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A taxonomy of policies to support geological carbon dioxide removal

Johanna Arlinghaus*[1,2], Siyu Feng[1], Joseph Stemmler[1], Samuel Fankhauser[1], and Stephen M. Smith[1]

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Abstract

Choosing well-suited policies to support geological carbon dioxide removal (CDR) is vital to successfully reach net zero goals. We construct a taxonomy that categorizes various policies implemented and under consideration to support CDR efforts. We evaluate the stringency, efficiency, feasibility, strategic fit, and potential trade-offs associated with each policy. We also assess policy sequencing along different stages of technological readiness levels, and we illustrate our framework with policy examples from the EU, the UK and the US. Our work highlights the need to introduce mandatory and complementary policy bundles, which ideally change over time as CDR technology matures. In addition, the objective to provide stable and effective policy signals must be balanced with the flexibility required to keep up with technological change, while also aligning with government budget constraints.

JEL classification: Q52, Q58, O31, O33
Keywords: Carbon dioxide removal; climate policy; innovation; net zero

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Executive Summary

Implementing effective and equitable policies to support carbon dioxide removal (CDR) is crucial to generate sufficient demand for removals, kick-start a new CDR industry and successfully reach net zero goals. In short, if we continue to generate emissions, reaching net zero goals will not be possible without also deploying removals. However to date, a significant gap exists between national proposals for CDR and the scenarios consistent with climate goals, highlighting the urgent need for effective policy frameworks to accelerate CDR efforts globally. We assess the most commonly discussed policies using a set of criteria for policy evaluation (Stringency, Efficiency, Feasibility and Strategic Fit, with a range of sub-questions). We also evaluate policy combinations and interactions, with a particular focus on containing government expenditure and ensuring that policy combinations support technology development at different technology readiness levels. Among CDR technologies, we focus on methods that can store carbon permanently at geological time scales, as only permanent storage without the risk of re-release ensures a durable net zero. Many of the technologies underlying permanent, geological CDR (e.g. Direct Air Capture with Carbon Capture and Storage, or Enhanced Weathering) are still in pilot to very early commercial stages, thus necessitating stronger policy support to bring down costs to become viable and reliable CDR options, making these technologies an interesting focus. Our key messages are as follows:

- Mandatory compliance instruments are likely more effective at reaching net zero goals than voluntary markets. Voluntary markets are subject to the priorities of firms and investors, which can be volatile, and may not align with regulatory targets.
- Policies that explicitly target removal methods while also providing a relatively high price per tonne of carbon removed tend to be highly visible and effective. Of the policies currently observed in practice, the US 45Q tax incentive, as well as a number of direct grants provide highly salient and generous investment signals for CDR projects and technologies. When well communicated, CCfDs also have the potential to provide effective investment signals. These policies can come at a high cost to governments and taxpayers, thus requiring close monitoring as markets and technologies mature, to maintain appropriate cost-efficiency per tonne of carbon removed.
- Given the longevity, size and risk associated with CDR investments, providing reliable price signals with little risk of reversal are needed in order foster a stable market environment. Any policy that can be adjusted year-on-year (e.g. tax incentives) thus provides less investment certainty. Contract-based policies, such as CCfDs or Advanced Market Commitments, are attractive in that they provide a longer-term price signal. Although price signals can be volatile, ETS have proven to be relatively stable and long-lived policy mechanisms. In the case of direct grants, reversal risk depends on time scales and individual payment structures.

- While it is crucial for policy to provide investment and price stability, this goal can be in tension with the ability to adjust for cost changes and maturing technologies. Maintaining this balance can help avoid large windfall gains for owners of CDR technology and ensure that governments and taxpayers can reap the benefits of cost reductions, while also providing a stable market environment and profitable investment opportunities. CCfDs are good for adjustment
- Policy incidence is crucial for feasibility but will largely be empirically determined, as pass-through of policy costs depends on market structures. For large investments, such as those associated with BECCS or DACCS methods, there is a risk that market concentration will be high, which could lead to oligopolistic market structures.
- Monitoring, Reporting and Verification (MRV) appear easier to ensure for mandatory compliance instruments, and permanent CDR methods. Strict and credible MRV could in principle be ensured for voluntary markets, too, but is so far subject to intense criticism. In addition, MRV for nascent CDR methods is developing quickly.
- Administrative ease is harder to ensure for CCfDs or integration of removals into ETS, as these policies build on relatively elaborate market structures and underlying policies. Grants, or tax incentives are easier to administer, particularly for countries with less administrative capacities.
- Policy combinations should target different Technology Readiness Levels (TRLs) and market barriers, and they ideally evolve as technologies mature. Tax breaks and direct grants emerge as the most versatile policies, applicable across all stages of development. Public procurement schemes, AMCs, CCfDs, ETS integration and VCMs primarily focus on effective deployment and technology diffusion.

We discuss CDR policy in the European Union, the United Kingdom and the United States. The EU and the UK have both adopted a diverse and well-rounded approach to initiating CDR, but meeting ambitious net-zero targets may require more stringent policies to maximise involvement and effectiveness. Expanding the set of technologies eligible for the policy incentives within the US (primarily tax credits and grants/subsidy-adjacent policies) would likely further increase deployment, along with inclusion of geological CDR methods (namely DACCS and BECCS) into emissions trading schemes at the state-level.

1 Introduction

Implementing effective and equitable policies to support carbon dioxide removal (CDR) is vital to successfully reach net zero goals [Fankhauser et al., 2022, Lamb et al., 2024]. "Net zero" describes a state in which any gross residual emissions are balanced over a given period of time by an equivalent amount of removals from the atmosphere. While abatement measures, such as switching to renewables or adopting zero carbon production methods, reduce the emissions that are produced, CDR is essential for achieving the "net" in net zero. Simply put, we cannot reach net zero emissions if we continue to generate emissions without removals.

There is a significant gap between national proposals for CDR and the scenarios consistent with climate goals. To date, a minority of countries worldwide have outlined their strategies for scaling up CDR by 2050 [Smith et al., 2024], highlighting the urgent need for effective policy frameworks to accelerate CDR efforts globally. Given the extensive list of policy instruments available and under consideration worldwide, along with a range of trade-offs associated with each, selecting the appropriate policy option or combination of policies presents a considerable challenge.

Among CDR technologies, the focus needs to be on methods that can store carbon at geological time scales, as only geological storage without the risk of re-release ensures a durable net zero [Allen et al., 2025]. Many of the technologies underlying geological CDR (e.g. Direct Air Capture with Carbon Capture and Storage, DACCS or Enhanced Weathering) are still in pilot to very early commercial stages, thus necessitating stronger policy support to bring down costs to become viable and reliable CDR options [Smith et al., 2024], making these technologies an interesting focus.

By analysing existing and proposed CDR policies, this paper aims to highlight the advantages and trade-offs associated with these policies and their combinations. We select a set of criteria (Stringency, Efficiency, Feasibility and Strategic Fit, with a range of sub-questions) rooted in prior economic analyses to evaluate CDR policies. Using these criteria, we assess the most commonly discussed policies to support CDR at different stages of technology development. Recognizing that policies are rarely introduced in isolation, we also evaluate policy combinations and interactions. Reflecting fiscal realities and the need for technological progress, we put particular emphasis on containing government expenditure and ensuring that policy combinations support technology development at different stages of technology readiness levels (TRLs).

