

Annual Review of Environment and Resources

Are Carbon Offsets Fixable?

Joseph Romm,¹ Stephen Lezak,^{2,3} and Amna Alshamsi⁴

¹Center for Science, Sustainability, and the Media, University of Pennsylvania, Philadelphia, Pennsylvania, USA; email: rommj@sas.upenn.edu

²Berkeley Carbon Trading Project, Goldman School of Public Policy, University of California, Berkeley, California, USA

³Smith School of Enterprise and the Environment, University of Oxford, Oxford, United Kingdom

⁴School of Global Studies, University of Sussex, Brighton, United Kingdom

Annu. Rev. Environ. Resour. 2025. 50:649–80

The *Annual Review of Environment and Resources* is online at environ.annualreviews.org

<https://doi.org/10.1146/annurev-environ-112823-064813>

Copyright © 2025 by the author(s). This work is licensed under a Creative Commons Attribution 4.0 International License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited. See credit lines of images or other third-party material in this article for license information.



**ANNUAL
REVIEWS CONNECT**

www.annualreviews.org

- Download figures
- Navigate cited references
- Keyword search
- Explore related articles
- Share via email or social media

Keywords

carbon offsets, net zero, climate neutral, additionality, Paris Agreement, corresponding adjustment, mitigation contribution

Abstract

This article provides a systematic review of the literature on carbon offsets. A growing number of studies have found that the most widely used offset programs continue to greatly overestimate their probable climate impact often by a factor of five to ten or more. Credit quality has remained a problem since the inception of carbon credits, despite repeated efforts to address the core challenges of additionality, leakage, double counting, environmental injustice, verification, and permanence. Combined, these issues have led many to conclude that overcrediting in carbon offsets is an intractable problem. These challenges helped stall the rapid growth in the voluntary carbon market (VCM) earlier this decade. They warrant renewed focus in the wake of COP29, where 200 nations significantly advanced the effort begun with the Paris Agreement to create the rules governing a global compliance market for carbon credits. But COP29 did not substantially address the quality problem, creating the risk the Paris compliance market will be rife with overcrediting and other problems—and that the VCM could undermine the Paris market. We recommend that all stakeholders begin focusing on high-integrity, durable carbon dioxide removal and storage, while recognizing that the recent literature has raised the question of whether durable means 100 years, 1,000 years, or longer. Ultimately, we find that many of the most popular offset project types feature intractable quality problems. We should focus on creating rules to find and fund the relatively few types of

high-quality projects while employing alternative finance and strategies such as contribution claims for the critical projects in conservation, renewable energy, and sustainable development.

Contents

1. INTRODUCTION	650
2. BACKGROUND	652
2.1. The Clean Development Mechanism	653
2.2. Joint Implementation	653
2.3. Other Compliance Programs	654
2.4. The Voluntary Carbon Market	654
3. THE UNDERLYING REASONS FOR POOR QUALITY	655
3.1. The Overcrediting Problem	655
3.2. Additionality, Counterfactuals, Imperfect Information, and Gameability	656
3.3. Leakage	657
3.4. Permanence, Carbon Dioxide Removal, and Monitoring	658
3.5. The Persistent Demand for Low-Quality Credits	659
4. OFFSET USE, DOUBLE COUNTING, AND PARIS	660
4.1. Do Offsets Incentivize Direct Emissions Reductions?	660
4.2. The Double Counting Problem and Solution	661
4.3. Implications of Corresponding Adjustments for Paris	661
4.4. Implications of Corresponding Adjustments for the Voluntary Carbon Market	662
5. ENVIRONMENTAL JUSTICE AND COBENEFITS	663
5.1. Cobenefits in Practice	663
5.2. Safeguards	664
5.3. Local Sovereignty and Tenure	665
5.4. A Way Forward	665
6. CURRENT EVOLUTION AND TRENDS	666
6.1. Causes of the Market Contraction	666
6.2. Market Responses and Innovations	666
6.3. Recent Developments on Article 6	667
7. CONCLUSION	668

1. INTRODUCTION

Carbon offsets are projects that generate credits meant to represent the reduction, avoidance, or removal of greenhouse gas (GHG) emissions from the atmosphere (1). These credits, generated from a project in one place, are generally purchased to compensate for emissions in another place. In a typical transaction, a developed country or company claims to negate some or all of its own heat-trapping GHG emissions by paying a developing country, or an entity in that country, to undertake projects that generate an equivalent number of credits, which are then claimed against the buyer's GHG inventory.

In principle, each carbon credit should correspond to one metric ton of carbon dioxide equivalent (CO₂e)—that is, any combination of GHGs with a global warming potential equal to that

of one ton of CO₂. Credits are generated by many offset mechanisms, each of which fits into one of three broad categories: (a) reducing current emissions from a baseline, such as by capturing landfill gases or switching to a fuel source with lower emissions; (b) avoiding new emissions, such as by deploying clean energy or by preventing deforestation; or (c) removing CO₂ from the atmosphere, such as by deploying direct air capture of CO₂ or by afforestation. For decades, carbon credits have been widely used to meet regulatory emissions caps and voluntary commitments such as net zero or other emissions targets. Net zero claims are generally made when a buyer purchases enough offsets to cover all of its reported emissions. Some companies also use offsets to compensate for the emissions of individual products like coffee, bottled water, and even gasoline and jet fuel, which they then label carbon neutral.

In recent years, the number of voluntary net zero commitments has grown rapidly. In the same period, the size of the voluntary offset market also grew until credit quality issues triggered a backlash in the early 2020s (see Section 6). At the same time, at the Twenty-Ninth Conference of the Parties (COP29) to the United Nations Framework Convention on Climate Change (UNFCCC) in November 2024, world leaders significantly advanced the decade-long effort begun with Article 6 of the Paris Agreement in 2015 to create the rules needed to launch a global compliance market for carbon credits. The goal is to help nations achieve their national emissions reduction commitments through several international compliance markets for carbon credits.

The decision at COP29 contrasts starkly with the scientific consensus and a “growing literature highlighting the practical limitations of offsets and the potential for offset schemes to credit abatement that is nonexistent, nonadditional and potentially impermanent” (2). If an offset project would have occurred without the sale of a carbon credit, it is called nonadditional. Determining that a project is additional is one of the core issues with credit quality or integrity, along with ensuring that the credits awarded are not significantly overestimated, that they do not lead to excessively increased emissions outside of the project boundary (called leakage), and that they are permanent (3, 4).

An increasing number of journal articles on carbon offsets and their quality have found that offset programs routinely overestimate their climate impact, in many cases by as much as a factor of five to ten, or more (5–10). A 2024 meta-analysis of studies covering nearly one billion tons of credits, or nearly 20% of the total credit volume issued to date, estimated that actual emissions reductions from the studied projects in the meta-analysis generated fewer than one in six of the credits issued (4). The remaining credits issued likely did not represent any real emissions reductions whatsoever. Such findings are consistent with previous large-scale analyses of the offset market (3, 4, 11).

The most recent assessment of the climate change mitigation literature and science by the Intergovernmental Panel on Climate Change (IPCC) found that “to realize the mitigation potential of net zero emission targets” might require changes within the targets, including “focusing on direct emission reductions within their own territory; minimal reliance on offsets; scrutiny of use and risks of CO₂ removal” (12, p. 1408). Similarly, in 2022, during COP27, the United Nations High-Level Expert Group on the Net Zero Emissions Commitments of Non-State Entities released a report on offset integrity (13). Over a 7-month period, the Group received over 300 written submissions and conducted more than 40 consultations that included over 500 organizations worldwide. It recommended that nonstate actors should not use offsets purchased in the voluntary market to make any claims about emissions reductions or net zero for the foreseeable future. Instead, the Group advocated for “urgent and deep reduction of emissions across their value chain” to achieve net zero commitments built around science-based targets, “with any residual emissions neutralised by permanent greenhouse gas removals” (i.e., not by avoided or reduced emissions) that are verified by a credible third party (13, p. 16).

In 2023, the Science Based Target Initiative (SBTi) conducted a large, independent solicitation and review of journal articles and other high-quality publications, such as government and civil society reports (14). Its findings suggest that the preponderance of carbon credits issued to date across a wide range of project types failed to deliver their stated climate benefits. The SBTi, which works with thousands of companies to develop and validate their net zero targets, identified 71 pieces of submitted evidence relevant to carbon credits involving emissions reductions or emissions avoidance. It noted: “There was no evidence submitted that identified characteristics or operating conditions associated with effective carbon credits and projects” (14, p. 8). The evidence showed that corporate offsetting had the potential to hinder the net zero transformation.

Similarly, a growing number of media exposés and studies from universities, nonprofits, academies of science, and other major independent organizations have raised serious issues about additionality, overcrediting, leakage, and permanence (15–20). Offset quality and integrity matter because bad credits are taking the place of real emissions reductions and are used to justify continued emissions by consumers and producers. This is a classic moral hazard that undermines ambition, distorts measurements of emissions reductions, and slows progress to meet urgent decarbonization targets. Moreover, finance directed toward purchasing bad credits conceivably displaces investment in direct decarbonization or other high-integrity approaches.

While these reports have raised serious doubts about carbon markets writ large, some studies have identified a small subset of offset projects that can be designed to address the biggest issues afflicting the large majority of the market. These include but are not limited to certain CO₂ removal (CDR) technologies, certain clean cookstove approaches (10), and landfill gas capture (3). While these approaches also exhibit perverse incentives and opportunities for mismanagement, they do not suffer from the same fundamental problems that have characterized the rest of the offset market to date.

This review summarizes the scientific consensus on carbon offsets, why they so rarely work as intended, and whether their problems are fixable within the current parameters of carbon markets—and, if so, how. Section 2 briefly recounts the history of carbon offsets and explains key elements of how the offset market works. Section 3 looks at the research on why credit quality has remained a problem for more than two decades despite efforts to combat it—with a focus on additionality, overcrediting, leakage, and permanence. Section 4 examines credit demand: whether offsets incentivize greater direct emissions reductions and whether they displace direct emissions reductions. It also examines a major challenge for offsets under the Paris Agreement: double counting, whereby two different parties claim the same emissions reduction. Section 5 looks at issues surrounding environmental justice and offset cobenefits, namely the positive, non-GHG impacts of offsets that are often cited in defense of offsetting. Section 6 discusses the evolution of the offset market in recent years, the outcome of the 2024 UNFCCC negotiations on how offsets will be treated in the Paris compliance market, and the various proposals to address long-standing issues in carbon markets.

2. BACKGROUND

To date, approximately 5.2 Gt of credits have been issued from the registries responsible for crediting the overwhelming majority of carbon offsets. The two biggest issuers, the Clean Development Mechanism (CDM) and the Joint Implementation (JI) program, were created by the UNFCCC Kyoto Protocol. The CDM and JI issued 2.4 and 0.9 Gt of credits, respectively, for a combined 3.3 Gt (63% of the total). The remaining 1.9 Gt (37% of the total) were issued by the four largest independent mechanisms: American Carbon Registry, Climate Action Reserve, Gold Standard, and Verified Carbon Standard (4).

The CDM and JI were compliance markets, which allowed countries and nonstate entities to meet mandatory emissions targets. In contrast, the voluntary offset market lets companies (and others) purchase credits with the understanding that a separate nonstate entity will reduce or avoid emissions by an amount equivalent to the credits issued. The first voluntary carbon offset was generated in 1989, but the overall voluntary market had only around US\$300 million in cumulative sales through 2005 (4, 21). In this section, we review the subsequent history of carbon offsets, starting with the CDM and JI, and the economic logic on which offsets were (and still are) based.

2.1. The Clean Development Mechanism

Carbon offsets took off in the mid-2000s, when the UNFCCC launched the CDM. The CDM, which laid the foundation for carbon credits today, was intended to help developed countries meet their GHG reduction targets under the 1997 Kyoto Protocol while promoting sustainable development in developing countries by funding offset projects that generated Certified Emission Reductions (CERs) (22).

These CERs, which represented one metric ton CO₂e each, allowed developed countries to offset an equivalent amount of their pledged reductions. If Germany had to reduce its emissions by 100 Mt, for example, it could fund a renewable energy facility in Cambodia that was projected to save (or avoid) 10 Mt of emissions. Germany would then have to reduce its own CO₂ emissions by only 90 Mt to meet its Kyoto goal.

The CDM has had more rigorous oversight, screening, and monitoring than any other offset program at the time (23). It had a multistage process of project development, approval, validation, registration, monitoring, verification, certification, and finally issuance of CERs. The process involved creating four different reports along with oversight by multiple bodies, including the host country's Designated National Authority; the CDM's Executive Board; and two different designated operational entities, which are businesses the Executive Board accredits to conduct validation, verification, and certification (24).

Even so, the CDM was criticized from its earliest days for overcrediting and other quality issues—and those issues persisted and even worsened over time (3, 25). A 2016 analysis (3, p. 14) of CDM projects for the European Commission's Directorate-General for Climate Action found that “85% of the covered projects. . . have a low likelihood of ensuring environmental integrity (i.e., ensuring that emission reductions are additional and not overestimated). Only 2% of the projects. . . have a high likelihood.” Subsequent reviews of large numbers of CDM projects found persistent quality issues (4, 23).

