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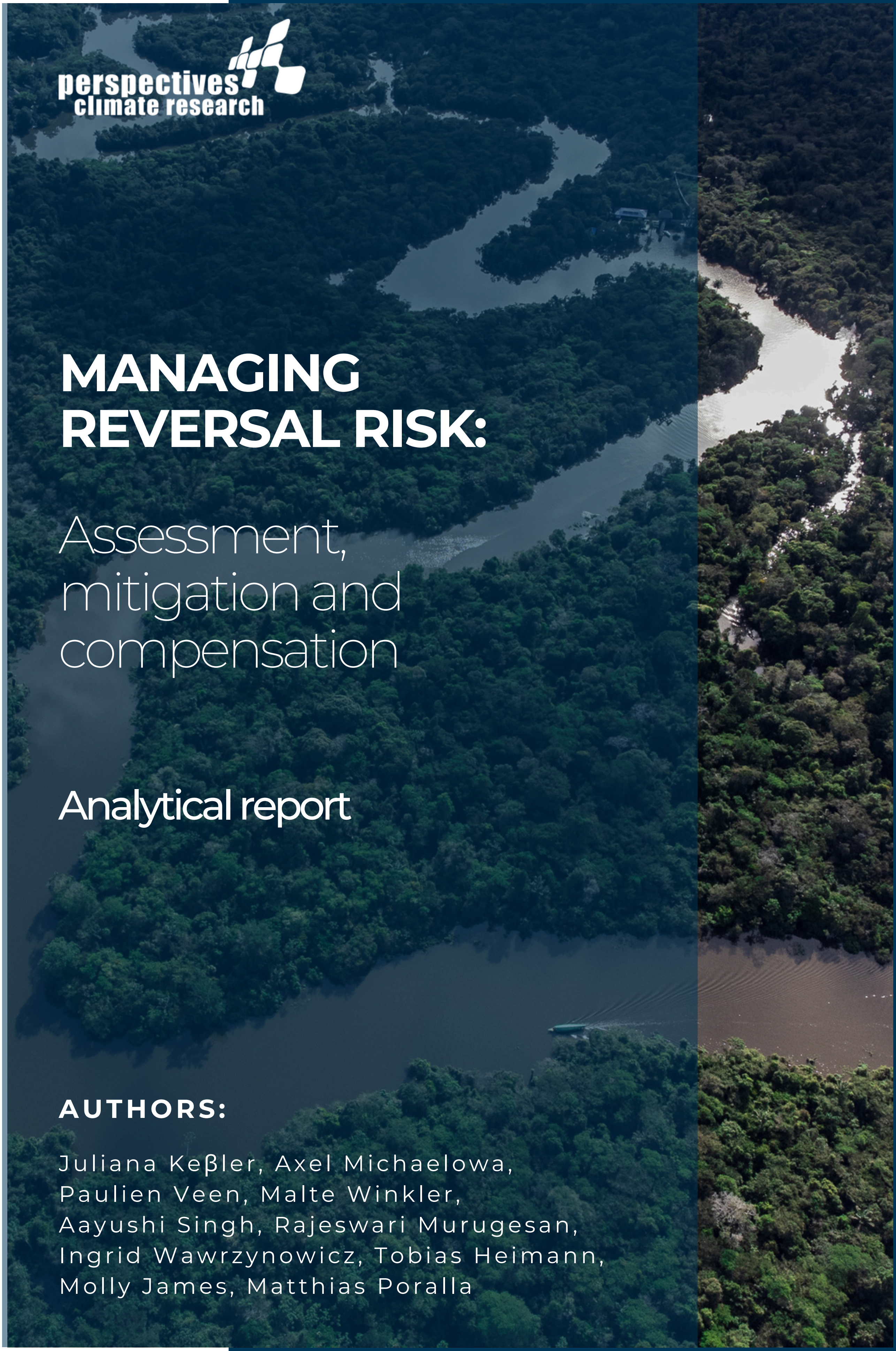

MANAGING REVERSAL RISK:

Assessment, mitigation and compensation

Analytical report

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Executive Summary

A central principle of high-integrity carbon markets is that credited greenhouse gas (GHG) emission reductions or removals must be **permanent, i.e. not reversed over time**. The term "**reversal**" is used if a **store of greenhouse gases (GHGs) resulting from previous emission reductions or removals is released into the atmosphere**, destroying the climate change mitigation benefit that had previously been credited. Ongoing efforts to rebuild **trust** in carbon credit markets lost due to high-profile failures of the Clean Development Mechanism under the Kyoto Protocol and voluntary carbon market (VCM) could be jeopardised **if reversals are not properly addressed, resulting in credits not representing the stated mitigation benefits**. This challenge is compounded by **significant trade-offs between interests of different stakeholder groups**, where researchers and NGOs call for prevention of reversals over very long periods, mitigation activity developers want to limit transaction costs and monitoring periods/liability, and government regulators and carbon market programme administrators seek manageable procedures. Thus, the challenge lies in developing **pragmatic approaches to address reversal risks** that **deliver environmental integrity and sustain trust without being prohibitive.**

Under the Paris Agreement Crediting Mechanism (PACM), reversals are categorised as avoidable (intentional) or unavoidable (unintentional), a distinction that determines liability and the type of compensation mechanisms triggered. There is an **ongoing debate** between supporters of the concepts of **"permanence" (a binary threshold of how long a GHG store needs to be sustained)** and **"durability" (the duration for which a store actually has been sustained without reversal)**. **Temporary storage has a value** if **climate change damages increase with the rate of change**, or if we can **"buy time" to prevent crossing of "tipping points"**, provided this time is used to develop widely applicable, permanent storage solutions.

Research shows that **reversal risks are activity-specific and regionally variable**. **Biospheric** carbon storage in, e.g., forests, soils, or wetlands, is generally **more likely to be reversed** than **geospheric** carbon storage (GCS) in sub surface reservoirs or achieved through mineralisation. There is thus a **trade-off between mitigation costs and durability of key mitigation activity types**. **Risk profiles differ even within the same activity type** depending on geography, plant species composition (for living biospheric pools), local climate, and storage management. The science-based framework developed in this report **differentiates risks at carbon pool and activity type level**.

Across the government regulations under the carbon offsetting reduction scheme (for international aviation (CORSIA), the UK emissions trading scheme (ETS), the EU carbon removal and carbon farming (CRCF), the PACM and the administrations of major private carbon crediting programmes and the Integrity Council for the Voluntary Carbon Market (ICVCM) trying to provide minimum quality guidelines for the voluntary carbon market, **a common architecture is emerging around four pillars**: (1) **explicit reversal risk assessment**; (2) **minimum durations for monitoring and compensation periods**; (3) **buffer pool mechanisms**; and (4) **clear liability allocation**. However, significant divergence remains in practice, as shown in Table 1 below.

Table 1: Permanence and reversal risk approaches

Framework / Programme	Storage duration	Minimum monitoring & compensation period	Key approach to address reversal risk
UK ETS Greenhouse Gas Removal (GGR)	200-year minimum storage period	**Geological carbon storage (GCS):** monitoring during injection and post-injection until negligible risk demonstrated (average 45-50 years before liability transfer)	Buffer pools; liability rules (in development)
EU CRCF	200-year reference (permanent removals); 40 years for **afforestation**; none for **peatland rewetting** (Temporary crediting (carbon farming)	**GCS:** monitoring during injection and post-injection until negligible risk demonstrated (average 45-50 years before liability transfer) **Biochar:** monitoring stops when end use starts (very short monitoring periods)	Collective buffer or insurance Direct cancellation as last resort
ICVCM (CCPs)	Applies to activity types with a material risk of reversal. Minimum 40 years for agriculture, forestry and land use (**AFOLU)** activities	≥40 years from first crediting period (material reversal risk activities)	Pooled buffer (≥20%); periodic stress testing planned. Cessation of monitoring before 40 years is counted as an avoidable reversal.
CORSIA	Project activity specific. Minimum 20 years.	≥20 years as lower bound; longer for **AFOLU**, to be changed to 40 years from 2027.	Programme-level buffer pools and eligibility criteria
PACM (Article 6.4)	Project activity specific	Methodology-specific; PCM period until negligible risk demonstrated	Buffer pool (all activities); insurance/guarantees permitted; stress tests every 3 years
Private programmes (e.g. Verra Verified Carbon Standard, American Climate Registry, Climate-Action Reserve)	Ranges from 40-100 years for **AFOLU** and to 1000+ for **GCS**	40–100 years for **AFOLU**; shorter for **GCS**	Activity-specific buffer pool contributions (risk-rated) aggregated in global pool

The result is **a patchwork of requirements in which nominally 'permanent' credits are of highly different quality regarding guaranteed storage time and protection against reversal risks**. These frameworks can be complex to navigate for those seeking to generate high integrity credits, and could create a perverse **incentive for mitigation activity developers to “shop around” for the least demanding interpretation of permanence**. Key divergences include:

- **Variation of buffer pool contribution rates for the same activity differing between programmes.**
- **How temporary or non-permanent storage is accommodated**. The EU CRCF is the only programme using **temporary crediting** which is of **high integrity but where there is a lack of demand from credit buyers**
- **Differing stringency of rules across different scales of crediting**. ICVCM applies less stringent requirements to jurisdictional REDD+ than project-level activities, on the grounds that government management enables coordinated deforestation control, reduces activity shifting, and aligns outcomes with national climate commitments. **.** This however **depends on whether there is good governance**. In cases of bad governance, it may be the case that jurisdictional REDD+ achieves lower permanence than a well-managed project. No studies have been published yet that validate the assumption of a general superiority of jurisdictional approaches**.**

Achieving a common level of alignment regarding risk assessment, buffer pool design, and minimum monitoring periods across CORSIA, PACM, government level regulation (UK, EU) and private carbon crediting programmes would be necessary in order to avoid a potential “race to the bottom” by activity developers.

Reversal risk assessments must be differentiated by reservoir (biosphere, geosphere, hydrosphere) and activity type. Because reversal drivers, timescales, and monitoring needs differ fundamentally across reservoirs and activity types, an undifferentiated approach systematically misestimates reversal risk and undermines the environmental integrity of the resulting credits

The PACM's Methodological Expert Panel (MEP) is currently developing a dedicated reversal risk assessment tool (discussed at MEP 11 and MEP 12, with finalisation during 2026. The tool covers i) Common financial, management and social risks; ii) Additional reversal risks for forest carbon storage (biosphere), geological carbon storage (geosphere) and biochar.

Current reversal risk assessment tools for biospheric carbon pools are often weakly grounded in empirical evidence. However, **good practices** emerging from the comparative analysis of major private carbon market programmes (ACR, ART TREES, CAR, Gold Standard, Verra VCS) **include**:

- **Structuring risk around likelihood × magnitude × spatial scale**, with 100-year time horizons

- **Using publicly accessible, spatially standardised datasets** (e.g. wildfire probability models, flood exposure layers, drought indices, landslide susceptibility maps)
- **Requiring climate change amplification factors**
- **Linking risk mitigation measures** (e.g. prescribed burning, fuel breaks) **to verified, quantified risk reductions**
- **Probabilistic rather than single-point risk estimation**, given stochastic disturbance regimes

Scientific evidence indicates **current buffer pool contributions underestimate reversal risks** for above ground biomass, especially those related to rising wildfire risks driven by climate change with wide agreement in the literature that these have already multiplied by two in the last 30 years and likely to rise rapidly in the future. For example, California's forest offset buffer pool has already proven to be undercapitalised despite only slightly more than a decade of operation. The global Verra buffer pool remains well capitalised for the time being.

Geospheric carbon storage (DACCS, BECCS, mineralisation, enhanced rock weathering (ERW)) generally carries lower reversal risk than biospheric storage. That said some reversal risks remain, and key risk factors include:

- For **CO_2 storage in geological formations** (saline aquifers, depleted hydrocarbon reservoirs): the dominant risks are **well integrity failure and caprock fracture**. Reversal rates decline over time as CO_2 becomes immobilised through self-correcting trapping processes.
- For **mineralisation** (in-situ in mafic rocks, ex-situ in concrete, enhanced rock weathering (ERW)): reversal risks are generally very low once mineralisation is complete; **key risks are high temperatures and low pH.** ERW carries the highest uncertainty and monitoring difficulty.

Pre-emptive measures to reduce the risks include careful site selection, detailed geological modelling, well integrity management, regulatory oversight, secured site closure funding and liability transfer.

