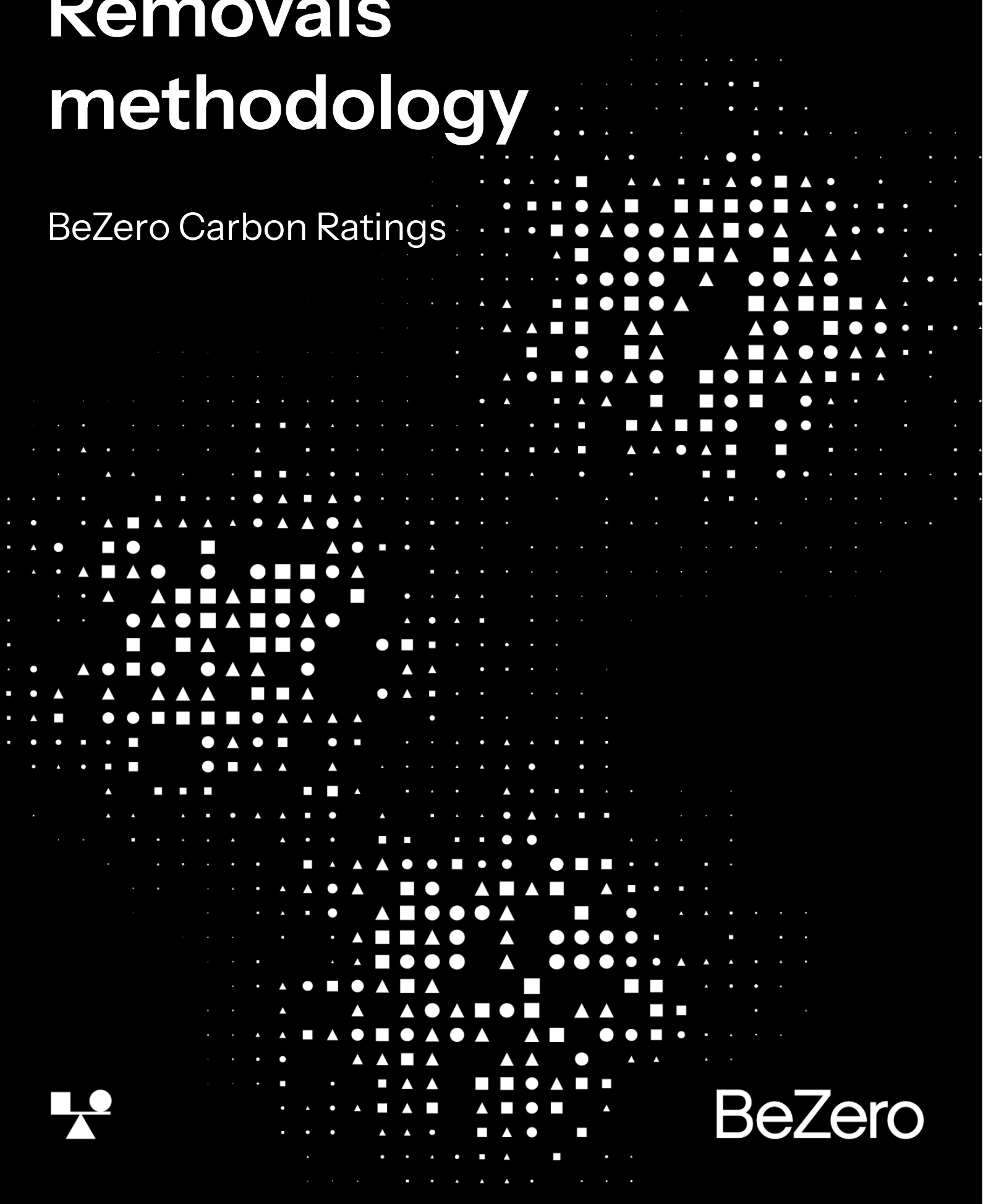
Engineered Carbon Removals methodology

BeZero Carbon Ratings



BeZero

Contents

Glossary **3**
Introduction **5**
What is the Engineered Carbon Removals sector group? 5
BeZero Carbon Rating analytical framework and process for Engineered Carbon Removals **6**
Holistic assessment 6
Carbon efficacy assessment **7**
Additionality 7
Carbon Accounting 11
Permanence 15
Appendix I: Sources as of January 2025 **19**
Third-party datasets 19
Literature sources 19
Appendix II: Additional reading **22**
Updates and reviews **23**

Introduction

BeZero Carbon is a global ratings agency for the carbon market. Our ratings provide a publicly available, risk-based framework for assessing carbon efficacy. We rate qualifying carbon credits in all sectors.

We take a research-first mindset, fusing traditional capital markets research practices with expertise in environmental sciences and technology. We think creatively about climate problems and build solutions the whole market can use.

We have developed extensive analytical frameworks to rate carbon credits on their likelihood of delivering on their promised carbon emissions avoidance or removal. These analytical frameworks are deeply sector nuanced and bring to the fore our extensive experience in rating hundreds of projects across dozens of sub-sectors.

Our Ratings, Geospatial, Data, and Research teams are made up of dozens of climate and data scientists, geospatial experts and financial market analysts. They bring with them the highest academic and industry credentials, a tenacious approach to scientific inquiry and a dedication to climate action through science. They hold PhDs and qualifications in disciplines from remote sensing, forest ecology, ecosystem disturbance, peatlands, and blue carbon to statistics, machine learning, artificial intelligence, financial research, industrial engineering, and public policy. They have published hundreds of academic papers and have been cited tens of thousands of times in peer-reviewed scientific academic literature.

As the market's number one risk metric, our ratings are available on our website and dozens of marketplaces, and alongside extensive analysis and research on our BeZero Carbon Markets platform.

What is the Engineered Carbon Removals sector group?

Engineered Carbon Removals sector group covers projects that use technical interventions to remove greenhouse gases from the atmosphere, storing atmospheric carbon in geological, ocean and stable terrestrial carbon pools.

In the BeZero Sector Classification system, Engineered Carbon Removals is one of six sector groups and contains four sectors and nine sub-sectors.

