Climeworks' framework to identify highest quality carbon dioxide removal

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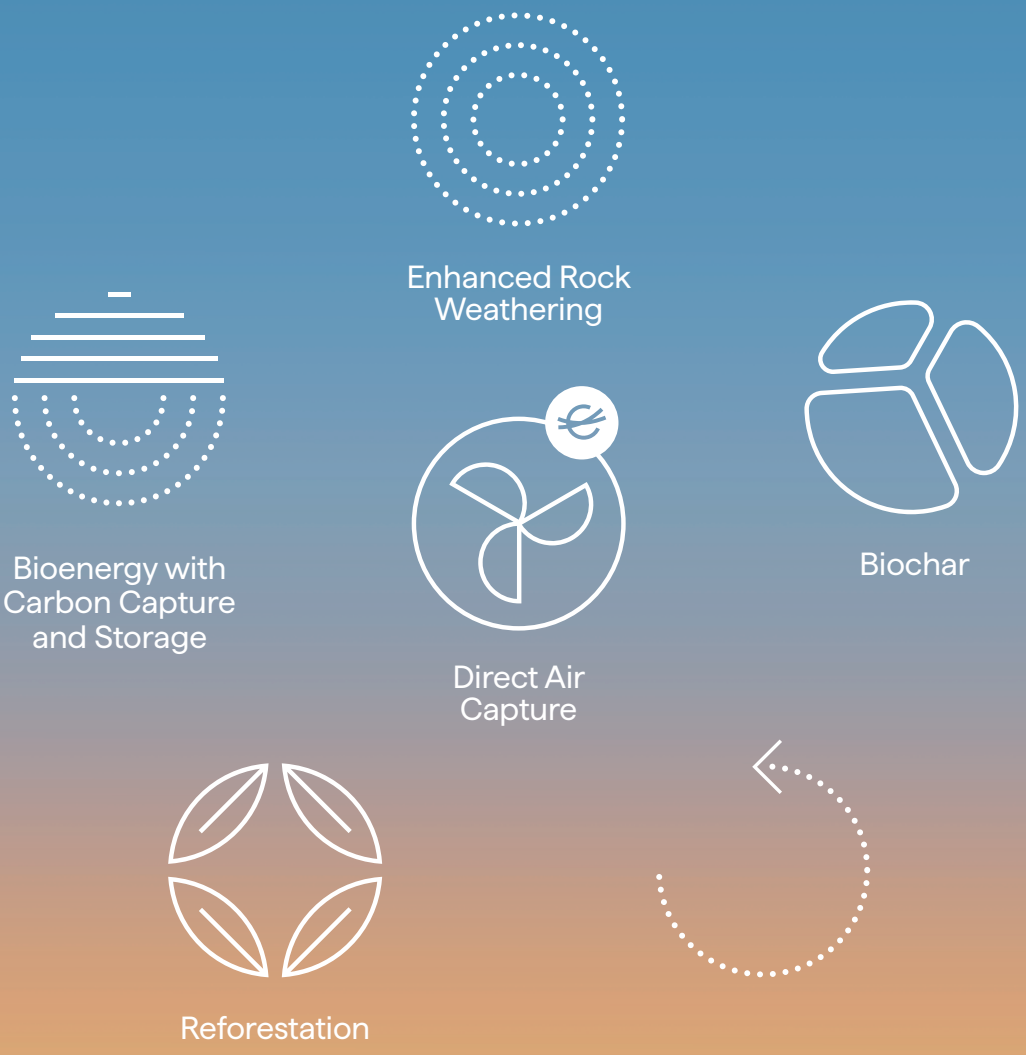

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Executive Summary

As the urgency to significantly reduce greenhouse gas emissions becomes increasingly apparent, so does the need for carbon dioxide removal (CDR). Furthermore, the longer significant emission reductions are delayed, the greater the need for CDR to mitigate the overshoot. Purchasing CDR credits can allow companies to compensate for their residual hard-to-abate emissions, but credits should be of high quality to ensure that they represent a meaningful impact.