2.2. Joint Implementation

JI, another compliance program of the Kyoto Protocol that was very similar to the CDM, allowed the generation and transfer of Emission Reduction Units (ERUs) only between countries that had emissions caps under Kyoto (i.e., more affluent nations). Research has found that, of the projects aimed at mitigating two of the most potent greenhouse gases, HFC-23 and SF₆, all had a perverse outcome and that they “increased waste gas generation to unprecedented levels once they could generate credits from producing more waste gas” (26, p. 1061). In other words, JI incentivized pollution by allowing polluters to monetize reduction from an inflated baseline.

One systematic analysis concluded that approximately 75% of JI offsets were unlikely to be additional (11). JI allowed host countries to either (a) create their own rules for project approval, additionality determination, and ERU issuance with no international oversight or (b) have the United Nations' JI Supervisory Committee oversee the review (see <https://unfccc.int/process/the-kyoto-protocol/mechanisms/joint-implementation>). Countries overwhelmingly chose the former approach. Approximately 97% of ERUs were issued without such review (27).

Host countries also chose and paid the firms that audited them. The biggest of these firms was Bureau Veritas Certification Holding SAS, which audited projects responsible for 78% of total ERUs, with its market share increasing over time. A random sample analysis found that 77% of the projects they approved “made additionality claims that were not plausible, and 17% had questionable claims”; for the other auditors, only 12% made implausible additionality claims, with 46% making questionable claims (11, p. 9). This flaw—the ability of developers to select and pay auditors that were subject to little independent monitoring and assessment—also became a fundamental problem within the voluntary carbon market (VCM).

2.3. Other Compliance Programs

Beyond the CDM and JI, many other compliance offset programs now exist in places such as Australia, California, Canada, China, Colombia, Japan, New Zealand, and several northeastern US states. Most of them are small contributors in terms of carbon credits issued, with the two largest being Australia and California (28).

In California’s offset program, entities covered by its Cap-and-Trade Program can use compliance offset credits to meet 6% of their total obligation from 2026 to 2030 (29). The program “was explicitly structured to prevent the quality issues experienced by the CDM” (30, p. 5), but research has still found large-scale overcrediting (30–34).

Australia’s offset program has also been criticized on similar grounds. Studies have identified both a significant risk that a large majority of projects for human-induced regeneration of forests “are being, and will continue to be, credited for nonadditional abatement” (35, p. 2) and limited evidence of actual regeneration (2).

2.4. The Voluntary Carbon Market

Thus far, we have discussed various compliance markets, which allow countries and nonstate entities to meet mandatory emissions targets. In contrast, the voluntary offset market lets companies (and others) purchase credits with the understanding that a separate nonstate entity will reduce or avoid emissions by an amount equivalent to the credits issued.

From 2007 to 2020, the VCM averaged approximately \$400 million in annual sales, albeit with many ups and downs, but then exploded to \$2 billion in 2021 because of a rapidly rising number of emissions reduction pledges by nations, companies, and other entities (21) and an accompanying growth in speculation by investors (18). The pledges were driven primarily by the 2015 Paris Agreement and the IPCC’s 2018 “Special Report on Impacts of Global Warming of 1.5°C” (36). At Paris, the world’s leading countries unanimously agreed to reduce GHG emissions to a level that would avoid dangerous climate impacts (37, p. 2), which meant “holding the increase in the global average temperature to well below 2°C [3.6°F] above preindustrial levels and pursuing efforts to limit the temperature increase to 1.5°C [2.7°F].” These targets implied that midcentury global emissions would need to be at or near net zero, with sharp reductions by 2030 (36), and unabated emissions mitigated by CDR.

Leading up to COP26 in the fall of 2021, more countries began making net zero pledges. President Xi Jinping announced in September 2020 that China would aim to achieve carbon neutrality before 2060. At the summit, India said it would aim for net zero by 2070. By the end of COP26, more than 70 countries—including most of the top emitters—had made a net zero pledge (38).

At the same time, many companies made similar pledges. More than 450 banks, pension funds, and other firms that together manage \$130 trillion pledged at COP26 to use their money to reach net zero by 2050 (39). During the summit, the management consulting firm McKinsey argued

that “COP26 made net zero a core principle for business” and that “net-zero commitments are the norm” (40).

Partly as a result of all these pledges, many companies pursued voluntary offsets to meet their ambitious near-term targets. The VCM grew rapidly in 2022 to \$2 billion; that same year, one market research firm projected that offset purchases could reach \$17 billion by 2027 (41), while Shell Group and Boston Consulting Group projected that purchases could reach \$10 to \$40 billion by 2030 (42). But growing concerns about VCM offset quality and integrity raised in the scientific literature and media investigations created a backlash that sharply reduced offset sales between 2021 and 2023, as we discuss in Section 6.

3. THE UNDERLYING REASONS FOR POOR QUALITY

For more than two decades, peer-reviewed studies have found offset quality to be poor across most of the largest (by volume) carbon offset programs. That literature has increased in recent years even as it has analyzed larger numbers of credits, suggesting that poor quality is widespread (4, 14, 43).

The quality of credits issued on both voluntary and compliance markets depends on several factors, the most important of which are additionality (Section 3.2), leakage (Section 3.3), permanence (Section 3.4), and double counting (Section 4). An offset may be robust on three of these four dimensions, but if it lacks in the fourth, it may represent a far lower emissions reduction than was credited—or no real reduction at all. As we discuss below, low-quality credits are endemic across protocols on both the VCM and compliance markets, including the CDM and California’s compliance program, and across various offset types, such as renewable energy, cookstoves, and improved forest management.

This section summarizes the literature and expert views on the underlying causes of this persistent quality deficit. Key factors include a combination of uncertainty and complexity that create plausible deniability and permissive rules that allow overcrediting, as well as a set of market incentives that encourage low-integrity approaches (30).

Since all credits have a *de jure* value of one ton of CO₂e, buyers have an incentive to purchase cheaper credits, which tend to be of lower quality (28, 43, 45). Indeed, the offset market is unusual in that the major buyers do not demand a quality product, as we discuss below, and so “individual companies are a major cause of persisting quality issues due to their demand for problematic and cheap offset types known to overstate emission reductions” (43, p. 2).

Focusing on price over quality drives a “race to the bottom” where project developers compete on price rather than quality. Exacerbating this downward spiral is the fact that project developers are generally tasked with hiring a third-party verifier—often called a validation/verification body. Because the third-party verifier is the client of the developer and not of the credit purchaser, its primary incentive is to deliver results that will please the developer—that is, to liberally validate the proposed credit issuance. Registries, meanwhile, are not motivated to adopt and enforce better standards and methodologies because they “compete for market share and are paid per account and credit issued” (30, p. 6). Other reasons for low quality involve additionality, information asymmetries, leakage, impermanence, and inadequate monitoring.

3.1. The Overcrediting Problem

Warnings that carbon offset projects are prone to overcrediting date back over two decades. A major analysis of CDM projects found that 85% had “a low likelihood of ensuring environmental integrity (i.e., ensuring that emission reductions are additional and not overestimated)” whereas only 2% had a high likelihood (3, p. 10).

A large majority of the California Air Resources Board's offset credits—and more than a third of all US offset project credits—are from improved forest management, but studies find that such projects have minimal benefit (6, 31, 32). The overcrediting can be considerable, as in the case of replacing inefficient, dirty cookstoves (used by more than two billion people globally; 46) with more efficient ones. A 2024 study noted that cookstoves represent more than 15% of projects in the VCM but found more than ninefold overcrediting in a large analysis (10). The VCM has a similar structure and similar problems as the CDM and California compliance markets. Avoided and reduced deforestation (REDD+) is the single biggest project type, comprising a quarter of the VCM (44). A recent review of REDD+ projects found an overcrediting ratio of 1:13, meaning that every real credit was likely issued alongside 12 fake ones (7).

The result is that project types known to be “severely overcrediting produced just under two-thirds” of the credits issued in the VCM so far (30). Similarly, a 2024 analysis of 65 relevant studies covering 972 million tons of CO₂e, approximately one-fifth of the total credit volume issued to date, found that at least 812 million are unlikely to represent genuine emissions reductions (4). Wind energy, improved forest management, and REDD+ accounted for 722 of those 812 million tons. The authors of this study note that 812 million should be considered a lower bound for overcredited emissions because they did not consider several key issues, such as double counting or impermanence, nor did they include a number of studies that indicate integrity issues with project types they did not analyze (3, 11, 47, 48; see <https://carboncreditquality.org>).

Many factors can complicate calculation of the correct number of credits to award a project, especially forestry projects. For example, a 2021 article in *Nature* reviewed 108 experiments involving elevated CO₂ to determine the impact on carbon storage in plants versus soils (49). The analysis suggests that forests will store less carbon in soil as CO₂ levels rise than models suggest—while grasslands will store more—reducing the net CDR benefit of planting trees in grasslands and savannas. Also, in 2019 the National Academy of Sciences noted that planting trees “in boreal zones will have a warming effect that exceeds the cooling effect of reducing GHGs” (50, chapter 3) and that, above the snow line, “an increase in forest cover reduces surface reflectivity causing more surface warming.” This albedo effect limits the benefit to the climate of planting trees in northern regions, as does the fact that “tree planting disturbs pools of soil carbon, which store most of the carbon in cold ecosystems” (51, p. 1087).

3.2. Additionality, Counterfactuals, Imperfect Information, and Gameability

Imperfect information is a problem inherent to the offset market because when offsets are based on counterfactuals, their additionality is inherently uncertain. As a 2007 *Nature Climate Change* article put it: “No test for additionality can provide certainty about what would have happened otherwise” (52, p. 86). In 2008, a US Government Accountability Office investigation of the CDM concluded that “it is impossible to know with certainty whether any given project is additional” (53, p. 39).

Consider the common case where an offset project pays a landowner not to cut down trees. The counterfactual is no payment. But how does one know if the trees would actually have been cut down? What if only half the trees were to be cut down? What if the company takes the payment but simply cuts down the same number of trees elsewhere (leakage, discussed in Section 3.4)? And what if the preserved forest is later burned down in a wildfire (permanence, discussed in Section 3.5)?

Significantly, while the CDM has had more oversight than any other offset program (23), it has been consistently criticized for awarding a great many offsets to clean energy projects throughout its history that were very unlikely to be additional (3, 19, 20, 23, 25, 48). Furthermore, a 2016

European Commission analysis found that the CDM's overall performance had declined over time, which the authors attribute to an increase in portfolio projects "with more questionable additionality" (3). A 2024 critique noted: "Project developers have been able to define exaggerated baseline scenarios and to register nonadditional projects" (30). This happened across the spectrum of offsets, including renewable energy and hydropower (3, 25), REDD+ (7, 45, 54), and improved forest management projects (5, 31, 32).

In 2021, a former offsets developer said that when offset rules are written, they often seem to "ignore the fact that there are 1,000 smart people next door that will try to game them" (55). These gaming issues have been rampant in offsets markets. A 2024 analysis matched all CDM projects proposed by Chinese manufacturing firms to contemporaneous firm-level data including emissions (23). It found that even though the CDM "arguably had more extensive monitoring and rigorous screening than any carbon offset market in the world" (p. 31), the asymmetric financial information between the regulators and the developers "can produce adverse selection even when monitoring of the technical side of investments and baseline emissions is essentially perfect" (p. 31). The regulator cannot know and analyze all the factors that go into the developers' decisions, both the social benefits (e.g., better public relations) and private benefits (e.g., higher efficiency). Thus "even rigorous screening" (p. 31), which is not the norm, may be unable to determine additionality.

Like JI, the VCM is gameable because an offset developer can usually choose a less rigorous market and/or methodology. In the 2010s, as the cost of many renewable energy sources plummeted, the vast majority of renewable energy-based offset projects became nonadditional (3). In 2019, the two largest offset certifiers, Verra and Gold Standard, stopped issuing offsets from grid-connected renewable energy projects in more affluent nations. Yet a 2024 report found that the use of renewable energy-based offsets in the VCM had climbed substantially since 2019; while those two certifiers no longer register those projects in most places, they continue to issue credits from existing projects (56). A climate news site noted in August 2024: "Despite long being written off as largely worthless by climate experts, renewable energy credits are still popular among corporate buyers" (57). Meanwhile, other certifiers have filled the game, like the Global Carbon Council, which now "signs off on the kinds of projects that fail to meet minimum standards anywhere else in the world," including renewables (58).

3.3. Leakage

Leakage occurs when emissions that are reduced, avoided, or removed within a project boundary are shifted, wholly or partially, outside of the boundary instead. For instance, an offset project may pay one landowner not to sell their trees to local timber companies, but the timber companies are then likely to find other trees to harvest. This is called direct or activity leakage, where those targeted by an intervention move their activities outside of the project boundary (45, 59). Market leakage occurs when entities that are not targeted change their actions based on changing economics. For instance, reduced harvesting inside a project boundary does not reduce demand for timber, so the same market incentives exist for lumber companies to find alternative forests to log (45).

From a practical perspective, the leakage resulting from REDD+ projects that avoid industrial logging likely cannot be known with any great certainty. There are too many factors involved to observe the regional or even global market impact of marginally constraining supply in a globalized industry. Still, the peer-reviewed literature suggests that leakage may be extremely high. One 2023 article analyzed a number of studies and noted that market leakage estimates "are typically above 70% . . . and can reach >100% (59, p. 794). The calculations for market leakage can be

project specific and complicated (45), and an accurate, replicable estimate method has not yet been found. Indeed, some studies choose to ignore market leakage, with methodologies often looking instead at local leakage in the immediate vicinity of a project (54).