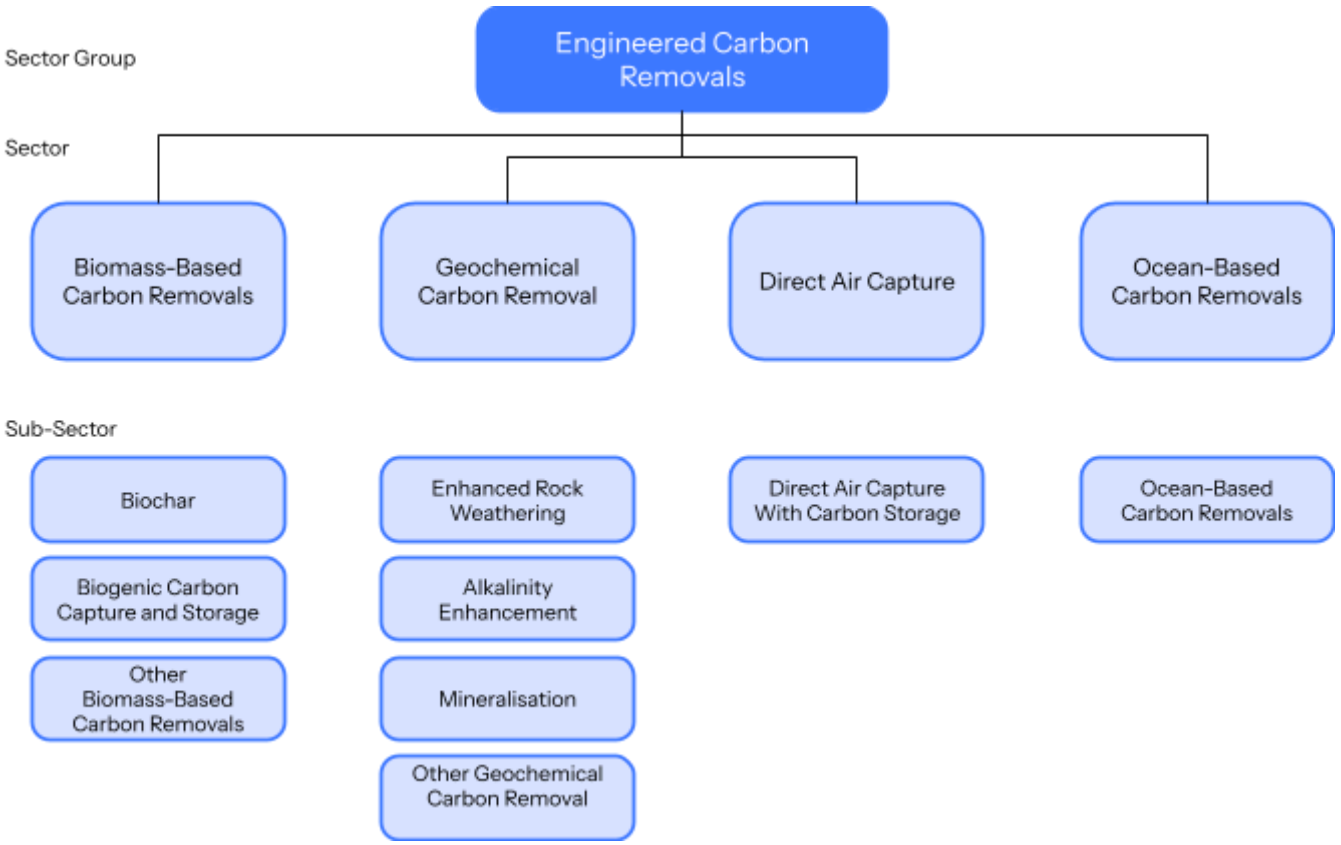


Figure 1. The Engineered Carbon Removals sector group within BeZero's sector classification system.

BeZero Carbon Rating analytical framework and process for Engineered Carbon Removals

We have designed an approach to assessing the carbon efficacy risk for issued carbon credits. This framework is applicable to any project type in any sector accredited by any standards body, and leverages a blend of qualitative and quantitative factors; financial, environmental, policy assessment techniques; and primary and secondary data sources.

Our BeZero Carbon Rating Methodology details our risk based assessment for understanding and interrogating the efficacy of issued carbon credits of any type, in any sector and country.

The BeZero Carbon ex ante Rating Methodology similarly describes our framework for assessing carbon efficacy of credits yet to be issued from projects of any type, in any sector and country. Ex ante ratings will also consider project execution risk.

Sector methodologies are nested within the overarching ex post and ex ante methodologies. The overall rating definitions, risk factors and risk driver categories are common across all projects while the sector methodologies provide more detail on our sector-specific analytical approach.

This document provides an extension to our overarching rating methodologies. It presents BeZero's detailed analytical framework and process for Engineered Carbon Removal projects. It showcases the various parameters through which we assess risk to the carbon quality of these credits, and how this sector group implements our overarching ratings methodologies.

Holistic assessment

The assessment of a carbon credit's efficacy includes a detailed, project-specific, bottom-up and top-down analysis to provide a comprehensive assessment of risk. Further details on the risk factor definitions, the rating process, and the overall risk assessment can be found in our BeZero Carbon Rating Methodology and BeZero Carbon ex ante Rating Methodology.

Important elements of the BeZero Carbon rating process that are applicable to all project types are described in detail in these overarching methodologies and are not repeated here. These include:

- The steps in the rating process
- The project governance assessment
- Project boundary auditing
- Assessing the risks of double counting
- The integrity of reported issuance
- Assessing rating eligibility (whether projects meet our three primary qualifying criteria)
- The rating assignment process
- The role of the BeZero Carbon Rating Committee
- Ongoing monitoring and 'rating watch' process

Carbon efficacy assessment

Additionality

The likelihood that a project's activities are materially different from the counterfactual or business-as-usual activities.

Whilst the foundational questions that underpin a BeZero Carbon Rating converge at the risk factor level, the inputs that are used to answer these questions show increasing specificity at the sub-sector and project levels.

In Table 3, we highlight sub-components of our assessment of additionality for Engineered Carbon Removals projects. In the sections that follow, we detail the key parameters that factor into each level of risk assessment and illustrate with case studies where relevant.

Table 3. Sub-components of additionality assessed.

Risk factor	Risk driver category	Risk driver
Additionality	Activity analysis	Common practice
		Alternatives to the proposed project
	Financial analysis	Prior consideration of carbon finance
		Investment analysis
		Barrier analysis

Activity analysis

Common practice

Our assessment of common practice examines the pervasiveness of the project activities or technology applied by the project within the region and sub-sector with and without access to carbon finance. Projects tend to assess common practice based solely on the number of similar carbon projects operating in the region or country. We think it is important to also assess similar activities in the region or country that have been implemented without carbon finance. This helps to inform additionality as we can evaluate the potential for project activities or outcomes to have occurred either in a business-as-usual scenario or as a result of similar initiatives.

