

# IMPROVING CARBON CREDIT MARKETS

## TRANSPARENCY, QUALITY, AND FUNGIBILITY

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### Key takeaways

Carbon credit markets can suffer from quality issues, information asymmetry, and lack of fungibility:

- Credits often fail to provide claimed environmental benefits
- Buyers and observers struggle to distinguish good credits from bad
- Credits that trade as identical instruments often represent substantially different outcomes

To address these challenges, policymakers should:

- Expand transparency frameworks to require public disclosure of project and transaction data
- Support a system of systemic ex-post evaluation to verify credit issuances
- Support the adoption of a portfolio approach to balance risks and benefits in credit procurement

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## DISCLOSURES

This paper is part of a workstream made possible by support from Bloomberg Philanthropies. The views expressed in this report are those of its authors and do not represent the views of Bloomberg Philanthropies, their officers, or employees.

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# Introduction

A project-based carbon credit is a tradable certificate representing the removal or avoidance of one metric ton of CO<sub>2</sub> (or equivalent greenhouse gas) emissions achieved by a specific project. Project-based carbon credit markets are designed to reduce the cost of addressing climate change by channeling capital to efficient mitigation opportunities. They are used by dozens of governments and thousands of companies worldwide, and have helped deliver hundreds of millions of dollars to mitigation projects in developing countries, financed the protection of valuable ecosystems, and created tangible benefits for local communities (Wetterberg et al. 2025; Forest Trends' Ecosystem Marketplace 2025; Floess et al. 2023; Wunder et al. 2024). Well-functioning carbon credit markets can complement government carbon pricing policies and enable ambitious voluntary action in sectors where direct regulation isn't feasible.

However, the integrity of carbon credits is frequently called into question. For carbon markets to work, carbon credits should consistently deliver the mitigation outcomes they claim to represent. Unfortunately, an extensive body of research documents that in many instances—across both compliance (i.e., required and regulated by law) and voluntary markets—projects fail to meet basic quality criteria for environmental integrity and accurate estimation (Sanders-DeMott et al. 2025; Gill-Wiehl et al. 2024; West et al. 2023). One recent study suggests that fewer than 16% of credits issued to investigated projects across the market represented real emissions impacts (Probst et al. 2024). As a consequence, credits purporting to represent equivalent one ton mitigation outcomes often vary dramatically in their true impact, and many fail to deliver what they promise.

Integrity issues are worsened by information asymmetry between buyers and sellers. Buyers often lack the information and expertise necessary to differentiate

high-quality and low-quality credits. This can cause reputational and legal damage for buyers when outside assessments reveal integrity shortfalls after credits have already been used. Information asymmetry also worsens public distrust of carbon markets and perpetuates perceptions of carbon credits as a tool for “greenwashing.”

For carbon credit markets to operate efficiently—with high trust and environmental integrity—information on credit quality should be readily available, and credits that claim to represent the same outcomes should be fungible. Carbon credits are most commonly used to offset emissions in regulatory systems or support corporate “carbon neutrality” or “net zero” claims (Broekhoff et al. 2026a). When credits are used to make equivalent claims, they should represent equivalent outcomes. When identical offsetting claims are supported by credits that fundamentally vary in their integrity, it undermines the validity of the claims. The same issue arises when carbon credits are allowed to substitute for emissions reductions in regulatory systems. Integrity and fungibility go hand-in-hand; credits should accurately represent claimed outcomes, and they should be interchangeable when used to support equivalent offsetting claims.

Policy intervention to address quality shortfalls, incomplete information, and lack of fungibility would help carbon credit markets operate more credibly and effectively. One key challenge is how to ensure the integrity of emissions impact without sacrificing the diversity of projects in the market. This report will lay out policy options to address this issue, including enhanced transparency requirements to allow for better assessment of credit quality, systemic ex-post evaluation to enable fungibility, and a portfolio approach for buyers to balance underlying risk.

# Why existing credits aren't fungible

Nearly every carbon credit on the market claims to represent a mitigation outcome equivalent to avoiding or removing one ton of CO<sub>2</sub>e emissions. Yet credits are far from homogeneous. The market encompasses projects offering different types of mitigation activities, risks, and co-benefits. Even among projects deploying the same methodologies, crediting based on alternative counterfactual baselines creates unavoidable uncertainty in emissions impact (Cross and Hepburn 2026). These challenges are exacerbated by information asymmetry between project developers, crediting programs, and credit buyers.

## DIVERSIFIED MARKET

Carbon credit markets harbor a diversity of project types, including renewable energy installation, nature-based projects like avoided deforestation, household projects like clean cookstove distribution, and engineered removals like biochar production, among many others (Broekhoff et al. 2024). In addition to delivering climate mitigation, many carbon credit projects provide substantial co-benefits, including the protection of biodiversity, the provision of sustainable livelihoods, and reductions in particulate matter pollution. Co-benefits are a substantial selling point for project types like forestry and community projects that might otherwise face challenges with proving additionality, permanence, or accurate estimation (Lou et al. 2023). For example, many projects are undertaken in developing countries because they are desirable to buyers interested in facilitating international climate finance transfers (even though climate impact does not vary based on where emissions avoidance or removal occurs).

The ability of carbon markets to fund mitigation across a diversity of sectors, locations, and communities is a desirable attribute, yet it complicates efforts to ensure climate impacts are accurately assessed. Projects deliver mitigation in vastly different ways and can carry varying levels of risk, yet offsetting claims treat them as functionally interchangeable. The diagram in Figure 1 shows how credits from different project scopes can vary across their offset achievement ratio (i.e., their

likelihood of achieving claimed impacts), durability, affordability (i.e., inverse of market price), and co-benefit provision. For example, credits from household and community projects can provide substantial co-benefits and be cheap to procure, but they tend to underperform on offset achievement and durability.

Although there are instances of project developers exaggerating benefits (Lehmann 2019; Pickering et al. 2017), transparent variability in co-benefit provision is generally beneficial for the market. It allows buyers to prioritize the credits that best match their objectives—whether simply financing mitigation for the lowest possible cost or advancing other sustainable development goals. Maintaining a diverse market of projects allows buyers to meet their diverse goals. Similarly, variance in durability or uncertainty in achieving claimed outcomes is not inherently negative, so long as it is transparent. If risk is transparent, buyers can avoid or manage it. When risk is opaque, it cannot be managed effectively, deterring market participation and exacerbating distrust.