Yet, evidence suggests that despite efforts to promote conservative (i.e., higher) leakage estimates, “the use of arbitrarily low estimates of possible leakage appears widespread” (59, p. 794). A 2022 study of 86 avoided forest conversion or degradation projects in Colombia, Indonesia, and Peru found that 29 claimed no leakage, 28 subtracted leakage estimated at a median rate of only 6%, and the rest provided no data (61). California’s offset leakage profile uses a rate of 20%, “when a rate of 80% or higher is supported by published studies of leakage rates from reduced timber harvesting in the United States” (62). At the same time, the majority of improved forest management projects in the state simply credit a big harvesting reduction in year one and deduct only the leakage averaged over 100 years. The overall result is overcrediting due to leakage by a factor of two to five (33).

Concerns about the danger of leakage in nature-based projects date back to the 1990s (63); warnings that leakage may be as much as 100% (or even more in some cases) date back to the early 2000s (64). But today, “there is little evidence that current practices to address leakage actually work,” and leakage estimates in practice appear to be far below what the scientific literature suggests (59, p. 790).

While leakage is an intractable problem for most REDD+ projects, it poses a smaller threat when interventions address the demand for deforestation rather than simply attempting to limit the supply of trees to integrated markets. For that reason, certain demand-side interventions, such as clean cookstoves, are able to partially resolve leakage considerations.

3.4. Permanence, Carbon Dioxide Removal, and Monitoring

The issue of permanence (or durability) has long been a salient concern for offsetting CO₂ emissions because when humans put CO₂ into the air, a large fraction stays in the air for centuries (65). Many researchers argue that offset projects should have a duration comparable to the emissions they are offsetting. While there is no absolute consensus on what constitutes an acceptable level of permanence, 100 years has been a likely mode (66). But nature-based solutions projects rarely promise such durability (67). Issues threatening offset permanence include limited land tenure, ecological disturbance, human disturbance, and mismanagement. Forestry durability concerns have only risen as climate change has worsened, as a number of impacts exacerbated by climate change—particularly pests, drought, and wildfire—directly threaten trees (68). At the same time, the kinds of monitoring, reporting, and verification needed to back up durability claims are often lacking. A 2021 review of 174 tree-planting organizations that planted more than one billion trees found that only 18% mentioned any postplanting monitoring, and only eight discussed their trees’ survival rates (69).

Significantly, researchers and other key stakeholders are increasingly advocating for a focus on CDR, rather than emissions reductions or avoidance (70). At the same time, many experts have begun arguing that CDR permanence needs to be considerably longer than 100 years (71–73). A *Nature* article published during COP29 by a global group of 25 authors who helped develop the science of net zero (74) finds that climate “targets should acknowledge the need for Geological Net Zero,” whereby for each ton of CO₂ generated from fossil sources, one ton of CO₂ should be “permanently restored to the solid Earth” (71, p. 343). Here, geological timescale storage is defined as “multi-century to millennial timescales” (p. 346). Thus, by midcentury, CO₂ uptake by the biosphere and oceans should not be used to offset fossil fuel emissions. A 2024 modeling study found that a storage duration of under 1,000 years “still leads to continuous warming” and

thus is insufficient to meet temperature targets like those in the Paris Agreement (72). Its results “reinforce the principle that credible neutralization claims” for CDR need to balance fossil CO₂ mitigation with permanent geologic storage.

Such findings reject the use of CDR from forestry projects to offset fossil CO₂ emissions, leaving various forms of geologic carbon capture and storage (CCS) as the most-modeled long-term CDR pathways (12). Yet, scaling up geologic-timescale CCS will require a quantum leap in mandatory monitoring, reporting, and verification. Consider the United States, a global leader in CCS investment and innovation (75). A 2020 investigation by a US Treasury Department Inspector General found that companies claiming 87% of the total CCS tax credits worth nearly \$900 million did not comply with rules requiring them to create and use a monitoring plan approved by the US Environmental Protection Agency (76). “The issue of companies claiming credits for unverified tons of captured carbon is rampant in the United States,” one group of climate experts and academics explained (77, p. 3).

Globally, the long-term rate of storage reversals in various geologies is not known (78), but we do know that expensive advanced monitoring equipment, like satellites and submersibles, can find unexpected problems (79). Consider the original—and biggest—offshore CO₂ storage site, Norway’s Sleipner gas field in the North Sea. After a \$14 million research effort discovered “unexpected fractures,” one marine geologist told *Nature*, “there is a much greater chance for some CO₂ to leak out,” than expected (80, p. 339). Sleipner overreported storage by approximately 30% during the period 2017–2021 due to faulty monitoring equipment (81). In 2011, the In Salah CO₂ storage project in Algeria, which had pumped 3.8 Mt of CO₂ underground since 2004, was shut down after a series of risk assessments revealed that CO₂ was apparently fracturing the caprock. The decision was based on a “time-lapse seismic, microseismic, wellhead sampling using CO₂ gas tracers, down-hole logging and core analysis, surface gas monitoring, ground-water aquifer monitoring” and advanced satellite data (82, p. 6226). At present, it is unclear what national and international bodies will be empowered to enforce long-term monitoring and regulate potentially profitable storage projects that cannot or will not comply.

3.5. The Persistent Demand for Low-Quality Credits

It has generally been understood for centuries that it is up to the buyer to ensure the quality of the product they buy under the principle of caveat emptor (83). Analysts of carbon offsets have argued that this principle particularly applies to a market as complex and opaque as the voluntary offset market (84) and that “the Voluntary Carbon Market as a whole should be labeled ‘caveat emptor’” (85). One major guide to offset buying notes: “It is common to tell credit buyers to ‘do their homework’” (86, p. 32).

What makes the offset market so unusual and prone to poor quality is that high quality is not a priority for many buyers (17, 43), because, to date, buyers have had little to gain from purchasing high-quality credits and little to lose from purchasing low-quality ones. Moreover, unlike almost every commodity, carbon credits do not correspond to a tangible object—they cannot be tested for purity or strength like steel, for instance. In fact, many companies have benefited from poor offset quality because it has reduced credit prices (43). Researchers have noted for a quarter-century that, even in compliance markets, “there are significant incentives for parties... to exaggerate a project’s net emission reduction effects” (87, p. 16). A 2001 analysis warned that, in a competitive market, “projects whose accomplishments are easiest to exaggerate will be chosen by developers” (64, p. 51–52).

Despite more than two decades of effort identifying the myriad problems with low-quality credits and suggesting strategies to improve quality, evidence suggests that, from 2020 to 2023,

the largest corporate offset buyers “continuously sourced these low-quality offsets because of their low cost” (43). An analysis of the 20 companies retiring the most offsets from the largest registries (VCS, CDM, and Gold Standard) during the period 2020–2023, comprising approximately one-fifth of all retired tons from those registries, found that 87% of the offsets came from higher-risk projects, like REDD+ and large-scale renewable energy that are prone to overcrediting (43).

This flaw in the carbon market has been compared to Gresham’s law (88, 89), which states that bad money chases out good money. A debased currency of lower intrinsic value will chase a currency of higher value out of the market, which is more likely to happen when there is “imperfect information about the quality” of the two currencies (90). In the same way, as the *New York Times* explained in 2023: “Bad carbon credits are driving out good carbon credits” (89).

4. OFFSET USE, DOUBLE COUNTING, AND PARIS

So far, we have discussed credit quality only on the supply side. But the demand side also determines quality—do offsets incentivize or disincentivize greater direct emissions reductions, and how much do they replace direct emissions reductions on the part of their buyers? These questions are inseparable from the double counting question. If both the seller of the offset and the buyer of the offset count the emissions reduction, then that double counting means emissions targets will not be achieved, which is why the 2015 Paris Agreement explicitly forbids double counting in its compliance market. That, in turn, leads to a discussion of whether voluntary offsets can exist in a Paris target-aligned world—and, if so, what kind. Moreover, because the vast majority of current offsets are not durable CDR, they displace emissions from one place to another and, thus, do not necessarily contribute to achieving deep emissions reductions (17).

4.1. Do Offsets Incentivize Direct Emissions Reductions?

Some industry reports have argued that purchasing voluntary offsets by corporations leads to more direct emissions reductions (91–93). They find that companies that use a significant number of offsets reduce their emissions faster than those that do not, “including renewable energy consumption and the purchase of Renewable Energy Certificates” (92), which are certificates representing the environmental value of one megawatt-hour of renewable electricity.

Several journal articles raise doubts about such claims (43, 95, 96). Correlation is not causation: Just because companies purchasing offsets may also reduce their emissions more does not mean that offset purchases drive direct decarbonization (97). An analysis of 89 companies that retired 24% of offsets in 2022 “reveals no significant difference in climate strategy ambition” (96, p. 8) between companies that offset emissions and those that do not; rather, offsets appear to be “a strategy to maintain or restore legitimacy without accelerating decarbonisation relative to their peers” (p. 9). Significantly, evidence suggests that, from 2020 to 2023, the largest corporate offset buyers “continue[d] to source low-quality, cheap credits with minimal climate benefits” (43).

In addition, companies that purchase offsets widely use renewable energy credits (also called certificates) to compensate for their Scope 2 indirect emissions from electricity purchases. But researchers have repeatedly found these credits do not represent genuine emissions reductions and are incompatible with science-based corporate targets (98–100). Removing renewable energy credits from the analysis may eliminate the correlation between offset purchases and direct emissions reductions (97).

A widely discussed concern is what constitutes greenwashing, whereby companies overstate climate action. Up to 40% of statements by corporations about offsets and other green claims are potentially misleading (101, 102). For example, a 2023 analysis of VCM purchases by oil

majority finds that most of their offset purchases are not high quality and calls into question their “claims that emissions from hydrocarbons in LNG [liquefied natural gas] trade, road transport and aviation have been ‘neutralised’” (103).

A related concern is what level of direct emissions reduction provides “the social license of the voluntary carbon market as a viable impactful pathway toward global carbon emissions reduction” (95). For instance, if a company makes a net zero pledge, how much of that pledge should be made through direct emissions reductions for it to be considered credible? A common approach is to require an emissions cut of at least 90% by 2050 and then neutralize the residual with permanent CDR (104).

4.2. The Double Counting Problem and Solution

Double counting, sometimes also called double claiming, occurs when both the offset seller and buyer (or the buyer’s jurisdiction) count the same emissions reduction. For example, consider an offset project that reduces the seller’s CO₂ emissions by 10 Mt. If the buyer can also count it, then this project would register as reducing emissions by 20 Mt. Such double counting could eliminate the entire emissions reduction benefits of the Nationally Determined Contributions (NDCs) made under the 2015 Paris Agreement (105), which is why that Agreement explicitly sought to address such double-counting scenarios.

The two central solutions to the problem are for either the seller or the buyer not to count the emissions reduction—solutions that the parties to UNFCCC adopted at COP26 and COP27, respectively. In Paris, the parties requested that the Subsidiary Body for Scientific and Technological Advice develop guidance to “ensure that double counting is avoided on the basis of a corresponding adjustment” (37, p. 6).

In practice, that adjustment means: “The country selling emission reductions makes an addition to its emission level, and the country acquiring the emission reductions makes a subtraction” (106, p. 181). To be clear, at the start of the transaction, the seller has already reduced its total emissions by 10 Mt. Then, after the sale, it must add back those 10 Mt to its official inventory. The seller must keep its official emissions total unchanged, as if it had never reduced its emissions in the first place.

To be Paris compliant in this scenario, “the host country will have to issue a guarantee that it won’t use the transferred credits against its own NDCs” (107). These emissions reduction credits transferred from one country to another are called Internationally Transferred Mitigation Outcomes. At COP26 in Glasgow, parties adopted the term authorized emissions reductions for this first case, where the seller makes the corresponding adjustment and does not count the emissions reduction. Such activities would be registered under the Paris Agreement’s Article 6.4 mechanism, “the new centralized UNFCCC baseline-and-credits mechanism (replacing CDM/JI)” and would be one of the two types of Article 6.4 emissions reductions (A6.4ERs) (108, p. 5).

In the second case, the buyer does not count the emissions reduction, so it is not treating the transaction as an offset. In that case, other names are used than the term offset, such as impact claim or contribution claim (109). At COP27 in Egypt in 2022, the world adopted the term mitigation contribution unit, or mitigation contribution A6.4ERs, for the second type of A6.4ERs.

4.3. Implications of Corresponding Adjustments for Paris

A key implication of the authorized offset is that the buyer has made achieving their Paris climate commitment easier, while the seller has made achieving theirs harder. Transferred mitigation outcomes contribute to the buyer’s NDC targets—not the seller’s. The seller must “uncount” these emissions reductions.

Yet, if developed countries skim off the cheapest emissions reductions as lower-cost authorized offsets today, then the host country is left with higher-cost options for reducing its own emissions (114). The same concern of “cream skimming” was raised in a 1999 book on the Kyoto Protocol, which discussed the “potent” fear that projects would “use up the cheapest reduction options in developing countries” so that when those countries “came to adopt emission commitments, they would only have more expensive options left” (111, p. 97). This observation raises issues of equity and climate justice (112), and thus authorized offsets may prove politically unpopular and some developing countries may choose to avoid them (113). This problem also raises the question of whether “host countries are disincentivised to adopt ambitious NDCs” (114), given that doing so will push them toward more expensive mitigation options.