Climeworks' framework for identifying high-quality CDR

Climeworks has developed a robust framework to help buyers distinguish between high- and low-quality CDR. This framework is built on internal knowledge and incorporates critical elements from publicly available methodologies. Applicable to any CDR approach today, the framework clusters quality criteria into three categories: trust, impact, and risk.

Trust: the confidence that each credit represents 1 ton of CO_2 removed

Trust can be broken down into four core attributes. The first, measurability, ensures that the method and frequency of measurement are suitable for accurate quantification of the carbon sequestered. End-to-end carbon accounting then considers how measured data is converted into net CDR, accounting for life cycle emissions and counterfactuals. The third attribute, additionality, is closely linked to the first two and checks that the removal would not have occurred without the sale of CDR credits. Finally, third-party certification under a recognized carbon standard is a requirement for high quality by Climeworks.

Impact: the consideration of the wider positive implications of a CDR intervention

The first impact attribute is permanence or durability, where the longer CO_2 is prevented from re-entering the atmosphere, the greater the climate impact can be. Co-benefits, both social and environmental, are then evaluated, such as job creation, biodiversity enhancement, and ecosystem preservation. The third attribute is the availability and scalability of a CDR approach, supplier, or project to deliver CDR credits. While greater availability today enables a more immediate impact, scalability is essential to address the size of the climate challenge. Finally, the price and the long-term affordability of credits is considered.

Risk: the review of potential negative consequences associated with the CDR intervention

A comprehensive risk assessment examining risk sources, probabilities, severities (if risks were to occur), and mitigation actions is key to ensuring high-quality CDR. Storage reversal is one such risk considered in the framework. High-quality projects include robust mechanisms to monitor and ensure the long-term stability of sequestered CO_2. The risk of emissions being leaked or displaced as a result of the CDR activity is carefully evaluated. Potential negative social and environmental risks to communities and ecosystems are addressed. Finally, any execution risks such as financial, technical, or operational issues that could prevent a project from delivering its promised CDR credits, are assessed, with the best projects showing minimal chances of such failures.

Conclusion

Investing early in a high-quality carbon removal portfolio helps increase the chances of achieving net-zero goals and secures access to quality CDR as demand accelerates. Climeworks' framework provides guidelines to evaluate CDR projects and suppliers, which can complement a thorough due diligence process. Climeworks uses this framework internally to guide its own due diligence and decide which suppliers to partner with to build CDR portfolios. Each portfolio is tailored to meet our customers' strategic priorities, with a strong focus on ensuring the quality of every project included.

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With the average global temperature in 2023 standing at **1.45°C** above pre-industrial levels[1], the **1.5°C** global warming limit established as the preferable aim of the Paris Agreement[2] is likely to be surpassed this decade, if not this year.

As the urgency to significantly reduce greenhouse gas emissions becomes increasingly apparent, so does the need for carbon dioxide removal (CDR). By now, all possible pathways to achieve a Paris-Agreement-compatible climate scenario include some share of CDR, with consensus lying in the range of 5-16 gigatons of CO_2 removal required by 2050[3]. The longer significant emission reductions are delayed, the greater the need for CDR to mitigate the overshoot[4].

There are many different approaches to CDR, each with different benefits and drawbacks.

It is important that CDR credits sold from CDR activities, where each credit should represent one ton of CO_2, are of high quality such that they represent meaningful climate action and result in actual long-term carbon sequestration. As businesses increasingly aim to reduce their carbon footprints and reach net-zero goals, they turn to CDR credits as a tool to compensate residual, hard-to-abate emissions that cannot be mitigated directly. For companies, investing in reputable, high-quality credits not only enhances their sustainability efforts but also helps maintain trust with stakeholders, reduces the risk of greenwashing, and contributes to overall environmental and social governance (ESG) goals. See our previous article on the business case for CDR for more insight.

Although the benefits of high-quality credits are clear, identifying highest quality can seem challenging, in particular when quality claims from CDR suppliers are abundant within a rapidly expanding market. In this article, we outline the most important aspects to review when considering carbon removal credits and walk through Climeworks' framework to vet CDR suppliers and projects to ensure the highest quality.

