Consistent temporal accounting supports credible CDR use

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Abstract

Carbon dioxide removal (CDR) is increasingly used to support national targets and corporate net-zero commitments, yet the timing of atmospheric drawdown remains poorly represented in carbon accounting frameworks. Many CDR pathways exhibit temporal lags—either because drawdown occurs only after physical or counterfactual processes unfold, or because excess emissions are incurred before CDR begins. Using the FaIR climate model, we quantify the warming implications of four archetypal lag structures. Temporal lags consistently increase near-term warming relative to instantaneous removal and delay the point of atmospheric neutralization when used to offset fossil emissions. Under continuous global deployment in a low emissions scenario, lagged CDR increases peak global temperatures, and some lag types increase the likelihood of peak temperatures exceeding 2°C by up to 6% across 841 ensemble members. These effects arise even when cumulative removals equal cumulative emissions. We propose tractable approaches to addressing these temporal lags, enabling more credible climate claims and consistent treatment across CDR pathways.

Main Text

Carbon dioxide removal (CDR) is increasingly being used to support nationally determined contributions (NDCs), compliance under cap-and-trade systems, and voluntary corporate net-zero commitments (Smith et al., 2024). In these contexts, CDR is often framed as "offsetting" or "neutralizing" fossil CO_2 emissions. For such claims to be physically unambiguous, CDR should counterbalance the warming effects of fossil emissions from the time the claim is made through the atmospheric lifetime of CO_2 (Allen et al., 2025). While the ultimate durability of CDR has received considerable attention in this regard (e.g., Brunner et al. 2024), much less attention has been paid to the temporal dynamics that link a CDR intervention to its atmospheric impact.

Nearly all approaches to CDR exhibit a lag between the intervention – for example, transforming biomass, rock mineralization, or planting trees – and the point at which all of the atmospheric CO_2 drawdown is completed. These lags can range from months to decades (Fingerman et al., 2023; Bach et al., 2023; Kanzaki et al., 2025). Even in pathways where drawdown is immediate, such as direct air capture (DAC), upfront emissions from facility construction can delay the onset of net drawdown (Lawrence et al., 2025). Yet today, such lags are poorly characterized and inconsistently treated in accounting frameworks that estimate how much drawdown a CDR intervention has achieved at a given point in time.

This matters for two reasons. First, ignoring lags amounts to ex-ante crediting — granting credit for removals before they occur. If used to neutralize fossil emissions, ex-ante credits may cause temporary warming and, in turn, complicate the interpretation of neutralization claims. Second, inconsistent treatment of lags can distort comparisons across pathways and, in the worst case, could hinder the development of a balanced portfolio of effective CDR approaches. Clear and consistent language for describing temporal lags is essential to address these challenges.

We identify four archetypes of temporal lag, grouped into two broader classes: *delayed drawdown*, encompassing physical and counterfactual delays that postpone CO_2 removal, and *front-loaded emissions*, encompassing accelerated and up-front embodied emissions that increase near-term CO_2 emissions before removals accrue. Using the FaIR climate model (Leach et al., 2021), we quantify how these lags influence the temperature response when CDR is used to neutralize fossil CO_2 emissions. This analysis highlights the importance of accounting for temporal lags in CDR policy and crediting frameworks, and provides a foundation for doing so.

Results

A framework for temporal accounting in CDR systems

Many CDR pathways exhibit a **physical delay** — a lag between the intervention and atmospheric drawdown (Table 1). These delays occur because interventions initiate physical processes that take time to affect the atmosphere. For example, planting trees only leads to drawdown as those trees grow and photosynthesize. Similarly, it can take months to years for the atmosphere and ocean to equilibrate after an ocean alkalinity enhancement (OAE) intervention (Zhou et al., 2025). In some cases, these lags could span decades. Enhanced rock weathering (ERW), for instance, can experience drawdown delays both from slow rock dissolution and from cation sorption in soils — lags which are poorly characterized today and likely vary based on site-specific characteristics (Calabrese et al., 2022; Benettin et al., 2022; Kanzaki et al., 2025).

Group	Lag archetype	Description	Example CDR pathways
Delayed drawdown	Physical delay	Lag between CDR intervention and atmospheric impact due to prolonged carbon cycle response	ERW, OAE, ARR
	Counterfactual delay	Lag between CDR intervention and atmospheric impact due to an assumed counterfactual outcome that would play out over time	BiCRS, IFM
Front-loaded emissions	Accelerated emissions	The CDR intervention causes emissions to occur earlier than they would have in the assumed counterfactual	BiCRS
	Upfront embodied emissions	The CDR intervention causes emissions from upfront capital expenditures such as facility construction that precede any drawdown	DAC, BiCRS, ERW, OAE

Table 1. *Classification of temporal lag archetypes, and examples of CDR pathways to which each may apply. Acronyms: ERW, enhanced rock weathering; OAE, ocean alkalinity enhancement; ARR, forestation, afforestation, reforestation, and revegetation; BiCRS, biomass carbon removal and storage; IFM, improved forest management; DAC, direct air capture.*