Another implication is that if any such transactions do occur, these authorized offsets will not be low cost as the majority of voluntary offsets are. Indeed, a World Bank analysis finds that they could be quite high—and may ultimately be priced between the seller’s marginal costs of emissions abatement required to meet its 2030 NDC target and the buyer’s marginal abatement costs (115). After all, to meet its NDC, the host country would have to mitigate emissions beyond the original target—at a cost likely equal to or higher than the marginal cost of achieving that target. But the negotiation “will also be determined by the buyer’s willingness to pay, which, in turn, will be influenced by the marginal costs of the buyer’s NDC” (115, p. 8). Most host regions have marginal abatement costs ranging from \$31 to \$78 per ton of CO₂, but some are much lower; the marginal cost for likely buyers is considerably higher (e.g., \$129 per ton CO₂e for the European Union and \$155 per ton CO₂e for the United States) (115). Corresponding adjustments are a confusing concept even for many environmental executives (116). Perhaps because of the confusion inherent in this complicated system, adjustments are “currently trading in the \$7–22 range” (117), which appears to be well below their true value (115).

4.4. Implications of Corresponding Adjustments for the Voluntary Carbon Market

A remaining question is whether the VCM should require a corresponding adjustment for offsets that help a host country achieve its NDC target. If the adjustment cost is high, as the World Bank suggests—potentially \$100 per ton CO₂e or more—that could dramatically change the VCM, as many potential buyers might simply choose to pursue direct emissions reductions.

Some authors have argued that without a corresponding adjustment in the VCM, there would be double counting or double claiming just as in the compliance market (110) or that such double counting would exist in specific situations (118). But others argue that the Paris market and the voluntary market are two different accounting systems, so there is no double claiming (119), and that the need for a corresponding adjustment is “unconvincing” (118).

One review of the arguments concludes that a corresponding adjustment is needed to “address the fundamental requirement that voluntary offsets must achieve a lower level of emissions than would have happened anyway” (120, p. 1). Gold Standard, which develops methodologies for crediting and certifying, has stated that carbon credits without a corresponding adjustment should not be called offsets because it is “challenging to be sure that the impact of a carbon credit has not inadvertently displaced an equivalent impact for which the host country has stated targets” (121). A concern has been raised that without the adoption of the corresponding adjustment, the voluntary market could become irrelevant or even undermine the Paris Agreement (110). Finally, since all parties must achieve net zero or near net zero emissions, might it be self-defeating for a buyer to sell a significant quantity of authorized offsets now, given the risk that the price might be considerably higher for the replacements later on (17)?

5. ENVIRONMENTAL JUSTICE AND COBENEFITS

Cobenefits are positive outcomes delivered to communities or local ecosystems in addition to tons of reduced or avoided GHG emissions (122). In 2007, 28% of CDM projects explicitly claimed cobenefits in their project design documents, focusing primarily on job creation, training, and contributions to local social and economic development (123). Approximately 28% of projects listed in the VCM also report additional cobenefits, ranging from biodiversity conservation to community development (94). Demand for project types with cobenefits is expected to grow, driven by rising consumer and corporate preferences for carbon credits that deliver broader environmental and social outcomes, particularly those aligned with the United Nations' Sustainable Development Goals (94, 124). This trend is already reflected in the market, as projects with cobenefits trade at a premium compared with other credit types, demonstrating buyers' willingness to pay more for credits that deliver additional environmental and social benefits beyond carbon reduction (94).

While successful carbon offset projects with demonstrated cobenefits exist, particularly in cookstove programs, conservation, and ecosystem restoration (125–127), a complex picture emerges when examining the outcomes of the broader industry. This section examines these outcomes through four key perspectives. First, we discuss the successful projects that have delivered meaningful cobenefits to communities and the instances of support for such projects from Indigenous and local communities (125–127). Second, we examine how, despite established safeguarding measures, carbon offset projects tend to fall short of their promised outcomes at times, due to various factors including complex local socioeconomic and political conditions and, most importantly, insufficient accountability and enforcement mechanisms (126, 128–135). Extensive academic literature and investigative journalism document how cobenefits have been overestimated, highlighting a concerning pattern in the outcomes of such schemes (19, 128–133, 136–148). Third, we examine how the pattern of failures in safeguarding and lack of accountability has led scholars to characterize certain carbon offset projects as a form of neocolonial appropriation (135, 142–144, 149–152). Lastly, we discuss how, despite evidence that well-implemented carbon offset projects can deliver meaningful community benefits, the lack of robust enforcement mechanisms continues to pose risks of repeating historical injustices, such that the effectiveness of new and continued developments will ultimately depend on how well various stakeholders can ensure accountability and uphold both cobenefits and safeguards in practice.

5.1. Cobenefits in Practice

Carbon offset projects have provided substantial community benefits with local community support (125–127). Studies have documented economic improvements through job creation and new income streams from forest carbon initiatives (125, 127) as well as biodiversity conservation (126). Beyond these impacts, projects have delivered cobenefits through community empowerment and education programs (125, 127). Additionally, although some carbon offset projects are contested by Indigenous leaders (153, 154), other projects have been supported by Indigenous communities for their potential to provide an additional revenue stream to community-led climate mitigation and adaptation initiatives and to bolster Indigenous self-determination (155; see <https://www.klc.org.au/savanna-burning-carbon-projects>).

The evolution of carbon offset mechanisms since the CDM reveals implementation challenges in balancing global climate goals with local community needs. The insufficient recognition of community rights and the lack of proper engagement with local populations create a recurring challenge across carbon offset projects. Research by Haya & Parekh (136) and Fearnside (137, 138) has documented multiple instances where hydropower CDM projects proceeded without obtaining proper free, prior, and informed consent from affected local communities. Similar issues have

plagued other project types, such as REDD+, where researchers have identified systematic deficiencies in transparency and community engagement during project planning phases (128–131). Multiple organizations have documented serious concerns about human rights in certain REDD+ projects, including cases of forced eviction and displacement as well as arbitrary detainments (132, 133, 142, 149, 150).

Offset projects may also restrict resource access and disrupt local livelihoods. CDM hydropower projects have significantly affected fishery ecosystems and water security; for example, detailed studies in Brazil document how the disruption of river ecosystems led to severe reductions in fish populations, devastating communities that relied on these resources (137, 138). Similar impacts have affected downstream communities in China and Cambodia through water insecurity and flooding (19, 139). In REDD+ projects, restrictions on traditional forest use have disproportionately affected marginalized populations dependent upon common pool resources (129, 140). While some projects offer small payments for forest maintenance (125), they may often prove inadequate compensation for the loss of traditional livelihoods (128).

Impacts on land governance present another major area of concern. REDD+ projects have frequently exacerbated preexisting land tenure conflicts, particularly those affecting customary land rights (128, 131). Elite capture of benefits through corruption and back-channel land deals has also been documented (141, 143, 145). In other cases, a shift to plantation-style forestry has displaced traditional agriculture and jeopardized local governance systems (152). These issues may undermine social equity and community cohesion, and studies have documented patterns of uneven benefit distribution, often reinforcing existing socioeconomic inequalities and leading to increased community tensions, particularly in the context of contested land rights and inadequate safeguards (128, 147, 156).

While many of the above examples draw from CDM credits and REDD+ projects, similar challenges have been documented in other carbon offset project types (3, 157, 158). Despite the development of various safeguard mechanisms to protect local rights and interests, the practical implementation and effectiveness of these measures remain uncertain. This gap between intended outcomes and actual implementation underscores the need for fundamental reforms in how certain carbon offset projects are designed and executed.

5.2. Safeguards

The Voluntary Carbon Standard run by Verra, which registers most REDD+ projects today, has been updating its policies, with regular revisions, in an effort to protect the well-being of local communities over time (159, 160). The no-harm principle guiding many standards, including Verra's, prioritizes safeguarding human rights, preventing environmental harm, avoiding unintended consequences, and ensuring that projects contribute positively to both sustainable development and climate goals (160, 161). Project developers are also required to carry out additional procedures, including stakeholder consultation with a public comment period before implementation, and to provide a grievance mechanism for communities to communicate complaints directly to developers (160).

However, as outlined in the cases above, safeguarding principles and grievance mechanisms are sometimes omitted (133), ineffectively implemented, and undermined (128–131). In some instances, filing a grievance required a large fee or processing in offices far from remote areas where most communities are located (162, 163). In other cases, grievance mechanisms required submissions through physical letterboxes at developers' offices or direct communication with developers' representatives, raising concerns about confidentiality and anonymity, which may deter grievance filing (132, 162, 163). These instances exemplify the kinds of negative outcomes that can arise

when safeguarding policies are not applied with local contexts in mind or are not implemented in good faith.

Another issue of contention is conflicts of interest between auditors, project developers, and registries (164). In both compliance and voluntary markets, developers and registries usually rely on third-party independent auditors to assess developers' project documents and implementation to verify adherence to safeguard requirements in addition to standards and methodologies (164). While independent third-party auditors are required to validate and verify a project's technical performance, they are not specifically required to assess community impacts or oversee stakeholder engagement processes, which are typically carried out by the project developers themselves (160). Consequently, studies have found that auditors often certify projects with unaddressed safeguard violations and fail to hold developers accountable when safeguard requirements are not met (134). Additionally, scholars have documented instances of illegal timber harvesting, community rights violations, and violent eviction that have been overlooked or neglected in audit reports (45, 132, 133). Subsequently, researchers have concluded that this neglect is partly due to the inherent conflict of interest in the structure of crediting mechanisms, where auditors are directly hired by project developers and, therefore, are incentivized to prioritize favorable results over rigor or reputational standing (134).

While ambitious safeguards policies can be set, without enforcement mechanisms or compliance procedures other than withholding validation or verification, projects can still operate in violation of their own standards (45, 165, 166). The failures in safeguard implementation, coupled with weak enforcement mechanisms and a lack of accountability, have led to regular abuses of community well-being among a wide range of offsetting projects.

5.3. Local Sovereignty and Tenure

The repeated failures in project governance and community protection echo historical forms of resource exploitation. The commodification of carbon through neoliberal conservation has sometimes prioritized the interests of external investors and the Global North over local livelihoods, failing to address the underlying drivers of environmental destruction and, at times, exposing local communities to the risk of land grabs (143, 145, 152). The breakdown of community safeguards, coupled with the historically top-down approach of carbon offset projects, has led scholars to argue that the broader structure exhibits certain neocolonial characteristics (167). This characterization emerged directly from documented implementation failures, such as the cases outlined above (19, 128–133, 136–139, 142, 146, 149), where patterns of implementation failure have been attributed to a fundamental tension in the neoliberal framework underlying carbon markets, which prioritizes cost-efficient emissions reductions for developed nations (151) while deprioritizing protections for local community needs and traditional resource management systems (128, 141, 145, 147, 152, 156). The gravity of these implementation shortcomings is particularly evident in independent investigations that document Indigenous rights violations across REDD+ projects, revealing growing evidence of offset-related land grabs (144, 149, 150, 168).

5.4. A Way Forward

Well-designed and properly implemented projects can substantially benefit local communities, particularly when developed with Indigenous support and proper safeguards (125–127, 135). But the growing media scrutiny and independent criticism of carbon offsets have created significant challenges for market confidence and project implementation (169, 170). In response, offset developers and registries have undertaken various corrective measures in an attempt to prevent abuse, including the development of more rigorous standards, enhanced monitoring requirements, and

improved stakeholder engagement processes, reflecting a growing recognition of the need for stronger safeguards and more transparent verification processes (70, 169, 171).

However, without adequate enforcement mechanisms and clear accountability frameworks, there remains a significant likelihood that historical issues will repeat themselves. The persistence of implementation challenges, particularly around community rights and benefit distribution, suggests that new standards alone may be insufficient without robust enforcement mechanisms. This situation could potentially attract further criticism and erode market confidence if not adequately addressed. Looking forward, the effectiveness of recent developments in standards and outcomes remains to be determined. Emerging initiatives represent important steps toward addressing historical shortcomings. It remains to be determined how these new efforts will play out in practice and whether they will successfully uphold cobenefits and mitigate harms. The success of these reforms will ultimately depend on their ability to ensure genuine accountability while delivering both verifiable climate benefits and meaningful community outcomes.

6. CURRENT EVOLUTION AND TRENDS

In the first years of this decade, carbon markets have undergone a major disruption. In 2021, the VCM transacted \$2.1 billion in credits, but by 2023, it had contracted to \$723 million (172). In this section, we explore the factors contributing to this market contraction and the range of proposed responses and initiatives intended to address the well-documented problems affecting the voluntary and compliance markets. These include the growing shift away from compensation claims—where credits are said to negate other emissions—and toward nonoffsetting contributions claims. We also review the evolving policy environment, including the latest decisions (at the time of finalization) under the Paris Agreement and efforts to regulate offsets and liability in other jurisdictions.

6.1. Causes of the Market Contraction

The recent disruption to carbon markets followed a series of high-quality research outputs demonstrating pervasive overcrediting in both voluntary markets (4, 7, 10, 17, 45, 54, 173) and compliance markets (5, 6). Many of these articles generated press coverage in popular media outlets (55, 174–176). This body of research was augmented by high-quality investigative reports published by journalists in respected magazines and newspapers (16, 18, 177). These articles detailed deceptive business practices, adding narrative salience to researchers' incriminating, but impersonal, analyses. Many large companies that had previously embraced offsets reversed their positions. United Airlines stepped back from all carbon crediting, and in 2023 its CEO publicly denounced the majority of offsets as "fraud" (178). The same year, Delta Airlines was sued over its claim to be the world's first carbon-neutral airline, and the company later halted its purchasing of credits, joining a growing list of large firms reducing their reliance on the VCM (180).