## HETEROGENEOUS QUALITY

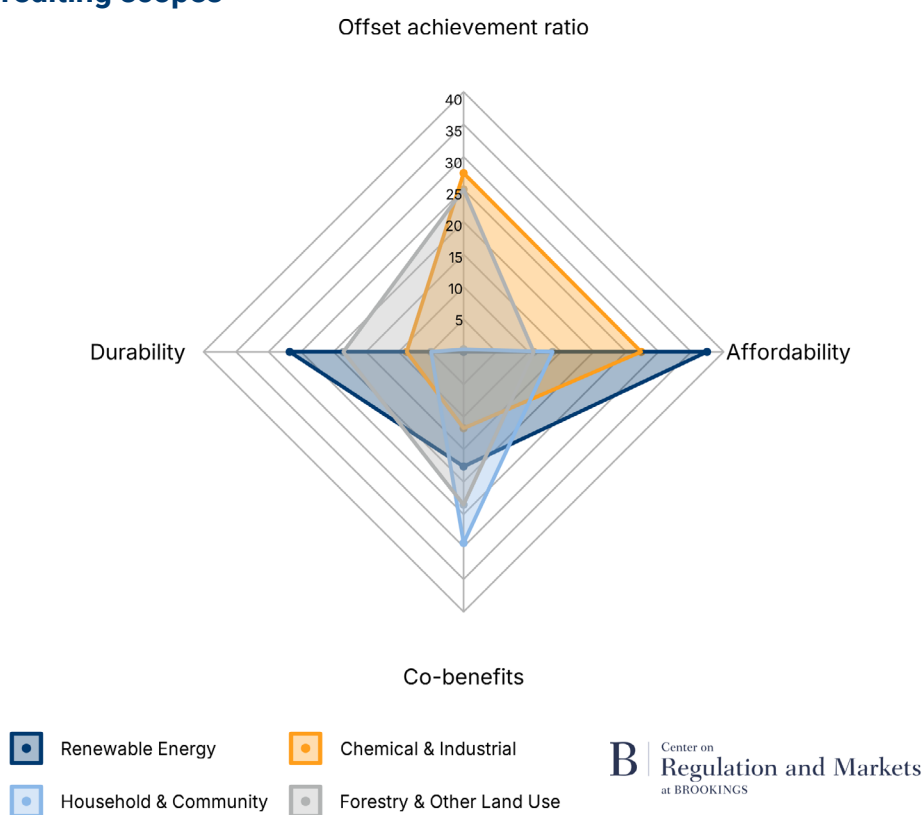
In today's market, carbon credit quality is shaped primarily by certification standards. The proliferation of standards across dozens of governmental and independent crediting programs makes comparing quality across programs difficult. Adding to this is that crediting programs face a stringency and participation tradeoff: programs attempting to maximize participation by project developers may implement lax rules, while programs with stricter rules may fail to receive participation (Delacote et al. 2024). Often, programs design standards to enable participation by specific constituencies at the expense of robust quality safeguards (Broekhoff et al. 2026a). In many cases, programs allow methodologies to be proposed and submitted by project proponents, leading to methodologies which are favorable to project developers' interests (Cabiyo and Field 2025). In other cases, third-party auditors are paid by project developers, leading to assessments which may be biased in developers' favor (Giles and Coglianese 2025).

## BOX 1

Broekhoff et al. (2026b) “Integrating North American carbon credit markets: Prospects and recommendations” discusses options to resolve fragmented and inadequate standards across crediting programs. Recommendations include developing a government-administered voluntary crediting program or establishing accreditation standards for independent crediting programs, crediting methodologies, project auditors, and rating services.

FIGURE 1

### Kiviat diagram of environmental integrity and diversity dimensions across carbon crediting scopes



**NOTES:** This figure is constructed across four dimensions: additionality (proxied by the Offset Achievement Ratio from Probst et al., 2024), durability (average intervention period, same source), co-benefits (number of SDGs potentially fulfilled out of 17, UN data), and affordability (inverse of 2024 average market price, Forest Trends’ Ecosystem Marketplace). To reflect the substantial uncertainty inherent in carbon credit evaluation, dimensions are scaled to a conservative 0–40 range rather than the conventional 0–100. Only project categories with sufficient and consistent data across all four dimensions were retained, to illustrate their heterogeneity.

Even when projects are developed according to stringent rules, there can still be substantial uncertainty in their true emissions impact. This is because projects are credited based on counterfactual baseline scenarios—i.e., scenarios estimating the emissions that would have occurred without the incentive to sell carbon credits. Projects are issued credits based on the emissions they avoid or remove relative to these hypothetical baselines. However, by virtue of being hypothetical, baselines are fundamentally uncertain, creating uncertainty in credit issuances (Cross and Hepburn 2026).

Relying on baselines can create adverse selection. This happens because credit sales are most attractive for projects that would happen anyway (i.e., are non-additional) or that have inflated baselines (Millard-Ball 2013; Bushnell 2011; Montero 1999). These projects can easily claim emissions reductions, so they are more likely to enter credit markets unless strict rules screen them out.

In addition to baseline uncertainty, some types of projects can carry other inherent risks. Removal projects have reversal risk that the carbon they store will be re-emitted in the future. The degree of reversal risk varies greatly from project to project. Nature-based removals, which store carbon in ecosystems like forests and wetlands, are more prone to reversal risk than some types of engineered removals, which store carbon geologically. Ecosystem carbon can be easily released by fire, disease, or man-made disruptions. Storage duration and monitoring periods for removals also vary. Some projects guarantee storage for periods as short as five years; others promise storage indefinitely (FAO 2024; Michaelowa et al. 2025).

Avoided emissions projects lack reversal risk, but carry other types of risk, such as leakage risk that avoided emissions in one area will simply be shifted elsewhere, e.g., if avoiding deforestation in one location leads to increased deforestation nearby (West et al., 2025). Monitoring for leakage is notoriously difficult and quantifying leakage events causally is fundamentally uncertain (Cross and Hepburn 2026). As with reversal risk, leakage risk varies dramatically among project types.