Many of the aspects considered may be familiar to those versed in CDR terminology, others perhaps less so. What becomes apparent when considered in aggregate is that many projects fail to meet the bar for high quality when assessed thoroughly. Of those that can objectively be considered high quality, there remain tradeoffs, particularly when drawing parallels between different CDR approaches. For this reason, a portfolio approach to removal credits is recommended, allowing for a balance of various aspects, depending on relative importance. This importance weighting largely depends on individual need, and thus the framework contained herein is only a guide to quality and not a final purchase recommendation.

In natural weathering, rock is slowly dissolved in a chemical reaction with water and CO_2 from the air. Enhanced rock weathering accelerates this process by using finely ground rock and spreading it over fields so that CO_2 is removed from the atmosphere more rapidly.

Climeworks' quality framework

Climeworks is the market leader in developing direct air capture and operates the two largest DAC plants on the planet to date, Orca and Mammoth.

Complementary to this CDR service, Climeworks offers holistic, high-quality CDR portfolios[5] comprised of various removal approaches (engineered and nature-based), tailored to the individual needs of companies.

With extensive experience in the CDR space, Climeworks has developed a robust framework to help buyers distinguish between high- and low-quality CDR. This framework is built on our internal knowledge while incorporating critical elements from other publicly available methodologies, such as Microsoft's Criteria for High-Quality CDR, Shopify's Buyers Guide, WBCSD's guide on carbon removal adoption, among others. We use this framework to guide our decision making on which CDR approaches to include in our portfolio offering and which suppliers to partner with to ensure that we only offer the highest quality credits to the market.

We cluster our quality criteria into three categories: trust, impact and risk. Trust is the foundation of quality, ensuring that a CDR credit truly represents a full ton of CO_2 removed. Impact evaluates the broader value of a credit, examining how durable and scalable the removal is and what other benefits are associated. Risk is a multi-faceted category that encompasses any negative consequences connected with a certain CDR activity or specific CDR supplier. To quantify these pillars, each category contains multiple attributes to allow for a science-based assessment. Objectively quantifying these categories and attributes can generate new insights and provide key decision metrics.

Core pillars of Climeworks' quality assessment framework for carbon dioxide removal

1 Ensure **Trust**

Confidence that each CDR credit **represents one ton of CO_2** removed from the atmosphere

2 Maximize **Impact**

Greatest impact for price, including aspects such as co-benefits, scalability, durability, etc.

3 Reduce **Risk**

Minimized potential **negative consequences** associated with the respective CDR

1 Trust

The foundation of CDR is that, after accounting for all associated emissions, the project or intervention results in the net removal of CO_2. Critics often question whether a CDR project has thoroughly considered all sources of CO_2 or CO_2-equivalent (CO_2eq) emissions during its construction and operation.

For the CDR market to thrive, it is crucial that buyers have confidence that what is sold is not only net removal, but that each CDR credit represents at least one ton of CO_2 removed from the atmosphere.

Our trust pillar is built on four attributes: measurability, end-to-end carbon accounting, additionality and third-party certification.

Measurability

Measurability ensures correct quantification of the amount of carbon sequestered. For a high-quality CDR project, it is crucial that both the measurement technique and the frequency of measurements are appropriate. Although each CDR approach has established measurement techniques, the exact methods used by project developers can vary. Thus, a thorough understanding of the intricacies of the measurement technique is essential. Ideally, a confidence interval should be determined for the measurement, with a lower confidence bound assumed, or a buffer applied to account for measurement uncertainty. This conservatism in measurement is key to reduce the risk of over-crediting.

Measurability involves not only determining the amount of CO_2 sequestered but also includes accurately quantifying the counterfactual scenario or baseline, i.e., what would have happened in the absence of the project. While the baseline is often set to zero, meaning that any net CO_2 removal by the project is carbon additional and can be credited (see more on additionality below), this is not always the case. For example, in reforestation projects, it is important to determine how much of the land can be expected to naturally regenerate and to account for this in project crediting. For this reason, many high-quality reforestation projects are implemented on land with a low chance of natural regeneration. Any natural regrowth is measured in control plots and subtracted from the growth in the project area to ensure only additional CO_2 sequestration is credited.