Interest in insurance as a complementary or alternative mechanism to buffer pools is growing. A small ecosystem of specialised insurers (CarbonPool, Kita, Oka, Cfc, Howden, WTW, AON) now offers **products covering reversal risk, delivery risk, cancellation, and buffer depletion**. Verra is running a three-year durability insurance pilot which was launched in December 2025. Whilst interest is growing and promising pilots have begun, presently the sector remains **nascent** and structurally limited due to the following barriers:

- **Insurance contracts are typically 1–3 years** (annually renewed), far shorter than the 40–100-year permanence horizons required by leading frameworks
- **Insurers cannot credibly guarantee coverage over multi-decadal periods** under current capital and actuarial constraints.
- **Premium affordability is a persistent challenge**, especially for smaller or high-risk projects; climate change may make some regions effectively uninsurable over time
- **Adverse selection risk**: low-risk projects may exit buffer pools for cheaper insurance while buffer pools are exhausted by high-risk projects.

To best incentivise innovation from the insurance sector and address the aforementioned barriers whilst safeguarding environmental integrity carbon crediting programmes and regulators should **integrate insurance into rules co-developed with insurers**, **avoid overly prescriptive criteria** incompatible with insurance regulation, and **gradually expand eligible tools** (buffer-plus-insurance, permanence funds) within clear guardrails. When developing these rules, regulatory frameworks could require continuous coverage as a condition of credit issuance, providing a practical pathway to address the short policy duration barrier without requiring insurers to commit to single multi-decadal contracts. There is an emerging consensus on **hybrid architectures**, combining insurance for specific, short-term, unavoidable risks with buffer pools and government guarantees for long tail and systemic risks. Such an approach may be the most feasible path forward, keeping the insured scope narrow and premiums more manageable, particularly for smaller or high-risk projects. **Insurance must not weaken or undermine other incentives for reversal prevention and remediation**: carve-outs for avoidable reversals, deductibles, and clear trigger definitions are emerging as essential safeguards to ensure coverage does not inadvertently reward negligence. A well-structured insurance market could deliver a system for addressing reversal risk that is more precise, more equitable, and more financially efficient than buffer pools alone, with risk priced according to actual project-level exposure rather than programme-wide averages.

The EU Carbon Removal and Carbon Farming Framework (CRCF) which is likely to become the key crediting approach for removals within the EU establishes differentiated permanence requirements for:

- **Permanent carbon removals** (DACCS, BioCCS), which rely on the CCS Directive, with robust monitoring and operator liability, but significant leeway for member state authorities.
- **Biochar** which is classified having low reversal risk with no buffer pool contribution and monitoring ending at point of application. This approach is criticised by NGOs and researchers as insufficiently rigorous, given that soil type, temperature and management can significantly affect biochar stability

- **Carbon farming** (peatlands, afforestation, soils) which applies temporary crediting with credits expiring at the end of the monitoring period. The risk assessment framework is a binary hazard-vulnerability model that omits political, financial and management risks, lacks empirical validation for mitigation measure discount factors and uses coarse spatial data that may miss local variation.

Overlaps with other policy instruments regarding **liabilities that lead to double or even triple coverage** need to be addressed. Currently the CRCF is **not aligned with ICVCM, CORSIA or the PACM**, and its rules would need to be strengthened to enable such alignment in the future. Governments and decision makers should use their **leadership in the Coalition to Grow Carbon Markets** to **spearhead high integrity approaches developed in this framework**, particularly to ensure that **buffer pools duly consider growing climate change impacts on the biosphere**, for example through regular stress tests. Under the PACM, governments should finance development of **components of PACM methodology submissions that reflect the reversal risk framework** as well as **publicly available hazard, biomass and SOC datasets and geological risk characterisation tools.** Regarding both PACM and the VCM, governments should **convene insurance providers, carbon market programme administrators and regulators to develop insurance and hybrid approaches to address reversal risks.**

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Abbreviations

ACR	American Carbon Registry
AFOLU	Agriculture, Forestry and Other Land Use
AGB	Above-Ground Biomass
ALARP	As Low As Reasonably Practicable
ART	Architecture for REDD+ Transactions
AR6	Sixth Assessment Report (IPCC)
BECCS	Bioenergy with Carbon Capture and Storage
BGB	Below-Ground Biomass
BioCCS	Biogenic Emissions Capture with Carbon Storage
CAR	Climate Action Reserve
CCP	Core Carbon Principles (ICVCM)
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilisation and Storage
CDM	Clean Development Mechanism
CDR	Carbon Dioxide Removal
CFR	Code of Federal Regulations (United States)
CGCM	Coalition to Grow Carbon Markets
CIWP	Constant Improvement Work Programme
CMA	Conference of the Parties serving as the Meeting of the Parties to the Paris Agreement
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CRCF	Carbon Removal and Carbon Farming (EU Framework)
DA	Delegated Act
DACCS	Direct Air Carbon Capture with Storage
DIC	Dissolved Inorganic Carbon
EPA	Environmental Protection Agency (United States)
ERW	Enhanced Rock Weathering
ETS	Emissions Trading Scheme
EU	European Union
EU ETS	European Union Emissions Trading System
FAO	Food and Agriculture Organization
FCPF	Forest Carbon Partnership Facility
FIRMS	Fire Information for Resource Management System (NASA)
GCS	Geological Carbon Storage
GGR	Greenhouse Gas Removal
GHG	Greenhouse Gas
GS4GG	Gold Standard for the Global Goals
HWP	Harvested Wood Products
ICAO	International Civil Aviation Organization
ICVCM	Integrity Council for the Voluntary Carbon Market
IETA	International Emissions Trading Association
IFM	Improved Forest Management
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
JNR	Jurisdictional and Nested REDD+
LULUCF	Land Use, Land-Use Change and Forestry

MAOC	Mineral-Associated Organic Carbon
MEP	Methodological Expert Panel
MRV / MRR	Monitoring, Reporting and Verification / Monitoring & Reporting Regulation
NASA	National Aeronautics and Space Administration
NBS	Nature-Based Solutions
NDC	Nationally Determined Contribution
NUTS	Nomenclature of Territorial Units for Statistics
PACM	Paris Agreement Crediting Mechanism
PCM	Post-Crediting Monitoring
PDD	Project Design Document
PP	Project Proponent
REDD+	Reducing Emissions from Deforestation and Forest Degradation (and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks)
SBM	Supervisory Body of the Article 6.4 Mechanism
SDG	Sustainable Development Goal
SOC	Soil Organic Carbon
SSP	Shared Socioeconomic Pathway
TAB	Technical Advisory Body (CORSIA)
TREES	The REDD+ Environmental Excellence Standard
UK	United Kingdom
UK ETS	United Kingdom Emissions Trading Scheme
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
VCM	Voluntary Carbon Market
VCMI	Voluntary Carbon Markets Integrity Initiative
VCS	Verified Carbon Standard
ZEP	Zero Emissions Platform
ZILMP	Zambezia Integrated Landscape Management Program

1. Introduction

Efforts to rebuild trust in carbon credit markets after the failures of the Clean Development Mechanism ((Michaelowa, Shishlov and Brescia, 2019)) and the voluntary carbon market (VCM) ((Probst *et al.*, 2024) have made substantial progress since 2024. The development of stringent rules under Article 6.4 as well as the Integrity Council for the Voluntary Carbon Market (ICVCM) have not only put environmental integrity on the very top of the agenda – they have also started to lead to a convergence regarding what is deemed as sufficient integrity and what is not. Still, discussions between different stakeholders regarding the interpretation of environmental integrity are continuing.

A key principle for building and maintaining trust in carbon markets is to ensure that carbon credits are real, additional and permanent. **Minimising the risk of non-permanence of GHG stored is therefore a key principle in carbon markets**.

1.1. (Non-) Permanence and durability

Non-permanence refers to the occurrence that GHG emission reductions or removals credited to a mitigation activity are later **reversed** (e.g. the loss of carbon stored in a forest due to a wildfire or deforestation), such that the associated climate benefit is not sustained over a period meaningful for climate change mitigation (ICVCM, 2025). A **reversal** may occur at any point during or after the implementation of the mitigation activity. Reversals need to be effectively addressed to uphold trust in the carbon markets. Given trade-offs between interests of different stakeholder groups, the critical issue is whether **pragmatic approaches can be developed to address reversal risks** in a way that **delivers environmental integrity and sustains trust without being prohibitive for activity types with high mitigation potential and significant sustainable development co-benefits**.

Reversals are usually categorised through the distinction between **avoidable (intentional)** and **unavoidable (unintentional)** reversals, e.g. under the Paris Agreement Crediting Mechanism (PACM) (UNFCCC, 2025b). This categorisation determines who bears responsibility and how **compensation mechanisms** (e.g., **buffer pools** or **insurance** policies) are triggered.

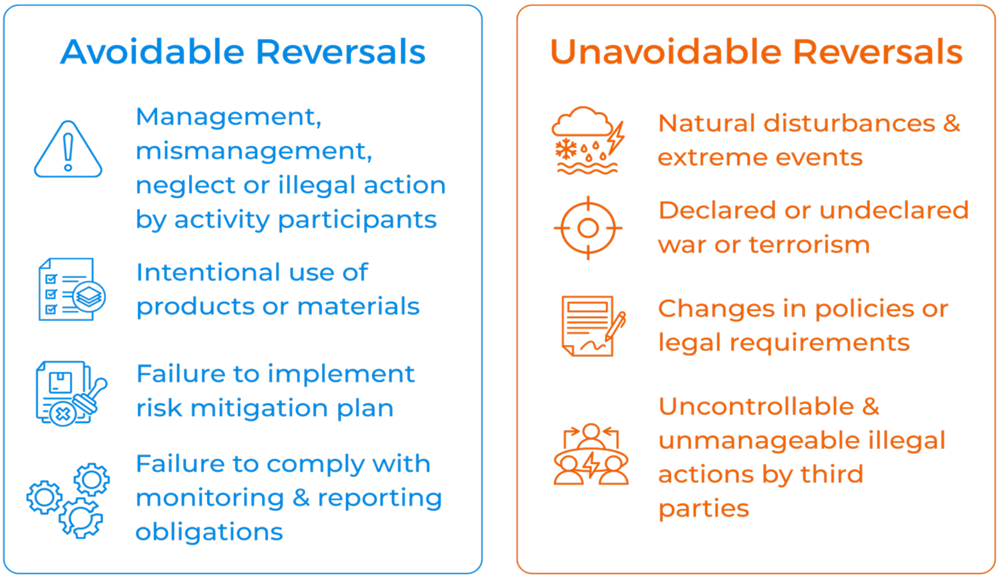

Figure 1: PACM distinction of reversals (Authors based on UNFCCC, 2025a)

The terms permanence and durability remain contested. **Permanence** establishes a binary normative threshold (often set at 100 years, but also up to millennia, see Fig. 2 below), and could be argued to be more a political rather than scientific choice **(Haya *et al.*, 2023). Setting such a threshold carries trade-offs**: A high threshold disadvantages shorter-term storage, despite its value in slowing the rate of warming ((Streck *et al.*, 2025a) see discussion in Box A1 in the Annex); a low threshold risks overstating mitigation benefits.

Some practitioners advocate replacing the binary permanence concept with the more flexible notion of **durability**, wanting to recognise shorter-term storage benefits and to reduce liability burdens (Hunnable *et al.*, 2024; IETA, 2025; Streck *et al.*, 2025a). This has led to debate over the term's usefulness. The IPCC treats durability as a physical continuum (IPCC, 2023), while SBTi defines it as the "timeframe over which carbon storage is reliably maintained" (SBTi, 2025). If this term is applied in the context of permanence for international carbon markets, it would enable to at least partially consider mitigation that is reversed before a permanence threshold is reached.

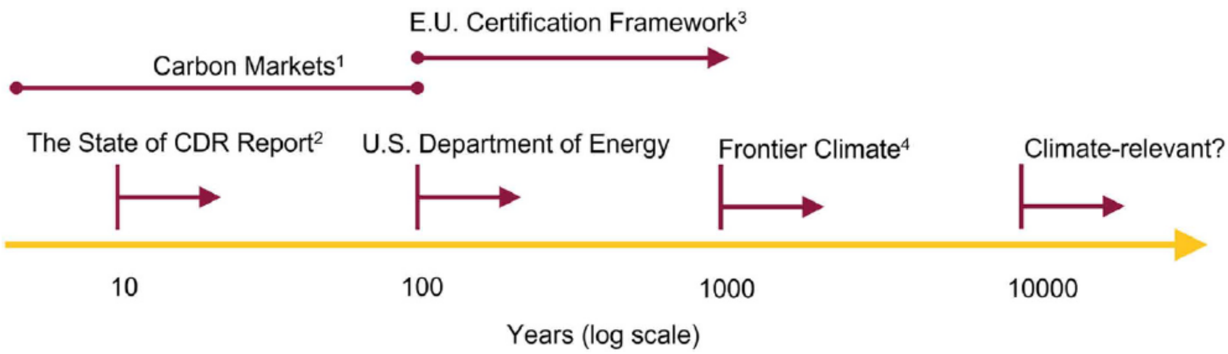

Figure 2: Different definitions of permanence (Arcusa and Lackner, 2025)

1.2. Reversal risk levels

Mitigation activity types are associated with differing levels of reversal risk. On the one hand, activities that do not rely on the storage of GHGs and therefore do not face the possibility of future reversals (i.e. replacement of fossil fuels by renewable energy, or destruction of industrial gases or methane) result in permanent emission reductions. On the other hand, many activities rely on storing CO_2[1]. According to the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC), the durability of carbon storage depends fundamentally on the storage medium (IPCC, 2023): **Carbon stored in vegetation and soils is typically the least durable**, as it is susceptible to reversals due to human activities and natural disturbances (Haya *et al.*, 2023; IPCC, 2023). Storage in more stable forms, such as biochar in soils or incorporation into materials like concrete, is generally more durable, and **storage in geological formations offers potential for near-permanent sequestration**. While this generalisation can be applied as a rule of thumb, the permanence of an activity depends on its non-permanence risk assessment and pre-emptive mitigation of the identified risks being case specific.