6.2. Market Responses and Innovations

In response to decreased demand and the prospect of regulation, several supply-side innovations have sought to address the market's current challenges. These efforts have generally taken one of two approaches: (a) increasing credit quality or (b) changing the fundamental claim behind offset projects.

6.2.1. Efforts to increase quality. Industry groups, eager to demonstrate to policymakers that developers can effectively self-regulate, have sought to chart a middle ground between increasing credit quality and preserving market access for incumbent firms (181). Chief among these efforts

is the Integrity Council for the Voluntary Carbon Market (ICVCM), which in 2023 published a set of principles meant to distinguish between high-integrity and low-integrity credits. The ICVCM is currently reviewing—and approving or rejecting—existing crediting methodologies. In November 2024, two members of the ICVCM’s expert panel, including the panel’s cochair from 2021 to 2023, resigned over the ICVCM’s decision to endorse methodologies for forestry credits they say do not adequately address the risks of overcrediting, nonadditionality, and impermanence (182).

Other recent supply-side developments include a growing interest in “engineered removals,” such as through direct air capture—which are generally more expensive but regarded as posing fewer challenges for quantification and additionality—and a shift toward jurisdictional REDD+ projects (183). On the demand side, institutions are actively debating how credits ought to be applied in corporate carbon accounting. In 2023, the Voluntary Carbon Markets Integrity Initiative published its Claims Code of Practice, which stipulates, among other things, that companies must phase out the use of carbon credits after 2035 in order to meet a certain (beta version) of its standard. As of July 2025, SBTi is also reviewing how it allows companies to apply carbon credits to their decarbonization targets.

Simultaneously, researchers and others are increasingly recommending a focus on removals rather than emissions reductions or avoidance (70). While often couched in the pithy phrase “we can’t offset our way to net zero,” the shift to removals is also driven by the view that quantifying removals and demonstrating additionality is an easier task because most removals do not depend upon a counterfactual scenario in the way that avoidance and reductions do. Because many counterfactual scenarios cannot be proven with high confidence and are highly susceptible to gaming, advocates of removals argue that they offer a more trustworthy pathway to addressing residual emissions. That may be the case, but major unresolved questions remain about scaling high volumes of durable removals globally given economic and geophysical constraints (see Section 7) (60).

6.2.2. The contributions approach. The second approach to resolving the quality issues underlying carbon credits has been to shift away from framing carbon credits as compensation that negate emissions within a purchaser’s inventory. Under this new approach, payment for climate mitigation projects is framed instead as a contribution that is not meant to neutralize or reduce a firm’s carbon footprint (184–186). This has been framed as “taking responsibility for emissions without offsetting” (187). As discussed above, the UNFCCC has embraced a similar approach for the mitigation contribution unit or mitigation contribution A6.4ERs in the Paris compliance market.

The contributions approach seeks to provide finance for conservation and other valuable environmental interventions while avoiding the issues that have plagued carbon markets since their inception. It remains to be determined whether prospective funders of contributions-style projects would still see value in contributing financial resources without receiving a corresponding credit against which they can reduce their reported emissions against their climate targets. A potential middle-path approach could involve a certification program for companies that pursue a science-aligned contributions approach across their operations, for instance, by paying a carbon tax equal to the social cost of carbon and contributing the proceeds to high-quality offset projects (187). Such a certification would not claim that a company was carbon neutral but could conceivably include other language (e.g., climate accountable).

6.3. Recent Developments on Article 6

In 2024, parties to the Paris Agreement agreed at COP29 to advance draft text that further operationalized Article 6 of the Agreement. Article 6 calls for creating UN-approved pathways for

countries to collaborate on emissions reductions and removals in ways that are recognized against national climate change pledges (NDCs). The Article 6.2 pathway calls for bilateral arrangements between nations, while the Article 6.4 market, a successor to the CDM, allows private developers to generate and sell authorized credits and MCUs.

Notably, the new text includes a “sustainable development tool” intended to promote environmental and social safeguards, and the mechanisms are instructed to prohibit credits issued against projects that could potentially lead to the “lock-in” of fossil energy infrastructure (188). But negotiators’ achievements seem unlikely to address the relatively intractable problems addressed above. For example, the proposed language on credit quality requires that methodologies ensure issued credits are additional and that leakage is accounted for. But many (if not all) relevant methodology developers operating today would contend that credits issued under their guidelines are already high quality. Put differently, the United Nations is not necessarily creating new rules but rather restating long-ignored tenets of carbon market development, with the specious expectation that this time the outcomes might differ significantly.

The new UNFCCC pathways retain many of the highly problematic features of their predecessors. These include a relative lack of enforcement mechanisms or penalties that would disincentivize parties from selling or buying dubious or fraudulent credits. For instance, the draft text only “requests” (rather than requires) countries to abstain from using Article 6.2 credits that have been identified in quality checks as potentially double-counted (189). In a telling decision, hundreds of millions of CDM credits are likely to be transferred over to become Article 6.4 credits, despite their well-documented problems.

How Article 6 is operationalized will now depend on the decisions of UNFCCC bodies, including the Article 6.4 Supervisory Body and the Technical Expert Review process. It will also depend on whether (and how) parties choose to rely on Article 6 credits to achieve their NDCs. As of 2022, 120 nations indicated in their NDCs that they might use UNFCCC market mechanisms; only 13 reported that they would not (190). Ultimately, the outcome of COP29 suggests that UNFCCC decision-makers have not sufficiently heeded decades of evidence regarding what works in carbon markets and what undermines credit quality.

7. CONCLUSION

A broad review of research on carbon credits suggests that many of the problems plaguing the market are likely intractable. Put differently, the present market failures are not due to a few bad apples but rather to systematic, deep-seated problems, which will not be resolved by incremental changes. In light of these findings, our primary recommendation is that all stakeholders focus on creating rules to find and fund the relatively few high-integrity approaches while employing alternative, nonoffsetting strategies (such as contribution claims) for the rest. In addition, a primary focus for offsets going forward must be on high-quality durable removals, which sharply constrain what CDR is viable (191, 192), along with strong and enforceable long-term monitoring, reporting, and verification.

Warnings of intractable offset quality problems date back a quarter-century (64, 87, 111). A 1999 book on the Kyoto Protocol discussed “the danger that the CDM could become a mechanism for weakening action in the industrialized world *without* any offset *additional* activity in the developing countries” (111, p. 229). This is the same fear we have today for both voluntary and compliance markets, especially as the latter starts accepting CDM projects.

We find that the only way to significantly improve offset integrity is by limiting projects to those highly likely to be additional (3). We also find that the leakage and durability problems rule out a large majority of forestry projects, including REDD+, for offsetting fossil CO₂ emissions (59, 71). We conclude that, due to intractable or nearly intractable problems in additionality, permanence,

and leakage, the following are generally not well-suited to offset approaches: REDD+ and improved forest management, renewable energy generation, and soil carbon sequestration. However, research has documented that high-integrity offsets are possible at the project level with certain rigorous approaches, including clean cookstoves (10) and landfill gas capture (3). While research on these project types still finds regular overcrediting, the underlying issues are not intractable and could conceivably be remedied with appropriate tools and conservative accounting. Further research is needed to ascertain whether other project types (e.g., wetland restoration) could reach reasonable thresholds of integrity.

In any event, these high-integrity approaches would still require that corresponding adjustments be made to avoid undermining Paris commitments. Exceptions to that rule might apply to CDR taking place outside of national boundaries, projects taking place in jurisdictions that are not party to the Paris Agreement, or engineered removals that are not counted toward any NDC.

A key question is whether a world that must approach net zero at midcentury can, in the long term, accommodate offsets that are not high-quality removals with geologic storage. The vast majority of current offsets are avoided emissions or emissions reductions, so they merely shift emissions from one place to another if they are used to neutralize other emissions. Thus, they are not driving rapid and deep decarbonization. Finally, since everyone has to go to zero or near zero, isn't it counterproductive for a country to sell a significant quantity of authorized offsets now with the risk the price might be considerably higher in the future for the replacements?

In terms of removals, the 2022 IPCC mitigation assessment looked at emissions pathways in the literature and found that CDR high-quality removals options “are mostly limited to BECCS [bioenergy with carbon capture and storage], afforestation and direct air CO₂ capture and storage (DACCS)” (193, p. 85). With afforestation unable to meet geologic net zero and other criteria, the focus shifts to DACCS and BECCS.

Yet CCS is not yet commercially scalable, as the IPCC's 2022 mitigation assessment noted: “Implementation of CCS currently faces technological, economic, institutional, ecological-environmental and socio-cultural barriers” (12, p. 28). Significant and unresolved questions remain about the possibility of achieving high volumes of CCS given economic and geophysical constraints (60). For reference, capturing and storing only 3.5 Gt CO₂ a year geologically generates a volume of supercritical CO₂ of approximately 100 million barrels a day—the current production level of the global oil industry, which took a century to develop (194). That would leave a quarter-century between now and midcentury to scale an industry capable of capturing, transporting, and burying a comparable volume to sequester approximately 7% of GHGs emitted annually today.

BECCS and DACCS are not commercially viable today. Together, they sequestered only 0.001% of global GHG emissions in 2023 (195). Trying to scale either one in the foreseeable future would be counterproductive (see the sidebar titled Scalability Challenges Facing BECCS and DACCS). Carbon removal has a “long history” of initial hype of innovations “that so far have all failed to live up to expectations” (196). If we do not “drastically reduce emissions first,” CDR “will be next to useless,” argues a 2023 *Nature* article (197, p. 9), which concludes: “We must be prepared for CDR to be a failure.”

So, the world's focus must be on rapid and deep GHG emissions reductions with the goal of reaching near zero emissions by midcentury. Governments, academic researchers, and industry partners must aggressively pursue research and development on CDR strategies to determine which are the most practical, scalable, affordable, durable, and verifiable over time. Those reductions and CDR strategies that do scale must be consistent with environmental justice and the protection of the rights of Indigenous people and local communities. Finally, non-CDR offsets must be used with extraordinary caution and should be phased out by 2035, as the Voluntary Carbon Markets Integrity Initiative recommended in 2023, especially if they lack a corresponding

SCALABILITY CHALLENGES FACING BECCS AND DACCS

In bioenergy with carbon capture and storage (BECCS), growing biomass removes CO₂ from the air, and a CCS system on the bioenergy plant buries it. A 2022 review by the European Academies' Science Advisory Council concluded that BECCS was not scalable and that "there are substantial risks of it failing to achieve net removals at all" (200, p. 2). Significantly scaling up BECCS would rely heavily on cutting down trees, which in turn would increase net emissions—and thus warming—for decades, since it would take that long for the replanted seedlings to grow and absorb enough CO₂ to make total BECCS life-cycle emissions negative as opposed to leaving the original trees alone and deploying the best low-carbon alternatives at that time (200, 201). As the IPCC concluded in 2022, "BECCS is not projected to be widely implemented for several decades" and it "is associated with early-on positive CO₂ emissions and net-negative effects are only achieved in time (carbon debt), and its potential is limited" (12). These positive emissions and warming keep growing as long as the biomass harvesting keeps scaling up, and the resulting carbon debt doesn't even start to decline until that scaling up ends (201).

Direct air carbon capture and storage (DACCS) pulls CO₂ directly out of the ambient atmosphere and sequesters it underground. The European Academies' Science Advisory Council noted that "up to 20 times as much energy is required to remove a tonne of CO₂ from the atmosphere than to prevent that tonne entering in the first place" (200, p. 16). DACCS is highly energy-inefficient (50), and until the grid is nearly carbon-free, the zero-carbon electricity needed to run DACCS would reduce far greater emissions more cheaply by directly replacing fossil fuels in power generation (202). Similarly, as the grid decarbonizes, powering electrification technologies like electric vehicles or heat pumps will be a better application of renewable energy than running DACCS, in terms of emissions abatement (203). Put differently, scaling up DACCS by 2050 past 1 Gt CO₂/year "could risk incurring significant energy-transition opportunity costs" (204). Tellingly, the median value of DACCS removals in 2050 in the pathways assessed by the IPCC is 0.02 Gt CO₂/year (193).

adjustment. As Energy Australia, one of the country's largest electricity and gas providers, acknowledged in a May 2025 settlement agreement, "Burning fossil fuels creates greenhouse gas emissions that are not prevented or undone by carbon offsets" (198).

Expending significant effort and funds to "improve" and expand the business-as-usual use of non-CDR offsets brings to mind the timeless advice from Peter Drucker in the *Harvard Business Review*: "There is surely nothing quite so useless as doing with great efficiency what should not be done at all" (199, p. 53).

SUMMARY POINTS

1. Carbon credits in both voluntary and compliance markets face seemingly intractable issues, leading to rampant overcrediting and undermining global climate progress.
2. The most severe issues are nonadditionality, impermanence, leakage, double counting, perverse incentives, and the gameability of crediting systems, where bad actors have been able to routinely circumvent even well-designed rules.
3. These intractable problems have persisted despite more than two decades of efforts at market reform and seem unlikely to be resolved in the foreseeable future by ongoing interventions by international and/or nonstate actors.
4. Irrespective of their climate impact, carbon credits demonstrate a pattern of major environmental justice violations. However, many projects are championed by local communities, Indigenous groups, and conservationists.