In some cases, the quantity of credits issued is adjusted based on risk. For example, most removal projects

contribute a percentage of their credits to “buffer pools” designed as insurance to compensate for reversal risk. Some projects (only around 25% according to one study) also have projected leakage deducted from their crediting volumes (Cross and Hepburn 2026). Even when present, deductions to credit issuances often fail to fully capture underlying risk and uncertainty. Research indicates that buffer pool contributions across multiple crediting programs are too small to adequately capture long-term reversal risk (Anderegg et al. 2025; Badgley et al. 2022). Fixed deduction values can also obscure project-level heterogeneity in risk.

## INFORMATION ASYMMETRY

While all markets harbor some low-quality products, the issue is pronounced in carbon credit markets because buyers and observers often lack the information necessary to determine credit quality. Unlike physical goods that can be inspected prior to consumption, carbon credits serve as certificates attesting to past events. Rather than constituting a claim on a real-world asset, a carbon credit represents the right to make a claim about a ton of CO<sub>2</sub>e emissions avoided or removed from the atmosphere. This makes carbon credits fundamentally quite different than more traditional assets and the markets they trade in (Roston 2026). In place of assessing projects themselves, which requires substantial expertise, buyers often rely on crediting programs or third-party verifiers to screen out low-quality credits. Furthermore, credits do not reveal additional information about their quality after being purchased and retired, reducing the ability for buyers to hold sellers and verifiers accountable.

These imbalances are not unique to carbon credit markets, but instead apply to a category of products that economists call “credence goods.” These are goods for which evaluation is highly complex and quality is not readily revealed after purchase (Cross and Hepburn 2026). Other common credence goods include medical services (e.g., it is hard to assess if a screening, prescription, or procedure was necessary) and financial products (e.g., advice from an investment advisor that is hard to evaluate) (Brown and Minor 2012). With credence goods, standard market mechanisms like reputation and competition are often insufficient to police quality (Dulleck et al. 2011). In these markets, regula-

tion is often necessary to address persistent informational asymmetry. This is why the U.S. has agencies like the Food and Drug Administration (FDA) to assess medications, medical licensing boards to evaluate physicians, and the Securities and Exchange Commission (SEC) to make sure risks of financial products are fully disclosed (FDA 2023; FSMB n.d.; SEC 2023).

Unlike other credence goods, carbon credits sold in the voluntary market lack centralized regulatory oversight. Instead, credits are issued by a wide range of governmental and independent crediting programs, all of which vary in the standards they apply. A handful of independent pseudo-regulatory bodies assess quality across voluntary crediting programs. The most prominent of these is the Integrity Council for the Voluntary Carbon Market (ICVCM) which labels individual methodologies as high-quality (Broekhoff et al. 2026a). However, because of fundamental uncertainty around counterfactual baselines and additionality, even credits issued by the same programs and produced using the same methodologies can differ in quality (Trexler et al. 2006). For example, high-quality projects can sometimes be registered under lenient methodologies and vice versa (West et al. 2020). This creates variation in quality that is often difficult to fully assess.

Credits produced using methodologies labeled as high-quality by the ICVCM command significant price-premiums (Berends et al. 2025). This is a positive sign; however, methodology-level certifications can still hide variability in the quality of individual projects registered under the same methodology. Multiple for-profit independent rating agencies exist to provide project-level assessments for individual buyers, but these ratings rely on proprietary methodologies and are often not made publicly available (Wawrzynowicz et al. 2023).

Lack of public availability makes it difficult for consumers to verify carbon-neutral and net-zero claims.

Demand dynamics reflect the difficulty of differentiating good credits from bad: credits from individual projects rated as higher quality still often fail to command higher prices (Trencher et al. 2024; Berends et al. 2025). Although this has improved in the past two years, prices for the lowest-quality credits can still exceed prices for the highest-quality (Berends et al. 2025). Information asymmetry also makes secondary trading between market participants more difficult. When credit quality cannot be readily ascertained, willingness to sell on the secondary market is simply interpreted as a signal that the seller deems the credit to be of insufficient quality (Roston 2026). In typical markets, secondary trading enables price discovery and improves efficiency, but carbon credit markets lack this feature. If left unchecked, information asymmetry can create a “Market for Lemons” where buyers’ inability to distinguish good credits from bad leads developers of high-quality credits (which are often more expensive to produce) to exit the market altogether (Millard-Ball 2013; Bushnell 2011; Akerlof 1970).

Some uncertainty in credit quality is unavoidable, but today’s lack of transparency about risk can create a dysfunctional market. If risk and uncertainty is clearly disclosed, markets can function better and support differentiated products. The answer is not to exclude projects that involve uncertainty. Many important mitigation efforts—especially nature-based, household, and community projects—carry higher integrity risks, but also deliver valuable co-benefits. With better rules, clearer risk disclosure, and improved measurement, these projects can remain in the market while buyers manage portfolios to meet their goals.

## BOX 2

Broekhoff et al. (2026a) “Project-based Carbon Credit Markets: Overview, Issues, and Future Directions” provides a more comprehensive overview of crediting programs and emerging governance bodies. The authors discuss how carbon credits are generated and used and provide detailed assessment of persistent quality challenges.

# Policy solutions

Implementing the policy options outlined in this brief requires a credible governance architecture. Such a framework should, at a minimum, include mandatory disclosure, operationalize a systematic ex-post evaluation mechanism, and ensure transparent dissemination of verified outcomes to market participants. In the U.S. this will likely require an act of Congress to designate any agency to regulate the voluntary carbon market. For international carbon markets, the Article 6.4 Supervisory Body represents the most legitimate institution, yet it currently lacks a sufficient mandate to discharge these functions.

## IMPROVING TRANSPARENCY REQUIREMENTS

Addressing the information asymmetry described above requires stronger transparency on the whole carbon credit value chain. Although some basic information about carbon credit projects is publicly available, it remains incomplete, inconsistent, and often unreliable. For instance, the geographic boundaries of many projects may be either missing, incorrect, or inconsistent with the areas they claim to cover (Delacote et al. 2024). Information about the reference areas used to calculate baselines is frequently absent, making it nearly impossible to assess whether projects are delivering real climate benefits. Impacts on local communities and ecosystems are even harder to evaluate, as data on the number of people affected, the compensation they receive, or the effects on biodiversity and water management are rarely, if ever, disclosed (Delacote et al. 2024). These gaps make independent scientific assessment of project quality extremely difficult, and in some cases entirely impossible.