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[1] Carbon dioxide (CO_2) is usually stored as solid carbon; we thus speak of “carbon storage” in the remainder of this study. Given that storage of other GHGs than CO_2 is currently not technologically mature it is not specifically addressed in this study.

1.3. How are reversal risks currently addressed?

Most carbon crediting programmes require (some or all of) the following components for ensuring permanence and addressing reversal risks (FAO, 2024; Hunnable *et al.*, 2024; Michaelowa *et al.*, 2025).

1. **Reversal risk assessment:** Activity participants must quantify reversal risks for specific (groups of) mitigation activity types, often guided by programme-specific tools or methodologies and yielding a risk score.
2. **Risk mitigation measures:** To lower the risk score, activity participants must implement risk mitigation measures, often outlined in a plan or report. Some programmes permit activities only if the risk score has been lowered below a specified threshold.
3. **Determination of scale and applicability of compensation mechanism requirement:** All programmes reviewed in this study apply compensation mechanism(s), the scale of which is usually informed by the reversal risk assessment.

I. Compensation mechanism requirements: **Most programmes set aside a share of issued credits ex-ante to feed buffer pools or reserve accounts. A reversal triggers cancellation of an equivalent number of credits as compensation. Other compensation approaches include insurance instruments (discussed in Chapter 4), tonne-year accounting and temporary crediting (see also**

II. Box A2: Is there a value in temporary storage?

There is a vivid academic debate whether **storage with low durability has a value in addressing climate change or not**. There are **two conceptual arguments why such a value exists**: **reducing the rate of climate change (e.g. the temperature increase per decade) reduces climate change damages** and **preventing that temperature exceeds tipping points that lead to irreversible and large climate change impacts**.

The first argument is intuitively appealing. A rapid temperature increase, and the impacts linked to it leave less time to adapt and thus generate higher adaptation costs. A slow rate of change allows autonomous adaptation, whereas a high rate of change requires planning and generates more "surprises" regarding impacts. There is evidence that the rate of temperature increase has accelerated significantly in the last decade (Foster and Rahmstorf, 2026), and that the frequency and severity of climate change-related events causing damages has increased as well (World Meteorological Organization (WMO), 2026). However, this topic has been researched to a very limited extent. (Pinsky *et al.*, 2025) and (Visser, 2008) find that impacts of climate change on biodiversity are positively related to the rate of change. **More research is needed to calculate the benefits of reducing the rate of temperature increase.**

There is a scientific consensus that several temperature-increase-related "tipping points" exist where specific climate change impacts become irreversible. (Lenton *et al.*, 2025) summarise current knowledge on tipping points and find that we may already have exceeded the temperature levels that trigger general coral reef dieback, whereas we are getting close to the temperature triggering collapse of land permafrost, the Greenland ice sheet, the West Antarctic ice sheet and the Southern Ocean sub-polar gyre. In that context, high volumes of **temporary storage could "buy time" to keep us from crossing the tipping points**. During this time, permanent storage technologies could be developed to the extent that they would be available at a scale large enough to ensure the tipping points are never crossed. Countries could point to temporary storage in their NDC, buying time until future, permanent CDR becomes available at attractive conditions (Beyer, 2025). But if the time is not used wisely and we get into a situation where massive reversals happen without alternative mitigation being available, then temperature increase would accelerate, and we would exceed multiple tipping points very quickly. Therefore, research is needed to assess the conditions under which temporary storage could successfully "buy time", including the policy instruments required.

An approach that **attributes value to the temporary storage for each year of effective storage** is the so-called **"tonne year" approach**, explained in Box 3 below. Many researchers continue to

emphasise that temporary storage does not contribute to limiting cumulative emissions, which is necessary to meet the Paris Agreement's temperature goal and thus the **value of temporary storage cannot be equivalent to an emissions reduction** (the effect of which is inherently permanent; Brander and Broekhoff, 2023; Cullenward, 2023; Watson and Bui, 2026).

I.

4. And Box A3: Alternative approaches to addressing non-permanence).
5. **Reversal risk monitoring, reporting and compensation period:** Activity participants must monitor and report reversal events during the crediting period and beyond. Monitoring frequencies, post-crediting monitoring periods, and compensation periods vary across programmes and are not always aligned with one another. Non-compliance is often sanctioned, e.g. by cancelling credits from periods without proper reporting.
6. **Reversal notification, report and consequences:** In case of a reversal event, activity participants must notify the programme and often prepare a full report on the event. Further consequences may include freezing the project registry account or suspending activity-related operations (e.g., issuance).
7. **Compensation for reversals:** Some programmes restrict the use of compensation mechanisms to unavoidable reversals and require activity participants to cancel a corresponding number of credits if avoidable reversals occur. Explicit quality criteria may be specified for the cancelled credits, often applying the like-to-like principle (see Box A4).
8. **Review of compensation mechanism performance**: Some programmes review the performance of the buffer pool on a regular basis. Others incorporate stress testing to ensure that the pool is sufficiently replenished.

Chapter 2 of this report provides a further detailed assessment of requirements.

1.4.Aim of this report

While most programmes incorporate a set of similar components to address reversal risks, specific rules, approaches and details remain heterogeneous across programmes. This leads to market fragmentation and varying carbon credit quality. This report aims to develop recommendations for addressing reversals based on high-integrity procedures rooted in scientific evidence, building on an analysis of current programmes and pool-specific reversal risks. It specifically targets the Article 6.4 SB, national and regional regulators and private carbon market actors. **Chapter 2** of the report provides an overview of current permanence requirements in carbon crediting programmes. **Chapter 3** explores the science behind reversal risk approaches for different carbon pools, while insurance as a tool to address reversal risks are discussed in **Chapter 4**. **Chapter 5** takes a closer look at permanence requirements in the EU, before the report closes with an overarching discussion (**Chapter 6**) and recommendations (**Chapter 7**).

2. Overview of permanence requirements

This chapter provides a detailed overview of permanence requirements across different schemes, initiatives and carbon crediting programmes. Across government regulations under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), the UK Emissions Trading Scheme (ETS), the EU Carbon Removal and Carbon Farming (CRCF) Framework, and the Paris Agreement Crediting Mechanism (PACM) and the administrations of major private carbon crediting programmes and the Integrity Council for the Voluntary Carbon Market (ICVCM) initiative trying to provide minimum quality guidelines for the voluntary carbon market, **a common architecture is emerging around four pillars**: (1) **explicit reversal risk assessment**; (2) **minimum durations for monitoring and compensation periods**; (3) **buffer pool mechanisms**; and (4) **clear liability allocation**. However, significant divergence remains in practice, as shown in Table 2 below.

Table 2: Permanence and reversal risk approaches (repeated from Executive Summary)

Framework / Programme	Storage duration	Minimum monitoring & compensation period	Key approach to address reversal risk
PACM (Article 6.4)	Project activity specific	Methodology-specific; PCM period until negligible risk demonstrated	Buffer pool (all activities); insurance/guarantees permitted; stress tests every 3 years
CORSIA	Project activity specific. Minimum 20 years.	≥20 years as lower bound; longer for **AFOLU**, to be changed to 40 years from 2027.	Programme-level buffer pools and eligibility criteria
ICVCM (CCPs)	Applies to activity types with a material risk of reversal. Minimum 40 years for **AFOLU** activities	≥40 years from first crediting period (material reversal risk activities)	Pooled buffer (≥20%); periodic stress testing planned. Cessation of monitoring before 40 years is counted as an avoidable reversal.
Private programmes (e.g. Verra VCS, ACR, CAR)	Ranges from 40-100 years for **AFOLU** and to 1000+ for **GCS**	40–100 years for **AFOLU**; shorter for **GCS**	Activity-specific buffer pool contributions (risk-rated) aggregated in global pool
UK ETS GGR	200-year minimum storage period	**Geological Carbon storage (GCS):** monitoring during injection and post-injection until negligible risk demonstrated (average 45-50 years before liability transfer)	Buffer pools; liability rules (in development)
EU CRCF	200-year reference (permanent removals); 40 years for **afforestation**; none for **peatland rewetting** (Temporary crediting (carbon farming)	**GCS:** monitoring during injection and post-injection until negligible risk demonstrated (average 45-50 years before liability transfer) **Biochar:** monitoring stops when end use starts (very short monitoring periods)	Collective buffer or insurance Direct cancellation as last resort

2.1. Article 6.2 requirements

Under **Article 6.2** of the Paris Agreement, Parties agreed on key principles governing market-based cooperation. Decision 2/CMA.3 requires that, for each cooperative approach, Parties must minimise the risk of non-permanence of mitigation outcomes across multiple NDC implementation periods and ensure that any reversals are fully addressed (UNFCCC, 2022). **The responsibility for operationalising this requirement rests with cooperating Parties**. An Article 6.2 cooperative approach may draw on existing methodologies – such as those developed by private programmes or the PACM – or adopt newly developed or adapted methodological approaches.

2.2. Article 6.4 (PACM) requirements

Compared to the accounting and reporting framework established under Article 6.2, the crediting mechanism under **Article 6.4** was mandated to develop detailed rules for minimising non-permanence. The crediting mechanism was established by Parties to the Paris Agreement and is overseen by an international governance body, the so-called Supervisory Body of the Article 6.4 mechanism (SBM). Eventually, in October 2025, the SBM adopted the Standard *Addressing non-permanence and reversals in mechanism methodologies* (Non-Permanence Standard) and the associated Information Note *Elements related to on-permanence and reversals for inclusion in relevant regulatory documents* (Information note).To this end, the SBM first worked on the **Standard on Removals**[2] which outlines higher-level requirements. The standard outlines requirements for monitoring, reporting, post-crediting period monitoring and reporting, accounting for removals, crediting period renewal, addressing reversal including reversal risk assessment and compensation, avoidance of leakage as well as avoidance of other negative environmental and social impacts (UNFCCC, 2024). Adopted in October 2024, the standard provided the basis for the further operationalisation of detailed requirements.

In Table 3 we first provide a comprehensive overview of non-permanence requirements of private programmes before Table 4 outlines the PACM-specific requirements that have been agreed upon to date.

2.3. CORSIA

Under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) of the International Civil Aviation Organization (ICAO), carbon credits eligible for the use toward offsetting obligations must meet a set of integrity assessment criteria, including the criterion that credits **must**

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[2] A6.4-STAN-METH-002: Standard – Requirements for activities involving removals under the Article 6.4 mechanism

represent permanent emission reductions, avoidance or carbon sequestration (ICAO, 2019). The document on eligibility criteria further specifies that if there is a reversal risk, the respective carbon credits are not eligible or mitigation measures are introduced to monitor, mitigate and compensate "**any material incidence** of non-permanence" (ICAO, 2019). The definition of material incidence is not further explained though. The associated *Guidelines for Criteria Interpretation* provide more information on the concrete permanence requirements (ICAO, 2025c). Specifically, the carbon crediting programmes should:

In addition to these documents, the scheme's Technical Advisory Body (TAB) has further clarified its interpretation of the eligibility criteria in November 2025 (see ICAO, 2025a). The document represents a compilation of TAB reports to the ICAO Council on credit eligibility over the years. In this compilation (ICAO, 2025a):

- The TAB considered the **monitoring and compensation periods** for reversals in some programmes' procedures to be **insufficiently robust** (e.g., limited to five or ten years). Its recommendation, therefore, was to require these programmes to revise their procedures so that the periods last at least 20 years.
- While recognising that another programme's oversight body (PACM's SBM) has prohibited tonne-year accounting to address reversal risks under the PACM, despite persistent concerns within the scientific community, the TAB nevertheless concluded in January 2024 that tonne-year accounting could be considered eligible as part of a multi-pronged approach and assessed as a package. Since then, the TAB has not addressed the issue further. (See also Box A3: Alternative approaches to addressing non-permanence).
- The TAB derives some **best practices for the full compensation of reversals,** such as:
    - Providing reversal risk assessment tools/guidance at the programme level and not only at the methodology level.
    - Reversal risk assessments to systematically identify all material risk factors and to quantify their scale and likelihood. For each identified risk factor, appropriate mitigation measures and monitoring are required. The assessment results are then combined into an activity-specific aggregated risk rating, which is periodically reviewed and updated at defined intervals using monitoring data. Monitoring arrangements, including the scope, frequency, and duration are calibrated to reflect the materiality of the underlying reversal risk.
    - Data generated from reversal risk assessments and monitoring is independently reviewed, and the outcomes are used to determine each activity's corresponding contribution to the buffer pool or reserve account.