We leverage our internal markets database to assess the prevalence of all other voluntary carbon market projects in the area. Furthermore, exhaustive literature reviews are also conducted to unearth any programs or interventions conducting similar activities that may have otherwise been overlooked.

For Engineered Carbon Removals, we often find there is a lack of common practice for these technologies. The sector is nascent, with a limited activity track record and limited global penetration. However, when looking closer, we find some technologies have greater common practice in some regions compared to others. For example, biochar has greater market pervasiveness in North America and some European countries than in other continents or regions. This regional aspect feeds into our assessment of common practice.

Alternatives to the proposed project

Another key aspect of additionality assessments is understanding the likelihood and extent of alternative scenarios that may occur in the absence of a project. For Engineered Carbon Removal projects, these may include the use of volume-limited feedstock for another purpose that also generates emissions reductions or removals, the use of a more common production method or technology to achieve an equivalent outcome, or the implementation of the project activity at a scale different from that proposed, among other examples. It is important to examine the credibility of each scenario to assess whether one is more likely to occur, as this necessarily influences the baseline.

This component of our analysis is interlinked with our assessments of common practice and barriers faced by the project, and also the quantification of baseline emissions and removals in the Carbon Accounting. Our analysis of alternative scenarios requires a nuanced approach, as there may be specific characteristics within the project area that make regional or even local common practices less favourable.

Financial analysis

Prior consideration of carbon finance

Our objective is to determine whether carbon revenue was taken into account by the party making the investment decision, before that decision was made, and whether it mattered to the outcome. Projects that committed to the activity without carbon revenue forming part of the decision proceeded on a business-as-usual basis, and present high additionality risk. Conversely, evidence that carbon revenue was modelled as a real and meaningful input to the decision, and pursued from that point, supports the case that the project depended on it.

We aim to establish when the investment decision was taken, identifying the earliest verifiable point of commitment and, if possible, assess the records generated before that date — board and investment committee papers, feasibility studies and financial models, financing and construction contracts. Risk is elevated where carbon revenue is not modelled or is immaterial to the appraisal and the decisions to invest in the project were made prior to the existence of methodologies supporting issuance of this type of carbon credits, and, more commonly in this sector, lowest where carbon

revenue is modelled as a meaningful or only revenue input and followed by continued action towards registration.

Investment analysis

The objective of this analysis is to determine whether the project's implementation and/or ongoing activities are dependent on carbon finance. For Engineering Carbon Removals projects, we may use a combination of indicators and approaches, depending on the sub-sector and project setup. Where the project entails a large upfront capital investment, the internal rate of return (IRR) is often a useful indicator of financial additionality. Here, our analysis uses project-specific data, or regional cost and revenue estimates for the activity, if these are not available or reliable. We use sensitivity analysis to test the project proponent's assumptions and assess the risk profile of the investment. This is crucial as key factors may have a relatively high level of uncertainty. We compare IRR with and without carbon finance to appropriate benchmarks to assess the likelihood that this revenue stream was the key factor influencing the investment decision.

Where upfront investment is small or where there is an opportunity cost associated with generating carbon removal, we use cash flow analysis with indicators such as net present value. For example, an artisanal biochar project may have low set-up costs but have high ongoing labour costs, or an industrial biochar project may forgo revenue from selling charcoal fuel briquettes. When an opportunity cost is identified, additionality requires demonstrating a more financially beneficial alternative and, crucially, that the extra revenue from carbon finance makes the project more attractive.

Our analysis considers the investment barriers project activities may face by corroborating the data underlying a project's additionality assessment with independent data sources, industry data, peer-reviewed research, and in-house expertise. In addition, the technology readiness level is considered, which is often relatively low for many pathways in the sector-group, and may justify higher rates of return than benchmarks and drive higher additionality. Engineered carbon removal projects may bring indirect benefits to the project proponent or associated organisations, such as improving crop yields, reducing waste management costs, or helping them meet corporate environmental, social and governance objectives. This is considered within the investment analysis and may weaken additionality if these indirect benefits are considered material.

Carbon revenues

For Engineered Carbon Removal projects, carbon finance can serve as a supplementary or primary revenue source. In direct air capture with carbon storage (DACCS), carbon finance is often the sole revenue stream. In biochar, it often supplements other revenues. For example, biochar projects may generate electricity that can be sold to the grid or earn additional revenue by selling the physical biochar as a soil amendment, in addition to the carbon credits associated with the carbon removal. Our assessment evaluates the relative contributions of each revenue stream to ensure project activities are at least partially dependent on carbon finance and that this additional revenue stream is necessary for the activity to occur.

Barrier analysis

For Engineered Carbon Removals projects, non-financial barriers may help explain why carbon finance is needed. These barriers are often unique to the project's location and circumstance. For example, enhanced rock weathering and biochar projects often require the enrolment of many farmers and for them to change land management practices in favour of a new approach. Often, practices are deeply entrenched and require considerable stakeholder outreach to implement project activities.

Our assessment considers not only the existence of barriers but also the role of carbon finance in alleviating them. This latter aspect is pivotal, as some barriers may be overcome through means other than carbon finance. Barriers can span several categories; some are tabulated below.

Table 4. An indication of the barriers that may affect the implementation of carbon projects.

Technical barriers	Technological challenges may similarly prevent a project's implementation where insufficient investment and financing exist. Examples include access to technical expertise and participant training, which a formalised structure such as the carbon market could facilitate.
Scientific barriers	Scientific challenges can arise when opposing views emerge about implementing emerging technologies. The scientific literature available for this sector group is rapidly expanding. As such, new insights may lead to changes in project monitoring requirements that were not expected at project inception. While scientific certainty in these removal activities is necessary, the scientific immaturity of this sector group can at times stall project development.

Legal and policy

Policy support

Our objective is to determine the extent to which existing policies, incentives and mandates encourage or require the project activities in the absence of carbon finance. Projects in jurisdictions with robust, effectively enforced policy environments that reduce barriers to implementation are likely to present higher additionality risk. Conversely, carbon finance may be essential to a project's successful implementation where relevant policies are weak, poorly enforced, or actively undermine project activities.