5. After nearly a decade of negotiations, COP29 launched the Paris Agreement's global compliance markets for carbon credits, in the form of a bilateral pathway and a credit-based successor to the Clean Development Mechanism. But the United Nations Framework Convention on Climate Change (UNFCCC) did not substantially address quality problems, creating the risk the market will be rife with overcrediting and other shortcomings.
6. The voluntary carbon market could undermine the UNFCCC approaches. We recommend urgently phasing out non-CO₂ removal (CDR) offsets over the next decade, especially if they lack a corresponding adjustment.
7. Going forward, all offset markets should prioritize developing high-integrity, durable CDR and storage, while recognizing that the recent literature has raised the question of whether durable means 100 years, 1,000 years, or longer.
8. Future research and investment is necessary to understand what role—and at what scale—CDR can play in helping meet global climate goals and limiting climate change.

FUTURE ISSUES

1. Are high-integrity offsets scalable, and if so, at what price? Answering this question will determine the size and volume of a hypothetical high-integrity offset market.
2. How will industry actors and policymakers use the nascent Article 6 credits?
3. Should renewable energy certificates be disallowed for offsetting corporate Scope 2 emissions?
4. Can durable CDR fill the gaps previously occupied by carbon credits and create robust demand for carbon-negative technology? How would large-scale CDR operate given finite resource constraints (particularly land) and high costs?
5. What national and international bodies might enforce the needed long-term monitoring of long-term CDR, and, if necessary, stop storage projects based on the results of a monitoring program?
6. What role should high-integrity credits and/or CDR play in corporate climate commitments? Should they be eligible to be claimed against corporate inventories, or should claims be restricted to the contributions model?

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

ACKNOWLEDGMENTS

The authors thank Dr. Barbara Haya for her input. The views expressed in this article are solely the responsibility of the authors.

LITERATURE CITED

1. Benton T, Calvo E, Cowie A, Masson-Delmotte V, Elbehri A, et al. 2022. Annex I: glossary. In *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the 6th Assessment Report of the Intergovernmental Panel on Climate Change*, ed. PR Shukla, J Skea, R Slade, A Al Khourdajie, R van Diemen, et al. Cambridge University Press
2. Macintosh A, Butler D, Larraondo P, Evans MC, Ansell D, et al. 2024. Australian human-induced native forest regeneration carbon offset projects have limited impact on changes in woody vegetation cover and carbon removals. *Commun. Earth Environ.* 5(1):149
3. Cames M, Harthan RO, Füssler J, Lazarus M, Lee C, et al. 2016. *How additional is the Clean Development Mechanism?* Study, Öko-Institut
4. Probst BS, Toetzel M, Kontoleon A, Díaz Anadón L, Minx JC, et al. 2024. Systematic assessment of the achieved emission reductions of carbon crediting projects. *Nat. Commun.* 15:9562
5. Badgley G, Freeman J, Hamman JJ, Haya B, Trugman AT, et al. 2022. Systematic over-crediting in California's forest carbon offsets program. *Glob. Change Biol.* 28(4):1433–45
6. Haya B, Evans S, Brown L, Bukoski J, Butsic V, et al. 2023. Comprehensive review of carbon quantification by improved forest management offset protocols. *Front. For. Glob. Change* 6:958879
7. West TAP, Wunder S, Sills EO, Börner J, Rifai SW, et al. 2023. Action needed to make carbon offsets from forest conservation work for climate change mitigation. *Science* 381(6660):873–77
8. Pierce MH, Strong AL. 2023. An evaluation of New York state livestock carbon offset projects under California's Cap and Trade Program. *Carbon Manag.* 14(1):2211946
9. Pickering AJ, Arnold BF, Dentz HN, Colford JM, Null C. 2017. Climate and health co-benefits in low-income countries: a case study of carbon financed water filters in Kenya and a call for independent monitoring. *Environ. Health Perspect.* 125(3):278–83
10. Gill-Wiehl A, Kammen DM, Haya BK. 2024. Pervasive over-crediting from cookstove offset methodologies. *Nat. Sustain.* 7(2):191–202
11. Kollmuss A, Schneider L, Zhezherin V. 2015. Has joint implementation reduced GHG emissions? Lessons learned for the design of carbon market mechanisms. Work. Pap., Stockholm Environment Institute
12. Shukla PR, Skea J, Slade R, Al Khourdajie A, van Diemen R, et al., eds. 2022. *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the 6th Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press
13. United Nations High-Level Expert Group on the Net Zero Emissions Commitments of Non-State Entities. 2022. *Integrity matters: net zero commitments by businesses, financial institutions, cities and regions*. Rep., United Nations
14. Science Based Targets Initiative (SBTi). 2024. *Evidence synthesis report. Part 1: Carbon credits*. Rep., SBTi
15. Rath A, White N, Pogkas D. 2024. More companies ditch junk carbon offsets but new buyers loom. *Bloomberg*, Oct. 24
16. Greenfield P. 2023. Revealed: More than 90% of rainforest carbon offsets by biggest certifier are worthless, analysis shows. *The Guardian*, Jan. 18
17. Romm J. 2023. *Are carbon offsets unscalable, unjust, and unfixable—and a threat to the Paris Climate Agreement?* White Paper, Penn Center for Science, Sustainability, and the Media, University of Pennsylvania
18. Elgin B. 2020. These trees are not what they seem. *Bloomberg*, Dec. 9
19. Baird IG, Green WN. 2020. The Clean Development Mechanism and large dam development: contradictions associated with climate financing in Cambodia. *Clim. Change* 161(2):365–83
20. Cael R, Colmer J, Dechezleprêtre A, Glachant M. 2021. Do carbon offsets offset carbon? Work. Pap. 398, Grantham Research Institute for Climate Change and the Environment
21. Bennett G. 2022. Today's VCM, explained in three figures. *Ecosystem Marketplace*. <https://www.ecosystemmarketplace.com/articles/todays-vcm-explained-in-three-figures/>
22. United Nations Framework Convention on Climate Change (UNFCCC). 2018. *Achievements of the Clean Development Mechanism, harnessing incentive for climate action (2001–2018)*. Rep., United Nations

23. Chen Q, Ryan N, Xu DY. 2024. Adverse selection in carbon offset markets: evidence from the Clean Development Mechanism in China. Work. Pap., Fudan University/Duke University/Yale University
24. Paulsson E. 2009. A review of the CDM literature: from fine-tuning to critical scrutiny? *Int. Environ. Agreem. Political Law Econ.* 9(1):63–80
25. Haya B. 2010. *Carbon offsetting: an efficient way to reduce emissions or to avoid reducing emissions? An investigation and analysis of offsetting design and practice in India and China*. PhD Thesis, University of California, Berkeley
26. Schneider L, Kollmuss A. 2015. Perverse effects of carbon markets on HFC-23 and SF₆ abatement projects in Russia. *Nat. Clim. Change* 5(12):1061–63
27. World Bank. 2018. *Carbon Markets Under the Kyoto Protocol*. World Bank
28. World Bank. 2023. *State and Trends of Carbon Pricing 2023*. World Bank
29. California Air Resources Board (CARB). Compliance offset program. CARB. <https://ww2.arb.ca.gov/our-work/programs/compliance-offset-program>
30. Haya B, Anderegg WRL, Axelsson K, Blanchard L, Lezak S. 2024. *Commentary on SBTi's discussion paper: aligning corporate value chains to global climate goals*. Comment, Berkeley Carbon Trading Project, University of California, Berkeley
31. Coffield SR, Vo CD, Wang JA, Badgley G, Goulden ML, et al. 2022. Using remote sensing to quantify the additional climate benefits of California forest carbon offset projects. *Glob. Change Biol.* 28(22):6789–806
32. Stapp J, Nolte C, Potts M, Baumann M, Haya BK, Butsic V. 2023. Little evidence of management change in California's forest offset program. *Commun. Earth Environ.* 4(1):331
33. Haya B. 2019. *The California Air Resources Board's U.S. Forest offset protocol underestimates leakage*. Response to Comments by the California Air Resources Board, Center for Environmental Public Policy, University of California, Berkeley
34. Randazzo NA, Gordon DR, Hamburg SP. 2023. Improved assessment of baseline and additionality for forest carbon crediting. *Ecol. Appl.* 33(3):e2817
35. Macintosh A, Larraondo P, Butler D, Ansell D, Waschka M, Evans M. 2022. Trends in forest and sparse woody cover inside ERF HIR project areas relative to those in surrounding areas. Work. Pap., University of New South Wales
36. Allen M, Babiker M, Chen Y, de Coninck H, Connors S, et al. 2022. *Global Warming of 1.5°C: IPCC Special Report on Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels in Context of Strengthening Response to Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*. Cambridge University Press
37. United Nations Framework Convention on Climate Change (UNFCCC). 2016. Decision 1/CP.21. In *Report of the Conference of the Parties on its 21st Session, Held in Paris from 30 November to 13 December 2015. Addendum. Part Two: Action Taken by the Conference of the Parties at Its 21st Session*. United Nations. <https://unfccc.int/resource/docs/2015/cop21/eng/10a01.pdf#page=2>
38. Schumer C. 2021. *How national net-zero targets stack up after the COP26 climate summit*. Tech. Perspect., World Resources Institute
39. Maizland L. *COP26: here's what countries pledged*. Brief, Council on Foreign Relations
40. Bowcott H, Pachthod D, Pinner D. 2021. What COP26 means for business. *McKinsey Sustainability*, Novemb. 12
41. Daedal Research. 2022. *Voluntary carbon market: analysis by traded volume, by credit retirements, by credit issuance, by project category, by type of project, by region size and trends with impact of COVID-19 and forecast up to 2027*. Daedal Research. <https://www.researchandmarkets.com/reports/5697812/voluntary-carbon-market-analysis-by-value-by>
42. Shell Group, Boston Consulting Group (BCG). 2022. *The voluntary carbon market: 2022 insights and trends*. Rep., Shell Group/BCG
43. Trencher G, Nick S, Carlson J, Johnson M. 2024. Demand for low-quality offsets by major companies undermines climate integrity of the voluntary carbon market. *Nat. Commun.* 15:6863
44. Haya B, Anderegg WRL, Axelsson K, Blanchard L, Lezak S. 2024. *Commentary on SBTi's discussion paper: aligning corporate value chains to global climate goals*. Comment, Berkeley Carbon Trading Project, University of California, Berkeley

45. Haya B, Alford-Jones K, Anderegg W, Beymer-Farris B, Blanchard L, et al. 2023. *Quality assessment of REDD+ carbon credit projects*. Rep., Berkeley Carbon Trading Project
46. International Energy Agency (IEA). 2024. *World energy outlook 2024*. Rep., IEA
47. Spalding-Fecher R, Achanta AN, Erickson P, Haites E, Lazarus M, et al. 2012. *Assessing the Impact of the Clean Development Mechanism*. Rep., High-Level Panel on the CDM Policy Dialogue
48. Schneider L. 2009. Assessing the additionality of CDM projects: practical experiences and lessons learned. *Clim. Policy* 9(3):242–54
49. Terres C, Phillips RP, Hungate BA, Rosende J, Pett-Ridge J, et al. 2021. A trade-off between plant and soil carbon storage under elevated CO₂. *Nature* 591(7851):599–603
50. Committee on Developing a Research Agenda for Carbon Dioxide Removal and Reliable Sequestration, Board on Atmospheric Sciences and Climate, Board on Energy and Environmental Systems, Board on Agriculture and Natural Resources, Board on Earth Sciences and Resources, et al. 2019. *Negative Emissions Technologies and Reliable Sequestration: A Research Agenda*. National Academies Press
51. Kristensen JÅ, Barbero-Palacios L, Barrio IC, Jacobsen IBD, Kerby JT, et al. 2024. Tree planting is no climate solution at northern high latitudes. *Nat. Geosci.* 17(11):1087–92
52. Gillenwater M, Broekhoff D, Trexler M, Hyman J, Fowler R. 2007. Policing the voluntary carbon market. *Nat. Clim. Change* 1(711):85–87
53. US Government Accountability Office (GAO). 2008. *International climate change programs: lessons learned from the European Union's Emissions Trading Scheme and the Kyoto Protocol's Clean Development Mechanism*. Rep. GAO-09-151, GAO
54. Guizar-Coutiño A, Jones JPG, Balmford A, Carmenta R, Coomes DA. 2022. A global evaluation of the effectiveness of voluntary REDD+ projects at reducing deforestation and degradation in the moist tropics. *Conserv. Biol.* 36(6):e13970
55. Song L, Temple J. 2021. The climate solution actually adding millions of tons of CO₂ into the atmosphere. *ProPublica/MIT Technology Review*, April 29
56. Wyburd I. 2024. *Hidden in plain sight: flawed renewable energy projects in the voluntary carbon market*. Rep., Carbon Market Watch
57. Civillini M, Lo J. 2024. Renewable-energy carbon credits rejected by high-integrity scheme. *Climate Home News*, Aug 7. <https://www.climatechangenews.com/2024/08/07/renewable-energy-carbon-credits-rejected-by-high-integrity-scheme>
58. White N, Ratcliffe V. 2022. How the 2022 World Cup rebuilt a market for dodgy carbon credits. *Bloomberg*, Novemb. 17
59. Filewod B, McCarney G. 2023. Avoiding carbon leakage from nature-based offsets by design. *One Earth* 6(7):790–802
60. Lamb WF, Gasser T, Roman-Cuesta RM, Grassi G, Gidden MJ, et al. 2024. The carbon dioxide removal gap. *Nat. Clim. Change* 14(6):644–51
61. Atmadja SS, Duchelle AE, De Sy V, Selviana V, Komalasari M, et al. 2022. How do REDD+ projects contribute to the goals of the Paris Agreement? *Environ. Res. Lett.* 17:044038
62. Haya B. 2019. *POLICY BRIEF: The California Air Resources Board's U.S. Forest offset protocol underestimates leakage*. Policy brief, Goldman School of Public Policy, UC Berkeley, May. https://gspp.berkeley.edu/assets/uploads/research/pdf/Policy_Brief-US_Forest_Projects-Leakage-Haya_2.pdf
63. Brown P, Cabarle B, Livernash ER. 1997. *Carbon counts estimating climate change mitigation in forestry projects*. Rep., World Resources Institute
64. Richards K, Andersson K. 2001. The leaky sink: persistent obstacles to a forest carbon sequestration program based on individual projects. *Clim. Policy* 1(1):41–54
65. Archer D, Eby M, Brovkin V, Ridgwell A, Cao L, et al. 2009. Atmospheric lifetime of fossil fuel carbon dioxide. *Annu. Rev. Earth Planet. Sci.* 37:117–34
66. Stubbs M, Hoover K, Ramseur JL. 2021. *Agriculture and forestry offsets in carbon markets: background and selected issues*. Rep., Congressional Research Service
67. Joppa L, Luers A, Willmott E, Friedmann SJ, Hamburg SP, Broze R. 2021. Microsoft's million-tonne CO₂-removal purchase—lessons for net zero. *Nature* 597(7878):629–32
68. Anderegg WRL, Chegwiddden OS, Badgley G, Trugman AT, Cullenward D, et al. 2022. Future climate risks from stress, insects and fire across US forests. *Ecol. Lett.* 25(6):1510–20