  - Larger reserves and pools covering various activity types, proponents and geographies are better equipped to manage higher risks.
  - Requirements should be in place for the programme to cover any reversal(s) that exceed the buffer pool or reserve account holdings.
- The TAB outlined that measures to address non-permanence should be proportionate to the **inherent materiality of reversal risks**, which depends on the activity type and storage site. It considered the reversal management timeframes to be most relevant for Agriculture, Forestry, and Other Land Use (AFOLU) removals, while noting that engineered Carbon Dioxide Removal (CDR) and biochar activities generally require shorter timeframes. Therefore, it concluded that programme procedures may reasonably require reversal management and monitoring for engineered CDR and biochar activities **until any residual reversal risk** and environmental or social risks are **demonstrably negligible**. However, the TAB did not engage in any definition of what constitutes "negligible" risk.

Noting that the decision on programme and credit eligibility is in the end taken by the ICAO Council, the TAB's interpretations and recommendations provide an important direction for programmes seeking CORSIA eligibility. For the scheme's first phase from 2024-2026, the following carbon crediting programmes were found eligible: American Carbon Registry (ACR), Architecture for REDD+[3] Transactions (ART), Climate Action Reserve (CAR), Global Carbon Council, Gold Standard, Isometric, Thailand Voluntary Emission Reduction Programme and Verra's Verified Carbon Standard (VCS) and Jurisdictional Nested REDD Programme (ICAO, 2025b). However, programme-specific exclusions were also specified in the document *CORSIA Eligible Emissions Units*. So, even if the programme was found eligible, it can still be that credits generated from specific underlying activity types are excluded. For example, in ACR's case credits from certain LULUCF activities are excluded (ICAO, 2025b). Also, some programmes such as the BioCarbon Fund Initiative for Sustainable Forest Landscapes, Cercarbono and the Forest Carbon Partnership Facility (FCPF) were found conditionally eligible, requiring further adjustments (e.g., provisions conferring liability on activity proponents to monitor, mitigate and respond to reversals, stricter procedures for avoidance of double counting) by the programmes (ICAO, 2025b).

For CORSIA's second compliance period covering the period from 2027 to 2029, so far ACR, ART, Gold Standard and Verra's VCS and Jurisdictional Nested REDD Programme are accepted.

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[3] REDD+: Reducing emission from deforestation and forest degradation in developing countries. Thereby, + represents additional forest-related activities such as sustainable forest management and conservation of forest stocks

2.4. ICVCM

The Integrity Council for the Voluntary Carbon Market (ICVCM) seeks to establish a global standard for high integrity carbon credits through its Core Carbon Principles (CCPs). Permanence is one of its CCPs specifying that “GHG emission reductions or removals from the mitigation activity shall be permanent or, where there is a risk of reversal, there shall be measures in place to address those risks and compensate for reversals” (ICVCM, 2024a). This principle is underpinned with concrete requirements outlined in its Assessment Framework. **The ICVCM requirements require compliance with CORSIA’s requirements on permanence and establish additional obligations. ICVCM operationalises how permanence must be addressed, with more prescriptive requirements on the buffer mechanism, the monitoring duration, and the treatment of different reversal scenarios and activity types.** The initiative differentiates the requirements for specific activity types according to their associated risk of reversals:

- Activity types with a **material risk of reversal** are required to **monitor** and **compensate for reversals**. The following activity types are considered to have a material risk of reversal:
    - Agriculture soil carbon sequestration
    - Conservation and avoided conversion (e.g., grassland/rangeland management, avoided deforestation)
    - Forestry sequestration (improved forest management (IFM), afforestation/reforestation, agroforestry)
    - Wetland and marine ecosystem restoration/management (including seagrasses, saltmarshes, mangroves, peatlands)
- For mitigation activities involving the displacement of non-renewable biomass, biochar, CCS with geological storage, enhanced weathering, CCS with mineralisation and CO_2 in concrete utilisation activities, ICVCM requires the **assessment of reversal risks** and in the case of identified material risks, the implementation of **appropriate measures to prevent material risks** of reversals.
- For jurisdictional REDD+ activities, the initiative establishes separate permanence requirements (see a detailed description in Box A1), noting that further work on their treatment will be carried out for future iterations of the Assessment Framework. In a blog post, ICVCM further stated that jurisdictional REDD+ programmes operate at a national or state level, using policy and regulation to protect large areas of forest, which reduces deforestation risk (ICVCM, 2024b). Similarly, ART argues that crediting at the jurisdictional level incentivises governments to regulate land use and enforce laws and that it also reduces reversal risks compared to project-based approaches (ART, n.d.). Carbon market experts, however, note that while reversal risk may be reduced at jurisdictional scale it is not eliminated, as

demonstrated by past reversals that occurred in jurisdictional programmes (Schneider *et al.*, 2024, Umweltbundesamt, 2022).

With respect to **activity types with a material risk of reversal**, the Assessment Framework specifies that the carbon crediting programme (ICVCM, 2024a):

- Or the activity proponents must cancel one carbon credit for every tonne of CO_2e reversed;
- Must ensure that monitoring and compensation are at least maintained until the later of (i) 40 years from the start of the first crediting period or (ii) the end of the crediting period;
- Must require activity proponents to monitor and report any reversals and to compensate for any avoidable reversals throughout the monitoring and compensation period;
- Must pause the issuance of carbon credits until the full compensation of avoidable reversals took place;
- Must intervene and surrender credits from the pooled buffer reserve where activity proponents fail to compensate for avoidable reversals;
- Must deem any cessation of monitoring and verification an avoidable reversal;
- Must quantify the reversal risk following a clearly defined, publicly available methodology;
- Must ensure activity proponents implement reversal risk mitigation measures;
- Must provide criteria for the categorisation into avoidable or unavoidable reversals;
- Must establish a pooled buffer across all relevant mitigation activities for the compensation of reversals from these;
- Must ensure that the pooled buffer pool
  - Is sized at no less than 20% of the total credits issued for these activities; OR
  - Reflects the reversal risk of the mitigation activity over the full monitoring and compensation period including the risk of non-compensation by activity proponents;
  - Publicly discloses buffer reserves including the origin of credits.

For jurisdictional REDD+ programmes, the carbon crediting programme must (ICVCM, 2024a):

- Establish a pooled buffer reserve requiring contributions from all programme proponents and from which reversals of the proponents' programmes can be compensated for as long as these participate in the programme;
- Enforce that programme proponents contribute a percentage of carbon credits proportional to the reversal risk and adequate to compensate for at least 40 years from the start of the first crediting period and provide evidence for that;
- Require the proponent to replenish the pooled buffer reserve to a level proportionate to risk where a reversal exceeds the proponent's prior buffer contribution;

- Require immediate cancellation of all buffer reserve credits contributed by a proponent upon exit from the carbon crediting programme.

This is an evolving landscape with the second version of ART's The REDD+ Environmental Excellence Standard (TREES) which requires for CORSIA-eligible credits that the participant monitors, reports and verifies carbon pools for at least 20 years approved in 2024. Alongside the decision IC-VCM has noted that it may require in the next iteration of the Assessment Framework that carbon-crediting programmes (i) commit to post-crediting monitoring for the permanence period required under the Assessment Framework, (ii) undertake periodic reassessments of buffer pool contributions to ensure these remain proportionate to the evolving risk profile of the project or jurisdiction and (iii) have provisions for increased transparency and reporting on buffer pool status . To note, the Assessment Framework is currently undergoing review with the next iteration expected in 2026 (ICVCM, 2024a).

To ensure further refinement of the CCPs and the Assessment Framework, the initiative has established Continuous Improvement Work Programs (CIWP) aiming to reflect evolving market practices in its requirements. In 2024, the first work programme on permanence was launched to identify best practices and key gaps in how permanence is addressed across carbon crediting programmes. Experts who formed part of the work programme identified key topics to be taken into consideration in the next iteration of the CCPs and Assessment Framework. Among these were the **definition and classification of avoidable and unavoidable reversals**, the clarification that **discontinuation of monitoring and verification triggers** a compensation obligation equivalent to previous buffer pool contributions and the consideration of including mandatory **buffer stress testing** as a requirement. Regarding reversal risk assessments, it was noted that the initiative should provide guidance on **which risk types to cover and what data** and information is to be used. Also, the **prolongation of the 40-year monitoring** and compensation period from the start of the crediting period should be explored (ICVCM, 2025). These findings indicate that existing rules remain insufficiently standardised and leave important methodological choices to carbon crediting programmes, potentially affecting consistency and comparability across the market. Recently, the initiative announced a follow-up work programme to refine permanence requirements with expert engagement scheduled throughout 2026 (ICVCM, 2026). This second CIWP places particular emphasis on monitoring and compensation work streams (ICVCM, 2026) with the aim to conduct research, convene and derive recommendations:

- Pilot a standardised **stress test for pooled buffer reserves** with interested CCP-eligible programmes to assess robustness and inform potential mandatory testing

- Establish standardised definitions and guidance for project-level risk assessment including risk categorisation and distinction between avoidable and unavoidable reversals
- Assess novel compensation options such as a permanence trust, industry-wide pooled buffers, and insurance products offering flexible, long-term coverage

2.5. Carbon crediting programmes

Table 3 provides a summarised overview of permanence requirements applied by **American Carbon Registry (ACR)**, **Climate Action Reserve (CAR)**, **Gold Standard** and its Gold Standard for the Global Goals (GS4GG), **Isometric**, **puro.earth**, **Verra** with its Verified Carbon Standard (VCS), and **Architecture for REDD+ Transactions (ART)** and its The REDD+ Environmental Excellence Standards (TREES)[4]. For ART, the analysis includes the assessment of the draft TREES Version 3.0, which has not yet been formally adopted. Version 3.0 includes more clarity on both the buffer pool contribution calculation and the increased pool contribution following a reversal (ART, 2025a). Note that ART is the only large scale jurisdictional crediting programme that has become operational – VCS JNR has not made inroads in the market yet.

For more detail per programme the reader is referred to Table A1. Private carbon crediting programmes' permanence requirements in ANNEX 1.

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[4] ART focuses on REDD+ activities except for removals from forests remaining forest

Table 3: Summary of private carbon crediting programmes' permanence requirements

Parameter	Description
Reversal risk assessment	Whether and how the programme requires proponents to assess reversal risks before crediting, and whether the assessment feeds into the buffer pool contribution rate. Most programmes provide a dedicated AFOLU risk tool and separate GCS requirements; the main distinction is whether the assessment outcome directly drives the buffer contribution (ACR, Verra VCS) or feeds a broader risk score with mitigation factors (CAR, Gold Standard). Isometric combines a programme-level questionnaire with protocol-level factors in the monitoring plan.
Risk mitigation measures	Whether the programme prescribes pre-emptive measures to reduce reversal risks, and whether implemented measures can lower the risk rating or buffer contribution. The key divergence is whether mitigation actively reduces the buffer contribution (CAR allows mitigation factors to lower the AFOLU risk rating; ART TREES allows three mitigation factors) or is simply required without affecting the rate (Gold Standard requires a mitigation plan above a risk threshold; puro.earth mandates pre-emptive mitigation for GCS where material risks are identified).
Buffer pool design	How compensation is structured, pooled across activities, segmented by activity type, or held in project-specific reserves. The main distinction is between pooled buffers shared across participants (ART TREES, Verra VCS, CAR with separate AFOLU/GCS sub-accounts) and project-specific reserves (ACR's GCS Reserve Account, Isometric's per-participant GCS accounts). puro.earth operates without a buffer pool for GCS.
Buffer pool / reserve contribution requirements	The percentage of issued credits contributed to the buffer, how it is calculated (risk-rated vs. fixed), and what types of credits are acceptable. Approaches diverge sharply: risk-rated contributions in defined ranges (ART TREES 5–30%; Verra VCS up to a 7% GCS cap) versus flat rates (Gold Standard 20% AFOLU / 2.5% GCS; ACR 10% annual GCS reserve). Isometric classifies CO_2 storage in reservoirs as very-low-risk with a 2% precautionary contribution. puro.earth requires no contribution at all, instead applying a deduction to reported output volume if the 100-year stored fraction falls below 99%.
Reversal coverage	Which categories of reversals the buffer compensates: unavoidable only, avoidable only, or both; and whether the pool must be replenished after avoidable reversals. Most AFOLU buffers cover only unavoidable reversals (ACR, CAR, Gold Standard). The broadest coverage is ART TREES (all reversals, no category distinction) and Verra VCS (both, with mandatory replenishment for avoidable). Isometric explicitly allows buffer credits to be used for avoidable reversals, conditional on participant reimbursement.
Alternative mechanisms & approaches	Whether the programme permits instruments other than buffer pools, e.g., insurance, guarantees, output-volume adjustments, or fund-based approaches, and whether these substitute for or supplement