Our analysis has two components. First, we identify policies that may disincentivise biomass or waste management practices, if applicable to the project. Such policies can make carbon removal activities more attractive as they may provide an alternative avenue for management. For example, agricultural residue burning bans could incentivise engineered carbon removal methods, as fines may otherwise be imposed. Conversely, policies may also add barriers that make changing biomass feedstock management difficult. We comment on how effectively those policies are implemented and enforced. Second, we assess whether existing laws, regulations, statutes, legal rulings, or other regulatory frameworks support implementation of project activities or other approaches that sequester carbon beyond the counterfactual. We consider policies, incentives, programs and subsidies that the developer or others in the value chain are eligible for or affected by, the level of uptake, their effectiveness and the relative level of support they provide.

Carbon Accounting

The likelihood that, or degree to which, climate benefits are accurately or conservatively quantified.

In Table 5, we highlight sub-components of our assessment of carbon accounting for Engineered Carbon Removals projects. In the sections that follow, we detail the key parameters that factor into each level of risk assessment and illustrate with case studies as relevant.

Table 5. Sub-components of our carbon accounting assessment.

Risk factor	Risk driver category	Risk driver	Risk sub-driver
Carbon accounting	Direct accounting	Baseline scenario	Validity of baseline claims
			Alternative feedstock scenarios
		Project scenario	Project emissions
			Measurement and monitoring practices
			Quantification of stored carbon
		GHG conversions	
	Leakage accounting	Activity displacement	
		Market leakage	
		Ecological leakage	

Direct accounting

Baseline scenario

Validity of baseline claims

A critical part of assessing a project's carbon accounting risk is evaluating the baseline scenario the project selects. The baseline emission quantification of a carbon project is the amount of emissions or removals that have previously occurred or would likely continue to occur in the absence of the project activities. This is compared with the emissions and removals from the project scenario, and the difference between these two values comprises the project's net impact after any leakage and uncertainty deductions.

An appropriate baseline relies on representative historical data, models to forecast future emission/removal scenarios, and/or measurements taken from a control plot. Ideally, the baseline would also assess the likelihood of the various scenarios, if multiple have been identified, and of emissions reductions or removals that would have occurred during the project's crediting period as a result of exogenous factors, such as improving industry standards, scheduled equipment upgrades and changes in regulation, if a precedent exists for this.

For Engineered Carbon Removals, the baseline is often presented as 0 tCO_2e emitted and/or removed. In our ratings analysis, we assess the likelihood of this statement based on project-specific information. For example, comparable activities may already have been underway in some form before the carbon project was formalised. In our assessment, we review activity in the project area before the carbon project was initiated and analyse whether the project's baseline scenario has captured it appropriately. We find that projects can overlook existing nature-based removals, slow counterfactual feedstock decay rates or alternative scenarios to the project, creating a risk of

over-crediting. We also find that some projects can conservatively opt for a 0 tCO_2e baseline scenario, thereby creating the potential for under-crediting. For each project, we assess the application of the chosen baseline scenario and its risk to the robustness of the carbon accounting.

Alternative feedstock scenarios

Our assessment of carbon accounting risk is informed by the alternative scenarios for feedstocks used in the activity in the baseline scenario. For biomass-based carbon removals, enhanced rock weathering and some ocean-based carbon removals, feedstocks are required as inputs. These can be biogenic, such as forestry and agricultural residues or sewage sludge, or contain a biogenic fraction, such as mixed municipal wastes. In the baseline scenario, these feedstocks may lead to carbon removal, albeit sometimes for a shorter time than the project, if they are used or disposed of in certain ways. This can include landfilling or use in the manufacture of construction materials. Similarly, enhanced rock weathering and some ocean-based carbon removals require mineral feedstocks. In the baseline scenario, some weathering of the feedstock and therefore carbon removal may still occur. To inform our assessment, we estimate the range of likely carbon stocks across all pools in the counterfactual using a range of sources such as calculations by the project proponent, landowner attestations, geospatial analysis, feedstock sustainability certifications and literature sources.

Project scenario

Under the project scenario, we consider how accurately or conservatively the amount of gross carbon removal is quantified, and how comprehensively, accurately and conservatively the project-induced emissions are calculated to be subtracted from the gross removals. This includes assessing the monitoring, reporting and verification system (MRV) and the life cycle analysis (LCA).

Quantification of stored carbon, measurement and monitoring practices

The basis of carbon removal issuance calculation is the quantification of gross carbon removal that the project delivered or plans to deliver over the crediting period. Gross carbon removal is either directly measured and monitored, or estimated through proxy measurements and modelling.

For Engineered Carbon Removals, measurement and monitoring practices vary between sub-sectors. Practices in closed-loop systems tend to be more reliable and accurate than those in open-loop systems. In closed-loop systems, CO_2 can be easily quantified through techniques such as flow meters to measure variables including amount, composition, concentration, and/or pressure.

Table 6. Closed versus open-loop systems for Engineered Carbon Removals.

Closed-loop system	Projects that involve a high degree of technical control or containment. This includes methods such as bioenergy with carbon capture & storage (BECCS), bio-oil sequestration, or direct air capture with carbon storage (DACCS). In these systems, there tends to be greater certainty in measurement and monitoring, as CO2 can be measured frequently with equipment such as flow meters.
Open-loop system	Projects that involve processes outside technical control or containment. This includes methods such as enhanced rock weathering, ocean alkalinity enhancement, or other ocean-based carbon removals. Open systems have greater uncertainty in their measurement and monitoring practices.

Our assessment of gross carbon removal considers the approaches taken to measure or estimate the quantity of carbon durably stored over the stated period. In closed-loop systems, including DACCS and BECCS, we evaluate how accurately and frequently measurements are taken, and verify that gross carbon removal excludes any carbon leaks and co-captured non-biogenic carbon.

In biochar projects, we assess measurements of biochar production weight and carbon content. We consider the appropriateness of the permanence (or persistence) factor under the carbon accounting risk factor.

In open-loop systems such as enhanced rock weathering, a mixture of measurements and modelling is often used to determine the quantity of stored carbon. In these systems, we assess the project measurements made, how statistical significance is established, and, if models are used, whether they are appropriate and aligned with current best practice.

Project emissions

Our assessment of over-crediting also considers project emissions, which are emissions that occur from project activities. These must be deducted from the project's gross carbon removal.