While no single policy excels in all dimensions considered, certain policies exhibit better fit with specific policy objectives. With regards to effectiveness, mandatory compliance instruments are likely better at helping to reaching net zero goals than voluntary ones (e.g. the voluntary carbon market (VCM)). In addition, policies that explicitly target removal methods while also providing a relatively high price per tonne of carbon removed (e.g. the US tax incentive 45Q and some grants) tend to be highly visible, thus scoring higher within our evaluation of effectiveness.

In addition, there appears to be a certain tension between providing legal investment certainty and flexibility. For example, Advanced Market Commitments and Carbon Contracts for Difference (CCfDs) provide investment certainty, stable prices and returns, but cannot be easily adjusted to changing circumstances.

In terms of political feasibility, the incidence of costs from the policy is crucial but is largely empirically determined, as pass-through of policy costs depends on market structure.[1] However in the case of oligopolistic market structures and imperfect pass-through, scaling (subsidy-based) CDR policies could lead to large windfall gains for owners of CDR firms and technology.

When combining policies, care should be taken to avoid targeting similar TRLs or market barriers, while also aligning with government budgets. For example, integrating removals into emissions trading systems (ETS)and carbon contracts for difference (CCfDs) tend to be more effective with mature technologies, supporting technology deployment and diffusion. Simultaneously, grants are better suited to support more basic research at earlier stages of technology development.

We apply these criteria to the current or proposed policy mixes within the European Union (EU), the United Kingdom (UK) and the United States (US). The EU and the UK have both adopted a diverse and well-rounded approach to initiating CDR[2], but they may not be sufficient to meet the ambitious net-zero targets in short term. Portfolio/product standards for CDR or more drastic regulatory measures, such as carbon take-back mandates (e.g. a (CTBO)) may be necessary to maximise involvement and effectiveness. The EU must also carefully tailor policy to account for the heterogeneity of member countries subject to policy (keeping in mind concurrent state aid).

[1] Incidence also depends on how revenues are raised, but this discussion is outside the scope of this article.

[2] This approach includes emissions trading, participation in the voluntary carbon market (VCM), a subsidy of sorts (direct grants), and a subsidy-adjacent policy (ongoing CCfDs in the UK and various EU countries).

The US tax incentive provided under §45Q has been very successful at attracting investment in geological CDR. Should the objective be to further accerelate CDR, mandates like a CTBO could further bolster the US policy portfolio. Expanding the set of technologies eligible for the policy incentives within the US (primarily tax credits and grants/subsidy-adjacent policies) could further increase deployment, along with inclusion of technological CDR methods (namely DACCS and BECCS) into emissions trading schemes at the state-level.

Our framework complements evaluations of pollution control instruments used for emissions mitigation [Fullerton et al., 2010, Goulder and Parry, 2008, Heine et al., 2012], with an application to CDR. Compared to prior evaluations of mitigation policies, we add nuance by taking account of the technological immaturity of many CDR technologies, the lack of a market for CDR and issues associated with accounting for the (im)permanence of removals, as well as mitigation deterrence. We also contribute to analyses of CDR policies and their design (e.g. Hickey et al. [2023], Vivid Economics [2019], Zhou et al. [2022]), to which we add an assessment of CDR policies along criteria typically used for economic policy evaluation.

Our analysis complements recent work on emission offsets and nature-based solutions, which are technologically more advanced and have higher reversal risks than geological CDR, covered in the present paper. Aldy and Halem [2024] discuss the role, governance and regulatory challenges in relation to the use of offsets in climate change mitigation. While we also include the Voluntary Carbon Market VCM as a policy to elicit carbon removals, our analysis is broader in the sense of covering more policies and focusing on geological CDR (Table 1). Barbier and Burgess [forthcoming] use similar criteria when discussing nature-based solutions with regards to their environmental effectiveness, costs, distributional impacts, additionality, leakage, permanence and their long-run mitigation potential.

The remainder of this document is organised as follows: Section 2 defines the scope of technologies that we focus on and gives an overview of the policies and evaluation criteria. Section 3 applies these criteria to CDR policies, while Section 4 evaluates policy interactions, focusing on complementarities along TRLs and cost containment/fiscal efficiency for governments. Section 5 applies our evaluation criteria to the policy environment of the EU, the UK and the US.

2 Scope and conceptual framework

Defining geological CDR

We adopt the definition of geological CDR used in the "State of CDR" report [Smith et al., 2024]. According to that definition, a method must meet three principles. It must "capture CO_2 from the atmosphere (Principle 1) and durably store it (Principle 2), as a result of human intervention in addition to Earth's natural processes (Principle 3)" [Smith et al., 2024]. An example of a technology that meets all three of these principles is direct air capture with geological storage, but direct air capture of CO_2 for use in short-lived products such as fuels does not meet the first.

Nature-based solutions are largely impermanent, as they store carbon temporarily in vegetation and soils, which can be subject to extreme weather events such as droughts, wildfires and floods, or diseases. Thus, natural processes such as tree growth or other nature-based solutions can only meet all three principles if additional carbon is captured and durably stored. Complementary to this analysis, Barbier and Burgess [forthcoming] review the economic opportunities and challenges of nature-based solutions as a climate change mitigation strategy.

Carbon capture and storage, a set of industrial methods for the chemical capture of CO_2, the concentration of this CO_2 into a pure stream and its subsequent geological storage, can be contained within the above-mentioned definition in certain cases, but only when it is applied to CO_2 streams from the combustion of biomass, from seawater or from the air. Similarly, carbon capture and utilization, set of industrial methods for the capture of CO_2 and its conversion into products, can be CDR when the carbon captured from the atmosphere is durably stored, such as in concrete aggregates and timber construction.

Policy instruments

We evaluate the most commonly considered policies to support geological CDR, i.e. integration in ETS), tax breaks, the VCM, extended producer responsibility (EPR), public procurement schemes, advanced market commitments (AMCs), direct grants, and carbon contracts for difference (CCfDs).[3] Our selection encompasses both policies that have already been implemented to support removals, but, given the lack of policy experience specific to CDR, we also discuss policies that have been proposed but not yet been im-

[3]Hickey et al. [2023] provides a comprehensive classification of these policy types in the CDR space.

plemented in this specific realm. The policies instruments selected for our evaluation are summarised in Table 1. Unlike in the case of emissions reduction policy, the theoretical benchmarks which CDR policies should be evaluated against are not yet well-defined. Table 1 proposes these benchmarks, drawing on reasoning inherent in microeconomic theory where possible. Our policy assessment evaluates individual policies assuming they are implemented in a manner that closely approximates the benchmark policies in Table 1. Table 1 also contains examples of enacted and proposed policies from the CDR policy realm. In terms of timelines, our primary focus for policy implementation is on the next ten years until 2035, to accelerate technology development and support reaching net-zero goals by 2050.

Evaluation criteria

Rooted in prior literature in economics and policy evaluation, we propose four broad criteria and evaluate them using sub-questions, set out in Table 2. We extend and adjust existing criteria for selecting policy instruments for pollution control (i.e. Goulder and Parry [2008]) to include considerations specific to CDR policies, e.g. trade-offs between emissions mitigation and removals, and technology development. We also build on evaluation criteria used to evaluate CDR, e.g. Vivid Economics [2019] and Zhou et al. [2022]. Our criteria are similar to those used in some applied policy evaluations of environmental tax reforms in the UK, Germany, Turkey and Vietnam (e.g Arlinghaus and Van Dender [2017], Fullerton et al. [2010], Heine et al. [2012]).

3 Evaluating Carbon Dioxide Removal Policies

This section presents our evaluation of each policy instrument to support CDR. Table 8 summarises our evaluation results, the Appendix contains the full detailed evaluation.