Other lags arise in relation to the counterfactual rather than the physical process of the CDR intervention. We refer to these as **counterfactual delays**. These lags are most relevant to biomass-based carbon removal and storage (BiCRS) projects, which deliver climate benefits only relative to the fate of the biomass in the absence of the intervention. For example, if biomass that would otherwise decay is used for BiCRS, the atmospheric impact of the intervention is only truly realized when the carbon content of the biomass feedstock would have otherwise been released through decay. This lag can span decades for large-diameter woody biomass in cool or dry environments (Fingerman et al., 2023), but may be short when the counterfactual involves rapid decay or combustion, such as agricultural residues or slash pile burning. Counterfactual delays are equally relevant for landscape-scale carbon stock accounting, such as when increased forest harvest for BiCRS causes temporarily lower standing carbon than the counterfactual (Cabiyo et al., 2025; Cheng et al., 2025).

Some BiCRS projects also create **accelerated emissions** of CO_2 relative to their counterfactual. In biochar production, for instance, the pyrolysis process typically converts only 25-50% of the biomass carbon into stable char, while the remainder is released as CO_2 during processing (Rodrigues et al., 2023; Tripathi et al., 2016). This means that a portion of the biomass carbon may be emitted earlier than it would have been in the counterfactual, while the rest is sequestered in a more durable form. Such front-loading of emissions can temporarily increase atmospheric CO_2 concentrations even as it enhances the long-term durability of stored carbon. Notably, this biochar example also exhibits the counterfactual delays described above, since both types of lags are linked to the counterfactual outcome for the same biomass feedstock.

Finally, nearly all CDR projects involve **upfront embodied emissions** from the construction and deployment of facilities and supporting infrastructure. DAC plants, for instance, require steel, concrete, sorbents, and other components whose production generates substantial greenhouse gas emissions. Published LCAs estimate these embodied emissions at tens of kg CO_2 per ton CO_2 captured, and typically amortize these emissions over a 15–25 year facility lifetime (e.g. Keith et al., 2018; Deutz & Bardow, 2021; Madhu et al., 2021). The same is true for energy infrastructure built to power CDR facilities (Brander et al., 2021). Yet in reality, these emissions occur before any CO_2 is removed, causing near-term warming that conventional amortization obscures. If a facility retires early or captures less than expected, its upfront emissions may never be fully offset and the near-term warming effect could persist indefinitely.

Climate impacts of lagged CDR

To evaluate the influence of temporal lags on climate outcomes, we used the FaIR climate model (Leach et al., 2021; Smith et al., 2024) to quantify the temperature response associated with each lag archetype (see Methods). Across all cases, lagged CDR scenarios result in higher near-term warming when used to neutralize ongoing fossil CO_2 emissions. When applied continuously, lagged CDR also increases peak warming. The largest effects will generally occur in cases exhibiting both accelerated emissions and counterfactual delays. The smallest effects occur in the upfront embodied-emissions archetype – which represents a one-time rather than continuous lag. However, individual CDR projects can differ widely, and the relative magnitude of these effects will depend on assumptions about feedstock used, lag duration, embodied emissions, and CDR timing.

We represent CDR deployments with temporal lags using four stylized removal profiles (Fig. 1). Each profile represents 1 Gt yr^{-1} of nominal CDR deployment. Physical and counterfactual delay profiles are modeled as 20-yr linear lags between the intervention and the atmospheric drawdown it generates, reflecting delayed carbon-cycle responses. The accelerated-emissions profile combines the same delayed-drawdown assumptions with an immediate release of 50% of biomass carbon, representing pyrolysis or other conversion processes that shift part of the feedstock's emissions forward in time. The upfront embodied-emissions profile applies a one-time construction pulse of 3 $GtCO_2$ followed by 1.15 $GtCO_2\ yr^{-1}$ of removals, approximating the 20-yr amortization of capital emissions in infrastructure-intensive pathways such as DAC. These parameterizations are illustrative rather than representative of specific projects. For example, well-designed DAC projects may have low upfront emissions relative to removals, and some biomass feedstocks will have relatively little counterfactual storage. In practice, the duration and functional form (for example, linear versus logarithmic) of the lag will vary by CDR pathway, deployment context, and feedstock. Similarly, while we assume the same lag function for physical and counterfactual delays, they may differ in real-world applications.