	buffer contributions. ACR is the only programme that allows approved insurance products to fully replace buffer/reserve contributions. Gold Standard permits insurance and guarantees specifically for engineered removals (GCS). Verra is currently piloting both insurance and a fund-based approach. ART TREES and CAR do not currently provide for alternatives, though CAR signals openness to future review.
Frequency of monitoring for reversals	How often monitoring reports must be submitted during the crediting and post-crediting (PCM) periods. The clearest divergence is between fixed schedules (ART TREES: years 1, 3 and 5 of the crediting periods, with no PCM report) and methodology- or risk-driven schedules (most others). Verra VCS's GCS requirement is the most prescriptive, annual reporting continuing for at least 10 years post-injection.
Length of monitoring period (incl. PCM specifications)	The minimum required duration of reversal monitoring, including any post-crediting obligation. Most AFOLU programmes converge around 40 years from the start of the crediting period (ACR, Isometric from end of crediting, Verra VCS). CAR's U.S. Forest Protocol (100 years following issuance) and Gold Standard (30–50 years with no PCM). For GCS, durations vary widely, from Verra VCS's 10-year minimum post-injection care to Isometric's 50 years, with most programmes tying cessation to demonstrated plume stability or ISO 27914 closure criteria rather than a fixed term.
Cessation of monitoring	How the programme treats early termination of monitoring. Most programmes deem cessation an avoidable reversal requiring full remediation (CAR, Isometric) or treat it as a full reversal of all credits issued (Gold Standard). ART TREES and Verra VCS notably do not specify particular consequences.
Reversal notification	The maximum time within which proponents must notify the programme of a reversal event. Deadlines vary by an order of magnitude — from Isometric's 1–3 days at programme level (5 days for GCS, as for puro.earth) and ACR's 10 business days, to Gold Standard's and Verra's 30 days. ART TREES and Verra VCS do not specify a deadline.
Consequences of reversal notification	What proponents must do following notification, and any interim consequences. ART TREES increases the annual buffer contribution by 5% for five years, during which no mitigating factors can be claimed. Detailed-report deadlines otherwise range from three months (Gold Standard) to two years (Verra). CAR requires a full AFOLU report within one year and ACR within six months.
Programme-level backstop	Safeguards where the proponent fails to compensate or where the buffer pool is insufficient. Most programmes retire buffer credits to cover the shortfall (ACR, CAR with cross-activity fallback, Gold Standard). ART TREES requires participants to cover any deficit exceeding their contribution by setting aside future credits or purchasing equivalent TREES credits. Isometric commits at programme level to ensuring full compensation by directing future removals from the same participant to the buffer. Verra VCS is the most punitive for GCS, projects become ineligible if a reversal exceeds 10% of injected volume.

2.6. UK ETS Authority

In July 2023, the ETS Authority committed to integrating engineered greenhouse gas removal (GGR) into the UK Emissions Trading Scheme (ETS) and published a consultation on ‘Integrating Greenhouse Gas Removals in the UK Emissions Trading Scheme’ (UK Government *et al.*, 2025a). The response (UK Government *et al.*, 2025b) outlines the UK ETS Authority’s position, proposing a **three-pillar framework** to ensure only robust and durable removal methods enter the UK ETS:

- **Minimum storage period** – engineered GGRs must meet the minimum storage period of 200 years to enter the UK ETS.
- **Liability measures** – the project operator is legally liable and accountable for any losses from carbon storage and the corrective actions.
- **Fungibility measures** – buffer pools will be used as an insurance mechanism; The operator will be awarded fewer allowances than carbon stored, the stored carbon in the buffer pool is then cancelled in the event of a reversal.

The response recognises that a **minimum storage period of 200 years** (preferred by only five stakeholders) is considerably longer than the median and modal response of 100 years. It argues that the longer period ensures environmental integrity and investor confidence while enabling the inclusion of a broad range of GGR. It also refers to the EU’s CRCF framework which states that long-term storage is 'several centuries i.e. at least 200 years’. The 200-year minimum storage period will make it difficult to include removals from nature-based solutions into the UK ETS, as they are often less durable and monitoring difficult to achieve over this time horizon (see section 3.2.1).

The Authority decided to apply **liability measures** to the operator obligating them to take corrective action in the event of a reversal. They are considering both pre-existing approaches (such as the purchase of UK Allowances in the case of emissions from Carbon Capture and Storage) and the novel ideas presented in stakeholders’ responses, such as **financial penalties and insurance products,** as well as

The Authority decided to proceed with **buffer pools as a fungibility measure.** Buffer pools are already used domestically in the Woodland Carbon Code and internationally in other compliance schemes. The Authority expects that in cases with low risk of reversal, such as GCS, there will be a zero-rate buffer contribution, however, a final decision has not been made.

In a forthcoming technical consultation the finer details of this three-pillar framework will be concluded, such as contribution rates (buffer pool) and review periods. The decision on whether to integrate woodland removals is ongoing. The Authority established that peatland restoration would not be eligible for inclusion in the UK ETS.

2.7. EU CRCF

The **EU Regulation 2024/3012** ("CRCF Regulation") establishes a certification framework for permanent carbon removals, carbon farming and carbon storage in products within the EU (European Parliament, 2024). The Regulation establishes overarching guidelines on environmental integrity including on non-permanence, while the **Delegated Acts** and the certification methodologies annexed to those provide activity type-specific details. The Regulation differentiates between **permanent carbon removals** that capture CO_2 from the atmosphere and store it for centuries, bearing a very low or no risk of reversal[5], and **non-permanent methods** with higher reversal risks[6] (European Commission, 2025a). The regulation differentiates between **four different types of mitigation units**, namely permanent carbon removal units, carbon farming sequestration units, soil emission reduction units and carbon storage in products units.

To address reversal risks related to these four-unit types, the Regulation stipulates the following overarching requirements:

- **Risk mitigation:** The activity shall mitigate of any identified risks of reversals.
- **Reversal remediation mechanism:** Appropriate liability mechanisms shall be in place to address reversals, including **collective buffer pools or up-front insurance mechanisms**. In cases of reversals, the last resort option shall be the direct cancellation of credits. Further liability rules and measures to address the risk of failure of these mechanisms shall be included in the applicable certification methodologies. For activities that generate a temporary net-carbon removal benefit, a liability mechanism is required. For soil emission reduction activities, a liability mechanism should be applied only to deter early termination of the activity.
- **Temporary crediting:** For activities based on temporary removals (such as carbon farming or carbon storage in products), credits shall have an expiry date, aligning with the end of the monitoring period. After this period, the carbon captured and stored shall be considered

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[5] Direct Air Capture with carbon storage (DACCS), biogenic emissions capture with carbon storage (BioCCS), biochar, Enhanced Rock Weathering (ERW) and ocean alkalinity enhancement as a possible candidate

[6] Carbon farming (e.g. rewetting peatlands, agroforestry, soil protection, reforestation) and carbon storage in bio-based construction materials (e.g. timber and agricultural crops)

released into the atmosphere unless the participant commits to prolonging the monitoring period. Certification methodologies shall incentivise extending the monitoring period to store carbon for at least several decades in soils or biomass. The Regulation does not specify requirements for buyers regarding the replacement of expired temporary credits. It also does not specify the validity period of emission reduction credits.

- **Monitoring:** For permanent carbon removals, monitoring reports shall be submitted at least once a year for DACCS and BioCCS. Biochar monitoring period depends on the intended use. For biochar applied to soil, the monitoring period extends either until the point of application or, at the latest, one year after the end of the certification period during which the biochar was applied to the soil. For biochar stored in products, monitoring continues until it is verified that the biochar has been incorporated into the respective product. Additional rules for monitoring shall be included in the applicable certification methodologies.

The **EU Commission Implementing Regulation 2025/2358** ("Implementing Regulation") adopted by the Commission in November 2025 introduces rules on CRCF certification schemes, bodies and audits (European Commission, 2025b). While the approach to addressing non-permanence is set out in the CRCF Regulation and in its Delegated Acts and annexes, the Implementing Regulation provides more specifications. It categorises non-conformity into three categories: minor, major and critical, which has a direct effect on the issuance of credits. The requirement to monitor reversals is defined in Article 11. For a group of activity developers applying the same mitigation activity, monitoring does not have to be complete but can be limited to a sample of developers (see Article 12). If a critical or major non-conformity is identified for one developer of the initial sample of group members an additional sample of the same size shall be audited. Systemic non-conformity across the whole sample shall lead to suspension or withdrawal of the whole group certification.

For the first **Delegated Act on permanent carbon removals**, the Commission, supported by a Carbon Removal Expert Group, focused on methodologies for DACCS, BioCCS, and biochar. The draft Act was released in July 2025 for public consultation. The Act was adopted by the Commission on 3 February 2026 and transmitted to the European Parliament and the Council of the EU for a two-month scrutiny period which can be prolonged by another two months (European Commission, 2026). Neither Parliament nor the Council have the right to make amendments, but they have the right to object to the draft. In the absence of objections by the European Parliament or the Council within the scrutiny period, the Act will enter into force 20 days following its publication in the Official Journal, at the earliest in April 2026 (European Commission, 2026). The preparation of the Delegated Act for permanent removal was closely monitored by NGOs and environmental groups, and early draft versions received heavy criticism (Sherger & Sharma 2023, ZEP 2024, Schneider et al. 2024 & 2025, ECOS 2025, NEP 2025, ZEP 2025). While some criticised aspects have been addressed in the final Delegated Act, others remained, leading to a disaffirmation of the final version by some researchers and environmental groups (Bellona 2025, Fallasch et al. 2025, Hernández 2025). The criticism is mainly related to the use, sustainability and assumption of automatic carbon neutrality of biomass for BioCCS and biochar.

The Commission is working on two additional Delegated Acts for certification methodologies: Carbon farming methodologies for activities and methodologies for carbon storage in bio-based construction products. The draft carbon farming methodologies have been released for public consultation on 22 January 2026. In the draft methodologies for certifying carbon removals and soil emission reductions from carbon farming, further non-permanence are stipulated, such as monitoring periods (incl. monitoring beyond the activity duration), monitoring parameters, types of risks to consider (e.g. mismanagement, natural hazards) and the definitions of unavoidable and avoidable reversal risks (European Parliament, 2026). Further, the draft includes instructions for the calculation of the risk rate, which is based on the combination of the hazard and vulnerability indicators and is expressed as the share of carbon at risk of being released. All (draft) methodologies are analysed in detail in this regard in **Chapter 5.**

The detailed PACM non-permanence requirements are elaborated in the **Non-Permanence Standard** and the accompanying **Information Note**, adopted in October 2025 (UNFCCC, 2025a, 2025b).