3.1 Effectiveness

To reach net-zero goals, the effectiveness of CDR policies at triggering carbon removal arguably is the most important criterion. An effective CDR policy is able to provide sufficient incentives to encourage removals at the scales required to reach net-zero goals. In addition, for a policy to induce private investment, the policy should make CDR an attractive investment opportunity. Acknowledging that this can entail different risk and

Table 1: Definitions of benchmark CDR policies and selected examples from policy practice

Policy	**Benchmark**	**CDR Example (selection)**
Integration of removals in Emissions Trading Systems (ETS)	Stricter cap to accommodate removals, sufficiently high carbon price for removals.	Japanese ETS accepts permanent removal credits; EU and UK ETS consider integration of negative emissions, several ETS worldwide accept carbon offsets (e.g. New Zealand, California ETS)
Tax Breaks	Per-tonne of credit for social value of tonne of carbon removed, additional tax breaks for upfront infrastructure capital.	Internal Revenue Code §45Q offers 180 USD per-tonne of carbon removed by Direct Air Capture technology.
Voluntary Carbon Market (VCM)	High degree of participation from high-impact firms, purchasing (voluntary) carbon credits on the VCM at a price reflecting the social value of removal. Stringent monitoring, reporting, and verification.	Project Hummingbird 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 remove the decreed amount of carbon proportional to their produced carbon emissions.	Carbon Take-Back Obligation (CTBO, proposed)
Public Procurement Schemes & Advanced Market Commitments*	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 £ invested, sufficient de-risking.	UK Research and Innovation's 5 demonstrators; Swiss grants under the Climate and Innovation Act (to kick off in 2025)
Carbon Contracts for Differences (CCfDs)	Sound, stable reference price corresponding to social cost of carbon. Strike price schedule set high enough to cover removal cost to minimize 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

*PPS and AMC differ in timing and the underwriter. A PPS involves direct government purchase of CDR, typically via an auction ("we are buying now"). An AMC guarantees *future* demand at a certain price, with payment conditional on delivery ("we will buy CDR if you deliver"). PPS are typically underwritten by the government, while AMCs may be either public or private actors.
Note: Policy examples are as of March 2025. We restrict our focus to policies geared toward permanent CDR, but these policies can be tailored to account for impermanent removals.

Table 2: Criteria and Questions for Policy Evaluation

Category	Question
Effectiveness	Does the policy provide sufficient incentive to encourage carbon removals at scales required? Does the policy provide sufficient legal certainty to attract private investment? Does the policy provide sufficient certainty on prices, risk and return to attract private investment?
Efficiency	Does the policy encourage the deployment of the most efficient CDR technology, in £/tCO2? Does the policy lead to the desired balance between removal and abatement across both negative emissions and emissions abatement?
Feasibility	Where is the main incidence of policy costs? How difficult is the policy to administer and monitor?
Strategic fit	At which stage of technology readiness level is this policy most effective? Is the policy technologically neutral? Is price differentiation by technology possible? Can the policy be adjusted over time to reflect increasing CDR scale and maturity?

return profiles which vary across projects and investors, we consider both market and political risk for this evaluation.

Does the policy provide sufficient incentive to encourage carbon removals?

Mandatory compliance mechanisms will be more effective at generating demand for removals that is sufficient to reach net-zero goals. While VCMs have driven some deployment of CDR to date Smith et al. [2024] VCMs at large have been criticised for insufficient quality control. In addition, VCMs are by definition voluntary, and are thus subject to firm and investor priorities, which can be volatile.

Policies that explicitly target removal methods while also providing a relatively high price per tonne of carbon removed tend to be highly visible and effective. For instance, the 45Q tax incentive for sequestered carbon includes specific provisions for BECCS and DACCS, with a per-ton-removed credit high enough to encourage deployment [Herald, 2023, International Energy Agency, 2023]. Similarly, direct grants for CDR technologies are by their very design structured to provide substantial incentives specifically for CDR initiatives. At the same time, since these policies grant high prices for removals, they tend to come at a relatively high cost to the regulator distributing these funds, potentially compromising on efficiency.

Other policies, such as integrating removals into ETSs or CCfDs, are more complex to design to effectively elicit removals at scale. For example, integrating removals into ETSs 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. 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, but not so high that CCfD expenditure becomes excessive (this is done primarily through auction design).[4] With this in mind, gauging whether or not a policy can effectively elicit carbon dioxide removal demands attention to the context (i.e. economic conditions and technology readiness level) in which the policy is implemented.

[4]Ongoing policy discourse has these potentially coinciding, with the possibility of using the EU ETS carbon price (or a tailored adaptation thereof) as the reference price within a well-designed CCfDs.

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

The possibility that a regulator may reverse a policy in place due to a change in government administration or a shuffling of spending priorities is unsavory to investors, as it endangers the return on their investment.[5] Consequently, investment may not take place or may be held up.

This risk of policy reversal is more salient when policy can be altered on a year-on-year basis, or when price levels can be subject to sudden change. This is the case with tax breaks, which the regulator can alter relatively swiftly. In addition, although ETS as a policy instrument turn out to be quite long-lasting, price fluctuations may impede investments. In contrast, CCfDs, and AMCs are based on longer-lived contracts that the regulator has more difficulty altering. Policies such as VCMs and AMCs can be entered by non-governmental organisations, which alleviates the risk associated with changes in government administration. The legal risk associated with these policies then depends upon the credibility of the non-governmental organisation in question to uphold their end of the contract.

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

Carbon removal presents a unique instance in which policy is crucial to create demand (and subsequently a price, and returns) for removals. Plainly, removals are the output produced by the firm engaging in CDR, and if an output has zero or a highly uncertain value, investment will not take place. Some policies may generate or allow for great deals of price volatility, while others can potentially completely remove price volatility.

Due to volatility in carbon prices, substantial market risk is present in the emissions trading systems, and this long-run price volatility would translate over to removals should they be integrated into the EU ETS market. Price corridors can serve as a tool to the regulator to blunt these swings in price, and manage market risk. In contrast, AMCs and CCfDs can in theory completely mitigate market risk by way of providing a guaranteed price to firms engaging in CDR, effectively providing investors with guaranteed revenue flows for their investment.

[5] [Yang et al., 2024] surveys financiers and executives involved in the CDR industry (specifically, BECCS and DACCS), finding that the two primary perceived barriers to entry are a "lack of inherent demand for removal" and "lack of long-term political certainty."

3.2 Efficiency

An efficient CDR policy stipulates carbon removal with the least amount of resources, time, or effort expended. This avoids wasting taxpayer money and might in turn increase public acceptability of funding removals. Achieving this requires adopting the most cost-effective CDR option, maintaining incentives for emissions abatement, while also promoting further cost-reducing innovation, and minimising administrative costs.

Does the policy encourage market players to deploy the most efficient CDR technology, in £/tCO_2?

Efficient CDR policies allow market players and investors to deploy the most cost-effective (in terms of currency per carbon removed, i.e. £/tCO_2) option for CDR, driven by their incentives to minimise costs and maximise profits.

While most policies considered here are subsidies or are subsidy-adjacent (in that they offer payment of some sort, even if indirect), some of these costs can be partially offset by revenues generated through a carbon price.[6] In contrast, policies such as tax breaks, public procurement schemes and direct grants are more costly. Conversely, voluntary policy interventions, such as voluntary carbon markets and advanced market commitments, are not government-led and do not require government expenditure. However, the prioritisation of cost efficiency does not necessarily align with the most socially efficient solution. For example, voluntary markets often attract participants capable of or interested in generating low-cost removals, leading to high cost effectiveness among participants, but only among a very limited and highly selective sample of suppliers. In contrast, a public procurement scheme imposes standardised tender requirements on all potential suppliers, despite their heterogeneous environmental performance, which cannot ensure social efficiency [Cheng et al., 2018].