Reforestation is the practice of planting trees in areas that were previously covered by forest but have been degraded, for example, due to wildfire, pests, or human activity. The goal is to create biodiverse forests that will capture CO_2 'via' photosynthesis.

End-to-end carbon accounting

End-to-end carbon accounting quantifies CO_2 removal by subtracting the baseline scenario from the measured CO_2 removed to obtain gross CDR, and then accounting for all related emissions to reach net CDR (see Figure 2). This comprehensive emission tracking is typically done through a life-cycle assessment (LCA), which quantifies all emission associated with the intervention, referred to as grey emissions, from cradle (e.g., feedstock sourcing or land preparation) to grave (e.g., final storage). Just as the measurement of CDR should be conservative, so, too, should the carbon accounting. To avoid over-crediting, it may be necessary to buffer for uncertainty and variability in data, whether included in the measurement and LCA or accounted for later. We refer to this as net-adjusted CDR. True end-to-end carbon accounting of CDR is therefore only possible after CO_2 sequestration has taken place. Such credits generated after sequestration are referred to as ex-post, whereas ex-ante credits are based on forecasted removals. Climeworks only considers ex-post credits due to the requirement for accurate carbon accounting.

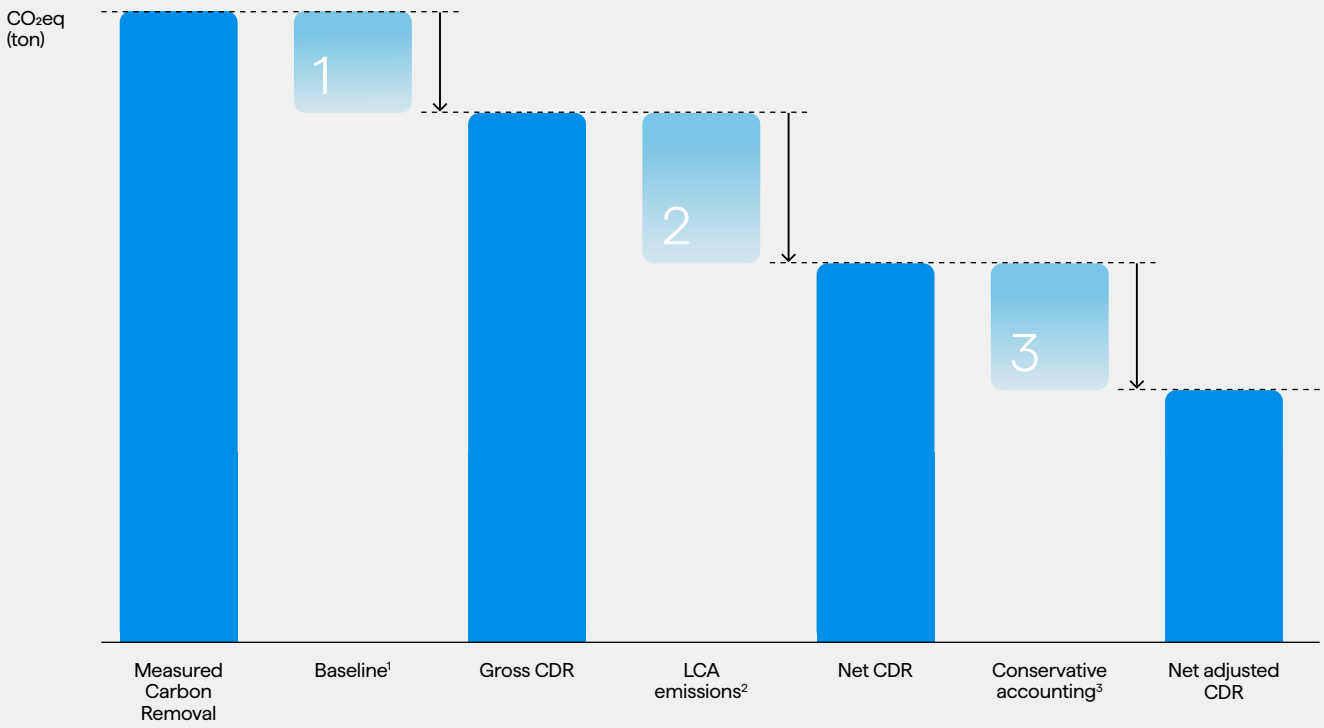
Additionality

Additionality essentially asks whether this removal activity would have occurred without the planned intervention or the subsequent sale of CDR credits. To answer this question for credits within the voluntary carbon market (VCM), three aspects should be considered: carbon additionality, financial additionality, and legal additionality.

A project is carbon additional if the net CDR is greater than zero.

A project is legally additional if it is not directly mandated by law such that it would have to be implemented regardless of this specific intervention. Finally, a project is financially additional if the sale of credits is essential for project feasibility. All three additionality aspects should be met for a high-quality CDR credit.

From measured CO_2 captured to conservative net CDR



1. CO_2 removal already occurring in the baseline scenario is subtracted to ensure only additional removal is credited
2. All greenhouse gas emissions associated with the CDR intervention are deducted from the CO_2 balance
3. The CDR balance is corrected downwards to account for any remaining uncertainties, ensuring conservative crediting of CDR such that each credit represents at least 1 ton of CO_2 removed

Third party certification