Table 4: PACM permanence requirements (UNFCCC, 2025a, 2025b, 2026a)

	PACM requirements
Risk assessment requirements	Application of reversal risk assessment tool with methodology-specific definitions (see below)
Risk mitigation requirements	Required implementation of risk mitigation plan. Details to be specified in reversal risk assessment tool
Buffer pool design	Buffer pool account across all activities.
Buffer pool contribution requirements incl. composition of contribution	Contributions in line with calculated percentage-based risk rating. Credits from the same activity are to be contributed
Reversal coverage	Buffer Article 6.4 credits to compensate for avoidable and unavoidable reversals. In case of avoidable reversals: PPs obliged to replenish pool with equivalent amount
Alternative mechanisms & approaches	An SBM-approved third party guarantor or insurance provider can take over responsibility for the PCM from the activity participants Para. 62 of the Removals Standard allows for the consideration of alternative means to compensate for reversals in addition to the buffer pool. The MEP is currently developing a concept note addressing measures to ensure the robustness and resilience of the buffer pool, explore alternative measures to it and outline a potential Monetary Permanence Reserve
Frequency of monitoring for reversals (during crediting period and PCM period)	Mechanism methodologies to specify minimum frequency for monitoring report submission during crediting period and in the post-crediting monitoring (PCM) period. Minimum frequency must be between 1-5 years, with the exact frequency being guided by the nature, type and reversal risk
Length of monitoring period incl. PCM specifications	Mechanism methodologies must determine a minimum monitoring period during the PCM period
Cessation of monitoring	Deemed avoidable reversal
Reversal notification	Within 30 days. Annual reversal reports must be submitted by 31 march each year (covering previous year)
Consequences of reversal notification	Late report submission entails suspension of activity- specific operations
Programme-level backstop	Periodic stress tests of buffer pool (at least every three years)

Despite the adoption of the standard and the information note, several elements still require further operationalisation or consideration. In particular, reversal risk assessment procedures are to be specified in a dedicated reversal risk assessment tool currently under development by the SBM's Methodological Expert Panel (MEP). In addition, in its final form the Non-Permanence Standard shifts several key decisions to the **methodology level**. This was partly a response to strong public criticism from market stakeholders during the consultation process. Some stakeholders had expressed concern that overly stringent non-permanence requirements could effectively exclude nature-based solutions (NBS) from credit generation under the PACM. In particular, they highlighted issues such as the potentially indefinite duration of the PCM period, the definition of the negligible-risk threshold and the extensive reporting obligations. Ultimately, the standard and information note stipulate that (UNFCCC 2025a,b):

- **Mechanism methodologies** must define a **minimum period for monitoring** – based on the activity type and associated reversal risk – during the PCM period, after which activity participants may request to end monitoring if they can demonstrate a negligible risk of reversal.
- The **PCM period** must continue for a duration proposed **in the methodologies** and approved by the SBM **or** until:
  - All potential future reversals are fully compensated for by cancelling an equivalent amount of Article 6.4 credits by the activity participant, guarantor or insurance provider
  - All potential future reversals are fully compensated through an insurance or guarantee mechanisms whose sufficiency has been approved by the SBM
  - A negligible reversal risk is demonstrated (after minimum PCM period) and verified by an independent third-party entity
- For demonstrating negligible risk, the **methodologies** must specify criteria for demonstrating negligible reversal risk, taking into account the activity type and its associated risks. These criteria must ensure that stored greenhouse gases are stable or in a steady state for at least 100 years from the time negligible risk is demonstrated.
- A negligible risk is a risk "that would result in a loss of no more than a maximum percentage to be specified **in methodologies** on the basis of **guidance to be developed in the reversal risk assessment tool** […] calculated over a 100-year timeframe starting from no earlier than the end of the last active crediting period" (UNFCCC 2025b, para. 3g)

By shifting these aspects to the methodology level, the Standard and Information Note imply that further operationalisation and detailed guidance – based on bottom-up proposals – will be required from the SBM. Discussions on how to implement the PACM's non-permanence requirements will thus continue at the activity type level, as methodology proposals are submitted.

3. A science-based framework and procedure for reversal risk assessment

Strengthening the approaches to address reversal risks, including risk assessment procedures, is relevant across all carbon crediting programmes to ensure the environmental integrity, financial viability, and long-term credibility of carbon credits. There is a growing recognition that reversal risk assessments must be differentiated according to reservoir type (**biosphere**, **geosphere** and **hydrosphere**). Reversal risks can be generally categorised into **natural** versus **human-induced** risk types. The combination of current good practices in carbon markets and scientific research on carbon storage reservoir, pool and activity type helps to inform the UNFCCC A6.4 Methodology Expert Panel and Supervisory Board on the drafting of the reversal risk assessment standard.

3.1. Reversal risk assessment approaches

Some carbon crediting programmes apply **detailed, activity-specific risk assessment approaches or tools** that generate differentiated risk scores to determine buffer contributions accordingly. However, these reversal risk assessments are often weakly supported by empirical evidence, and the resulting risk ratings seem more speculative than data driven.

Under PACM, the reversal risk assessment tool is currently developed by the MEP. It will determine the contributions to the reversal risk buffer pool account. All activities involving emission reductions or removals with reversal risks must apply the tool. An Article 6.4 activity may play into various GHG reservoirs. Therefore, the Non-Permanence Standard specifies that mechanism methodologies must first identify all applicable GHG reservoirs (UNFCCC, 2025b). The standard recognises three different reservoirs: the biosphere, geosphere and hydrosphere. Once the applicable reservoirs are identified, the respective reversal risk assessment is applied.

At the MEP's 11th meeting (MEP 011), the experts also decided to express individual reversal risk factors **as a percentage of total carbon**, rather than as a percentage of credited carbon (UNFCCC, 2026a). "Credited carbon" refers only to the portion of carbon storage that has been issued as credits, whereas "total carbon" covers **all carbon stored in the GHG reservoir**. A tentative agreement among MEP members is to develop the tool based on four procedures that are to be applied to each relevant GHG reservoir:

- Procedure to calculate individual reversal risk factors (expressed as % of total carbon)
- Procedure to combine individual reversal risk factors together (expressed as % of total carbon)

- Procedure to reduce reversal risk factors based on remediation measures (expressed as % of total carbon)
- Procedure to calculate the buffer pool contribution from the combined reversal risk factors (expressed as % of credited carbon)

The MEP is currently working on separate reversal risk assessment components (UNFCCC, 2026a, 2026b):

- Common financial, management, and social risks that apply to most or all project types
- Additional reversal risks applicable to forest carbon storage
- Additional reversal risks applicable to geological carbon storage; and
- Additional reversal risks applicable to biochar

At MEP 12 (9–13 March 2026), further progress was made on the development of the reversal risk tool. Building on the tentative framework established at MEP 11, the focus of MEP 12 was on operationalising the tool:

- Classifying reversal risks for different project types and reservoirs,
- Quantifying risk factors for both baseline risks and risk reductions achieved through mitigation measures,
- Identifying specific mitigation measures to reduce reversal risks.

The tool is designed to capture both the **inherent baseline risk of reversals and the effect of mitigation actions**. Work on finalising procedures and calculations is ongoing and will continue through MEP 13 (13-17 April 2026), after which the tool is expected to be finalised and ready for practical application.

Subsequently, we discuss considerations for the procedure to calculate individual reversal risk factors applicable to reservoirs in the biosphere and geosphere.

3.2. Reservoir- and pool-specific risk assessments

In this section, we focus on assessing **reversal risks** for reservoirs in the biosphere and the geosphere, differentiated by carbon pools, looking both at the practice of carbon crediting programmes and scientific literature, with the objective of providing clear recommendations to the PACM.

3.2.1. Biosphere

Table 5 provides a comparative overview of how **individual reversal risk factors** are assessed across major carbon crediting programmes. Particular attention is given to how these programmes define and structure their risk scope and taxonomy, differentiate between activity types and – where relevant – carbon pools, and operationalise the assessment of reversal risk likelihood, magnitude (severity) and spatial scale. Additional assessment factors examined include transparency and documentation requirements; minimum time-series expectations; treatment of conservativeness and uncertainty; identification of risk-specific mitigation measures; aggregation rules and overall risk rating methodologies; climate change risk amplification; the existence of risk thresholds or eligibility gates; and provisions for periodic review and update based on monitoring data. Building on this structured comparison, identified good practices are discussed, forming the basis for a subsequent examination of additional elements highlighted in the scientific literature.

While some programmes have dedicated tools in place, others specify their approaches within methodologies, protocols, or the standard itself. In many cases, the relevant approach is distributed across several of these documents. A detailed overview of these parameters per programme are given in ANNEX 1, Table A2. Comparative overview of individual reversal risk factors assessed across major carbon crediting programmes for biospheric carbon pools.

Table 5: Overview of reversal risk assessment approaches adopted by private carbon crediting programmes in the biosphere

Parameter	Description
Risk scope and taxonomy	How many reversal risk categories are defined and what types of risks are covered: i) Activity finance / management; ii) regulatory/political/governance/market; iii) naturally induced; iv) human induced
Differentiation by activity type and biospheric carbon pool	All the carbon crediting programmes distinguishes risks for different AFOLU activity types (e.g. forestry vs. wetlands) and other biospheric carbon pools.
Risk typology	All programmes have predefined risk (sub-)types are specified, and what categories of natural hazard are explicitly named, like natural disasters (wildfire, disease/insects, catastrophic events (wind, flooding)). GS4GG and Verra add climate variability (temperature, water, weather extremes), and future climate change and sea-level rise projections (Verra). TREES depends on the Cancún Safeguards for REDD+, where countries need to define their risk assessment and typology.
Assessment of reversal risk likelihood, magnitude and spatial scale	Whether carbon crediting programmes require characterisation of how likely a reversal is, how severe it would be, and how geographically extensive. All programmes have a severity score. ACR looks at it per sub-category level, CAR has protocol specific, but no consistent severity score, GS4GG applies high, medium, low score thresholds, TREES depends on Cancún Safeguards for REDD+ delivered by country and Verra designs likelihood and significance around historical data over the last 100 years.
Transparency and documentation requirements	All programmes require disclosing reversal risk assessments and pre-emptive and post reversal mitigation measures as per their standards (ACR, GS4GG, Verra), activity specific protocols (CAR), or external safeguard requirements (TREES)
Minimum time series requirements	The minimum historical or forward-looking time period over which risk must be assessed or evidenced. The timing differs per programme, but do not specify a fixed minimum period (ACR, CAR, GS4GG), monitoring stops when participant leaves the programme (TREES), and 100 years (Verra)
Conservativeness and treatment of uncertainty	How incomplete data, model uncertainty or knowledge gaps are handled: default scores (2%, ACR), if 100-year data is unavailable, conservative extrapolation needs to be applied (Verra), unspecified (CAR, GS4GG, externally defined (TREES, Cancún Safeguards)
Identification of risk-specific mitigation measures	Whether the programme prescribes concrete actions project proponents can take to reduce specific reversal risks, and whether effectiveness evidence is required. Basic (ACR) or specific (Verra) principles, Protocol specific (with state agency approval, CAR), mitigation measures required when severity score threshold is passed (GS4GG),

	legislative support, demonstrated interannual variability >15% and compliance with Cancún Safeguards lower the default reversal risk buffer pool attribution (TREES)
Aggregation rules and overall risk rating	How sub-category risk scores are combined into a final overall rating, and how that rating translates into a buffer pool contribution. Aggregated (ACR, GS4GG, Verra) or protocol specific: aggregated or default (CAR), default with adjustment factors (TREES)
Climate change risk amplification / consideration	Whether and how projected increases in climate-related hazards (more frequent/intense extreme events) are factored into risk scoring. Not explicitly specified (ACR, CAR), scored for in risk rating (GS4GG, Verra), externally determined (TREES, Cancún Safeguards)
Risk thresholds or pass/fail gates	Whether specific quantitative thresholds exist that render a project ineligible or trigger a required corrective action. Not explicitly specified (ACR), protocol specific (CAR), defined at sub-category level (GS4GG), overall risk and sub-category threshold dependent (Verra), externally determined (TREES, Cancún Safeguards)
Periodic review and update	How often risk assessments must be reviewed and under what circumstances they must be revised. Reviewed at every verification (Verra), every 5 years (ACR), periodically (TREES, unspecified time), protocol specific (CAR), at certification renewal (GS4GG)

Several good practices emerge from the comparison for assessing natural reversal risk:

- **A robust framework should begin with a clearly defined risk scope and taxonomy**. Good practice is to distinguish between broad categories (e.g. internal/management, external/social, and natural risks) and to further disaggregate these into predefined sub-categories.
- **Risk categories should be tailored to activity type characteristics** (e.g., forest, wetland or grassland projects) and, where feasible, explicitly consider the vulnerability of different carbon pools.
- **Protocol-specific mitigation (e.g. early warning systems or targeted grazing) should be required,** with quantified discount factors tied to the scientific evidence and programme approval, oversight and verification, similar to CAR's protocol requirements.
- **A key methodological good practice is to structure reversal risk assessment around core risk components:** likelihood (frequency), magnitude (severity of carbon loss), and spatial scale (extent of impact). For example, Verra assesses historic natural risk based on event frequency over a 100-year period and the percentage of average carbon stocks lost in a single event, with defined severity classes and conservative extrapolation where only 20–100 years of data are available. Gold Standard operationalises a three-factor model (Exposure × Vulnerability × Spatial Scale) with structured thresholds for each dimension.
- **Transparent, publicly available, and scientifically credible datasets should underpin risk assessments.** ACR demonstrates a strong dataset-driven approach, particularly for U.S. projects, referencing national hazard layers (e.g. wildfire hazard potential and national flood hazard maps) while also allowing regionally appropriate defaults or project-specific approaches.
- **Assessing risks over long temporal horizons is essential.** Verra’s requirement to assess historic natural risk over a 100-year period represents a strong benchmark.
- **Integrating climate change considerations systematically** – rather than implicitly – strengthens environmental integrity under changing risk baselines. Emerging good practice is to apply a climate change impact or amplifying factor.
- **Effective risk assessment frameworks link risk assessment to risk mitigation**. Good practice includes defining eligible mitigation measures for specific risk types (e.g. wildfire management treatments, conservation easements, deed restrictions), requiring evidence of effectiveness, and adjusting risk scores only where measures are demonstrably implemented.
- **Clear thresholds or corrected score requirements can act as safeguards against projects with excessive reversal risk.** While true theoretically, that more stringent requirements may raise implementation barriers and reduce project uptake, and hence reducing the climate benefit. The environmental integrity should be assessed against a credible counterfactual, e.g., what happens to the forest if the activity does not proceed under A6.4? the project could either continue in a different (domestic) carbon programmes with weaker safeguards

(financial displacement), or the land is converted, which could lead to increased GHG emissions. A balance between robustness and applicability is to be promoted.