### BOX 3

See Shortell et al. (2026) “Which Agency Should Regulate Carbon Credits” for a full analysis of what U.S. agency would be best to regulate the voluntary carbon market. The authors conclude based on mission alignment and technical capacity that either the Environmental Protection Agency or Department of Energy would be a well-suited regulator.

In particular, transaction data in the voluntary carbon market are notably scarce. Voluntary carbon credits are traded privately, and there is no legal obligation to report prices or reveal who is buying and selling, so this information is almost entirely unavailable to the public.<sup>1</sup> The little data that do exist consists of partial and aggregated snapshots derived from voluntary surveys, personal contacts, and proprietary datasets (Forest Trends’ Ecosystem Marketplace 2025; Berends et al. 2025). The situation is made worse by the long chain of intermediaries in the voluntary market, such as brokers, consultants, developers, and certifiers who sit between the projects generating credits and the companies buying them. Tracing most transactions to specific projects is nearly impossible. How revenues are distributed along this chain remains completely hidden from public view. Companies tend to invoke commercial confidentiality to avoid disclosing what they pay for credits or how they use them, and even major investigative journalism exposés have not prompted greater openness from the private sector.<sup>2</sup> The result is a market in which almost nothing can be independently verified, neither for primary nor secondary trading.

Greater transparency is a precondition for carbon credit markets to function properly and regain public trust. Being open about transactions would help prevent fraud and protect both investors and consumers. It would also allow companies with genuinely strong climate strategies to demonstrate the real impact of their investments, rather than simply making claims that cannot be checked by any outsider. Without such transparency, suspicions of greenwashing will continue to grow, and the market risks becoming dominated by low-quality, ineffective credits that drive out the good ones.

Transparency would also deliver important benefits for researchers, policymakers, and affected communities. Access to project and transaction data would allow independent experts to assess whether projects are actually avoiding or removing emissions, and whether the types of credits that sell well are the ones that deliver the greatest social and environmental value. This kind of analysis is currently impossible to conduct rigorously, and its absence is a serious obstacle to evidence-based policy. For communities living near carbon credit projects, most frequently in developing countries, better information about how revenues are distributed would help address the significant power imbalances that currently exist between local populations and the developers and companies that profit from their land. Many projects explicitly promise benefits for local livelihoods as well as for the climate; without transparency, there is no way to verify whether those promises are being kept.

One possibility is strengthening transparency within the existing system of voluntary certification. Some efforts are already underway, including the creation of registries and frameworks designed to track credits through their full life cycle, from project development to retirement. For example, the World Bank's Climate Action Data (CAD) Trust is developing a unified metadata platform to aggregate project data from multiple independent and national registries. However, the CAD Trust has thus far only integrated with a handful of registries and does not track transaction data (Climate Action Data Trust n.d.).

It is unlikely that voluntary initiatives alone will be sufficient to deliver necessary levels of transparency. Voluntary standards that try to attract broad participation tend to set low requirements, while stricter standards struggle to gain widespread uptake. The proliferation of competing certification schemes can add to the confusion, leaving buyers unable to reliably distinguish high-quality credits from poor ones. There is also a deeper and more troubling problem: evidence suggests that many buyers do not actually prioritize the environmental integrity of the credits they purchase, focusing instead on the number of co-benefits a project claims to deliver, such as biodiversity protection or community development, rather than its verified climate impact (Trencher et al. 2024). If buyers are not demanding en-

vironmental integrity, market incentives to supply it will be correspondingly weak.

For all these reasons, stronger regulation is likely the most reliable route to meaningful and lasting transparency. The market may be voluntary in name, but its role in supporting consumer-facing claims and addressing climate change justifies public intervention. Some encouraging signs do exist. Under the previous presidential administration, U.S. federal regulators advanced a handful of initiatives to tackle environmental fraud in carbon markets, although these efforts have since been halted (Broekhoff et al. 2026b). At the state level, the California Voluntary Carbon Market Disclosures Act, enacted into law in 2023, has introduced mandatory disclosure requirements for companies operating in the state<sup>3</sup>. Yet none of these measures require the disclosure of actual transaction data, the most critical piece of information for assessing whether the market is working as it should.

Making transparency a legal requirement for participation in the carbon market and incorporating carbon credit disclosure into financial and sustainability reporting frameworks is thus a path forward to greater transparency. Useful models already exist in other sectors. Federal healthcare regulations require hospitals and health insurers to publicly disclose negotiated rates and pricing data, with the explicit goal of reducing information asymmetries and promoting competition (Centers for Medicare & Medicaid Services 2020). In the EU, corporate sustainability reporting requirements, such as those recently introduced under the European Sustainability Reporting Standard<sup>4</sup> and the Corporate Sustainability Reporting Directive,<sup>5</sup> are beginning to oblige companies to disclose their use of carbon credits. However, these reporting requirements have been paired with an EU directive that bans the use of carbon credits in climate neutrality claims.<sup>6</sup>

Rather than outright preventing carbon credits from being used in offsetting claims, policymakers in the U.S. should introduce strong transparency requirements so that markets can operate with trust and claims can be verified. Transparency requirements should be extended to cover transaction-level data and harmonized across jurisdictions so that companies cannot simply

operate in the least transparent market available to them. Mandatory public disclosures should include:

- exact project location and boundaries
- project methodology and an explicit proposed counterfactual
- information about value sharing with local communities involved
- price paid by buyers
- ex-post verification of credit issuance (discussed below)

In the U.S., transparency requirements for the voluntary carbon market can be advanced under existing consumer protection frameworks. The Federal Trade Commission (FTC) is tasked with regulating unfair or deceptive advertising practices and already provides guidance on environmental marketing claims.<sup>7</sup> This guidance could potentially be expanded to require claims based on carbon credits to be substantiated with information on price and credit origin.

## SYSTEMATIC EX-POST EVALUATION

Heterogeneous quality in terms of environmental integrity, coupled with information asymmetry, requires strong effort to improve evaluation methods. Indeed, the available scientific evidence shows that carbon credits do not deliver the emissions impacts they claim in a consistent manner and that the ex-ante methods currently used to certify credits are not reliable enough to prevent widespread overcrediting (Tang et al. 2025; Probst et al. 2024). Shifting to more rigorous, science-based evaluation methods would help improve the accuracy of credit issuances and restore trust in carbon credit markets. However, applying these methods is far from straightforward, with three main challenges that need to be overcome (Delacote et al. 2025).