69. Martin MP, Woodbury DJ, Doroski DA, Nagele E, Storace M, et al. 2021. People plant trees for utility more often than for biodiversity or carbon. *Biol. Conserv.* 261:109224
70. Axelsson K, Wagner A, Johnstone I, Allen M, Caldecott B, et al. 2024. *Oxford Principles for Net Zero Aligned Carbon Offsetting*. Oxford Smith School of Enterprise and the Environment. Revis. ed.
71. Allen MR, Frame DJ, Friedlingstein P, Gillett NP, Grassi G, et al. 2024. Geological net zero and the need for disaggregated accounting for carbon sinks. *Nature* 638:343–50
72. Brunner C, Hausfather Z, Knutti R. 2024. Durability of carbon dioxide removal is critical for Paris climate goals. *Commun. Earth Environ.* 5(1):645
73. Allen MR, Friedlingstein P, Girardin CAJ, Jenkins S, Malhi Y, et al. 2022. Net zero: science, origins, and implications. *Annu. Rev. Environ. Resour.* 47:849–87
74. University of Oxford. 2024. Redefining ‘net zero’ will not stop global warming, new study shows. *University of Oxford News*, Novemb. 18
75. Global CCS Institute. 2024. *Global status of CCS*. Rep., Global CCS Institute
76. George JR. 2020. Letter to Senator Robert Menendez, Inspector General for Tax Administration, Department of the Treasury, April 15
77. Hoicka CE, Paterson M, Carter A, MacLean J, Eaton E, Homer-Dixon T. 2022. *Letter from scientists, academics, and energy system modellers: Prevent proposed CCUS investment tax credit from becoming a fossil fuel subsidy*. Open Letter, Environmental Defense
78. García JH, Torvanger A. 2019. Carbon leakage from geological storage sites: implications for carbon trading. *Energy Policy* 127:320–29. <https://doi.org/10.1016/j.enpol.2018.11.015>
79. Romm J. 2025. *The Hype About Hydrogen: False Promises and Real Solutions in the Race to Save the Climate*. Island Press
80. Monastersky R. 2013. Seabed scars raise questions over carbon-storage plan. *Nature* 504(7480):339–40
81. Donnelly E. 2024. Norway’s Equinor admits it over-reported amount of carbon captured at flagship project for years. *DeSmog*, Oct. 28
82. Ringrose PS, Mathieson AS, Wright IW, Selama F, Hansen O, et al. 2013. The In Salah CO₂ storage project: lessons learned and knowledge transfer. *Energy Proc.* 37:6226–36
83. Johnson AM Jr. 2008. An economic analysis of the duty to disclose information: lessons learned from the caveat emptor doctrine. *San Diego Law Rev.* 45(1):79–132
84. Smith JB. 2019. California compliance offsets: problematic protocols and buyer behavior. Work. Pap. 120, Mossavar-Rahmani Center for Business and Government, Harvard Kennedy School
85. Cloutier D, Robinson S, Sullivan G. 2021. The coming U.S. regulatory oversight of, and demand for, climate disclosure. *CRE Real Estate Issues* 45(28). <https://cre.org/real-estate-issues/the-coming-u-s-regulatory-oversight-of-and-demand-for-climate-disclosure>
86. Broekhof D, Gillenwater M, Colbert-Sangree T, Cage P. 2020. *Securing climate benefit: a guide to using carbon offsets*. Rep., Greenhouse Gas Management Institute/Stockholm Environment Institute. https://www.offsetguide.org/wp-content/uploads/2020/03/Carbon-Offset-Guide_3122020.pdf
87. Stavins RN. 1997. Policy instruments for climate change: How can national governments address a global problem? *Univ. Chicago Leg. Forum* 1997:293–329
88. Victor DG. 2010. The politics and economics of international carbon offsets. In *Modeling the Economics of Greenhouse Gas Mitigation: Summary of a Workshop*. National Academies Press
89. Coy P. 2023. To fight climate change, we need a better carbon market. *New York Times*, Aug. 23
90. Dutu R, Nosal E, Rocheteau G. 2005. *The tale of Gresham’s law*. Econ. Comment., Federal Reserve Bank of Cleveland
91. Watanabe K, Saunders J, Turner G, Nishikawa L. 2024. *Corporate emissions performance and the use of carbon credit*. Res. Rep., MSCI
92. Ecosystem Marketplace Insights Team. 2023. *New research: Carbon credits are associated with businesses decarbonizing faster*. Ecosystem Marketplace
93. Sylvera. 2023. *Carbon credits: permission to pollute, or pivotal for progress?* Mark. Anal. Rep., Sylvera
94. Ecosystem Marketplace. 2023. *State of the voluntary carbon markets 2023*. Rep., Forest Trends Association
95. Trouwloon D, Streck C, Chagas T, Martinus G. 2023. Understanding the use of carbon credits by companies: a review of the defining elements of corporate climate claims. *Glob. Chall.* 7(4):2200158

96. Stolz N, Probst B. 2024. *The negligible role of carbon offsetting in corporate climate strategies*. Work. Pap., Max Planck Institute for Innovation and Competition
97. Dufresne G. 2023. Correlation or causation: Is there a link between carbon offsetting and climate ambition? *Carbon Market Watch*, Dec. 2
98. Elgin B, Rangarajan S. 2022. What really happens when emissions vanish. *Bloomberg*, Oct. 31
99. Gillenwater M. 2008. Redefining RECs. Part 1: Untangling attributes and offsets. *Energy Policy* 36(6):2109–19
100. Bjørn A, Lloyd S, Brander M, Matthews H. 2022. Renewable energy certificates threaten the integrity of corporate science-based targets. *Nat. Clim. Change* 12(6):539–46
101. Guix M, Ollé C, Font X. 2022. Trustworthy or misleading communication of voluntary carbon offsets in the aviation industry. *Tour. Manag.* 88:104430
102. Competition and Markets Authority. 2021. *Global sweep finds 40% of firms' green claims could be misleading*. Press Release, UK Government, Jan. 28
103. Trencher G, Blondeel M, Asuka J. 2023. Do all roads lead to Paris? Comparing pathways to net-zero by BP, Shell, Chevron and ExxonMobil. *Clim. Change* 176(7):83
104. Watson E, Massei M, Farrelly A, Castro E, Ernest-Jones H. 2024. *SBTi Corporate Net-Zero Standard, version 1.2*. Standard, Science Based Targets Initiative
105. Environmental Defense Fund. 2018. *How to avoid double counting of emissions reductions*. Handbook, Environmental Defense Fund
106. Schneider L, Duan M, Stavins R, Kizzier K, Broekhoff D, et al. 2019. Double counting and the Paris Agreement rulebook. *Science* 366(6462):180–83
107. Favasuli S. 2021. Paris accord Article 6 approval set to jump-start evolution of voluntary carbon market. *S&P Global Commodity Insights*, Novemb. 17
108. United Nations Framework Convention on Climate Change (UNFCCC). 2023. *Overview of Article 6.4: the mechanism*. Webinar Slides, United Nations Climate Change Regional Collaboration Centres
109. Gold Standard for the Global Goals. 2022. *Claims guidelines*. Guidel., Gold Standard Foundation
110. Kreibich N, Hermwille L. 2021. Caught in between: credibility and feasibility of the voluntary carbon market post-2020. *Clim. Policy* 21(7):939–57
111. Grubb M, Vrolijk C, Brack D. 2018. *Kyoto Protocol 1999: A Guide and Assessment*. Routledge
112. Choudhury SR. 2021. *Shades of REDD+: corresponding adjustments, equity, and climate justice*. Rep., Ecosystem Marketplace
113. Schneider L, Kollmuss A, Lazarus M. 2014. Addressing the risk of double counting emission reductions under the UNFCCC. Work. Pap. 2014–02, Stockholm Environment Institute
114. Moura Costa P. 2022. *Opinion: corresponding adjustments and their impact on NDCs and additionality*. Rep., Ecosystem Marketplace
115. The World Bank. 2023. *Corresponding Adjustment and Pricing of Mitigation Outcomes*. World Bank Working Paper
116. Porsborg-Smith A, Nielsen J, Owolabi B, Clayton C. 2023. *Why the voluntary carbon market is thriving*. Rep., Boston Consulting Group
117. Padin-Dujon A. 2024. COP29: Correspondingly adjusted carbon credits trading at \$7–22, says market analytics firm. *Carbon Pulse*, Novemb. 20
118. Streck C, Bouchon S, Rocha M, Trouwloon D, Dyck M. 2023. *Double claiming and corresponding adjustments*. Rep., Climate Focus
119. International Carbon Reduction and Offset Alliance (ICROA). 2020. *ICROA's position on scaling private sector voluntary action post-2020*. Rep., ICROA
120. Brander M, Broekhoff D, Hewlett O. 2022. The future of the voluntary offset market: the need for corresponding adjustments. Work. Pap., University of Edinburgh
121. Gold Standard Foundation. 2020. *Operationalising and scaling post-2020 voluntary carbon market*. Tech. Rep., Gold Standard Foundation
122. UN-REDD Programme. Cancun safeguards. UN-REDD Programme. <https://www.un-redd.org/glossary/cancun-safeguards>
123. Olsen KH, Fenhann J. 2008. Sustainable development benefits of clean development mechanism projects. *Energy Policy* 36(8):2819–30

