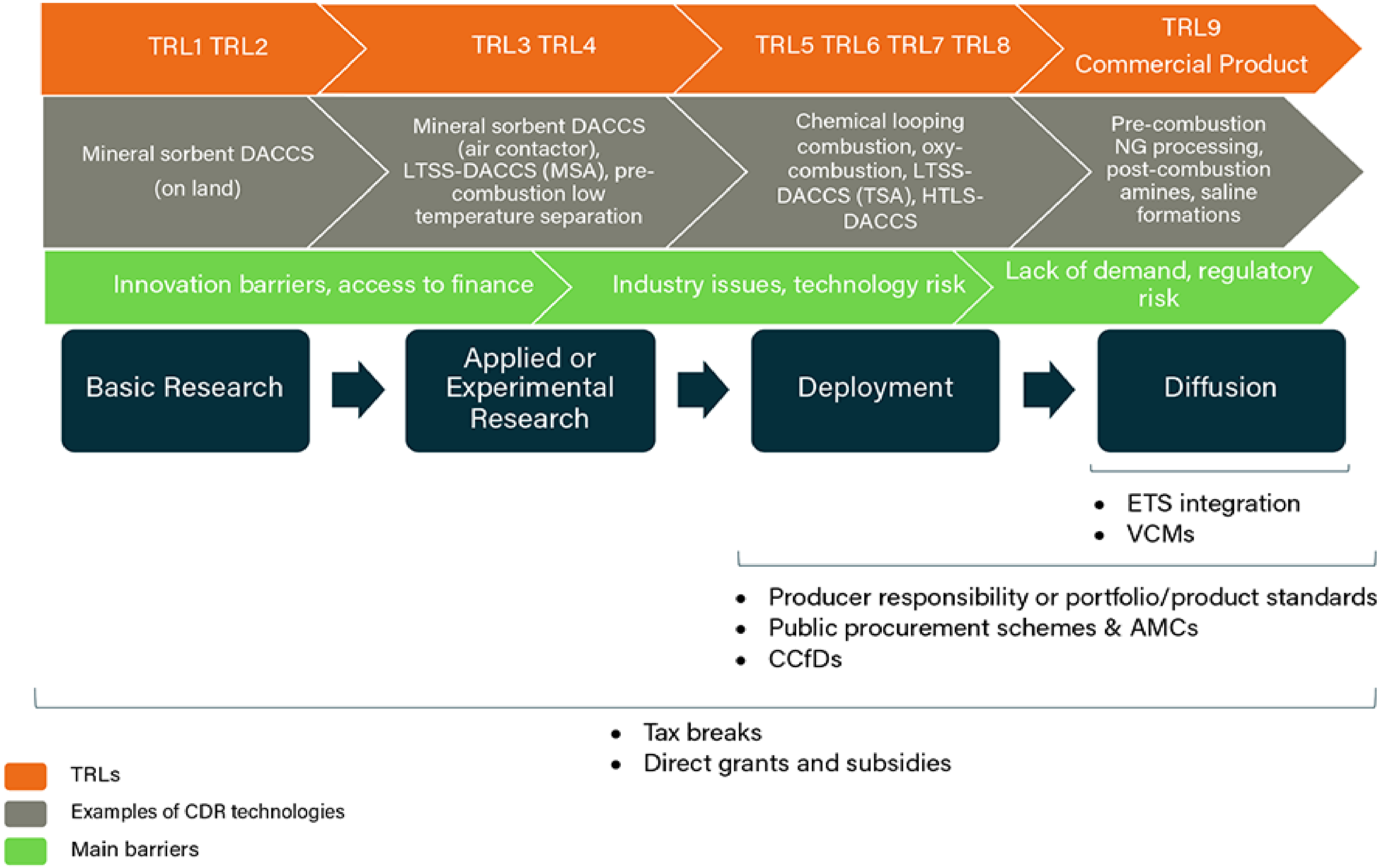
Can the policy be adjusted over time to reflect increasing CDR scale and maturity?

Some instruments, like CCfDs and grant-based approaches, offer long-term certainty but are less flexible. Others, such as ETS integration and tax breaks, are more adaptable but may require legislative changes. This highlights an inherent trade-off between flexibility and investment certainty, and the right balance will depend on regulatory priorities and the broader economic context.

3 Policy Interactions to Enhance CDR

Individual policy instruments do not operate in a vacuum, and bundles of policies ought to be evaluated—no single policy will unlock CDR at the speed and scale required to reach climate goals. CDR technologies vary significantly in both their maturity and the types of barriers they face. To support policymakers in designing tailored policy bundles, Figure 1 presents a practical framework that links stages of technological development with appropriate types of policy support.[5] By aligning policy instruments with technology readiness levels (TRLs),[6] this framework helps identify where support is most needed, whether in unlocking early-stage innovation or enabling large-scale deployment.