Other important insights from the comparative analysis are:

- **While disturbance frequency and severity are taken into account, often the underlying numbers appear to rely on internal data and expert judgement** without public, independently assessable scientific justification (Haya *et al.*, 2024; Anderegg *et al.*, 2025a).
- **Conservativeness is not a built-in principle in most assessment frameworks**. Where historical data are incomplete or uncertain, conservative extrapolation should be required.
- **Default factors should be used only where spatial or historical data are unavailable or where a clear justification exists.** CAR applies such factors in soil organic carbon (SOC) methodologies: the Grassland Protocol and the Soil Enrichment Protocol. In the first, a 2% buffer contribution is required, with a temporary 5% risk value applied to projects that have not yet undergone a site visit during verification. The Soil Enrichment Protocol requires a minimum 5% deduction and increases this to 7.5% where more than 50% of the project area is concentrated in one region, while dispersed projects remain at 5%. These relatively low factors are justified on the basis that fires, and catastrophic floods would not typically release SOC and that the risk is not considered to vary significantly by location or land management.

Another insight from the assessment is that **few programmes explicitly consider carbon pool–level dynamics.** In the following, we highlight key insights at carbon pool-level from the scientific literature on reversal risks assessment. The biosphere includes several carbon pools: **above-ground biomass** (AGB) (e.g., trees, crops), **below-ground biomass** (BGB) (roots), **dead organic matter** (litter, dead wood), **soils** (SOC) and biomass embodied in human infrastructure, particularly **harvested wood products** (HWP). Activity types influence one or several of these pools.

Above-ground biomass

AGB is defined as: all above-ground living biomass, including stems, stumps, branches, bark, seeds, and foliage (IPCC, 2003). AGB is a material carbon pool in all forestry-related activity types. Most methodologies only include woody AGB as a relevant carbon pool, while non-woody AGB may be selected or generally excluded (Gold Standard, 2024a; Verra, 2025g). For annual crops (e.g., grains, vegetables, annual forage) carbon fixed in their AGB is typically released back into the atmosphere within months when residues decompose or are consumed (IPCC, 2019). **Factors such as geographic context, species composition, and forest stand structure can substantially influence both the likelihood and nature of potential reversals** (Anderegg *et al.*, 2020). Recent work on IFM and REDD methodologies underscores that these structural and biogeographic differences are not well captured when programmes rely on coarse regional averages or generic risk categories, which can systematically understate reversal risk in high-hazard areas or for older, high-biomass stands (Haya *et al.*, 2023). Also, forest ecosystems are inherently resilient, and empirical research confirms that stocks can recover from disturbance (e.g. wildfire, pest, windfall), given sufficient time and conditions, while recovery time depends on location and type of forest (Jones and Schmitz 2009, Poorter et al. 2016, Dabor et al. 2018). Older forests (typical of IFM and REDD+ portfolios) tend to require larger buffers because regrowth is slower and recovery from disturbance is less able to "backfill" losses over a 100-year horizon (Anderegg *et al.*, 2025a). Moreover, protection of such old forests leads to high biodiversity and adaptation co-benefits that need to be properly valued. These co-benefits may justify prioritising avoided deforestation to other activity types with lower reversal risks, if the trade-off is properly assessed.

Using a validated tropical forest biomass model with Monte Carlo simulations, (Anderegg *et al.*, 2025a) find that disturbance impacts on 100-year AGB trajectories are much larger than assumed in Verra's AFOLU Non-Permanence tool. In a representative scenario (50–70% biomass loss every 25 to 50 years), simulations retained ~57% of initial biomass on average after 100 years, whereas Verra's implied insurance level assumes >96% remains. This implies that reversal risk assessment should explicitly model distributions of outcomes (no single-point expectations) and benchmark buffer contributions to ensuring a chosen percentile (e.g., mean and/or ≥80% of trajectories).

Wildfire risk

Wildfires directly destroy AGB. Warmer, drier conditions triggered by climate change are increasing fire frequency and severity (Henner and Kirchengast, 2021; Chu, Grafton and Nelson, 2023). Ballard et al. (2023) show that nearly half of the 190 global forest carbon projects they analyse have already experienced at least one wildfire since 2001, and 39 projects saw more than 10% of their project area burn during 2010–2021, indicating that severe AGB loss within project boundaries is already common even before future risk amplification is considered (Ballard *et al.*, 2023). Climate change can exacerbate this risk. A model predicts that wildfire exposure of 190 globally distributed forest carbon projects could increase by up to 55% by 2080 under medium climate scenarios (Ballard *et al.*, 2023). The AI-based model couples satellite fire detections, drought indices and land-cover/topographic variables to generate annual fire probabilities at ~300 m resolution, and is explicitly proposed as a tool for project-level fire risk scoring and for adjusting buffer contributions or eligibility in high-risk regions (Ballard *et al.*, 2023).

Projects in regions where projected fire probability and severity exceed certain thresholds (e.g. Ballard's upper quantiles under SSP2-4.5/SSP5-8.5) may warrant either substantially higher buffer contributions or ineligibility for crediting if mitigation options are constrained. Historical wildfire losses within the first decade of California's forest offset programme depleted at least 95% of the buffer pool allocation intended to cover 100 years of wildfire risk (Badgley *et al.*, 2022). This indicates that buffer contributions were not calibrated to empirically observed disturbance intensity.

For reversal risk assessment, indicators such as ladder fuels, canopy layering, canopy base height and surface fuel loads are critical predictors of fire behaviour and should be incorporated into reversal risk assessments alongside total biomass (Stephens *et al.*, 2020; Herbert *et al.*, 2022). Also, declines in vegetation greenness may signal reduced fuel moisture and increased flammability, suggesting that remote sensing-based vegetation trends can provide early warning signals of rising reversal probability. In addition, Stephens et al. (2020) emphasise that ongoing warming and drying are expected to increase wildfire extent and severity in seasonally dry forests, implying that reversal risk assessments should rely on projected (not only historical) fire regimes.

Regarding the mitigation of wildfire-related reversal risks, the literature notes that prevailing forest carbon accounting methodologies tend to prioritise readily quantifiable aboveground carbon stocks in order to comply with established greenhouse gas (GHG) accounting and verification standard (Buchholz *et al.*, 2022). This emphasis on maximising measurable stocks may, however, create perverse incentives. In fire-prone systems, maintaining high aboveground biomass without implementing fuel reduction measures can elevate disturbance risk and increase the likelihood of large-scale carbon losses (Stephens *et al.*, 2020; Buchholz *et al.*, 2022; Herbert *et al.*, 2022). Carbon crediting structures that reward initial stock accumulation and penalise biomass removal may unintentionally discourage proactive fuel treatments, thereby increasing long-term reversal risk (Herbert *et al.*, 2022). As a result, approaches that focus exclusively on near-term stock accumulation may inadvertently heighten reversal risk and shift liability to buffer mechanisms (Buchholz *et al.*, 2022). **To address this tension, Buchholz et al. (2022) argue for probability-based accounting frameworks that more fully incorporate disturbance risk.** Such approaches would allow for lower initial AGB (e.g., from thinning or prescribed burning) where these interventions demonstrably reduce the probability of severe wildfire and associated long-term carbon losses.

Mitigation measures for wildfire risk should be linked to quantifiable reductions in expected carbon loss rather than treated qualitatively. Methodologies could allow defined reductions in natural risk scores where interventions meet evidence-based design thresholds – such as minimum area treated, treatment intensity, or treatment return intervals – and where their effectiveness is independently verified (Buchholz *et al.*, 2022; Haya *et al.*, 2024). **Typical risk mitigation measures include prescribed burning to remove understory fuels, mechanical thinning and fuel breaks to reduce biomass continuity while retaining fire-resistant trees, grazing management to limit**

grass and shrub buildup, and landscape measures such as firebreaks, access roads for suppression, and early-warning systems based on satellite and weather data (Regos, 2025). Thinning must avoid leaving logging debris as this, in turn, increases the fire hazard (Stephens *et al.*, 2020). Programme frameworks can also incorporate policy and land-management measures – such as restrictions on slash-and-burn practices or incentives for fire-resilient species – to enhance landscape resilience. When led by government agencies, such programmes have high potential for jurisdictional crediting management. Moreover, where such interventions demonstrably reduce reversal risk, buffer contributions may be adjusted proportionally. For example, CAR requires vegetation management treatments that lower wildfire risk to be approved by state agencies or the programme itself, although they are not independently verified (CAR, 2023). Evidence also indicates that the effectiveness of such interventions is more uncertain in many tropical forest contexts (Anderegg *et al.*, 2025a).

Drought risk

A slow onset reversal can be triggered by droughts causing tree dieback in longer periods. Observational evidence shows that warming combined with drought can switch ecosystems from biomass gain to loss, especially in northern temperate and boreal regions where biomass stocks began declining in some areas after ~2016 due to heat and drought constraints (Anderegg *et al.*, 2025a). Nature-based climate solutions in Earth's forests could strengthen the land carbon sink and contribute to climate mitigation but must adequately account for climate risks to the durability of carbon storage. The REDD and IFM methodology assessment highlights that current durability tools rarely include explicit probabilistic modelling of drought-induced mortality or growth decline (Haya *et al.*, 2024). In practice, AGB in water-limited or warming-sensitive biomes may require much higher effective risk scores. Drought-induced mortality is often not explicitly modelled in buffer design, despite growing evidence of large-scale tree mortality linked to warming and water stress (Badgley *et al.*, 2022). **Reversal risk frameworks must explicitly model slow-onset climate mortality as a distinct disturbance category (Badgley *et al.*, 2022)**.

Given the slow-onset character, **risk assessment frameworks should include indicators like recent trends in net biomass change, climatic water balance anomalies, and site-level growth and mortality data** rather than only episodic disturbance records and should update risk scores when multi-year negative trends in AGB are detected.

Landslide risk

Landslides pose a significant risk to AGB. In Southeast Alaska's Tongass National Forest, landslides redistributed up to 57% of the carbon lost to logging between 1954-1995 (Vascik *et al.*, 2021). Caleca et al. (2025) conceptualise landslide risk through four components (susceptibility, hazard, exposure, vulnerability). Their continental case study of European mountain ranges demonstrates how this structured approach can identify landslide-prone areas and estimate potential economic losses, offering a transferable framework for landscape-level risk analysis in forested and mountainous regions.

Riverine and coastal flooding risk

Riverine and coastal flooding can directly destroy AGB (Yang, Lin and Xue, 2024; Qadri and Ceccato, 2025). According to (Tabasi, Fereshtehpour and Roghani, 2025), flood risks arise from a combination of hazard and vulnerability, the latter being shaped by the exposure and susceptibility. Resilience (defined by coping and adaptive capacities) reduces overall risk by counterbalancing vulnerability; it thereby complements hazard- and exposure-focused approaches. Multiple flood hazard indicators (flood extent, depth, and proximity to channels) can be integrated into composite hazard layers for local or regional risk assessment (Tabasi, Fereshtehpour and Roghani, 2025). These hazard layers, when combined with exposure and vulnerability data, support more detailed flood-risk analyses that account for the spatial distribution of potential impacts.

Windthrow risk

Empirical and modelling studies on windthrow in temperate and boreal forests show that AGB loss from storms is strongly controlled by stand structure (height, density), species composition (shallow- versus deep-rooted species), edge exposure, soil wetness and topography (Mitchell, 1998). Even-aged monocultures on wet, shallow soils or exposed ridges are particularly vulnerable, while structurally diverse, multi-layer stands are less prone to catastrophic blow-down (Mitchell, 1998). A recent study uses spatial models in Central Europe to predict windthrow probability, combining wind-climate data, topography and stand characteristics, and show that risk maps can be generated at management-relevant scales to inform silvicultural planning and protection forests (Stadelmann *et al.*, 2025). **Risk mitigation options such as promoting mixed species stands, reducing height/diameter ratios through thinning regimes, and avoiding abrupt edges (e.g., narrow clear-cuts) can measurably reduce AGB losses from storms and could justify partial reductions in wind risk scores if backed by site-level data or recognised risk models**. However, where return intervals for severe storms are short and exposure is high (e.g., certain mountain ranges and coastal wind corridors), AGB may not meet long-term durability expectations.

Pest and disease risk

Pests and diseases are a growing risk to AGB, exacerbated by higher temperatures and altered precipitation patterns. Generally, monocultures are more susceptible to a wide range of reversal risks including fire, windthrow and pests (Forest Research, 2026), whereas forests with higher biodiversity and complex structures tend to be more resilient (Pickering *et al.*, 2025). Scenario analysis of sudden oak death demonstrates that mortality affecting a single species could fully deplete the entire disease and insect risk allocation (Badgley *et al.*, 2022).