124. World Bank. 2021. *State and Trends of Carbon Pricing 2021*. World Bank
125. Sills EO, Atmadja S, de Sassi C, Duchelle AE, Kweka D, et al., eds. 2014. *REDD+ on the ground: a case book of subnational initiatives across the globe*. Rep., Center for International Forestry
126. Imai N, Samejima H, Langner A, Ong RC, Kita S, et al. 2009. Co-benefits of sustainable forest management in biodiversity conservation and carbon sequestration. *PLOS ONE* 4(12):e8267
127. Rahman MM, Zimmer M, Ahmed I, Donato D, Kanzaki M, Xu M. 2021. Co-benefits of protecting mangroves for biodiversity conservation and carbon storage. *Nat. Commun.* 12:3875
128. Alusiola RA, Schilling J, Klär P. 2021. REDD+ conflict: understanding the pathways between forest projects and social conflict. *Forests* 12(6):748
129. Duker AEC, Tadesse TM, Soentoro T, De Fraiture C, Kemerink-Seyoum JS. 2019. The implications of ignoring smallholder agriculture in climate-financed forestry projects: empirical evidence from two REDD+ pilot projects. *Clim. Policy* 19(Suppl. 1):S36–46
130. Milne S, Mahanty S. 2019. Value and bureaucratic violence in the green economy. *Geoforum* 98:133–43
131. Milne S, Mahanty S, To P, Dressler W, Kanowski P, Thavat M. 2019. Learning from “actually existing” REDD+: a synthesis of ethnographic findings. *Conserv. Soc.* 17(1):84
132. Lachnitt J, Tilianaki M. 2023. *Carbon offsetting at the cost of human rights? The case of TotalEnergies’ BaCaSi project in Congo*. Rep., Secours Catholique, Caritas
133. Counsell S. 2023. *Blood carbon: how a carbon offset scheme makes millions from Indigenous land in Northern Kenya*. Rep., Survival International
134. Battocletti V, Enriques L, Romano A. 2024. The voluntary carbon market: market failures and policy implications. *Univ. Colo. Law Rev.* 95(3):519–78
135. Sawathvong S, Hyakumura K. 2024. A comparison of the free, prior, and informed consent (FPIC) guidelines and the “Implementation of Governance, Forest Landscapes, and Livelihoods” project in Lao PDR: the FPIC team composition and the implementation process. *Land* 13(4):408
136. Haya B, Parekh P. 2011. Hydropower in the CDM: examining additionality and criteria for sustainability. Work. Pap., University of California, Berkeley
137. Fearnside PM. 2013. Credit for climate mitigation by Amazonian dams: loopholes and impacts illustrated by Brazil’s Jirau Hydroelectric Project. *Carbon Manag.* 4(6):681–96
138. Fearnside PM. 2015. Tropical hydropower in the clean development mechanism: Brazil’s Santo Antônio Dam as an example of the need for change. *Clim. Change* 131(4):575–89
139. Hultman N, Lou J, Hutton S. 2020. A review of community co-benefits of the clean development mechanism (CDM). *Environ. Res. Lett.* 15:053002
140. Angelsen A, Jagger P, Babigumira R, Belcher B, Hogarth NJ, et al. 2014. Environmental income and rural livelihoods: a global-comparative analysis. *World Dev.* 64(Suppl.):12–28
141. Chomba S, Kariuki J, Lund JF, Sinclair F. 2016. Roots of inequity: how the implementation of REDD+ reinforces past injustices. *Land Use Policy* 50:202–13
142. Hengeveld M. 2023. *Carbon offsetting project and human rights abuse in Kenya*. Rep., SOMO
143. Scheba A, Rakotonarivo OS. 2016. Territorialising REDD+: conflicts over market-based forest conservation in Lindi, Tanzania. *Land Use Policy* 57:625–37
144. Human Rights Watch. 2019. *Carbon credits or land grabs? A case study of the Rimba Raya REDD+ project in Central Kalimantan*, Indonesia. Rep., Human Rights Watch
145. Poudyal M, Ramamonjisoa BS, Hockley N, Rakotonarivo OS, Gibbons JM, et al. 2016. Can REDD+ social safeguards reach the ‘right’ people? Lessons from Madagascar. *Glob. Environ. Change* 37:31–42
146. Benjaminsen G. 2014. Between resistance and consent: project–village relationships when introducing REDD+ in Zanzibar. *Forum Dev. Stud.* 41(3):377–98
147. Mickels-Kokwe G, Mangwanya L. 2015. *Carbon Conflicts and Forest Landscapes in Africa*. London: Routledge
148. Yeang D. Community tenure rights and REDD+: a review of the Oddar Meanchey Community Forestry REDD+ project in Cambodia. *Aust. J. South-East Asian Stud.* 5(2):263–74
149. Chávez LT. 2024. *Carbon offsetting’s casualties*. Rep., Human Rights Watch
150. Oakland Institute. 2019. *Evicted for carbon credits: Norway, Sweden, and Finland displace Ugandan farmers for carbon trading*. Rep., Oakland Institute. https://www.oaklandinstitute.org/sites/oaklandinstitute.org/files/evicted-carbon_0.pdf

151. Lane R, Newell P. 2016. The political economy of carbon markets. In *The Palgrave Handbook of the International Political Economy of Energy*, ed. T Van De Graaf, BK Sovacool, A Ghosh, F Kern, MT Klare. Palgrave Macmillan
152. Kansanga MM, Luginaah I. 2019. Agrarian livelihoods under siege: carbon forestry, tenure constraints and the rise of capitalist forest enclosures in Ghana. *World Dev.* 113:131–42
153. Boyle L. 2021. Carbon offsetting ‘a new form of colonialism,’ says Indigenous leader at COP26. *The Independent*, Novemb. 4
154. Pham L, Gilbertson T, Witchger J, Soto-Daneco E, Goldtooth TBK. 2022. *Nature-based solutions*. Clim. Justice Prog. Brief., Indigenous Environmental Network
155. Middleton Manning BR, Reed K. 2019. Returning the Yurok Forest to the Yurok Tribe: California’s first tribal carbon credit project. *Stanford Environ. Law J.* 39(39):71–124
156. Schmid DV. 2023. Are forest carbon projects in Africa green but mean? A mixed-method analysis. *Clim. Dev.* 15(1):45–59
157. Docena H, ed. 2010. *Costly dirty money-making schemes: the Clean Development Mechanism projects in the Philippines*. Rep., Focus on the Global South
158. Lee CM, Lazarus M, Smith GR, Todd K, Weitz M. 2013. A ton is not always a ton: a road-test of landfill, manure, and afforestation/reforestation offset protocols in the U.S. carbon market. *Environ. Sci. Policy* 33:53–62
159. Verra. 2017. *VCS version 3 rules and requirements*. Verra. <https://verra.org/programs/verified-carbon-standard/vcs-version-3-archive-rules-and-requirements/>
160. Verra. 2024. *VCS Standard, Version 4.7*. Verra, April 15. <https://verra.org/wp-content/uploads/2024/04/VCS-Standard-v4.7-FINAL-4.15.24.pdf>
161. European Commission. 2023. Technical guidance on the application of “do no significant harm” under the EU taxonomy regulation. Recovery and Resilience Facility, European Commission. 2023 O.J. (C 111) 33
162. Dev T. 2023. *Discredited: the voluntary carbon market in India*. Rep., Centre for Science and Environment India
163. McConnell C, Maina N, Woolfrey S. 2024. *Carbon offset deals and the risks of green grabbing*. Rep., International Institute for Sustainable Development
164. Partnership for Market Readiness. 2021. *A Guide to Developing Domestic Carbon Crediting Mechanisms*. World Bank
165. Chomba S, Kariuki J, Lund JF, Sinclair F. 2016. Roots of inequity: how the implementation of REDD+ reinforces past injustices. *Land Use Policy* 50:202–13
166. Luttrell C, Sills E, Aryani R, Ekaputri AD, Evinke MF. 2018. Beyond opportunity costs: Who bears the implementation costs of reducing emissions from deforestation and degradation? *Mitig. Adapt. Strateg. Glob. Change* 23(2):291–310
167. Lyons K, Westoby P. 2014. Carbon colonialism and the new land grab: plantation forestry in Uganda and its livelihood impacts. *J. Rural Stud.* 36:13–21
168. da Silva CA, dos Santos SC, Rossetto OC. 2024. The Paiter Suruí Indigenous people in defence of their territory: the case of the Suruí Forest Carbon Project (PCFS)—Rondonia/Brazil. In *Traditional Knowledge and Climate Change*, ed. A Penteado, SP Chakrabarty, OH Shaikh. Springer
169. Brown HC. 2024. Forest-preservation credits win seal of approval from industry watchdog. *Wall Street Journal*, Novemb. 20
170. Mundy S. 2024. Solving the carbon market ‘integrity crisis.’ *Financial Times*, Aug. 7
171. Integrity Council for the Voluntary Carbon Market (ICVCM). 2024. *ICVCM annual review 2023–2024: building integrity in carbon markets*. Annu. Rep., ICVCM
172. Forest Trends Association. 2024. *State of the voluntary carbon market 2024*. Rep., Ecosystem Marketplace
173. West TAP, Börner J, Sills EO, Kontoleon A. 2020. Overstated carbon emission reductions from voluntary REDD+ projects in the Brazilian Amazon. *PNAS* 117(39):24188–94
174. Elgin B. 2023. Carbon offsets undercut California’s climate progress, researchers find. *Bloomberg*, Sept. 21
175. Greenfield P. 2024. Cookstove carbon offsets overstate climate benefit by 1,000%, study finds. *The Guardian*, Jan. 23

176. Pontecorvo E. 2024. Clean cookstoves are kind of bogus, too. *Heatmap*, Jan. 23
177. Blake H. 2023. The great cash-for-carbon hustle. *New Yorker*, Oct. 16
178. Parker B. 2023. Carbon offsetting schemes are ‘fraud’, says major airline CEO. *The Independent*, July 26
179. Greenfield P. 2023. Delta Air Lines faces lawsuit over \$1bn carbon neutrality claim. *The Guardian*, May 30. <https://www.theguardian.com/environment/2023/may/30/delta-air-lines-lawsuit-carbon-neutrality-aoe>
180. Rathi A, White N, Pogkas D. 2024. More companies ditch junk carbon offsets but new buyers loom. *Bloomberg*, Oct. 24
181. Ødegård C. 2024. *Governing the voluntary carbon market*. Master’s Thesis, University of Oslo
182. White N. 2024. Resignations at carbon oversight body raise quality questions. *Bloomberg*, Dec. 10
183. West TAP, Wunder S, Sills EO, Börner J, Rifai SW, et al. 2023. Action needed to make carbon offsets from forest conservation work for climate change mitigation. *Science* 381(6660):873–77
184. Blanchard L, Haya B, Lezak S, Anderegg W. 2024. The history of “contribution” approaches for climate mitigation: a narrative review. SSRN Scholarly Pap. 4971756. <http://dx.doi.org/10.2139/ssrn.4971756>
185. Dufrasne G. 2020. *Above and beyond carbon offsetting: alternatives to compensation for climate action and sustainable development*. Policy brief., Carbon Market Watch. <https://carbonmarketwatch.org/wp-content/uploads/2020/12/AboveAndBeyondCarbonOffsetting.pdf>
186. Kreibich N, Fraling J, Schulze-Steinen M, Köhlert M. 2024. *A guide to implementing the contribution claim model*. Foundation Development and Climate Alliance. https://allianz-entwicklung-klima.de/wp-content/uploads/2024/09/2409_Guide_Contribution-Claim-Model.pdf
187. Fearnough H, Skribbe R, de Grandpré J, Day T, Warnecki C. 2023. *A guide to climate contributions*. Rep., New Climate Institute
188. UNFCCC Article 6.4 Supervisory Body. *Application of the requirements of Chapter V.B (Methodologies) for the development and assessment of Article 6.4 mechanism methodologies (v.01.1)*. Standard, UNFCCC
189. United Nations Framework Convention on Climate Change (UNFCCC). 2024. *Guidance on cooperative approaches referred to in Article 6, paragraph 2, of the Paris Agreement and in decision 2/CMA.3*. UNFCCC. https://unfccc.int/sites/default/files/resource/cma3_auv_12a_PA_6.2.pdf
190. Fransen T, Henderson C, O’Connor R, Alayza N, Caldwell M, et al. 2022. *The state of nationally determined contributions: 2022*. Rep., World Resources Institute
191. Romm J. 2023. *Why direct air carbon capture and storage (DACCS) is not scalable and ‘net zero’ is a dangerous myth*. White Paper, Penn Center for Science, Sustainability, and the Media, University of Pennsylvania
192. Fankhauser S, Smith SM, Allen M, Axelsson K, Hale T, et al. 2022. The meaning of net zero and how to get it right. *Nat. Clim. Change* 12(1):15–21
193. Pathak M, Slade R, Pichs-Madruga R, Ürges-Vorsatz D, Shukla PR, et al. 2023. Technical summary. In *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the 6th Assessment Report of the Intergovernmental Panel on Climate Change*, ed. PR Shukla, J Skea, R Slade, A Al Khouradajie, R van Diemen, et al. Cambridge University Press
194. Mac Dowell N, Fennell PS, Shah N, Maitland GC. 2017. The role of CO₂ capture and utilization in mitigating climate change. *Nat. Clim. Change* 7(4):243–49
195. Smith S, Geden O, Gidden M, Lamb W, Nemet G, et al., eds. 2024. *The State of Carbon Dioxide Removal—2nd Edition*. Smith School of Enterprise and the Environment, University of Oxford. DOI: [10.17605/OSF.IO/F85QJ](https://doi.org/10.17605/OSF.IO/F85QJ)
196. Carton W, Asiyambi A, Beck S, Buck HJ, Lund JF. 2020. Negative emissions and the long history of carbon removal. *Wiley Interdiscip. Rev. Clim. Change* 11(6):e671
197. Ho DT. 2023. Carbon dioxide removal is not a current climate solution—we need to change the narrative. *Nature* 616(7955):9
198. EnergyAustralia. 2025. *Go Neutral Litigation – EnergyAustralia acknowledges issues with “offsetting” and moves away from carbon offsets for its residential customer products*. News Release, May 19, <https://www.energyaustralia.com.au/about-us/media/news/go-neutral-litigation-energyaustralia-acknowledges-issues-offsetting-and-moves>
199. Drucker PF. 1963. Managing for business effectiveness. *Harvard Bus. Rev.* 41(3):53–60

200. European Academies' Science Advisory Council (EASAC). 2022. *Forest bioenergy update: BECCS and its role in integrated assessment models*. Rep., EASAC
201. Romm J. 2023. *Why scaling bioenergy and bioenergy with carbon capture and storage (BECCS) is impractical and would speed up global warming*. White Paper, Penn Center for Science, Sustainability, and the Media, University of Pennsylvania
202. McQueen N, Desmond MJ, Socolow RH, Psarras P, Wilcox J. 2021. Natural gas versus electricity for solvent-based direct air capture. *Front. Clim.* 2:618644
203. Lattner J, Stevenson S. 2021. Renewable power for carbon dioxide mitigation. *AIChE J.* 2021(3):51–58
204. Kahsar R, Bloch C, Newcomb J, Wohl G. 2022. *Direct air capture and the energy transition*. Strategic Insight, RMI, July 18. <https://rmi.org/direct-air-capture-and-the-energy-transition/>