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

Achieving net zero targets necessitates a dual focus on reducing emissions and implementing effective CDR strategies [Carton et al., 2020]. For example, in the presence of strong opposition or lobbying efforts, regulators may have an incentive to deploy CDR technologies

[6] That said, revenues from carbon prices tend to be subject to manifold demands, including for *per capita* compensation payments.

extensively, especially with decreasing marginal costs of removals (due to technological progress) and increasing marginal abatement costs (when cheap abatement becomes scarce) [Edenhofer et al., 2023]. Policy thus needs to ensure that incentives for emissions reductions are maintained, avoiding so-called "mitigation deterrence" [Carton et al., 2023].

While most policies do not explicitly diminish incentives for emissions reductions, the competition for limited resources, such as government budgets and public attention, may inadvertently arise when CDR policies are introduced. Within mechanisms like ETS integration or CCfDs, where emissions reductions and removals occur simultaneously, there is a risk that removals may be prioritised if they are cheaper and yield greater benefits. Additionally, policies such as direct grants and public procurement schemes, while aimed at advancing CDR, may impose significant financial burden on governments, diverting resources from other emissions reduction initiatives.

3.3 Feasibility

We refer to the likelihood of a policy being introduced in a given regime as "feasibility." We focus on the incidence of policy costs (i.e. distributional effects of a policy) and administrative ease, which we consider to be main elements determining a policy's feasibility. While public acceptance is a crucial aspect of political feasibility, too, we do not include it here.[7] In addition, while most of the policies considered are expenditure-based, we remain agnostic as to where the funds to finance these policies stem from, although this too has its own distributional implications. The discussion of adequate tax- or revenue-raising mechanisms to finance CDR support policies is beyond the scope of this work and can be found in other literature.

Where is the main incidence of policy costs?

The final incidence of who bears the burden of policy costs depends on how costs are passed through to the buyers of removal credits. Applying basic economic principles to CDR policy, a subsidy paid by the government or regulator to firms will decrease the price of removals. However, pass-through rates vary substantially, according to the slopes and shapes of demand and supply curves and the level of market power [Pless and van Benthem, 2019]. Thus, the ultimate cost incidence remains unclear *ex ante*, and is largely

[7] For a detailed analysis of public acceptance in the CDR space, see e.g. Cox et al. [2022] and Waller et al. [2024].

an empirical question to be answered upon the emergence of new data in the coming years. While evidence for the pass-through of CDR policies remains absent, the empirical literature studying pollution control instruments offers some insights.

Evidence reviewed in Arlinghaus [2015] suggests that the pass-through rates of EU ETS allowance prices to wholesale electricity prices have been between 60% and over 100%, whereas pass-through rates are more moderate in the manufacturing sector, between 20% and 100%. This implies that producers often only bear a minor share of carbon prices. Where carbon allowances are allocated for free, cost pass-through of emissions prices implies that producers are able to reap windfall profits. As in the realm of pollution control, the ultimate cost incidence of CDR policy will depend on market structure and the associated pricing behavior. If the technologies for carbon removal are largely privately owned, with a currently relatively concentrated market structure for some technologies (which may or may not lead to moderate pass-through of subsidies to prices), subsidising CDR technologies at scale could end up being a transfer of funds to the private sector. This reasoning is corrobated by Andreoni et al. [2024] which simulates the inequality implications of financing DACCS, assuming a single carbon market for emission reductions and removal, and private ownership of carbon removal companies, predicting an increase in within-country inequality.

How difficult is the policy to administer and monitor?

We next ask whether or not the policy is easy to administer and monitor, focusing on the ease of Monitoring, Reporting and Verification (MRV). MRV is crucial to ensure that removals are effective, to track progress against government targets, as well as securing the public acceptability of deploying CDR. The ease of MRV is most prominently an issue that varies across jurisdictions and across technologies. For example, Smith et al. [2024] find that while the EU and UK prioritise the development of standards and guidelines across technologies, the US focuses on scaling CDR at the deployment stage, and developing MRV for specific methods, such as ocean alkalinity enhancement. In addition, MRV is more strongly developed for conventional technologies, while MRV for more novel technologies (e.g. BECCS, DACCS) remains nascent and imperfectly documented [Smith et al., 2024]. When assessing MRV across policies, the main distinction we draw is between voluntary and mandatory compliance approaches. The VCM is a largely unregulated market, in which private actors buy carbon offsets to reach their emissions reductions commitments [Battocletti et al., 2023]. Emissions removals are generally certified by standard setters, which in turn rely on validation and verification to audit projects. Battocletti et al. [2023] illustrates that project developers, standard setters, and validation and verification bodies have economic incentives to inflate the quantity of offsets, eroding the quality of offsets traded on the VCM. In addition to offset quality, additionality (the notion that emissions reductions would not have occurred without the incentive of the offset program) is key to sound MRV approaches in the VCM. Calel et al. [Forthcoming] develops a new method to quantify the additionality of CDM-supported windfarms in India, which includes a careful comparison to counterfactual, unsupported projects. Calel et al. [Forthcoming] estimate that at least 52% of approved carbon offsets were allocated to projects that were not additional: that is, they would very likely have been built anyway. Cames et al. [2016] arrives at similar results, using more traditional methods to establish additionality. Their results suggest that 85% of the projects covered in their analysis have a low likelihood that emission reductions are additional to baseline scenarios. Currently most projects in the VCM are emissions reductions, but similar problems with MRV can be expected to apply in the case of carbon removals going forward. While the transaction costs that arise for MRV are also a topic in mandatory compliance markets, as well as for the comparison of instrument choice [Heindl, 2015, Joas and Flachsland, 2014], the extent of over-reporting of reductions and fraud appear less important.

3.4 Strategic fit

Strategic fit considers at which point of technological maturity a policy is best applied, whether policies can reflect cost differences across technologies, as well as how policy design can be adjusted to reflect changing circumstances.

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

While some policies (e.g. tax breaks or direct grants) can target more than one stage of technology readiness, a significant number of policies target technologies with a more developed TRL. For example, by creating demand for removals, measures such as integrating removals into the ETS or allowing tax breaks akin to IRA §45Q for the use of specific CDR technologies will target more mature, demonstrated technologies in the deployment phase. While this is likely to foster learning-by-doing and innovation, subsidies or grant-based mechanisms can explicitly support technologies in earlier stages of research and development, and subsequently induce more basic research and development. Figure 1 and its discussion depicts at which stage of technology development CDR policies can be applied. We discuss technology development both for our individual policies, as well as when we assess policy combinations, in Section 4.

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

Our next question considers whether a policy is able to support CDR across technologies, or whether it is best suited to support a narrow set of technologies. Despite potentially high informational requirements, differentiating policy by technologies along removal cost is desirable in some settings, as this prevents windfall profits and thus increases efficiency [Edenhofer et al., 2023]. Thus, a key consideration is whether or not a policy is able to reflect different costs and cost structures by technology.[8] Although most of the policies are sufficiently flexible and able to achieve this, policy administration is likely to become more costly. For instance, administering different prices under a single ETS is administratively quite complex. In contrast, under a CCfD policy, prices can be set or negotiated for individual contracts, making it easier to set technology-specific prices.