The first one is an evaluation challenge. The best way to assess whether a carbon project is genuinely reducing emissions is to compare what happened in the project area to a counterfactual. In other words, the right counterfactual has to be defined. The gold standard for this kind of assessment is the randomized controlled trial (RCT). Yet, applying RCTs at scale in carbon markets would be enormously costly and logistically complex.

A more feasible alternative is to use quasi-experimental methods, which draw on statistical techniques to construct a credible comparison without the need for a randomly assigned control group. These techniques are widely used in scientific research and were recognized with a Nobel Prize in 2021 (Angrist and Pischke 2010; Royal Swedish Academy of Sciences 2021). Multiple studies have applied quasi-experimental methods to assess overcrediting and additionality in carbon projects (e.g., Calel et al. 2025; Gill-Wiehl et al. 2024; West et al. 2023; among many others). These approaches are less disruptive and less expensive than RCTs, but they come with their own challenges. No single method works well across all project types, and carbon markets cover an extraordinarily diverse range of activities, from avoiding deforestation and improving cookstoves to capturing industrial emissions and developing renewable energy. Each context requires different data and different analytical choices, and getting those choices wrong can lead to biased conclusions. Data availability is also a serious constraint: while satellite imagery has made it relatively straightforward to monitor changes in forest cover, tracking emissions in the energy or industrial sectors, which together account for the majority of carbon credits issued, remains far more difficult. Addressing the risk of carbon leakage (when a project simply displaces emissions to nearby areas rather than eliminating them altogether) adds yet another layer of complexity.

The second challenge concerns credit supply. Beyond the methodological challenges, shifting to ex-post evaluation, that is, assessing project outcomes after the fact rather than predicting them in advance, creates significant financial risks for project developers and the communities that depend on carbon revenue. Under the current system, developers receive credits based on projected future emissions reductions, giving them a degree of financial predictability. If credits were only issued after independent verification of actual outcomes, developers would face much greater uncertainty about their revenues, potentially making it harder to finance projects in the first place. For local communities in developing countries, who often rely on carbon payments for their livelihoods, this uncertainty could be particularly damaging. At the same time, the current system simply transfers the risk of inaccurate projections to

society at large, because credits that overstate their impact allow companies to claim mitigation that has not actually occurred.

Eventually, the third challenge concerns demand. Even if high-quality, rigorously evaluated credits were available, there still needs to be an incentive structure for buyers to reward quality and to pay a premium for quality. Evidence from recent years suggests that the majority of large companies purchasing carbon offsets are buying low-quality, high-risk credits that are unlikely to deliver meaningful climate benefits (Trencher et al. 2024). Whether this reflects a genuine preference for cheaper credits, or simply a lack of good alternatives, is difficult to say.

Addressing these challenges requires simultaneous action on several fronts. On the scientific side, the research community needs to converge on a set of agreed, rigorous methods for evaluating different types of carbon projects. No single method will be perfect for every context, but establishing clear standards, backed by peer-reviewed evidence and compiled in a public reference document, would provide a credible foundation. Although RCTs are too costly to be implemented on a systemic basis for carbon credits evaluation, a small number of RCTs, conducted alongside quasi-experimental evaluations on the same projects, could help calibrate the accuracy of the less costly methods and build confidence in their results. RCTs have already been conducted on non-carbon credit clean cookstove and forestry interventions providing a real-world template to build from (Hanna et al. 2016; Jayachandran et al. 2017).

On the organizational side, a fundamental gap exists at the heart of the voluntary carbon market: no public institution currently verifies the quality of carbon credits at the individual project level. Addressing this requires a credible institutional framework grounded in independence, scientific rigor, and transparency. Independence is essential to ensure that project evaluations are free from commercial conflicts of interest. Scientific rigor requires that evaluations follow up-to-date, peer-validated methods consistently applied across project types. Transparency ensures that findings can be scrutinized, challenged, and improved over time.

A proven model for this kind of organization already exists in a related field. The Abdul Latif Jameel Poverty Action Lab — known as J-PAL — was founded at MIT in 2003 and has become the world’s leading organization for the rigorous, evidence-based evaluation of poverty-reduction programs. Operating through a global network of over 1,000 university-based researchers, it has demonstrated that independent, scientifically credible evaluation can be institutionalized, scaled, and sustained over time (The Abdul Latif Jameel Poverty Action Lab n.d.). A similar organization dedicated to carbon credit evaluation could be established. If it were to rely primarily on quasi-experimental methods rather than full randomized controlled trials, it would not need to replicate J-PAL’s full scope or cost structure and it could operate with a leaner structure and significantly lower implementation costs, while still delivering credible and independent results. Funding could be drawn from a combination of public sources — foundations and governments — and private ones, including carbon credit project developers and companies seeking to use credits as part of verified corporate climate strategies. Such an organization would apply agreed methods consistently, make its findings publicly available, and provide a trusted signal of credit quality that the market currently lacks.

Perhaps most importantly, the rules of the game need to change. The regulatory environment would need to create the right incentives: specifically, making independent ex-post evaluation a prerequisite for credits to count as offsets toward corporate climate commitments or compliance market obligations. With appropriate incentives in place, the demand for rigorous evaluations would be strong, and the supply could be delivered at modest cost relative to the scale of the market. Credits that do not meet this standard could still be sold as voluntary mitigation contributions, but would not be recognized as offsets against a company’s emissions targets.<sup>8</sup> This distinction between a contribution and a fungible carbon credit may seem technical, but it is fundamental: it is the difference between recognizing good intentions and verifying real results.

To make this work financially viable, risk-sharing mechanisms are essential. Project developers and communities need protection against the possibility that a project,

despite genuine efforts, fails to generate the expected emissions reductions. One approach is for developers to pool risk across multiple projects in different locations, so that a poor outcome in one place can be offset by stronger results elsewhere. Another is for buyers to make upfront payments that cover basic project costs, with additional payments linked to verified outcomes. Many buyers already include upfront payments in credit purchase agreements (Broekhoff et al. 2024). These arrangements give developers financial security while maintaining strong incentives for performance.