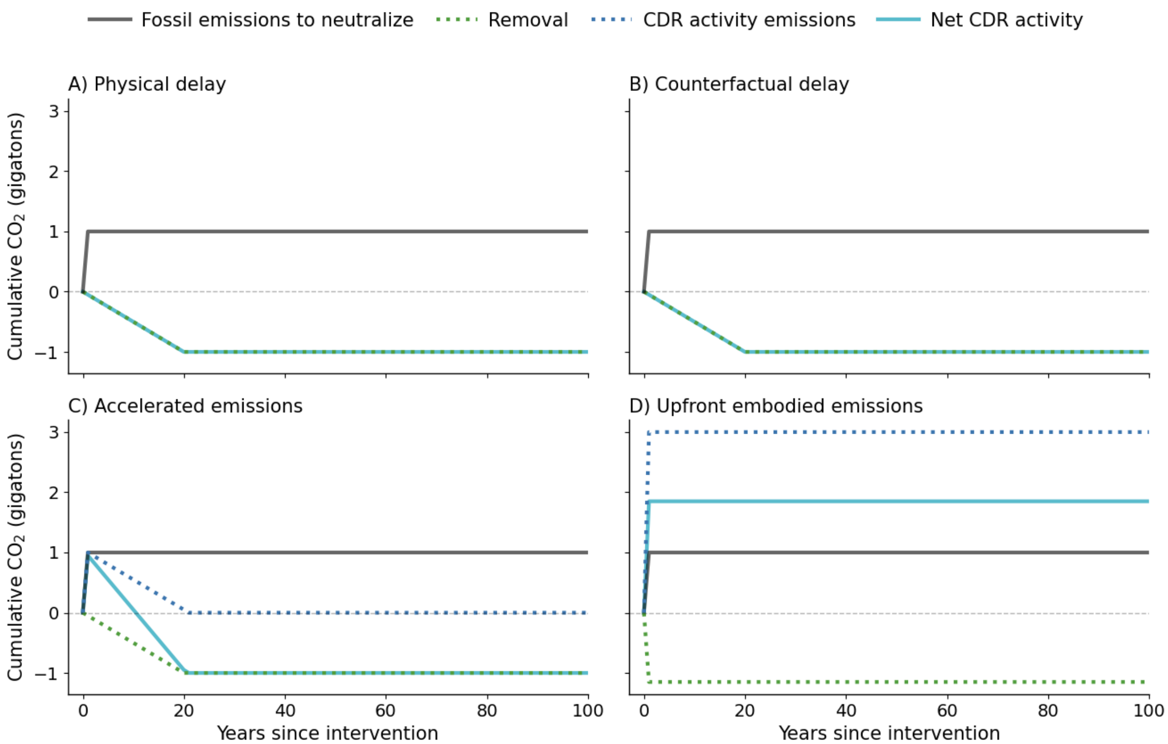

Figure 1. *Stylized annual pulse profiles for the first year of operation for four CDR deployments exhibiting each temporal lag archetype. Each profile nominally results in 1 $GtCO_2$, with distinct temporal patterns of emissions and removals following the intervention. The CDR activity is plotted alongside 1 $GtCO_2$ fossil CO_2 emissions that may be neutralized by CDR. Here, physical and counterfactual delays are modeled with the same removal profile, though they may differ in practice. The upfront embodied emissions case is unique in that all activity emissions occur only in the first intervention year; subsequent years of the same intervention would occur with no activity emissions.*

In all experiments, removals were paired with equal emissions at the time of intervention, representing the use of CDR to neutralize emissions without accounting for temporal lags. Experiments were structured such that total cumulative removals equaled total fossil emissions. When extended over a 20-yr deployment period of 1 Gt CO_2 yr^{-1}, these removal profiles yield distinct emissions–removal trajectories (Fig. 2) despite identical cumulative carbon balances, isolating the effect of timing alone on the resulting climate response.