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

Lastly, we consider whether or not policy design can be easily adjusted to reflect changing policy, political or technological circumstances. This might be necessary if, for example, costs reductions occur via innovation or learning by doing, or if emissions targets change.

We observe substantial differences with regards to this criterion across policies. Notably, policies that are associated with longer contracts (e.g. CCfDs or grant-based approaches) are not easily able to accommodate for changing circumstances — this is deliberate, as they are able to provide long-term certainty as a result. Other policies are easier to adjust in principle (e.g. ETSs or tax breaks), but may require parliamentary approval to do so. In general, there is an inherent trade-off between the ability to flexibly adjust policies and the ability to provide investors with reduced risk and reduced uncertainty - both are desirable, but the chosen balance depends upon the objectives of the regulator and economic context operated in.

[8] [Fabra and Montero, 2023] shows that in the presence of heterogeneity, technology specific prices and policies are superior.

Table 3: Evaluating policies to support permanent CDR - A Summary.

Criteria	**ETS integration**	**Tax breaks**	**VCM**	**EPR, Portfolio & Product Standards**	**PPS**	**AMCs**	**Direct grants & subsidies, governments**	**Direct grants & subsidies, banks**	**CCfDs**
Stringency									
Does the policy provide sufficient incentives to encourage carbon removals at scales required?[1]									
Does the policy provide sufficient legal certainty to attract private investment?[1]									
Does the policy provide sufficient certainty on prices, risks, and return profiles to attract private investment?[1]									
Efficiency									
Does the policy encourage the deployment of the most efficient CDR technology, in £/tCO2?[1]									
Does the policy lead to the desired balance between removal and abatement across both negative emissions and emissions abatement?[1]									
Feasibility									
Where is the primary incidence of policy costs?[2]									
How difficult is the policy to administer and monitor?[3]									
Strategic Fit									
At which stage of TRL is this policy most effective?[4]									
Is the policy technologically neutral? Is price differentiation by technology possible?[1]									
Can the policy be adjusted over time to reflect increasing CDR scale and maturity?[5]									

[1] : Yes; : Unclear; : No.
[2] : Companies; : Both; : Regulators.
[3] : Easy; : Medium; : Difficult; blank: non-applicable.
[4] : All stages; : Deployment and diffusion.
[5] : Flexible; : Medium; : Inflexible.
For detailed evaluation results, see Appendix Table 8. For abbreviations used in this table, see the list of abbreviations in Abbreviations.

4 Policy Interactions

While the previous section has analysed standalone policies supporting CDR, policies are rarely introduced in isolation. This section explores the dynamic complementarity between CDR policies. CDR technologies vary widely in their TRLs, requiring different policy interventions at each stage. First, we are interested in "policy sequencing" along TRLs, i.e. which TRL stage(s) is (are) targeted by particular policies. Policies should evolve as technologies progress through TRLs: they can be perfect complements if they target different TRLs and are deployed sequentially. Second, we explore which policy instruments are best suited to address the main barriers to technological innovation and development of CDR along each TRL stage. We are particularly interested in complementary policies that can not only target different TRLs, but also be deployed simultaneously to address different barriers associated with CDR deployment.

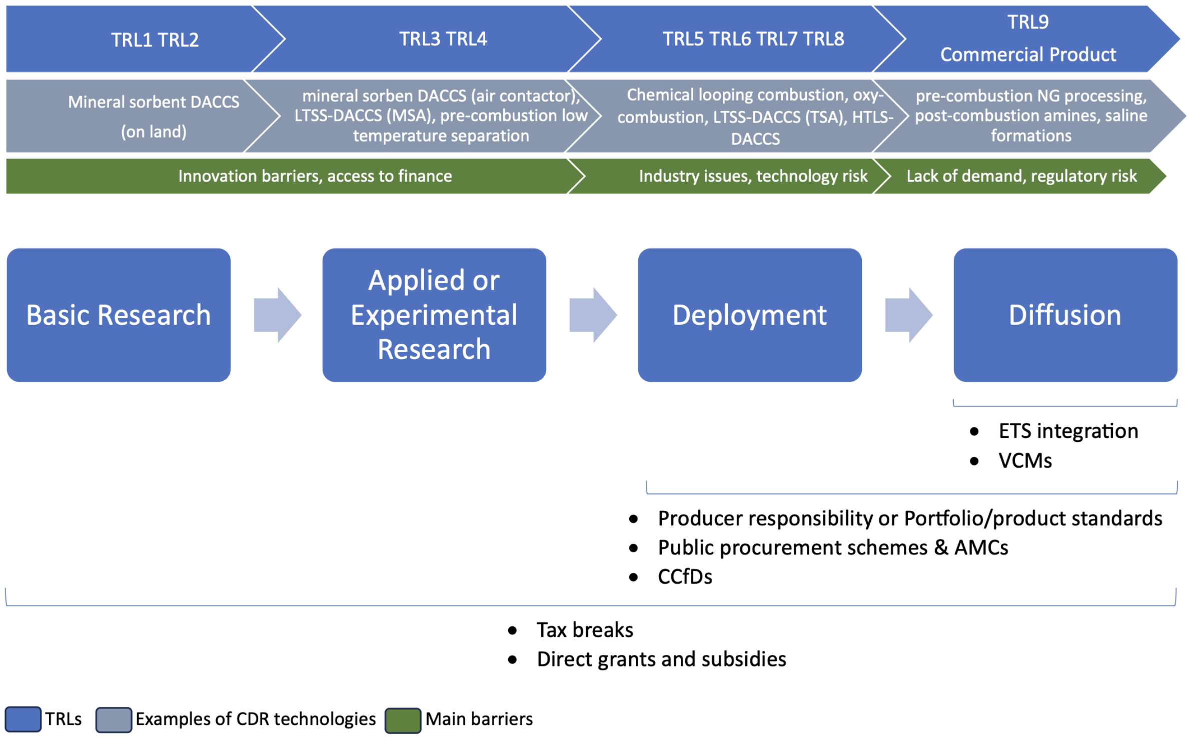
Figure 1 presents a technology innovation and development process diagram which closely aligns with TRLs and the characteristics of CDR technologies, building on the insights of Eveleens [2010], MacDowell et al. [2010], Nemet et al. [2018], Salazar and Russi-Vigoya [2021], Surana et al. [2014], Weaver et al. [2017], and in accordance with the UK Advanced Power Generation Technology Forum[9]. The technology innovation and development process is structured into four key phases: basic research, applied or experimental research, deployment, and diffusion.[10] Selected examples of CDR technologies at various TRLs are depicted in grey blocks based on [e.g. Bui et al., 2018, Cobo et al., 2023]. Barriers to innovation, shown in green, are drawn from a broad literature on technological transitions[Faber and Hoppe, 2013, Foxon et al., 2005, Long et al., 2016, Luthra et al., 2014, Weber and Rohracher, 2012], including financial, institutional, and market-related challenges that vary across stages. This framework informs our policy evaluation by providing a structured basis for assessing which instruments are best suited to support CDR technologies at different TRLs and address the corresponding barriers.

One of the most striking patterns emerging is the wide applicability of tax breaks and direct grants and subsidies. These policies are applicable in all stages of development, highlighting their versatility in supporting the entire innovation cycle from basic research

[9] See Advanced Power Generation Technology Forum.