For Engineered Carbon Removals projects, project emissions often result from

- The emissions associated with fossil fuel consumed on-site;
- The emissions from any electricity consumed on-site;
- The emissions of non-carbon dioxide greenhouse gases, like methane;
- The transportation on-site or to the site for the project activity;
- The emissions associated with monitoring activities;
- The embodied emissions of materials used during operations on-site;
- Loss of carbon pools as a result of site establishment.

These sources are small for certain project types but can be significant in some instances. Accurate accounting also depends on the validity of the baseline scenario.

In some projects, co-products may be produced, which may, in turn, lead to emissions reductions outside the project boundaries (positive leakage). Various carbon accounting approaches allocate emissions generated from shared activities between co-products and on different bases, such as economic value. Projects may also claim an emissions reduction from co-products generated within the project scenario that essentially offset some of the emissions generated by the activity. As part of our assessment of the project scenario, we consider the approach to the attribution of emissions and emission reductions to the project and the sensitivity to the net carbon removal calculation if a different approach is taken.

GHG conversions

This risk driver assesses whether appropriate multipliers have been used to convert project values into carbon dioxide equivalents. Engineered carbon removal projects may emit or reduce quantities of greenhouse gases other than carbon dioxide. These gases, such as nitrous oxide and methane, can be multiplied by their global warming potential (GWP), which the IPCC designed to allow comparisons of the global warming impacts of different gases. It measures how much energy the emissions of one tonne of a given gas will absorb over a set period, compared with the emissions of one tonne of carbon dioxide. Projects should account for all greenhouse gases that materially impact the net carbon removal calculation once multiplied by their GWP. Our analysis uses the 100-year GWP value.

Emission factors may be used in carbon accounting to convert project input consumption into emissions of carbon dioxide equivalents. In engineered carbon removal projects, emission factors are often used to estimate emissions associated with electricity consumption, feedstock transportation, and equipment purchases. We assess whether the selected emission factors are sufficiently conservative, using a consequential basis. For example, if a project consumes electricity from the grid, we assess the emission factor based on the mix of additional generators that would supply the network, rather than the average grid emissions factor.

Leakage accounting

Activity displacement

For Engineered Carbon Removals projects, the risk of activity displacement likely depends on the specific project activity. Where projects involve using either biomass or mineral feedstock, there is a risk of displacement owing to competition for finite resources with other activities. Projects may facilitate or dissuade other activities, which could lead to leakage. For example, harvesting biomass feedstock could make land more accessible for livestock farming, increasing agricultural emissions. In projects that retrofit an existing facility, which is often the case for BECCS, changes in the output of other products and the carbon intensity of their likely replacement is assessed in this section. Retrofitting power stations with carbon capture typically reduces electricity output and would likely increase emissions outside the project's boundaries for a replacement product. We evaluate any potential source of activity displacement that could lead to material levels of leakage.

If we believe there is evidence that a project will likely prevent additional emissions beyond those caused by the core project activity, we may assess the project to display positive leakage. This may reduce a project's overall carbon accounting risk level.

For engineered carbon removals projects, we find positive leakage can occur when projects credit solely for the CO_2 removal activity and not other greenhouse gas (GHG) reductions that can occur due to the project activity. Some GHG reductions associated with engineered carbon removals are uncertain because of the limited scientific literature and project-level monitoring. However, when these positive effects are likely and sufficiently evidenced, they are included in our assessment.

Market leakage

Market leakage can occur when a project's activities alter the supply and demand equilibrium. As a result, shifting market dynamics may lead to increased emissions due to market activities moving elsewhere, and projects may need to deduct from their issuance to account for this risk. However, for this to be likely, in our view, a carbon project must influence a significant portion of the supply and/or demand for a specific supply chain. For Engineered Carbon Removals projects, we find this risk is often negligible given the small scale of projects operating in the market. As projects scale and supply increases, market leakage could increase.

Ecological Leakage

Ecological leakage in Engineered Carbon Removals projects refers to the unintended ecological consequences that may occur as a result of implementing such projects. It refers to the displacement or shifting of environmental impacts from the project area to other ecosystems or regions. These impacts can occur in both terrestrial and marine ecosystems.

Ecological leakage can be positive or negative, affecting biodiversity, habitat connectivity, and ecological processes. For example, biomass-based carbon removals or enhanced weathering projects could positively affect plant productivity, crop yield, water-use efficiency, or reduced greenhouse gas leaching. Meanwhile, negative impacts could arise from feedstocks that impact other carbon stocks by consuming scarce water resources.

Permanence

The likelihood that the climate benefits of the project will persist for the time committed.

Our analysis of this risk factor considers the permanence of a project's credited carbon removal over the commitment period. If the commitment period is not defined, we usually assume it to be equal to the durability period with which the credits are marketed. While permanence often means the durability of carbon avoided or removed over 100 to 1,000 years or longer, the concept as applied in

the VCM is beset by inconsistencies and contradictions. In engineered carbon removal projects, it is often claimed that carbon removal is durable for centuries to millennia, yet the contractual commitment can be much shorter or unspecified. We use the minimum timespan quoted by the project or methodology for which the removal is considered durable as the basis of the permanence assessment, in lieu of a clearly defined commitment period. This ensures our permanence risk assessment aligns with market expectations for the durability of carbon removal for projects in this sector group.

In Table 7, we highlight sub-components of our assessment of permanence for Engineered Carbon Removals projects. In the sections that follow, we detail the key parameters that factor into each level of risk assessment and illustrate with case studies as relevant.

Table 7. Sub-components of permanence assessed.

Risk factor	Risk driver category	Risk driver
Permanence	Technical risks	Carbon stock integrity
	Anthropogenic risks	Project management and carbon rights
	Natural risks	Fire
		Geological hazards
		Other natural risks
	Risk mitigation instruments	Stakeholder engagement
		Risk buffer and mitigation

Technical risks

Carbon stock integrity

This risk driver considers the relative permanence of carbon stocks saved or sequestered by the project activity. For engineered carbon removal projects, the carbon stock integrity is based on either the design of the containment system (e.g. the sequestration site in BECCS and DACCS, or the burial chamber in biomass storage projects), the material in which the carbon is stored (e.g. biochar or CO_2 mineralised in concrete), or a combination of both. In addition to this, the robustness of monitoring, reporting, and verification (MRV) processes that confirm the carbon stock integrity are considered in this section.