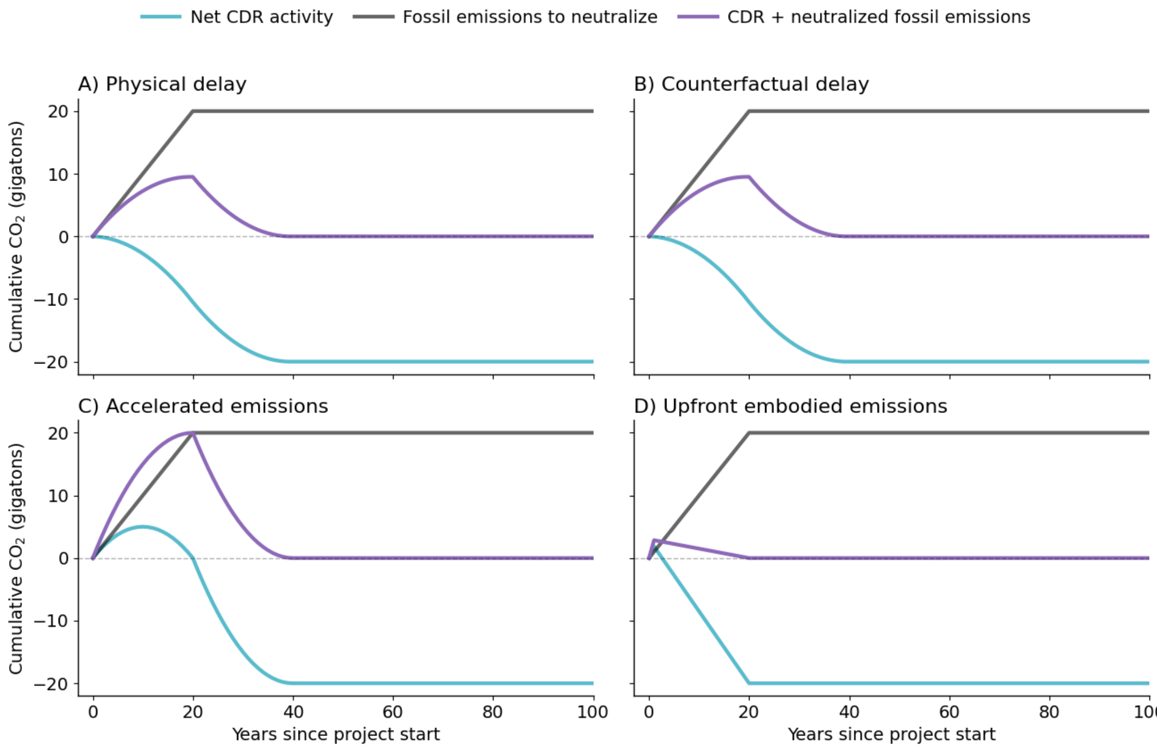

Figure 2. *Cumulative emission and removal profiles for four scenarios illustrating the temporal lag archetypes and their use for neutralization of fossil fuel emissions. Each scenario represents 20 yrs of a CDR activity (nominally 1 $GtCO_2$/yr) with associated lags. The accelerated emissions case combines both accelerated emissions and counterfactual delay, which are described separately in Table 1. The dashed line represents instantaneous emissions neutralization.*

All lagged CDR deployments result in elevated near-term warming relative to instantaneous drawdown (Fig. 3). Using lagged CDR to neutralize fossil emissions results in a delayed offsetting effect because atmospheric drawdown occurs gradually while the fossil emission is instantaneous. As a result, the atmosphere retains excess CO_2 for years to decades until the lagged CDR catches up. Global temperatures achieve the net-zero outcome implied by the neutralization claim, and converge with the instantaneous-removal case, between 20 (upfront embodied emissions) and 47 yrs (accelerated emissions) after the deployment period begins (and zero to 27 yrs after the 20-yr CDR project deployment period ends). In the accelerated-emissions case, global mean temperature remains elevated from deployment (2025) through roughly 2062, whereas the warming from upfront embodied emissions is brief and shallow.

When lagged CDR is deployed without neutralizing concurrent fossil emissions, the temperature response differs across archetypes but still reflects the influence of timing.

In the physical and counterfactual-delay scenarios, CDR begins reducing temperatures immediately, but more gradually than instantaneous drawdown. In contrast, accelerated emissions and embodied emissions cause temperatures to rise initially and then decline as removals dominate, with the duration and magnitude of the warming determined by the structure and scale of the lag.