[10] The *Basic Research* phase involves fundamental R&D aimed at ideal generation scenarios, while *Applied or Experimental Research* focuses on scientific demonstrations. *Deployment* marks the transition from a packaged form to an operational working state, while *Diffusion* denotes the acceptance of a new idea or product by the market.

Figure 1: Technology Innovation and Development Process



Note: Technology-specific acronyms are presented in the Abbreviations section.

(e.g. R&D subsidies) to commercial deployment (e.g. a per-unit-captured tax credit). It suggests that they can function not only as entry points for nascent technologies but also as enabling complements to more targeted instruments. In contrast, policies such as AMCs, public procurement, and CCfDs cluster around the deployment and diffusion stages to transition CDR technologies out of demonstration and into commercial-scale operations. These policies are critical to provide certainty and stimulate demand by setting clear technical requirements or criteria for products and services but often carry high fiscal costs. Public procurement schemes, for instance, are among the most effective policy mechanisms for governments due to their broad scope and scale, but can come at a significant cost[Dunford et al., 2021]. Moving to higher TRLs, market-led instruments, such as ETS integration and VCMs, are best suited for mature technologies capable of participating in broader carbon markets and complying with standardized removal criteria.

However, effective CDR policy is not about selecting a single optimal instrument, but about assembling a combination or portfolio that evolves with TRLs while addressing different barriers at a given stage. Early-stage phases are associated with challenges such as limited R&D funding and high innovation uncertainty, which underscore the need for targeted subsidies and R&D support. The deployment and diffusion phases face a broader and more layered set of barriers including technology risk, industry issues, and lack of demand. These barriers align with well-documented innovation system failures and suggests that CDR technologies advance requires a more complex mix of policy tools [Foxon et al., 2005].

We assess the dynamic complementarity of each policy when combined with a given additional policy in Table 4. The first symbol represents the complementarity in terms of the sequencing along TRLs, i.e. whether they target the same TRL. The second symbol indicates whether the policies address different barriers when deployed for the same TRL.

The versatility of tax breaks and direct grants and subsidies makes them well-suited to support early-stage innovation and complement a wide range of policies through effective policy sequencing along TRLs. Most of the other policies, shown in Figure 1, primarily target technologies at a more developed stage, yet they can still exhibit strong complementarity when addressing distinct barriers. For example, CCfDs reduce political and market uncertainty of investors by guaranteeing a fixed carbon price over the contract duration[Richstein and Neuhoff, 2022]. This price stability makes CCfDs a valuable complement to ETS integration or VCMs, which play a crucial role in creating niche markets to scale up CDR in the early stages [Smith et al., 2024]. A compelling example is the pairing of the Low Carbon Fuel Standard (LCFS) in California, a product standard, with the Inflation Reduction Act §45Q tax credit, a tax break. The LCFS establishes a regulatory requirement and generates demand for CDR, while the Inflation Reduction Act §45Q reduces the deployment cost of CDR projects such as DACCS, providing project developers with a strong financial incentive [Townsend and Havercroft, 2019].

Despite targeting later TRL stages, such CDR policies can also contribute to dynamic efficiency by fostering incentives for ongoing innovation. Given the relatively recent emergence of CDR technologies, policies that either support research activities or establish carbon removal markets both play a critical role in promoting learning-by-doing and driving further innovation. This section has provided a framework for designing policy portfolios that can be both TRL- and barrier-targeted. Well-sequenced and well-matched policy combinations or portfolios can help ensure technological advancements, smooth transition from innovation to commercialisation, and guarantee long-term efficiency.

Table 4: Policy interactions: sequencing and overlaps

	ETS Integration	Tax Breaks	VCM	EPR, Portfolio/ Product Standards	PPS & AMCs	Direct Grants & Subsidies	CCfDs
ETS Integration		🟢 🟡	🔴 🟡	🟡 🔴	🟡 🔴	🟢 🟡	🟡 🟢
Tax Breaks			🟢 🟡	🟢 🟡	🟢 🟡	🟢 🟡	🟢 🟡
VCMs				🟡 🟢	🟡 🟢	🟢 🟡	🟡 🟢
EPR, Portfolio/ Product Standards					🔴 🔴	🟢 🟡	🟡 🔴
PPS & AMCs						🟢 🟡	🔴 🔴
Direct Grants & Subsidies							🟢 🟡
CCfDs							

Table 5: This Table indicates the complementarity between policies. The first symbol indicates whether a policy targets the same Technology Readiness stage. The second symbol indicates whether a policy targets the same market barrier when deployed to address the same Technology Readiness stage.

5 Applications across jurisdictions

This section discusses the policy environments for CDR for the UK, the EU and the US along the criteria presented in Section 3. The respective policy environments are summarised in Boxes 1 and 2. This type of analysis can be extended for other regions or countries.

5.1 The United Kingdom and the European Union

Box 1: The United Kingdom and the European Union's policy mixes to support CDR

The United Kingdom aims to achieve "net zero" GHG emissions by 2050 and a CDR pathway involving scaling technological CDRs (including BECCS and DACCS) to 5 $MtCO_2$/year by 2030 and 75-81 $MtCO_2$/year by 2050 [UK Government, 2021]. Similarly, the European Union has committed to achieve climate neutrality by 2050. The contribution of removals to the EU's target is expected to be 310 Mt CO_2 equivalent of net removals by 2030, which will be divided across member states [European Commission, 2023]. The policies currently in place or under consideration to support achieving these goals include the following:

- **Grants**: In terms of government grants, the UK Woodland Carbon Fund, the DAC and CDR competition (UK Government 2024), and UKRI grants (e.g. the GGR Demonstrators Programme) are in place in the UK.[a] Similarly, the EU (at the EU level) has provided funding for R&D paid out from multiple sources, including the Innovation Fund and Horizon 2020. An increase in grant funding for R&D was recently announced in the Industrial Carbon Management strategy. At the member state level, CDR funding varies across member states, with Germany and the Nordic countries having the most advanced funded CDR research programmes.
- **ETS**: The EU ETS was launched in 2005, and currently covers 30 countries across Europe (all 27 European Union member states and Iceland, Liechtenstein and Norway). Technical and political discussions about the integration of removals into the EU ETS are on-going, including at the level of the member states [Edenhofer et al., 2023, Lessmann et al., 2024, Sultani et al., 2024]. The

UK ETS replaced the EU ETS within the UK as of 1 January 2021, and was revised to align with net-zero goals in 2024. The UK ETS Authority has recently decided that the UK ETS is an appropriate long-term market for CDR.

- **CCfDs** are implemented for DACCS, BECCS and direct ocean capture in the UK.[b] While the UK approach may be balanced from the point of view of policy instrument types, the range of CDR methods in scope is arguably narrower than in the EU. Although key contractual details such as the reference price for carbon are still being developed, we assume these instruments will be operational in the near future.[c]

- **VCM** credits can be bought and sold across jurisdictions, which private or government players can subsequently participate in. As set out in Table 2, the VCM also includes projects relating to geological CDR.

- The EU recently launched the **Carbon Removals and Carbon Farming Certification (CRCF)**, a standardised and more credible framework to categorise eligible carbon removals into carbon farming, products, and permanent removals. These certified carbon credits can be traded in the **VCM** allowing businesses and individuals to offset their emissions by purchasing credits from EU-based carbon farming projects, aiming at enhancing the integrity and transparency of the VCM and supporting the EU's climate goals.

[a] For instance, projects innovating CDR receive £54 million in government funding (UK Government 2024).

[b] See Greenhouse gas removals (GGR): business model.