Third party certification is the process by which CDR credits are certified and recognized under a carbon standard and registry. To secure third-party certification, a project developer must remove CO_2 according to a methodology established by the carbon standard; these methodologies detail how to implement key aspects of CDR projects such as measurement methods and calculation of lifecycle emissions. Once the project developer has selected a methodology, an independent organization (the validation and verification body, VVB) assesses on a periodic basis whether the project is removing emissions in accordance with the selected methodology. Once verified, the carbon standard issues the removals on a public registry, ensuring transparency on the removal activity while also protecting against double counting.

At Climeworks, we require that **all CDR credits** have gone through this process and are thus certified under a recognized registry.

As well as facilitating the sale and transfer of credits, certification provides a minimum quality check. However, it is worth noting that there are many carbon registries in operation today, each with multiple methodologies for different approaches to CDR. We observe significant differences between methodologies with regards to quality and as such highest quality CDR is not guaranteed by certification alone. Hence Climeworks always performs a dedicated technical due diligence on each project to ensure that the quality bar is met.

Direct air capture (DAC) is the use of chemical or physical processes to extract carbon dioxide directly from the ambient air. The extracted CO_2 is then sequestered in safe long-term storage.

2 Impact

In the field of CDR, there is a tendency to focus exclusively on the amount of CO_2 to be removed, neglecting the wider implications of a project.

While CDR projects can pose various risks (addressed in the next section), they also offer significant benefits beyond maximizing sequestration volumes. High quality projects offer the greatest impact for price, with impact stemming from many avenues, including social and environmental co-benefits, and the unlock of future scaling potential. Each avenue should be considered when weighing up whether to purchase credits from a project, and trade-offs often need to be considered. For example, a reforestation CDR supplier might not offer long credit durability (see more on permanence below) but may have strong environmental co-benefits that make the project appealing over a direct air capture project with the opposite traits, or vice versa. A portfolio of diverse CDR approaches helps balance key aspects such as cost, scalability, and co-benefits, providing a more comprehensive and resilient solution.