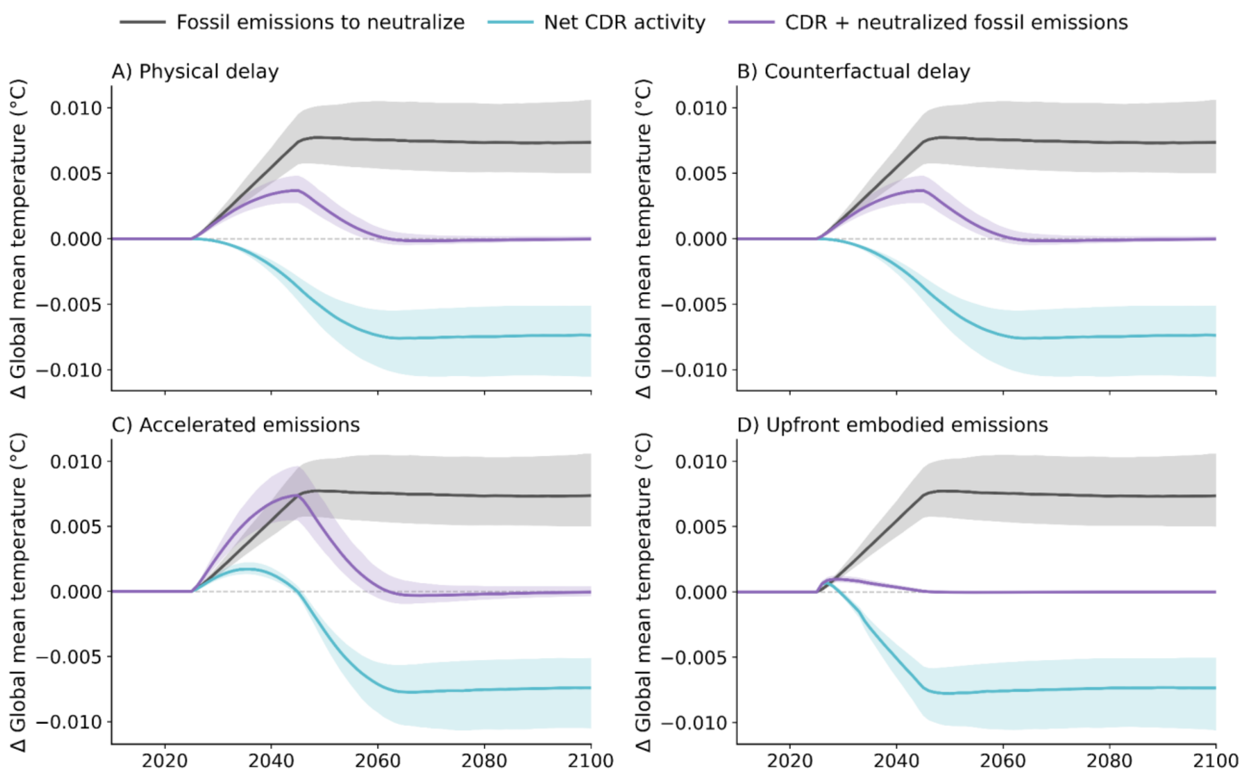

Figure 3. Modeled global mean surface temperature response for four scenarios illustrating each temporal lag archetype. Each plot shows 20 yrs of CDR activity (nominally 1 $GtCO_2$/yr) with associated lags, 20 yrs of fossil CO_2 emissions to be neutralized, and the combination of both reflecting the use of lagged CDR for neutralization. Shaded regions indicate the 5^{th}-95^{th} percentile range across ensemble members. The dashed line represents instantaneous emissions neutralization.

We next examined continuous application of CDR in a single century-scale mitigation pathway (Fig. 4; see Methods), which reaches 11.1 Gt CO_2 yr^{-1} of deployment by the end of the century. In all cases, lagged CDR fails to reconverge with the baseline so as long as lagged deployment continues. This occurs because each year's emissions–removals pair retains a timing mismatch. In this setup, neglecting temporal lags increases the share of ensemble members exceeding 2 °C peak warming by up to 6% (from 380 to 432 of the 841 ensemble members in the accelerated-emissions deployment scenario (Table S1)).

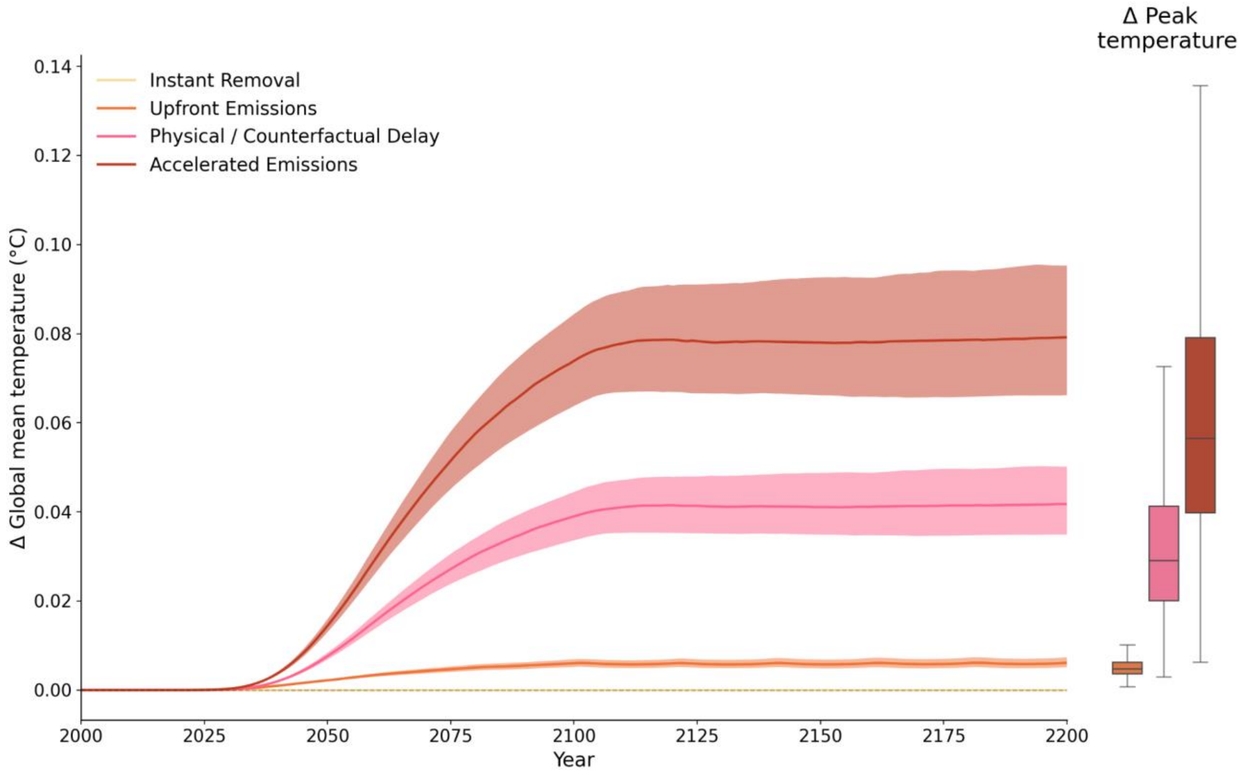

Figure 4. Modeled global mean surface temperature response for continuous deployment of CDR with and without illustrative lag archetypes, in the context of a low-emissions pathway (SSP1-2.6). Uncertainty bounds in the time series indicate the 15th-85th percentile range across ensemble members. Changes in peak temperature compare each lagged deployment scenario to a no-lag baseline. Peak temperature is calculated using a 20-year running mean of global mean temperature, relative to the 1850–1900 baseline.