## PORTFOLIO APPROACH

Another issue is how to address environmental integrity concerns while managing to keep the diversified nature of carbon credit markets. Price is important for buyers, but in carbon markets it often fails to reflect environmental integrity (Lee 2026). This issue illustrates a broader problem: value in carbon markets is difficult to capture, given the information asymmetry of the market and its multidimensional nature. Individual quality ratings are a partial remedy, but they assess assets in isolation, and that is precisely their limit.

As Nobel Laureate Harry Markowitz demonstrated, value in portfolio management comes not from selecting individual assets in isolation, but from understanding how they interact. In his Mean-Variance Efficient Frontier model (Markowitz 1952), he shows that for any given level of portfolio risk, measured as the variance of returns, there exists a combination of assets that maximizes expected return, and vice versa. The set of all such optimal combinations traces the efficient frontier: a curve in risk-return space that no individual asset can reach alone, but that becomes accessible through diversification. The translation to carbon markets requires only one adaptation: replacing the financial axes with ones suited to the asset class. The axes are no longer financial risk and return, but environmental integrity per dollar, capturing the probabilistic reliability of a credit's climate impact, and services rendered per dollar, capturing the breadth of value a credit delivers beyond carbon alone and turning cost-per-ton into cost-per-unit-of-frontier-position.

Carbon credits are widely used in net-zero strategies to manage the risks and uncertainties inherent in reducing

emissions. Applying a portfolio-based framework to the credits themselves is therefore a natural extension, one that moves beyond asset-by-asset assessments toward a multidimensional structure better suited to the complexity and heterogeneity of carbon markets. The goal is not to replace existing practices, but to bring rigorous quantification and transparency to choices that buyers are already making, often implicitly, along two principal axes: environmental integrity per dollar and services rendered per dollar.

The environmental integrity per dollar axis captures, for a given price paid, the risk profile of a credit across three core metrics: additionality, leakage, and exposure to reversals. Together, these reflect the inherently probabilistic and time-varying nature of carbon sequestration and emission avoidance, dimensions that a single binary rating fundamentally fails to capture. The evidence suggests that these metrics are increasingly measurable. On reversals, the Carbon at Risk (CaR) framework offers a direct analogue to Value at Risk in finance: rather than classifying credits as simply permanent or non-permanent, it expresses carbon removal outcomes as a probability distribution over a given time horizon; for instance, that a project will retain at least 68% of targeted removals in 95% of future scenarios (Lee et al. 2025). This enables meaningful comparisons across heterogeneous removal approaches and supports portfolio-level risk management. On additionality, Probst et al. (2024) develop the Offset Achievement Ratio (OAR), which quantifies achieved emission reductions relative to issued credits across project types, providing a standardized, ex-post measure of whether credits delivered what they promised. Leakage remains the most methodologically challenging dimension, but partial equilibrium trade models have provided tractable approaches, particularly in the forestry sector (Murray et al. 2004). None of these tools are universal or perfect. But taken together, they establish that probabilistic, evidence-based scoring of environmental integrity is not a theoretical ambition, but an emerging practice. Expressed relative to price paid, these scores transform an abstract quality assessment into a directly comparable measure of climate value per dollar spent.

The services rendered per dollar axis asks, for a given price paid, how much combined value the co-benefits and timeline profile a credit delivers. Co-benefits en-

compass the broader positive externalities a project generates: e.g., biodiversity preservation, water quality improvement, and socio-economic resilience for local communities. Quantifying these impacts is methodologically uneven across project types. Biodiversity effects are most tractable for land-use and ecosystem-based projects (forestry, wetland restoration, or improved land management) where tools such as the LIFE metric (Land-cover change Impacts on Future Extinctions) can estimate the likely change in species extinction risk attributable to a project (Eyres et al. 2025). For other project categories, such as engineered removals or energy-efficiency interventions, biodiversity impacts are typically lower or indirect, and co-benefit assessment shifts toward other dimensions: air quality improvements, energy access, or local employment. Any practical implementation of a co-benefit score must therefore be project-type-sensitive, applying relevant sub-metrics rather than a single universal measure.

Timeline considerations capture when a given credit is most climatically relevant; accounting for permanence horizons, contributions to long-term temperature stabilization, and the potential to reduce the likelihood of tipping points. Drawing on an integrated climate-economic framework, Groom and Venmans (2025) show that temporary removals should not be systematically discounted relative to permanent ones: under the right conditions of timing and repetition, they can deliver equivalent climate value, and may even generate lasting effects by reducing the probability of crossing critical thresholds. This reframes the portfolio question away from a simple permanent-versus-temporary hierarchy, toward a more nuanced assessment of how credits are sequenced relative to a buyer's decarbonization trajectory. Expressed relative to price paid per ton, scores across these three dimensions make otherwise incommensurable projects directly comparable, surfacing tradeoffs that per-ton price alone cannot reveal.

Each project would receive a score along each of these axes, enabling systematic comparison across heterogeneous credit types. One mathematical design of such a framework, explicitly inspired by Markowitz portfolio theory, is developed by Lin and Qi (2025).

A concrete illustration: an improved forest management project developed in partnership with local communities might score high on biodiversity co-benefits and short-term climate impact, with moderate additionality risk and some exposure to reversals, yet trade at a relatively modest price per ton, yielding strong services per dollar. Paired with a direct air carbon capture and storage (DACCS) project, lower on biodiversity co-benefits but offering high permanence, minimal leakage, and lower additionality risk, typically at a higher price per ton, the combined portfolio achieves a balance across both axes, and across the price dimension, that neither project delivers individually. The blended cost per ton may sit between the two, but the portfolio's position on the efficient frontier, in terms of environmental integrity per dollar and services rendered per dollar, exceeds what either credit achieves alone. This pairing logic extends across a continuum of diverse project types.