[c] With regards to this piece, we are agnostic to whether the reference price is set as the EU ETS price for carbon, or a different reference price. The priority should be to set a well-established and acceptable reference price that is able to trigger the investment needed to achieve decarbonisation goals.

The current (and proposed) policy mix within the EU and the UK is diverse in that each offers a market-based solution via their respective emissions trading schemes, and various subsidies (direct and government grants) or subsidy-adjacent policies (CCfDs in the UK) which bite at different TRL levels (Section 4). The inclusion of removals into the respective ETSs creates a long-term framework for investment in CDR, while providing polluting firms with a recognized and relatively stable compliance tool. Furthermore, the VCMs in each region can be used as a point of reference for policy decisions (for instance, as a basis for a reference price within a CCfD) and as a backup to mandatory measures.

On their own, these policy environments are unlikely to foster the appropriate amount of removals. To meet imminent goals, a portfolio/product standard would lead to a further increase in CDR volumes and the number of participating firms (e.g. a carbon takeback obligation (CTBO) [Jenkins et al., 2021] or emissions trading with clean-up certificates [Lessmann et al., 2024]). While this may come at a higher cost, they would likely increase the quantity of removals, further rounding out each region's CDR policy portfolio through the more stringent measures, and ensure emissions reductions are paired with effective carbon removal efforts. Due to the diversity in fiscal capacity across EU member states, uniform policy implementation presents an obstacle for equitable progress — wealthier nations may be able to support more ambitious initiatives while nations with limited fiscal space, e.g. Italy, may struggle more [Bednar et al., 2021]. Ensuring financial strategies consider these disparities is crucial for equitable progress in the CDR space.

Erbay et al. [2025]

5.2 The United States

Box 2: The United States' policy mix to support CDR

As per its Nationally Determined Contribution published in 2021 and updated in 2024, the United States set itself an economy-wide target of reducing its GHG emissions by 50-52% below 2005 levels by 2030, and achieve net-zero emissions by 2050 United States Government [2024]. The US Long-Term Strategy [Government, 2021] includes the removal 1 to 1.8 billion tonnes of CO_2e per year by 2050.

- **Tax breaks**: While primarily supporting point-source capture (as opposed to removal), the Inflation Reduction Act (IRA) §45Q also offers a per-unit-captured tax credit for carbon removal. Specifically, carbon removed and stored in saline geologic reserves via DACCS receives $180 USD/tonne, and via BECCS receives $85 USD/tonne.[Carbon Gap, 2024, Clean Air Task Force, 2023].

- **Grants and subsidies**: A broad range of grant-based or subsidy initiatives for CDR are present in the US. The Bipartisan Infrastructure Law (2021) has allocated $3.5 billion USD to the Department of Energy for the development of four regional DAC hubs, along with $115 million USD for prize competitions focused on DAC technologies [of Energy, 2021]. The Bipartisan Infrastructure Law (2021) also provide cost-shares for afforestation and reforestation, as well as funding for point-source capture. The Department of Energy (DOE) has invested \$100 million USD to support the Carbon Negative Shot program, whose goal is to decrease removal and storage costs across several CDR technologies (e.g. DAC, forests and soil storage, mineralisation) to below \$100 USD per tonne [International Energy Agency, 2022].

- In terms of **AMCs**, Stripe Inc.'s Frontier has committed over \$1 billion USD to the purchase of geological CDR by 2030, with purchases across the world (including, for instance, a \$40 million USD investment funding the removal of 61,500 tonnes of CO_2 through 280 Earth in Dalles, Oregon [Herald, 2024]).
- Like in the EU and US, **VCM** credits can be bought and sold across jurisdictions, which private or government players can subsequently participate in. As set out in Table 2, the VCM also includes projects relating to geological CDR.
- At the state level, California's equivalent of an **ETS**, the Cap-and-Trade Program, allows for the limited use of carbon removals as part of its offset system (up to 4% of their compliance obligations from 2021-2025, and up to 6% through 2030 [Partnership, 2024]), although this is limited to nature-based methods such as afforestation, rather than methods such as BECCS and DACCS [Board, 2024]. Similarly, the Regional Greenhouse Gas Initiative (RGGI) comprised of 11 states in the northeast US allows complying firms to use offsets (currently also limited to nature-based methods) within a similar "cap-and-invest" program [Initiative, 2024].

Historically, tax breaks, grants, and subsidy-based approaches have been implemented in the US (e.g. for renewables) at the federal level, and their approach to CDR has followed suit by providing rewards for the deployment of CDR.[11] Despite the flexibility of these incentives to target all TRLs, this policy mix is less diverse than its UK or EU counterpart, due to its focus on tax breaks and grants at the national level. Expanding existing policies to include additional CDR methods would likely lead to an increase in the CDR deployed, necessitating a careful eye to MRV for each particular method, for instance, by allowing for technological removals like DACCS and BECCS in California's Cap and

[11] Although the November 2024 elections have been associated with heightened uncertainty regarding the future of US climate policy, including the IRA, Mihan and Fankhauser [2025] show that 32 representives of the governing Republican Party might vote against a possible repeal of the IRA.

Trade Program and RGGI. Additionally, mandates like a CTBO or a portfolio standard can help push CDR technologies beyond the pilot phase and encourage wider deployment, or allow removals to offset GHG mitigation mandates, albeit at the cost of political feasibility. The use of purely incentive-based measures will tend to be more costly, as noted in Section 4, and the use of compliance measures (i.e. a federal roll-out of a scheme similar to the California's Cap and Trade Program or RGGI) may aid in offsetting these costs.

6 Conclusions

As the urgency to scale up CDR deployment intensifies in order to to meet imminent net-zero goals, the need for effective and impactful CDR policy has never been greater. This paper proposes criteria for evaluating policy instruments in the CDR context, drawing on insights from economics literature and highlighting the strengths and weaknesses of current and proposed policies.

No single policy can be deemed the "best" for encouraging the widespread roll-out of CDR. Effective policy selection requires a detailed assessment of the CDR technologies (e.g. the maturity/stage of development) and the existing policy environment, considering potential interactions with other policies. We evaluate each proposed and existing policy for incentivising CDR, demonstrating the associated benefits and drawbacks.

Further, we assess pairwise combinations of policies, examining their complementarities — such as targeted CDR obstacles and TRL stages — and cumulative costs.

Finally, we discuss the current state of CDR policies in the EU/UK and the US through our criteria. While the EU and the UK's policy ecosystem appears well-rounded in theory, it may not be adequate to meet their ambitious net-zero targets. The extent to which this is true depends on the design of CCfDs and the integration of removals into the each respective ETS, though more stringent measures, such as mandates (e.g. a CTBO), may be necessary to achieve net-zero goals. For the EU specifically, we note that care that must be taken to tailor policy for a more heterogeneous set of member regions.

Given the nascency of the CDR space, there is ample room for future research, and limitations to our work. Policies that have only been proposed, such as the CTBO, or are too recent, like CCfDs, lack the necessary data for a rigorous empirical assessment of their outcomes. We further abstract from other important facets of policy design, such as equity, environmental justice and impacts on biodiversity, leaving these areas for future exploration.

There are numerous policy combinations described here that can elicit meaningful deployment of CDR. The task of the policymaker is to design a policy portfolio that aligns their particular goals by determining which drawbacks they are comfortable to internalize, such as the extent of costs they are prepared to incur or pass through to constituents. This paper aims to inform policymakers in making these trade-offs between benefits and compromises, ultimately shaping the path forward for effective roll-out of CDR toward a net zero future.

Abbreviations

AMCs Advanced Market Commitments.