The magnitude of the additional warming varies systematically across temporal lag archetypes (Table S1). The accelerated-emissions case produces the largest shift in peak temperature, with a ΔT_{peak} of 0.061°C (σ=0.028) relative to the instantaneous-removal baseline. Physical and counterfactual delays yield intermediate warming of 0.032°C (σ=0.015). upfront embodied emissions generate the smallest effect, 0.005°C (σ=0.002), reflecting the single early-emission pulse rather than per-ton timing distortions.

These results show that even when cumulative emissions and realized removals are equivalent over the long term for individual CDR projects, differences in the timing of carbon drawdown can yield substantially different near-term temperature trajectories. Observed warming reflects the fact that temporal lags cause cumulative net emissions to exceed those in an instantaneous-removal baseline. This effect is temporary in the pulse experiments, and persistent under continuous deployment where each year's lag introduces a new mismatch that is never fully reconciled.

Discussion

Today, temporal lags are rarely considered in carbon accounting for CDR pathways, or they are addressed in ways that fail to capture their climatic forcing effects. This is especially problematic in carbon markets, where the primary product is claims of climate impact, and issued credits are used to neutralize fossil emissions. Ignoring or inconsistently treating temporal lags in this context undermines the idea that CDR credits are fully interchangeable with one another or with fossil CO_2, weakening the credibility of neutralization claims and distorting assessments of the most cost- and carbon-efficient pathways (Groom and Venmans, 2023). Given uncertainty about the ultimate scale and mix of technologies needed for a net-zero-aligned portfolio (Fuhrman et al., 2023) and the limited resources available for early-stage investment, such distortions could advantage or disadvantage pathways in ways that do not reflect their true carbon removal efficiency.

Today, temporal lags are not treated consistently in crediting protocols. The uneven treatment of counterfactual delays across BiCRS protocols offers an instructive example. Depending on the registry, these lags may be unaddressed (Verra, 2025), addressed indirectly through prescription of eligible biomass sources (Puro.earth, 2023), ignored if biomass is sourced from a stable or growing sink (Puro.earth, 2024, European Union, 2024), or ignored if shorter than a temporal threshold (e.g. 15 years; Isometric, 2025). By contrast, for physical delays there is usually an expectation that credits are not issued until some physical process has occurred. Approaches range from fully ex-post crediting — as in ocean alkalinity enhancement (Isometric, 2025b) and ARR (Verra, 2025b; Isometric, 2025c) — to intermediate crediting, where a measurable milestone in the physical process triggers credits, but subsequent delays are ignored. For example, current enhanced weathering protocols (Isometric, 2025d; Puro.earth, 2022) issue credits once evidence of rock weathering is observed, even though in some cases, it may be years or decades before the released cations capture carbon dioxide and sequester it in the ocean.

The consequences of this inconsistency are illustrated starkly by comparing two of the most widely credited CDR pathways: biochar and forestation. Forestation projects typically earn credits only after measurable biomass accumulation following tree planting, which can take at least three to five years (Löfqvist et al., 2023). Biochar protocols, by contrast, generally allow full crediting at the time of project intervention, even though the process often accelerates some biomass emissions and net drawdown accrues gradually after the project intervention due to the associated counterfactual delay. From a strictly climatic forcing standpoint, crediting a biochar project in full at the time of the intervention is in some ways similar to crediting a reforestation project upfront for its projected growth — a practice that has not generated significant demand because it awards credits for CDR that has not yet occurred. This comparison overlooks key differences, such as the reversibility and durability of carbon stored through each pathway and the length of counterfactual delay relative to tree growth. Nonetheless, since credit issuance is necessary for revenue generation, this asymmetry could disadvantage forestation projects, particularly those involving slower-growing or native species (Löfqvist et al., 2023).

There are several options for aligning temporal accounting practices in carbon markets and addressing the fungibility problem highlighted by our results. One option is strict ex-post crediting, under which all project types earn credit only once atmospheric drawdown has occurred. A second option is vintaged crediting, in which credits are issued at the time of intervention but dated to the year when drawdown is expected to materialize. A third option is to adopt a standardized short lag (e.g., five years) below which temporal adjustments are not required, thereby simplifying accounting for many projects and only requiring the use of one of the other options for lags exceeding the threshold. Finally, horizontal stacking pairs lagged CDR with temporary removals or abatement, using a temporary cooling benefit to bridge temporal gaps until durable drawdown is realized.