Projects can thus be plotted on an environmental integrity per dollar–services rendered per dollar graph (shown in Figure 2), and portfolios optimized across that space. As in Markowitz's original framework, individual credits occupy the interior of the feasible region: no single project sits on the frontier, because the frontier is a property of mixing, not of individual quality. Some portfolio combinations will be dominated, delivering less integrity or fewer services than an alternative at equal risk, while others will be efficient, tracing the upper boundary of what is achievable given a buyer's budget. The added value of this representation is two-fold and operates at two distinct visual layers. In the first, individual credits appear as fixed points in the integrity per dollar – services rendered per dollar space, immediately making mispricing legible: credits scoring poorly on both axes relative to their cost sit far from the frontier, exposing overpricing relative to their portfolio contribution, while credits with strong scores trading at modest prices cluster near it, signaling undervaluation. This gives buyers a principled, quantitative basis for procurement decisions that today rest largely on intuition or incomplete ratings. Some buyers already invest in careful due diligence; this framework can both sharpen that practice and bring it to scale.

In the second layer, portfolios, weighted combinations of those individual credits, populate the feasible region,

fanning out from the fixed credit anchor points. This is where diversification earns its keep. Just as Markowitz showed that combining assets with partially uncorrelated risk profiles dampens the volatility of financial returns, blending credits across project types, geographies, and permanence horizons reduces the probability that a single invalidation, reversal, or regulatory challenge undermines the integrity of the entire portfolio. Such adverse events are the carbon market equivalent of negative returns, and guarding against them generates what might be termed avoided liability or reputational yield, a form of risk-adjusted value that per-ton price entirely fails to capture. This logic applies not only to buyers diversifying across project types, but also to those with deep expertise concentrated in a single category, whether within their value chain or a familiar geography, since heterogeneity exists within project types as well as across them.

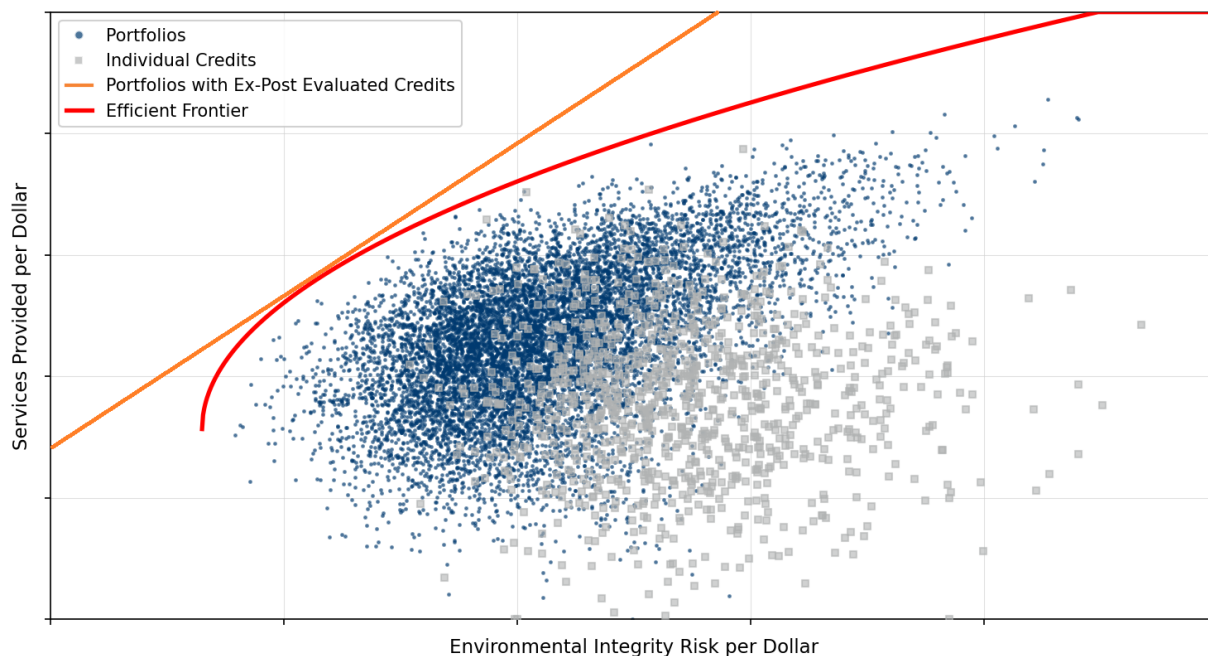
Crucially, diversification in this framework does not truncate the upside. In standard mean-variance theory, diversification reduces variance without sacrificing expected return; here, the axes add a further asymmetry: credits that exceed their expected integrity or services

scores per dollar contribute positively to the portfolio's frontier position, and buyers are not penalized for out-performance. The frontier is not merely an optimization surface: it is the boundary of what becomes accessible only through mixing, and visible only when price is properly accounted for.

Markowitz's framework also admits a risk-free asset: in finance, this is typically a government bond. Applied to carbon credits, its analogue would be a credit that has undergone rigorous, multidimensional ex-post evaluation (verified against the OAR, CaR, and comparable metrics) and whose environmental integrity can therefore be treated as near-certain. This carbon-credit equivalent to a government bond would serve as a standard unit or reference ton of CO<sub>2</sub> removal or avoidance against which all other carbon credits can be evaluated. To make sure that the standard unit is clearly verifiable, it should be generated by a project that has undergone ex-post evaluation with the least possible uncertainty. Just as the inclusion of a risk-free asset transforms the efficient frontier into the Capital Market Line in finance, the inclusion of high-certainty ex-post verified credits reshapes the carbon portfolio frontier,

**FIGURE 2**

### Services provided and environmental integrity of randomly generated portfolios and credits



**SOURCE:** Authors' estimation.

enabling combinations of lower and higher uncertainty credits that would otherwise be suboptimal. Critically, diversification is not merely a financial convenience here: it is structurally built into the framework, because constructing a portfolio across heterogeneous project types is the mechanism by which integrity and services are jointly maximized.

The practical value of this framework lies in what it enables buyers to do. Rather than selecting credits project by project on the basis of price per ton alone, buyers would construct portfolios by defining thresholds of tolerance or preference along the environmental integrity per dollar—services rendered per dollar axis, optimizing not for the cheapest credit, but for the best frontier position achievable within a given budget. This approach can be applied by individual companies, government-supported carbon credit buyers' coalitions, and countries seeking to procure Article 6 credits to meet their Paris Agreement targets. Critically, portfolios must be calibrated to buyers' emissions profiles: the nature of their emissions (scope, gas type, intensity), their geographic footprint, and their supply chain or economic characteristics. A company with a large near-term methane footprint, for example, might prioritize short-duration, nature-based credits with high co-benefits, paired with longer-horizon engineered removals to manage permanence risk, as modelled by Venmans et al. (2025). The blended cost per ton of such a portfolio may be higher than the cheapest available credit, but its position on the efficient frontier would justify the premium in ways that a per-ton price comparison cannot. Another buyer with a geographically concentrated supply chain might prioritize leakage resilience in specific regions, accepting a lower services score in exchange for stronger integrity per dollar.