When we assess the containment system, we consider the track record of the design, process, or technology when deployed in similar situations. Because many engineered carbon removal pathways are novel, we review the latest academic literature and models as a key part of our analysis. Where relevant regulatory guidance or ISO standards exist, such as for the geological storage of carbon dioxide, we compare them to the project's design to assess whether it follows current best practice. We also assess the integrity of the containment system through first principles, as many projects in the sector group use new or unique designs. Here we consider reversal pathways, how the design counteracts them, and whether any fail-safes provide an added level of protection. Our assessment of carbon stock integrity is based on the likelihood of reversals over the timespan for which the carbon removal is considered durable.

When carbon stock integrity is derived through the physical transformation of the carbon into a stable form, such as via mineralisation or carbonisation into biochar, we assess how the material has been characterised and how it will likely interact with the storage environment over the assessment period. Where the carbon is incorporated into a product, such as concrete or a soil amendment, we assess

how physical transformation and manufacture protect the carbon stock during use and at end-of-life. For example, when biochar is manufactured for use as a soil amendment, it may be mixed with compost, which would prevent it from being used as a fuel after distribution. This may reduce permanence risk if, in the project's regional context, charcoal is still used as a traditional cooking fuel. At the end of product life, carbon stocks may be subjected to recycling or disposal processes that could compromise carbon removal. We assess what these processes are, whether new processes may be introduced that could change what happens at end-of-life, and whether these processes could cause reversals.

For some engineered carbon removal pathways, such as biochar used as a soil amendment and enhanced rock weathering, some carbon loss after sequestration is almost certainly expected through, for example, microbial decomposition or outgassing. For these pathways, a conservative deduction in issuance, in line with current best understanding, is expected, and we consider its appropriateness under the carbon accounting risk factor. Our permanence risk assessment considers only carbon loss through factors that are not certain to occur or from events that cannot be reasonably foreseen and accounted for at the point of issuance. For some pathways, our understanding of carbon stock integrity is still improving, especially over long assessment periods (e.g., over millennia), so residual uncertainty may remain that issuance deductions in carbon accounting cannot mitigate.

MRV systems and steps that provide extra assurance of the carbon stock integrity are assessed under this risk driver. The assessment is often forward-looking, even in ex-post ratings. We assess whether the monitoring plan is likely to detect reversals via the identified pathways and accurately quantify them. These MRV steps may mitigate not just technical but also anthropogenic and natural risks. As a result, if no risks are identified, the lack of MRV would not increase permanence risk. If risks are identified and no appropriate MRV exists, reversals would not be compensated for with the risk buffer, leading to risk. For most engineered carbon removal pathways, monitoring will end before the end of the period during which the carbon removal is considered durable. In these cases, we assess whether the monitoring period is sufficiently long to mitigate risk and whether a set of conditions must be met for MRV to end; for example, in geological carbon storage, it might be when the plume becomes stable. This part of the assessment overlaps with the project management risk driver. MRV may sometimes also be considered as part of risk mitigation instruments, depending on the role it plays in the project.

The output from assessing technical risks associated with the form in which carbon is stored and the containment system, and whether the MRV steps are likely to detect these, feeds into the assessment of risk buffer and mitigation. Only reversal risks deemed detectable can be alleviated through a risk buffer.

Anthropogenic risks

Anthropogenic risks are those introduced by human activities, and that could result in the reversal of carbon sequestration. For the Engineered Carbon Removals sector, these risks can include a lack of long-term ownership rights to the stored carbon or the area in which it is stored. Other risks relate to project management of storage sites after the crediting period ends. For example, if a project lacks a plan and an appropriate financial assurance mechanism, wells used to store carbon may not be properly monitored or sealed after the project, leading to reversals.

We assess whether projects hold all the necessary land and carbon rights in the project area as well as the strength and stability of these rights within the relevant jurisdiction. In some regions, land rights can be complex, with a mix of formal and customary arrangements and competing claims, which can increase risk. We assess the project management plan for the duration of all project activities for appropriateness in the context of the region and project type. Finally, we assess the effectiveness of project management and carbon rights in preventing reversals caused by both legal and illegal activities.

Carbon rights are a form of property rights that allow accredited carbon units to be owned and traded. Our assessment evaluates who owns the carbon rights for the project area and whether the ownership is likely to confer permanence risk. Carbon rights may be detailed in project documentation or through project-specific literature. Risk may be reduced when the project developer owns the carbon rights. In contrast, risk may be introduced where carbon rights are unclear.

Natural risks

Fire

Our objective is to determine the extent to which project carbon stocks are at risk from fire over the commitment period. If fires are likely to occur within the project storage area and precautions are not in place to prevent reversals, permanence risk increases.

We establish whether the area has a fire history using earth observation data on burned areas and active fire detections, literature sources, and in-house fieldwork experience. Typically, fire risk to carbon stocks is low, but in biochar and biomass burial projects, when carbon is not protected by water or an inert material, risk can be material. Our assessment considers the likelihood and severity of a fire event. For example, a biomass burial project that stores carbon in multiple cells would have a different risk profile compared to one that uses a single store. We also consider mitigatory activities that could constrain risk.

Geological hazards

This risk driver is typically not applicable for most engineered carbon removal projects but can be relevant for some BECCS, DACCS and biomass burial projects. Where salient geological hazards - such as earthquakes, volcanic eruptions, landslides or tsunamis - are identified during analysis, they are assessed and reflected here.

Other natural risks

Due to the broad scope of engineered carbon removal projects, there are a range of natural risks not captured in the above that may be relevant. These could include pests and diseases, extreme weather, sea level change and flooding. Where such risks are identified during the analysis, they are assessed and reflected here.

Risk mitigation instruments

Stakeholder engagement

This risk driver typically does not apply to most engineered carbon removal projects but can be relevant when communities play a large role in sequestering carbon. For example, biochar projects may distribute biochar to community members for free, relying on them to apply it correctly to fields. Ensuring communities' free, prior, and informed consent through a robust consultation process mitigates permanence risk as it imparts a level of community support. Voluntary community adherence to the project and involvement in project activities and achievements are often fundamental to a project's success. We assess what withdrawal or dissatisfaction would mean for the project carbon stocks.

In some cases, stakeholder engagement through training may be required to ensure processes are followed correctly. For example, if biochar is distributed to farmers but they are not trained to apply it correctly to improve crop yields, they are more likely to use it for other purposes, which could impact carbon stocks. Where relevant, we review training records and materials, as well as participant feedback, to assess the efficacy of this mitigation strategy.