Each option represents a distinct balance of physical fidelity and practical feasibility. Ex-post crediting most accurately reflects atmospheric outcomes but delays revenue for pathways with long or uncertain lags, potentially suppressing investment. Vintaged crediting preserves early revenue but requires governance systems to ensure that neutralization claims ultimately align with vintages and creates uncertainty about who bears the risk if drawdown diverges from expectations. A standardized lag is operationally simple and treats pathways consistently, but explicitly codifies some degree of ex-ante crediting and thus allows periods of near-term warming. Horizontal stacking is physically robust—ensuring no net warming at any timestep—but operationally complex, deviates from conventional greenhouse-gas accounting, and would require new diligence frameworks for buyers seeking rigorous neutralization claims.

Accounting for temporal lags becomes less fraught outside the offsetting context. If removals are not being used to neutralize ongoing fossil emissions, and are instead utilized as a net negative contribution to climate change mitigation, the risk of exacerbating near-term warming is reduced. Physical and counterfactual delays no longer result in warming, and the additional warming from accelerated and upfront emissions becomes smaller in magnitude and shorter in duration. However, even in this case, consistent and transparent characterization of lags is essential for organizations or jurisdictions reporting on efficacy of their climate change mitigation investments and for funneling limited resources towards the most effective CDR pathways.

The challenge of accounting for complex temporal dynamics is not unique to CDR. Other areas of decarbonization, including life-cycle assessment for low-carbon fuels and materials, have long grappled with temporal dynamics — and have not reached perfect consistency. For sectors like green hydrogen or renewable energy, which involve substantial, upfront, embodied emissions, accounting norms are not consistent across technologies or jurisdictions. For example, under the Greenhouse Gas Protocol, organizations purchasing electricity from the grid report only the operational emissions from electricity generation in their Scope 2 inventories (WRI & WBCI, 2015), while the EU Renewable Energy Directive amortizes embodied emissions over standardized technology-specific lifetimes (European Union, 2018).

Together, our results show that temporal lags can meaningfully alter near-term temperature outcomes even when cumulative removals ultimately balance cumulative emissions. These timing effects complicate the use of CDR as an instrument for offsetting, challenge the assumption that different credits are fungible, and highlight the need for greater transparency in accounting frameworks. Resolving these issues will require explicit choices about how to balance physical fidelity, operational feasibility, and the imperative to enable durable CDR at scale. Better time-series data on CDR interventions would greatly strengthen the field's ability to characterize temporal lags. A consistent lexicon for describing temporal lags can help standards bodies, regulators, and researchers make these choices more deliberately and advance CDR in ways that reflect both atmospheric reality and practical constraints.

Online Methods

Modeling framework

To model the global mean surface temperature effects of each CDR scenario, we used the Finite amplitude Impulse Response model (FaIR) calibrated constrained ensemble (v1.4.1) to reflect the range of climate parameters (climate sensitivity, carbon cycle feedbacks) as assessed in the IPCC AR6 report (Smith et al., 2024). We created a 841 member ensemble of runs of the SSP1-2.6 emissions pathway, reflecting the range of model parameterizations, as well as a separate 841 member ensemble perturbed to reflect the changes in each of the pulse emissions and cumulative emissions scenarios described below (Figures 1 and 2).

Global mean surface temperature responses were determined by differencing the set of ensemble runs for each of these scenarios from the base SSP1-2.6 emissions pathway. SSP1-2.6 was used as it is consistent with the Paris Agreement target of limiting warming to well-below 2C by 2100, but the results should not be particularly sensitive to the choice of SSP in any deep mitigation pathway where large amounts of CDR deployment are likely to occur. In each scenario we examined baseline emissions, CDR only, and CDR plus baseline emissions temperature outcomes (Figure 3).

In addition, we provided simulations of global mean surface temperature evolution over the 2025-2200 period in SSP1-2.6 under the assumption that each pulse of annual CDR deployed in that pathway was subject to each of the four lag scenarios explored (Figure 4).

Scenario details

We examine two types of scenarios: (1) cumulative-pulse experiments, which integrate annual pulses of emissions and removals over a 20-year period; and (2) global-scale deployment experiments, which incorporate lagged CDR into a multidecadal mitigation pathway. Together, these scenarios quantify the effects of using lagged CDR at the scale of an offsetting project and at the scale of global CDR deployment, respectively.

The cumulative pulse experiments convolved 20 years of annual pulses for the physical delay, counterfactual delay, and accelerated emissions scenarios. For upfront embodied emissions, we assume 3 $GtCO_2$ upfront embodied emissions in year zero, followed by -1.15 $GtCO_2$ annual removals for 20 years (where the additional 0.15 $GtCO_2$ removal over 20 years reflects the amortization of the 3 $GtCO_2$ upfront emissions).