Portfolios can also be dynamically rebalanced as verification data evolves; new project vintages become available, or the buyer's own emissions profile changes. Dynamic equilibria can thus be reached that no single project could achieve alone: a portfolio can pursue climate aims (temporal, geographic, and qualitative) that are simply impossible at the individual credit scale, and do so in a way that remains transparent, quantifiable,

and anchored to price. Literature on carbon crediting projects has expanded substantially (Lück et al. 2025), and MRV tools are becoming more granular and reliable (Lugato and Migliavacca 2026). The framework proposed here does not require perfect measurement, it requires transparent, science-based, and consistently applied metrics, developed through ongoing dialogue with practitioners and stakeholders across the carbon credit market.

Unified metrics of this kind would also serve as the foundation for broader risk-management mechanisms. Hickey et al. (2025) formalize this logic: drawing on insurance principles, they show how collective buffer pools can absorb reversal risks across heterogeneous removal approaches, from forestry to direct air capture, while preserving the ability to meet long-term temperature stabilization goals at the portfolio level. The Permanence Trust, conceived by the American Forest Foundation, offers a concrete institutional illustration: fees paid at the point of credit sale, calibrated to a standardized reversal risk assessment, fund a shared mechanism that monitors projects and remedies non-permanence events over time, shifting liability away from individual actors and toward a collective structure (Truitt and Riley 2025). With sufficient standardization, carbon credit portfolios could be managed and tranced by risk and co-benefit profile, reducing the opacity that currently deters institutional capital and enabling investors to take calibrated exposure to carbon markets in ways that are currently not possible.

This framework has limits. Capturing the complexity and heterogeneity of carbon credits within unified metrics will inevitably involve simplification, and the dimensions outlined here are not independent: additionality, leakage, reversals, co-benefits, and timeline considerations are deeply interrelated, and any scoring system must grapple honestly with that interdependence. The portfolio approach developed here does not make carbon credits simpler: it makes their complexity legible and tractable. A portfolio that earns its position on the efficient frontier cannot be built through financial engineering alone; it requires that every dimension of integrity and value, at every price point, be taken seriously.

## Conclusion

Creating carbon credit markets that can scale with trust and integrity will require reforms to address the severe informational asymmetry and lack of fungibility that impair current markets. Carbon credits today are portrayed as representing equivalent one-ton mitigation outcomes, yet individual projects fall across a wide spectrum of environmental integrity risk and co-benefit provision. Often, the degree of integrity risk is opaque and uncertain, creating a market that is prone to adverse selection and risky for even well-meaning buyers. Resolving these issues requires both supply- and demand-side reforms aimed at improving the flow of information, updating how credits are verified and issued, and ensuring they are responsibly and efficiently used. Without such reforms, attempts to treat carbon credits as perfectly fungible instruments are unlikely to succeed.

Foremost to creating a functional market is providing participants with accurate and verifiable information. For carbon credit markets, this means that buyers and the general public must have access to information on project locations, methodologies, benefit sharing, and importantly, prices and transactions. For the market to gain credibility, claims made by buyers and sellers must be independently verifiable. Voluntary certification programs can begin by expanding their existing disclosure requirements, although widespread uptake will likely require regulatory action.

In addition to improving transparency requirements, environmental integrity should be further safeguarded by verifying credit issuances through systemic ex-post evaluation, rather than relying on ex-ante assumptions. Ex-post evaluation can be conducted using existing

peer-reviewed methodologies already applied by numerous independent studies of credit quality (Calel et al. 2025; Gill-Wiehl et al. 2024; West et al. 2023). To incentivize uptake, ex-post evaluation should be made the legal standard for credits to be counted towards corporate climate targets or used as regulatory compliance instruments. To mitigate the financial risk from projects that fail verification, project developers will need to update their revenue models or employ risk-sharing mechanisms to pool risk across projects.

Buyers can also pool credits using a portfolio approach that allows for a better balance of integrity risk and benefit provision than any individual project can provide alone. This approach is commonly applied in financial markets, where portfolios can provide more finely tailored risk-return profiles than individual assets. A portfolio approach to carbon credits can allow buyers to manage risk even when measurement, additionality, leakage, and permanence are uncertain. In a portfolio, ex-post evaluated credits could function analogously to risk-free assets (typically government bonds) in finance.

The challenges of credibility, incomplete information, and lack of fungibility are not unique to carbon credit markets. These are issues that have been faced by numerous markets throughout history. Resolving them will require regulatory oversight and reform to disseminate market information, reduce uncertainty, and effectively manage risk. Implementing these reforms can allow carbon credit markets to operate efficiently and scale effectively to deliver on the urgent need for climate mitigation.

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## Endnotes

- 1 Transaction data in compliance markets is generally more complete. Most compliance markets, like California's cap-and-trade system, use centralized exchanges where prices and transactions are tracked.
- 2 See Greenfield and Chingono (2024), Greenfield (2023), and Oliver (2022).
- 3 Voluntary Carbon Market Disclosures, Cal. Health & Safety Code §§ 44475–44475.3.
- 4 Commission Delegated Regulation 2023/2772, Supplementing Directive 2013/34/EU of the European Parliament and of the Council as Regards Sustainability Reporting Standards, (2023) (EU).
- 5 Directive (EU) 2022/2464, of the European Parliament and of the Council of 14 December 2022, Amending Regulation (EU) No. 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU, as Regards Corporate Sustainability Reporting, (2022) (EU).
- 6 Directive (EU) 2024/825 of the European Parliament and of the Council of 28 February 2024, Empowering Consumers for the Green Transition through Better Protection against Unfair Practices and through Better Information, (2024) (EU).
- 7 Guides for the Use of Environmental Marketing Claims, 16 C.F.R. pt. 260 (2012).
- 8 For further discussion on the distinction between offsets and contributions, see Blanchard et al. (2024).

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