Permanence

Permanence refers to how long the CO_2 removed by a project will remain out of the atmosphere. This is determined by where and how the captured CO_2 is stored. Generally, the longer CO_2 is prevented from re-entering the atmosphere, the greater the climate impact and thus the credit quality. A common differentiation is made between CO_2 stored in the short, biological carbon cycle and the long, geological carbon cycle. In the short carbon cycle, removed CO_2 is released back into the atmosphere after decades to centuries, whereas CO_2 in the long carbon cycle returns to the atmosphere on a timescale of thousands of years. The durability, or permanence, of a CDR credit is thus largely limited by the nature of the removal itself. Nature-based removals, such as reforestation, are therefore less durable than solutions that leverage geological storage, such as direct air capture. However, even within each removal method and between projects, there are significant variations in permanence, making it essential to assess this aspect. For example, measures taken by pro ject developers for long-term protection and monitoring of forests can allow for carbon stocks (and the credits that represent them) to endure well beyond the lifetime of an individual tree.

From a buyer's perspective, the importance of permanence is grounded on the intended use-case of the credit. In accordance with the Oxford principles[6] "like-for-like", durably stored CDR (in the long carbon cycle) should be used to offset residual fossil-based emissions, since the timescale of storage is equivalent to the timescale for which the emitted CO_2 was originally stored. We strongly encourage adherence to this principle to comply with current and future legislation and widely accepted voluntary frameworks (e.g., the EU's Carbon Removals and Carbon Farming Regulation, or the Net Zero Standard by the Science Based Targets initiative).

Social and environmental benefits

Social and environmental benefits generated in addition to CO_2 sequestration are not only plus points to differentiate projects. They can be strong indicators to the likely success of a CDR intervention and help in meeting Sustainable Development Goals[7]. Creating new jobs and market opportunities, for example, can be a core social co-benefit that many projects will aim to meet, with high-quality projects directly contributing to local

economies by strengthening supply chains and offering fair living wages. Engaging with local communities increases the probability that on-the-ground impact will be achieved where it is most needed, enabling and encouraging local communities to support CDR activities. This, in turn, has positive consequences for sequestration permanence and future scaling. Some projects go further by actively supporting marginalized communities, including Indigenous groups, through financial benefit sharing and equitable inclusion during the entire project. CDR projects can also benefit communities non-monetarily, for example, by improving food security. The application of biochar or rock powder for enhanced rock weathering on farm land has been shown to boost agricultural productivity by 20-100%[8-9].

On the environmental side, robust CDR initiatives can contribute to an increase in biodiversity, enhance nature preservation, and improve critical ecosystem parameters such as water and air quality. Protection from soil erosion and mitigation of natural hazards such as wildfires, flash floods and droughts also fall into this category. A thorough assessment must therefore differentiate between projects that generate significant co-benefits and those that do not, ensuring that CDR investments drive comprehensive, sustainable outcomes.

Availability and scalability

Availability and scalability are impact factors that examine the volume of CDR credits on offer, both today (availability) and in the future (scalability). As with permanence, specific trends are identifiable for different CDR approaches. However, it is also important to assess the differences between suppliers of a given approach. For buyers requiring large volumes of CDR over longer time horizons to compensate for hard-to-abate emissions, the scaling potential of a particular solution may be more critical than the short-term availability. However, investing today is typically required to unlock future volumes, particularly for high-quality credits. Determining whether a CDR solution is scalable involves examining the potential of a supplier (e.g., project roadmap and resources) in conjunction with the limitations of their approach. At Climeworks, we distinguish between scaling and sustainable scaling by examining resource requirements, such as energy, land, water, and the quantity of waste produced. This is particularly relevant, for example, in CDR approaches that rely on biomass such as biochar and bioenergy with carbon capture and storage, as the requirement for sustainable biomass (e.g., forest residues or organic waste) places greater limitations on future scaling.

Price

Price per credit and its evolution with time can be a concern for cost-sensitive buyers, particularly when purchasing large volumes with a limited budget. To understand what CDR prices may be appropriate, a company may consider the cost to abate the CO_2 emissions in-house, the profit per ton of CO_2 emitted, as well as the social cost of carbon. The social cost of carbon estimates the monetary loss caused by emitting one additional ton of CO_2 through factors such as increased human mortality and illness, damages by extreme weather events, and loss of biodiversity, and ranges between USD 100 per ton to USD 1000 per ton[10-11] depending on underlying assumptions. We have observed that price and other quality metrics (such as permanence, co-benefits, measurability) can correlate in many cases, although a high price does not guarantee high quality.