BECCS Bioenergy with Carbon Capture and Storage.

CCfDs Carbon Contracts for Differences.

CDR Carbon Dioxide Removal.

CRCF Carbon Removals and Carbon Farming Certification.

CTBO Carbon Take-Back Obligation.

DACCS Direct Air Carbon Capture and Storage.

EPR Extended Producer Responsibility.

ETS Emissions Trading Systems.

HTLS-DACCS High Temperature Liquid Solvent DACCS.

LCFS Low Carbon Fuel Standard.

LTSS-DACCS Low Temperature Solid Sorbent DACCS.

MRV Monitoring, Reporting, and Verification.

MSA Moisture Swing Adsorption.

TRL Technology Readiness Level.

TSA Temparature Swing Adsorption.

VCM Voluntary Carbon Market.

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Table 6: Evaluating CDR policies - Stringency

	ETS integration	Tax breaks	Voluntary carbon market	Producer responsibility or portfolio/product standards	Public procurement schemes	Advanced market commitments	Direct grants and subsidies, governments	Direct grants and subsidies, banks	Contracts for differences
Does the policy provide sufficient incentives to encourage carbon removals at scales required?	Yes, so long as the cap is effectively adjusted to account for equilibrium effects of inclusion of removals.	Yes, if rates are high enough to close the gap between the cost of delivering the carbon removals and the rate of the tax credit.	Yes, under the strong condition that the entity engaging in the VCM must credibly commit to such a scheme.	Yes: if in place, guarantees delivery of CO_2 storage, albeit only to the scale of matching current CO_2 production.	Yes. One of the most effective policy mechanisms available due to its scope and scale.	Yes, so long as the committing entity is able to credibly promise a sufficiently high "market" price. Since it is effectively a future subsidy, AMCs effectively encourage CDR so long as the price exceeds the cost.	Yes. Government funding programmes go towards large-scale projects or research directly.	Yes. It brings private investment to overcome the early-stage challenges such as high costs.	Yes, provided that the reference price is stable and the strike price is set high enough to encourage deployment, but not too high to lead to over-expenditure.
Does the policy provide sufficient legal certainty to attract private investment?	Yes: based on experience with existing systems, ETSs have been relatively long-lived and stable, so policy risk is likely to be low.	Unclear: shifts in government spending or budget priorities lead to some risk of policy reversal.	Yes: policy risk is low since this is a voluntary mechanism and not government-led.	Unclear: not yet observed in practice, with uncertainty contingent on commitment of administration..	Unclear: uncertainty mainly caused by different awarding criteria or scoring rules.	Depends upon entity. Regulator: no, there is enormous risk, entirely dependent on the administration. If philanthropic organization, yes: little to no policy risk.	Unclear: policy risk is lower than tax credits but depends on their longevity and payment structures.	No: high policy risk, since green projects and investments can be heavily influenced by policies.	Yes: as a contract, less policy risk.
Does the policy provide sufficient certainty on prices, risk and return to attract private investment?	Yes: despite long-run ETS price volatility, market risk manageable through price corridors.	Unclear: stable rates in short-term, with long-term stability depending on institutional trust or commitment.	No: risks are limited, since investors do not commit, but uncertainty is high due to limited MRV.	Unclear: prices will fluctuate, but there exists volume uncertainty (hinges upon regulatory risk).	Unclear: low risk if simply incorporating the requirements in the calls for tenders; high risk if involving requirements in the selection process. Yes: with credibly committed participants, market risk smoothed through guaranteed revenue flows.	Yes: with credibly committed participants, market risk smoothed through guaranteed revenue flows.	Unclear: previous failure can impose a sense of buyer remorse upon those that spent money. General volatility/uncertainty in failure rates of government-funded CDR projects.	Yes: grants compensate for real and perceived risks, and build confidence of investors in new technologies.	Unclear: depends on the basis for the reference price. Without a meaningful nonzero carbon price, highly unlikely to attract private investment.

Table 7: Evaluating CDR policies - Efficiency and Feasibility

		ETS integration	Tax breaks	Voluntary carbon market	Producer responsibility or portfolio/product standards	Public procurement schemes	Advanced market commitments	Direct grants and subsidies, governments	Direct grants and subsidies, banks	Contracts for differences
Efficiency	Does the policy encourage the deployment of the most efficient CDR techology, in £/tCO2?	Yes, with broad sectoral coverage of ETS.	Yes	Yes, but within the system across a highly self-selected sample.	Yes: if in place, guarantees delivery of CO_2 storage, albeit only to the scale of matching current CO_2 production.	Yes, provided the "right"/efficient technology is selected.	Yes	Yes	Yes	Yes
	Does the policy lead to the desired balance between removal and abatement across both negative emissions and emissions abatement?	Yes, but removals might be prioritised	Yes	Yes, within the system.	Yes	Yes	Yes	Yes	Yes	Yes, but removals might be prioritised
Feasibility	Where is the main incidence of policy costs?	Initial costs fall on companies; pass-through depends on market structure.	Initial costs fall on companies; pass-through depends on market structure.	Initial costs fall on companies; pass-through depends on market structure.	Initial costs fall mainly on fossil fuel extractors; pass-through depends on market structure.	Initial costs fall on regulators; pass-through depends on market structure.	Initial costs fall on companies; pass-throughs depend on market structure.	Initial costs fall on regulators; pass-through depends on market structure.	Initial policy costs fall on both private and public sectors; pass-through depends on market structure.	Initial costs fall on regulators; pass-through depends on market structure.
	How difficult is the policy to administer and monitor	Difficult	Medium	Medium	Easy	Easy	N/A: no administration for regulator.	Medium	Medium	Medium

Table 8: Evaluating CDR policies - Strategic Fit

	ETS integration	Tax breaks	Voluntary carbon market	Producer responsibility or portfolio/product standards	Public procurement schemes	Advanced market commitments	Direct grants and subsidies, governments	Direct grants and subsidies, banks	Contracts for differences
At which stage of TRL is this policy most effective?	diffusion	all stages	diffusion	deployment & diffusion by setting criteria for products and services.	deployment & diffusion by setting technical requirements or criteria for products and services.	early deployment & diffusion	all stages	all stages	deployment & diffusion by setting clear technical requirements.
Is the policy technologically neutral? Is price differentiation by technology possible?	Neutral, price differentiation by technology is possible.	Neutral, price differentiation by technology is possible.	Neutral, price differentiation by technology is possible.	Neutral, price differentiation by technology is possible.	Often with detailed technical and performance specifications; price differentiation by technology is possible.	Neutral, price differentiation by technology is possible.	Neutral, price differentiation by technology is possible.	Generally a narrow mandate focusing mainly on mobilising private LCR investment, but sometimes on broader green infrastructure investment.	Neutral, price differentiation by technology is possible.
Can the policy be adjusted over time to reflect increasing CDR scale and maturity?	Very flexible, since ETS cap can be adjusted and prices fluctuate.	Medium flexibility, since the level of tax credits can be adjusted with parliamentary approval, and so cost changes can be accomodated for.	Very flexible, since largely unregulated.	Flexible, since policy can be tailored to achieve specific technology scaling.	Flexible, since government and suppliers can reflect market demand and development in tender processes	Inflexible by design - smoothes revenue flows in the future by way of committing to a market price.	Inflexible by design, since research outcomes are slow to materialise.	Inflexible by design, since research outcomes are slow to materialise.	Inflexible by design, since predictability and stability lead to an agreed upon strike or reference or term length that necessitates inflexibility.