Figure 1: Technology Innovation and Development Process



Source: Arlinghaus et al. (2025)

5 The technology innovation and development process diagram draws on insights from Eveleens (2010), MacDowell et al. (2010), Nemet et al. (2018), Salazar and Russi-Vigoya (2021), Surana et al. (2014), and Weaver et al. (2017). The examples are informed by Bui et al. (2018) and Cobo et al. (2023), while the main barriers are based on Faber and Hoppe (2013), Foxon et al. (2005), Long et al. (2016), Luthra et al. (2014), Weber and Rohracher (2012), and Zhou et al. (2022).

6 Technology Readiness Levels (TRLs) are a type of measurement system used to assess the maturity level of a particular technology. There are nine technology readiness levels. TRL 1 is the lowest and TRL 9 is the highest.

Effective policy design benefits from considering policy bundles based on their dynamic complementarity. Policies can be structured complementarily by:

(a) evolving alongside technological advancements, targeting different TRLs in a sequential manner; and

(b) addressing distinct barriers when applied to the same TRL.

Key financial mechanisms such as tax breaks, direct grants, and subsidies are highly versatile. They can support both early-stage innovation and mature technologies, and they also complement other policy tools when deployed in a sequenced manner.

Other policy instruments chiefly target the later stages of deployment and diffusion of CDR technologies. These policies aim to scale up further implementation of CDR and create markets, based upon the rationale that greater deployment can in turn stimulate further innovation.

Public procurement schemes, AMCs, and CCfDs focus primarily on market deployment, and provide direct market support to these more mature technologies by setting clear technical requirements and price guarantees.

Market-based mechanisms, such as ETS integration and VCMs, have played a crucial role in financing early-stage CDR deployment (Smith et al. 2024). VCMs, in particular, can alleviate the financial burden on governments, making them a valuable complement to policies that facilitate diffusion.

Policymakers should build coordinated policy bundles that mix supply- and demand-side instruments across different stages of technological maturity. Blending versatile financial tools with targeted market support can accelerate development and deployment while maintaining fiscal and political feasibility.

4 What do good CDR policy bundles look like, and how does the UK compare?

Effective policy design must tailor support measures to specific TRLs—for example, supply-side instruments such as tax incentives and research subsidies for early-stage technologies, and demand-driven instruments like ETS integration and CCfDs for more mature technologies—while also addressing wider barriers and market failures (Zhou et al. 2022).

In line with this, the UK has proposed the integration of removals into its ETS and CCfDs, with a particular emphasis on targeting BECCS and DACCS. ETS integration encourages deployment of CDR as a compliance mechanism. CCfDs can reduce political and market uncertainty for investors by guaranteeing a fixed carbon price over the contract duration, making them a valuable complement to ETS integration through price stabilisation (Smith et al. 2024).

However, these policies are not without challenges. Integrating removals into the ETS requires a careful adjustment of the emissions cap in order to ensure that prices obtained for removals are sufficiently high, and that the effectiveness of the ETS at eliciting abatement within the existing permit market is not adversely impacted.[7] Similarly, CCfDs require careful design to ensure that both the reference and strike price schedule are stable and high enough to encourage meaningful CDR deployment, as well as sourcing long-term funding.

7 Integrating greenhouse gas removals in the UK Emissions Trading Scheme. Consultation open from May 23 to August 15, 2024. https://www.gov.uk/government/consultations/integrating-greenhouse-gas-removals-in-the-uk-emissions-trading-scheme.

5 Path forward

Geological CDR is essential to achieving the UK's net zero targets, but it will not scale without sustained and carefully targeted policy intervention. While the UK and many other countries have made a strong start by supporting deployment of comparatively mature technologies like BECCS and DACCS, innovation across CDR techniques remains in flux and this focus risks sidelining other promising geological CDR approaches.

To avoid locking the industry into a narrow set of technologies, the UK government must expand support to a wider portfolio, including earlier-stage options like enhanced rock weathering and biochar. These approaches are less developed but hold significant long-term potential. Without targeted public investment—grants, subsidies, or tax incentives—they won't reach the necessary scale in time.

Policymakers should act now to fill these gaps. This means:

- Creating a transparent and stable, mandatory regulatory framework to support the scale-up of CDR research and deployment;
- Matching policy instruments to a CDR's TRL;
- Combining policy instruments to address externalities and technology-specific barriers—financial, technical, and regulatory;
- Ensuring that today's deployment support does not come at the expense of tomorrow's innovation.

A diversified, forward-looking policy package is the best insurance against uncertainty—and the best chance of building a robust, scalable, and politically durable CDR sector.

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UK Research and Innovation

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