Biochar is a charcoal-like material produced by heating biomass at high temperatures with little or no oxygen (pyrolysis process). This thermal decomposition breaks and rearranges chemical bonds in the biomass, forming very durable carbon structures.

3 Risk

Projects in the CDR space can come with several risks, ranging from those related to CO_2 directly, such as risk of reversal or leakage, to adjacent risks, like negative impacts on societies or ecosystems. Quantifying these risks by assessing their probability of occurrence and severity if that risk were to be realized (see matrix on the right), as well as the effectiveness of mitigation actions, can enable a better understanding of which risks are tolerable. This, in turn, can support the overall assessment of whether a CDR credit is high enough in quality to purchase.

3×3 Risk matrix

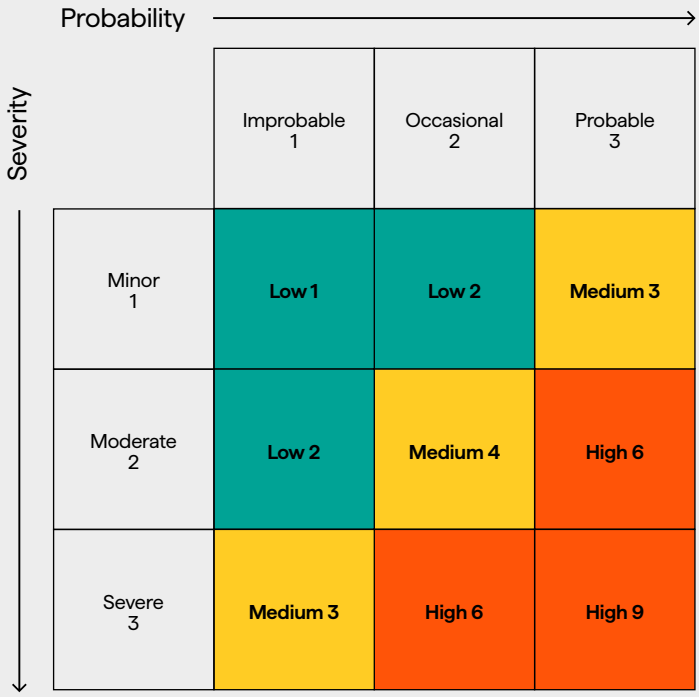


Figure 3: 3×3 risk matrix showing probability on the horizontal axis and severity on the vertical axis. Each cell within the matrix represent the product of probability and severity, resulting in a risk score categorized as low (green), medium (yellow) or high (red), which can be used to guide risk management decisions.

Storage reversal risk

Storage reversal risk refers to the risk that sequestered CO_2 might be unintentionally or deliberately released back into the atmosphere, negating the climate benefits. The probability and severity of a reversal event should be determined for each potential cause (within reason). High-quality projects demonstrate robust mechanisms to monitor and ensure the long-term stability of sequestered CO_2, with appropriate mitigation actions where possible. Reforestation projects, for example, often have higher reversal risks, ranging from natural events, such as wildfires, storms, and pests, to social issues like uncontrolled harvesting for timber production. Projects leveraging geological CO_2 storage tend to have lower reversal risks but should consider the likelihood of seismic activity disturbing storage foundations. For our direct air capture plants, proper site selection is key to ensure that Climeworks' air-captured CO_2 is stored safely and permanently. We only partner with CO_2 storage providers that follow best practices in reservoir characterization and monitoring, and strict engineering and safety protocols at their storage sites.

The probability of storage reversal is therefore always site-specific and assumptions underlying the quantification must be adjusted accordingly. This is also true for mitigation efforts, which should correspond to the total magnitude of the risk (product of probability and severity). Monitoring of storage reversal is important to ensure proper accountability during and after a project. Buffer pools or reserve credits are a common strategy to account for storage reversal risk and need to be proportioned accordingly.