Risk buffer and mitigation

Our objective is to determine whether the project's buffer pool contributions, or comparable mitigatory measures, are sufficient to counter the residual permanence risk our analysis identifies. Our assessment considers two aspects: first, the adequacy of buffer pool contributions or similar mitigatory measures. We use the project's permanence risk assessment and compare it with the risks identified through our own analysis. A buffer contribution consistent with our assessment of residual risk indicates adequate mitigation; a contribution that falls short, and in particular the absence of any contribution, indicates that reversal risk is unaccounted for. We also consider whether buffer pool credits can be transferred between projects or used in some other way other than compensating for reversals. This can lead to risk due to poor credit fungibility if reversals can be compensated with credits from other projects.

Second, we examine how the buffer pool is managed and whether a reversal event would trigger credit cancellation. In some cases, a project may be required to contribute to a buffer pool but does not monitor reversals, meaning residual permanence risk is not mitigated. As part of the assessment, we consider whether management processes are clear and whether changes can be made retrospectively.

Further, we find that some project developers implement project-specific mitigatory activities beyond methodology requirements to adopt a conservative approach where methodological or scientific uncertainties remain. For this reason, we assess mitigatory activities for each project as they are applied.

Appendix I: Sources as of January 2025

Third-party datasets

We also incorporate many third-party or industry datasets and sources into our assessments of individual risk factors. These include but are not limited to:

National and regional government information on industrial emissions, regulations, trade flows, production, consumption and commodity pricing; policy trackers for impact, legislation, governance and action; emission factor databases, such as from IGES; the NDC registry; carbon credit pricing databases; UN Least Developed Countries; World Bank governance indices; IPCC datasets for global warming potentials; Lawrence Livermore National Laboratory Roads to Removal; cdr.fyi dashboard; Ocean Visions database.

Literature sources

Our curated database of literature sources spans all types of peer-reviewed literature and industry research, with hundreds of entries for every sector, region, or risk factor.

The number of relevant literature-based sources specific to the Engineered Carbon Removals sector runs to over 420 as of January 2025. In Figure 14, we show how these sources are split by carbon risk factor.

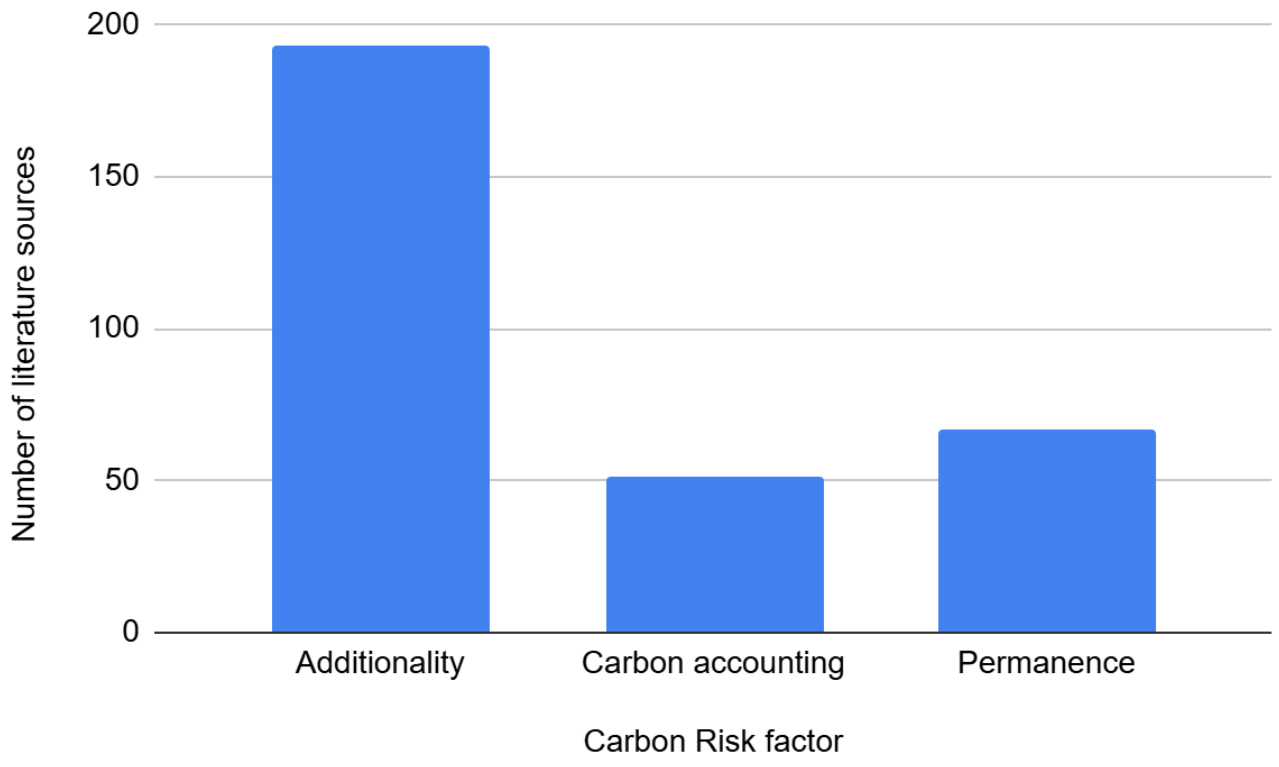


Figure 14. The number of literature sources relevant to the Engineered Carbon Removals sector used by BeZero Carbon Ratings as of January 2025.

Sample of literature sources

1. Li, S. & Tasnady, D. Biochar for Soil Carbon Sequestration: Current Knowledge, Mechanisms, and Future Perspectives. C 9, 67 (2023).

2. Foteinis, S., Andresen, J., Campo, F., Caserini, S. & Renforth, P. Life cycle assessment of ocean liming for carbon dioxide removal from the atmosphere. J. Clean. Prod. **370**, **13**3309 (2022).

3. Huang, Y.-F., Chiueh, P.-T. & Lo, S.-L. Carbon capture of biochar produced by microwave co-pyrolysis: adsorption capacity, kinetics, and benefits. Environ. Sci. Pollut. Res. **30**, 22211–22221 (2023).