To quantify the impact of lagged CDR under continuous global deployment, we split the net SSP1-2.6 CO_2 emissions into its gross emissions and CDR components (Figure S2a), and then applied each lag archetype to the CDR time series (Figure S2b). We defined the CDR time series as the mean CDR across integrated assessment scenarios having ≥ 50% probability of limiting warming to 1.5 °C by 2100 (from Fuhrman et al., 2024; green line in Figure S2a) and then held deployment constant at 2100 levels (~10 Gt/yr) in subsequent years. We applied lag archetypes by assuming that the volume of CDR represented in the original time series represented the timing of the intervention (forecasting to its ultimate drawdown effect), rather than the volume of drawdown in that year.

Data Availability

Input and output data for our model simulations are available at https://github.com/carbonplan/temporal-lags.

Code Availability

The FaIR model source code is available at https://github.com/OMS-NetZero/FAIR. The code to reproduce our analysis is available at https://github.com/carbonplan/temporal-lags.

Author Contributions

B.C., F.C., Z.H., K.S.H., K.F., and C.M.Z. contributed to study conceptualization, analysis, writing, and editing of the manuscript. C.B.F. contributed to conceptualization and editing. Z.H. and C.M.Z. conducted the FaIR analysis.

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Declaration of Interests

The views expressed in this paper are those of the authors and do not necessarily reflect the views or positions of any organization with which they are affiliated. B.C. is employed by Carbon Direct Inc. K.S.H is employed by Amazon.com, Inc. Z.H. helps manage Frontier, an advanced market commitment on the part of corporate carbon removal buyers.

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Supplementary material

Consistent temporal accounting supports credible CDR use

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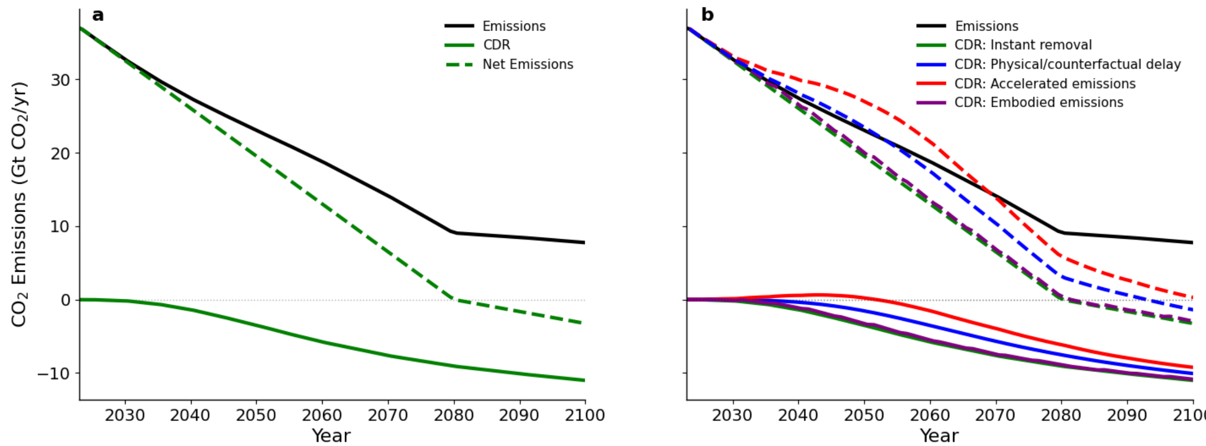

Figure S1: Emissions and CDR pathways used to model the impact of temporal lags under global-scale deployment. We split net emissions in SSP1-2.6 into its gross emissions and CDR components (a) and then applied each lag archetype to the CDR time series (b). For the physical/counterfactual delay and accelerated emissions archetypes, we do this by convolving the CDR time series (green line in a) with each lag archetype's single-pulse emission and removal profile (Figure 1). For the upfront embodied emissions case, we use the example project-level emissions and removal profile discussed in the main text, which applies a one-time construction pulse of 3 $GtCO_2$ followed by 1.15 $GtCO_2\ yr^{-1}$ of removals, approximating the 20-yr amortization of capital emissions in infrastructure-intensive pathways such as DAC. We apply the project-level profile at the global scale by assuming that every time global CDR deployment levels increase, that marginal increase in capacity requires new project development, so there are upfront emissions in that construction year and then the CDR capacity lasts for 20 years.

	Peak warming	Change in peak warming relative to reference case	Probability of peak warming > 2.0 C	Change in probability of peak warming > 2.0 C relative to reference case

Instant removal (reference case)	2.02 ($\sigma=0.41$)	-	45.2%	-
Physical / counterfactual delay	2.05 ($\sigma=0.42$)	0.032 ($\sigma=0.015$)	47.8%	2.6%
Accelerated emissions	2.08 ($\sigma=0.44$)	0.061 ($\sigma=0.028$)	51.4%	6.2%
Embodied emissions	2.03 ($\sigma=0.41$)	0.005 ($\sigma=0.002$)	45.7%	0.5%

Table S1: Impact of temporal lags on peak warming. Peak warming is calculated based on a 20-year running mean of global mean temperature, relative to the 1850-1900 baseline. Probability of peak warming exceeding 2.0°C is calculated as the percentage of ensemble members with peak warming greater than 2.0°C.