Leakage

Leakage occurs when CDR efforts lead to unintended increases in emissions elsewhere. Typically, this can be split into activity shifting leakage and market leakage. Activity shifting leakage refers to the displacement of an emitting activity. For example, if land designated for an agricultural activity is repurposed for a CDR project and the agricultural activity moves elsewhere, it can cause deforestation or land-use change emissions, negating the project's CDR efforts. The effect is usually local, though outside of the immediate CDR project boundary. Market leakage is typically broader and thus harder to assess, referring to emissions generated from the economic consequences of implementing a CDR project. An example here would be reduced timber production resulting from a new CDR project leading to increased timber prices and thus more harvesting of wood elsewhere, with associated emissions. To remain conservative in end-to-end carbon accounting (see trust section above), only negative leakage risks should be considered in CDR quantification, with appropriate monitoring across a defined boundary and counteractions taken to avoid and mitigate leakage, where possible. Given the obvious challenges in monitoring leakage, best-in-class projects minimize it to the greatest extent possible in the project development phase by carefully selecting locations and materials.

Social and environmental risks

Social and environmental risks are the inverse of the benefits similarly categorized and discussed in the section on impact. Social risks associated with CDR projects arise when local communities, especially marginalized or Indigenous groups, are adversely impacted by the implementation of CDR efforts. For instance, large-scale land use for afforestation or bioenergy with carbon capture and storage might displace local communities or interfere with traditional land-use practices. When considering the quality of a CDR activity, project, or supplier, criteria to evaluate include whether the project displaces communities or their income source, whether local land rights are affected, or if a risk to human health is posed in any way. Safeguards include mechanisms for transparent and continuous stakeholder engagement prior to project implementation and throughout the project lifetime to resolve any potential conflicts. For our direct air capture projects, establishing strong two-way engagement with host communities is an essential part of Climeworks' strategy for responsible deployment.

Environmental risks can be broad in nature and their impact varies by CDR method and location. For example, for cost efficiency and implementation ease, large-scale reforestation or bioenergy with carbon capture and storage may opt to leverage monoculture plantations, which reduce biodiversity, disrupt local ecosystems, and are typically far less durable than biodiverse forests. Soil contamination of agricultural fields poses a significant risk for enhanced rock weathering and biochar when materials contaminated with heavy metals are used. Projects involving ocean-based CDR, such as ocean fertilization, could alter marine ecosystems and disrupt food chains. Additionally, over-extraction of water for certain CDR technologies, like Direct Air Capture, could strain local water resources. To minimize these potential adverse impacts, projects must undergo comprehensive environmental risk assessments to ensure they do not harm ecosystems, biodiversity, or natural resources and that those risks are adequately addressed. This is a key aspect of any due diligence we perform of potential CDR suppliers for Climeworks, while also at the heart of our direct air capture technology advances. Climeworks integrates health, safety, and environmental management with a 'zero harm' policy to protect people and the environment through an ISO standard aligned approach.

Execution risk

Execution risk assesses whether a project will be able to deliver the promised and forecasted CDR credits. Financial risk plays a central role, as insufficient funding or financial instability can jeopardize long-term project viability. Operational risk can be significant, as efficient day-to-day operations with minimal downtime is critical for timely credit delivery and inexperienced leadership or poor decision-making can derail project timelines and outcomes. Transparency is crucial for ensuring that project progress and setbacks, methodologies, and results are all openly communicated. Many of these softer factors are best assessed by knowing project developers in-person and assessing projects on the ground.

Conclusion

Investing in CDR can be daunting, given the relative infancy of the market, breadth of criteria to consider, and the variety of projects appearing almost daily.

However, the case for carbon removal is clear and investing early in a high-quality carbon removal portfolio greatly increases the likelihood of meeting net-zero targets and ensuring access to quality supply as demand accelerates.

This framework provides the basic guidelines that Climeworks follows for objective quality vetting of CDR projects and suppliers. However, a thorough due diligence process is recommended to convert this framework into a full quantitative assessment, allowing for confidence in the authenticity, effectiveness, and known risks assumed in the purchase of any CDR credit.

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