4. Fuhr, M. et al. Kinetics of Olivine Weathering in Seawater: An Experimental Study. Front. Clim. **4**, 831587 (2022).

5. Michaelowa, A., Hermwille, L., Obergassel, W. & Butzengeiger, S. Additionality revisited: guarding the integrity of market mechanisms under the Paris Agreement. (2019).

6. Okoko, G. O. & Olaka, L. A. Can East African rift basalts sequester CO2? Case study of the Kenya rift. Sci. Afr. **13**, e00924 (2021).

7. Wang, Z., Aili, A., Minami, M. & Maruyama, I. Verification Method of Direct Air Capture by Cementitious Material Using Carbon Isotopes. J. Adv. Concr. Technol. **21**, 934–940 (2023).

8. The Royal Society and Royal Academy of Engineering. Greenhouse gas Removal. (2018).

9. Arroyo-Currás, T. et al. Carbon leakage in a fragmented climate regime: The dynamic response of global energy markets. Technol. Forecast. Soc. Chang. **90**, 192–203 (2015).

10. Fawzy, S. et al. Atmospheric carbon removal via industrial biochar systems: A techno-economic-environmental study. J. Clean. Prod. **371**, 133660 (2022).

11. Fasihi, M., Efimova, O. & Breyer, C. Techno-economic assessment of CO2 direct air capture plants. J. Clean. Prod. **224**, 957–980 (2019).

12. Woolf, D. et al. Greenhouse Gas Inventory Model for Biochar Additions to Soil. Environ. Sci. Technol. **55**, 14795–14805 (2021).

13. Ozkan, M., Nayak, S. P., Ruiz, A. D. & Jiang, W. Current status and pillars of direct air capture technologies. iScience **25**, 103990 (2022).

14. Buss, W. et al. Mineral-enriched biochar delivers enhanced nutrient recovery and carbon dioxide removal. Commun. Earth Environ. **3**, 67 (2022).

15. Smith, S. M., Geden, O., Minx, J. C. & Nemet, G. F. The State of Carbon Dioxide Removal - 1st Edition. doi:10.17605/osf.io/w3b4z.

16. Fajardy, M., Chiquier, S. & Dowell, N. M. Investigating the BECCS resource nexus: delivering sustainable negative emissions. Energy Environ. Sci. **11**, 3408–3430 (2018).

17. Socolow, R. et al. Direct Air Capture of CO2 with Chemicals: A Technology Assessment for the APS Panel on Public Affairs. (2011).

18. Meyer, A. M. & Spalding, Mark J. A Critical Analysis of the Ocean Effects of Carbon Dioxide Removal via Direct Air and Ocean Capture – Is it a Safe and Sustainable Solution? (2021).

19. Schmidt, H. et al. Biochar in agriculture – A systematic review of 26 global meta-analyses. GCB Bioenergy **13**, 1708–1730 (2021).

20. Tanthana, J. & Chuang, S. S. C. In Situ Infrared Study of the Role of PEG in Stabilizing Silica-Supported Amines for CO2 Capture. ChemSusChem **3**, 957–964 (2010).

21. Keith, D. W., Holmes, G., Angelo, D. St. & Heidel, K. A Process for Capturing CO2 from the Atmosphere. Joule 2, 1573–1594 (2018).

22. Daniel, T. et al. Techno-economic Analysis of Direct Air Carbon Capture with CO2 Utilisation. Carbon Capture Sci. Technol. **2**, 100025 (2022).

23. Babarinde, O. et al. An overview of geological carbon sequestration and its geomechanical aspects. Geol. Soc., Lond., Spéc. Publ. **528**, 61–72 (2023).

24. McQueen, N. et al. A review of direct air capture (DAC): scaling up commercial technologies and innovating for the future. Prog. Energy **3**, 032001 (2021).

25. Cross, J. et al. Problem solving in Marine Carbon Dioxide Removal (mCDR); Identifying important questions and capabilities for studying new human perturbations to the Ocean Carbon System. (2022).

26. Lamb, W. et al. A global, independent scientific assessment of Carbon Dioxide Removal. (2023) doi:10.21203/rs.3.rs-3255532/v1.

27. Beaulieu, J. J., DelSontro, T. & Downing, J. A. Eutrophication will increase methane emissions from lakes and impoundments during the 21st century. Nat. Commun. 10, 1375 (2019).

28. Leonzio, G., Fennell, P. S. & Shah, N. A Comparative Study of Different Sorbents in the Context of Direct Air Capture (DAC): Evaluation of Key Performance Indicators and Comparisons. Appl. Sci. **12**, 2618 (2022).

Appendix II: Additional reading

Check out the ratings resources page on our website to find links to all of our published methodologies, in addition to our series of risk factor assessment frameworks, our frameworks for assessing project methodologies and country-level risks, deep dives on factors influencing the carbon efficacy of projects in various sectors, and more.

Updates and reviews

Version number	Date	Description
1.00	26/02/24	Initial release
1.01	03/10/24	Clarification on additionality as a limiting factor
2.0	19/02/25	Updated risk factor framework
2.01	05/03/2025	Update to sector classification
2.02	27/10/2026	Removal of example boxes, revisions to sector group risk drivers, and updates to market context

Disclaimer

The BeZero Carbon Rating of voluntary carbon credits represents BeZero Carbon's current opinion on the likelihood that carbon credits issued by a project achieve a tonne of CO_2e avoided or removed. The BeZero Carbon Rating and other information made publicly available or available through the BeZero Carbon Markets platform ("Content") is made available for information purposes only. The Content and in particular the BeZero Carbon Rating sets out BeZero Carbon's opinion on a particular carbon credit or project based on publicly available information as at the date expressed and BeZero Carbon shall have no liability to anyone in respect of the Content, opinion and BeZero Carbon Rating. The Content is made available for information purposes only and you should not construe such Content as legal, tax, financial or investment advice. The Content is a statement of opinion as at the date expressed and does not constitute a solicitation, recommendation or endorsement by BeZero Carbon or any third party to invest, buy, hold or sell a carbon credit. The Content is not a statement of fact and should not be relied upon in isolation. The Content is one of many inputs used by stakeholders to understand the overall quality of any given carbon credit. BeZero Carbon shall have no liability to you for any decisions you make in respect of the Content. If you have any questions about BeZero Carbon, the BeZero Carbon Rating, the BeZero Carbon Rating methodology, qualifying criteria, rating process, any element of Content, the BeZero Carbon Markets platform or otherwise please contact us at: commercial@bezerocarbon.com.