Continental-scale modelling demonstrates that reversal risks to AGB are multi-hazard, spatially heterogeneous, and strongly climate-sensitive (Anderegg *et al.*, 2022). Fire, drought-driven climate stress, and insect mortality each contribute substantially to projected increases in forest disturbance risk over the 21st century. Haya et al. (2023) argue that current buffer pool contributions may be materially undercapitalised even when considering wildfire risk in isolation. When analysing the severely undercapitalised buffer pool of California's cap-and-trade programme, Badgley et al. (2022) observed that the buffer pool design did not account for increasing wildfire intensity, geographic variation in fire risk, or climate-driven amplification of disturbance. Similarly, drought mortality and invasive pathogens were not adequately incorporated at programme design.

Reversal risk assessment must incorporate climate projections, not rely on static historical baselines (Badgley *et al.*, 2022). Climate stress-driven tree mortality is projected to rise by factors of 1.3 to 1.8, and insect-driven mortality by 1.2 to 1.7, depending on emissions pathways (Anderegg *et al.*, 2022). These risks diverge significantly after mid-century and are particularly pronounced in western and intermountain regions, though expansion into additional geographies is projected. Importantly, disturbance pathways interact and are not simply additive, and mortality risk is mediated by species-level physiological traits, including drought tolerance. Projections indicate a shift toward younger, lower-biomass stands with reduced carbon density (Haya *et al.*, 2023). At the same time, intensifying disturbances such as drought, wildfire, and pest outbreaks are expected to increase tree mortality (Anderegg *et al.*, 2020, 2022). As a result, the carbon stored in these forests is likely to become more vulnerable and less persistent over time. **Reversal risk must therefore be assessed using spatially differentiated and forward-looking approaches that incorporate local climate trajectories, species composition, and disturbance interactions** (Anderegg *et al.*, 2020; Haya *et al.*, 2023).

Also, reversal risk assessment should incorporate **climate-amplified hazard trends** and explicitly consider regeneration failure and biome shifts as drivers of non-permanence (Anderegg *et al.*, 2025a). Both Verra and Gold Standard are currently the only programmes incorporating climate change considerations in the AFOLU reversal risk assessment. However, Haya et al. (2024) argue that Verra's tool (version 4.2) does only coarsely consider climate-change effects and relies on disturbance-regime tables that are not clearly grounded in peer-reviewed data. The lowering impact of the "adaptive capacity" criteria on climate change risk amplification is also criticised as likely to underestimate the climate change risk (Haya *et al.*, 2024). **This could be addressed, inter alia, by grounding risk reductions in peer-reviewed science, capping reductions, independently verifying claimed measures, and anchoring assessments to empirical historical data.**

Key considerations for reversal risk assessment for AGB

- **Reversal risk assessment must be geographically differentiated to avoid cross-subsidisation that destabilises the pool**. To effectively assess natural disturbance risks, the project-specific vulnerability of AGB must be considered, accounting for differences in risk type and magnitude across forest types and geographical context
- **Risk estimates should be anchored in transparent, spatially standardised datasets rather than developer discretion**. Readily available datasets combing probability and severity of every natural and climate risk for each carbon pool on a global level do not exist. Hence, hazard probabilities and potential loss magnitudes should be derived from publicly available scientific datasets and regionally consistent hazard layers (e.g. wildfire probability, flood exposure, windthrow risk, drought indices, landslide susceptibility). Where global hazard datasets are incomplete, project-level AGB data should be combined with regional hazard databases and climate projections.
- **Creditable mitigation should be linked to clear criteria and verified by independent parties.** Risk mitigation should only reduce assessed risk where there is strong, region-specific empirical evidence of measurable risk reduction.
- **Reversal risk should be assessed probabilistically rather than through single-point estimates**. Disturbance regimes affecting AGB (e.g. fire, drought-induced mortality, storms, pest outbreaks) are stochastic and often heavy-tailed.
- **Risk scoring should incorporate climate projections and scenario-based hazard modelling.** Climate change is expected to amplify disturbance regimes – including wildfire, drought stress, pest outbreaks, and extreme storms – and to shift their spatial distribution.
- **Slow-onset disturbances should be explicitly considered alongside acute events**. Gradual biomass losses driven by drought stress, climate-induced mortality, growth decline, or regeneration failure can significantly affect long-term AGB durability but are often overlooked in reversal risk frameworks.
- **There is a gap in research on compound disturbance risks.** Most studies still assess hazards such as drought, wildfire, and flooding separately, despite clear interactions between

them (e.g. drought increasing fire risk or fires amplifying flood impacts). For example, Piao *et al.* (2022) use machine learning to map multiple hazards but still treat them independently. **Future work could better capture cascading risks using approaches such as Bayesian networks or event-based compounding frameworks, alongside standardized damage indicators (Kappes *et al.*, 2012).** Further research on this matter is needed.

Data to assess AGB and respective risks

- Several global datasets and models are available to assess AGB and respective risks, e.g.:
  - Multiple universities are working on the “Global Reference Dataset for Above-Ground Biomass” (Azra et al. 2026), which combines harmonised ground observations with remote sensing to provide spatially explicit biomass estimates and uncertainties. It offers consistent benchmarks across regions and forest types, supporting more robust validation of AGB stocks and trends, enabling better detection of anomalous biomass losses.
  - For fire-related reversal risk of AGB, risk assessments can draw on complementary global datasets and a modelling framework that together capture fire occurrence, severity and future probability. NASA’s FIRMS (NASA 2026) provide near–real-time global active fire detections, allowing users to characterise where and how frequently fires affect forest areas. The global forest burn severity dataset offers 30 m historical information on the intensity of past forest fires and associated biomass loss, enabling users to quantify typical damage patterns across forest types (He, Shen and Anagnostou, 2024). Finally, the AI–based wildfire risk model from Ballard et al. builds on long time series of satellite fire observations to project how wildfire probabilities may change under future climate conditions, supporting forward-looking assessments of reversal risk.
  - In 2024, a global dataset for forest regrowth following wildfires was published. The researchers used satellite data to create the first global at 30m resolution showing how forests regrow after wildfires, tracking height, biomass, leaf cover, and light absorption from 2000–2020. For each area, they calculated regrowth ratios and rates every 5 years. Models used in the study revealed that forest height growth patterns varied across regions; however, most forests required approximately 20 years to reach an average tree height of 15 meters. The dataset does not capture the complete recovery trajectory for the different forest types (Zang, Qiu and Zhang, 2024). Recent global datasets for forest recovery under other individual disturbances are not available and require further research.
  - In 2022, Senf & Seidl mapped post-disturbance (anthropogenic and natural) canopy recovery across 35 European countries using Landsat data (1986–2018), finding a median recovery time of 18 years and a mean of 35 years, with 87% of forests recovering within

30 years. Recovery was strongly driven by disturbance severity. Low-severity events recovered within 30 years, while very high-severity events often took over 100 years or failed entirely. Most of Europe's forests (69%) showed high resilience, but 14% had low or critical resilience, concentrated in the Iberian Peninsula where frequent, intense fires outpace recovery (Senf and Seidl, 2022).

- For other risks, non-AGB/forest related databases can be used and combined with AGB data, e.g. for landslide risks, the globally distributed dataset of landslide from Fang et al., providing a mapping via multi-source high-resolution remote sensing images can be used (Fang *et al.*, 2024).
- As for droughts, the Global Database of Meteorological Drought Events lists around 4,500-4,800 dry spells worldwide from 1951 to 2016. It uses rain and temperature measures to spot events by country or region, noting start/end dates, length, strength, affected area, and a score for major ones like mega-droughts (Spinoni *et al.*, 2019).
- In 2023, the Accelerating Innovative Monitoring for Forests (AIM4F) programmes was launched by FAO and the UK. It aims to empower countries to monitor their forests using modern technologies, technical innovation, space data and remote sensing. It supports 20 countries to increase the robustness of their National Forest Monitoring Systems to generate high-integrity forest data, in support of domestic policy and decision-making as well as participation in emerging carbon accounting standards. Moreover, it initiates relevant technical reports (e.g. FAO 2024). Going forward, this programme should be followed closely (FAO, 2023).

Below-ground biomass

BGB refers to the carbon stored in living biomass in the soil, e.g. roots with >2mm diameter (Ravindranath and Ostwald, 2008). BGB is a material carbon pool in forestry-type projects, accounting for approximately 15 to 25% of a forest's total living biomass (Haya *et al.*, 2023). BGB is often not treated as a significant carbon pool in carbon market methodologies, except when it involves woody biomass. Non-woody BGB biomass may be selected or generally excluded (Gold Standard, 2024a; Verra, 2025h). **None of the existing methodologies explicitly addresses reversals in BGB carbon stocks.** BGB may not be directly destroyed by wildfires and flooding but decay slowly if the forest does not recover after the fire. **Biomass burial** is an activity that involves sequestering organic biomass, by burying it in the ground or in submerged environments where decomposition is almost halted. By placing biomass in anaerobic/anoxic conditions, the activity prevents microbial decomposition and the subsequent release of CO_2 back into the atmosphere. The burial of biomass can be carried out in shallow geological storage, an activity type already undertaken, is generating artificial below-ground biomass stores. Its proponents argue storage can be assured for over 100 years (Zeng *et al.*,

2024) (Gooding, 2026). Reversal risks arise from wildfires and other events that could compromise or destroy the storage site; these risks generally decrease the deeper the storage is located. Isometric and Puro crediting programmes have published methodologies for this activity type. Isometric mandates the answering of a reversal risk questionnaire for each project, and the resulting score informs the buffer pool contribution (Isometric 2026). Puro.earth considers the technology having a low to very low risk of reversal and states that sufficient mitigation measures can be applied to address risks. The project proponents are asked to fill in a risk matrix calculating the risk with and without mitigation measures, to demonstrate that risks are mitigated and to state the residual risk (puro.earth 2023).

Dead organic matter

Deadwood and litter refer to carbon stored in litter, and dead trees, branches, logs, either still standing or lying on the ground. This carbon is released back into the atmosphere through decomposition, combustion (e.g., wildfires), or decay, but the process can take significant time depending on environmental conditions and forest management practices. Deadwood and litter are included in baseline emissions calculations of forestry-related methodologies. The CDM (AR-TOOL12) and VCS (VMD0002 / VMD0003) provide modules to estimate deadwood and litter carbon stocks (UNFCCC 2015, Verra 2023). Project emission calculation usually excludes deadwood and litter assuming that the project activity either increases or stabilises deadwood and litter. This is deemed conservative and reduces transaction costs. **Reversals of deadwood and litter carbon stocks are not specifically addressed in any methodology.** Deadwood and litter are highly susceptible to wildfires and flooding.

Soil organic carbon

SOC refers to the main component of soil organic matter, which is the portion of organic residues in soil in various stages of decay (FAO, 2026). Soil represents the largest terrestrial carbon sink, storing roughly twice as much carbon as the atmosphere and about three times more than all vegetation combined (Ramesh *et al.*, 2019), making SOC a highly relevant carbon pool for reversal risk assessment of all biomass-related activity types. Risks differ according to soil texture and moisture. Breure *et al.* (2025) see mineral-associated organic carbon (MAOC) saturation as the key parameter for reversal risk in soils. SOC is highly sensitive to extreme weather events, including droughts, flooding and windstorms, and temperature fluctuation, which can directly destroy soils (e.g., through landslides and more gradual water and wind erosion), accelerate microbial decomposition and increase soil carbon turnover rates (European Commission, 2011). SOC is especially vulnerable in areas where moisture is the dominant factor driving microbial activity, such as temperate and tropical zones (Wang *et al.*, 2019).

SOC in peatlands presents a different, higher-risk scenario. Peatlands are less prone to reversals due to floods and heavy rainfall owning to their capacity to absorb vast amounts of water (Wetlands International, 2025), but if they are lost, for example in severe drought events through burning, as has been repeatedly the case in Indonesia, the losses are massive. For example, Page et al. estimate that between 0.81 and 2.57 Gt of carbon were released into the atmosphere by Indonesian peat and vegetation fires in 1997. This is equivalent to 13–40% of average annual global fossil fuel emissions, contributing significantly to the largest single-year rise in atmospheric CO_2 recorded since monitoring began in 1957 (Page *et al.*, 2002). SOC of soils under mangroves is highly responsive to temperature variation, salinity shifts, and more frequent storms (Lin *et al.*, 2025); it can vary by an order of magnitude in a small area (Yang and Ray, 2021).

Biochar is a form of charcoal produced by heating organic material and can be added to the soil. Known as “terra preta”, biochar has persisted for millennia in otherwise impoverished soils in tropical Amazonia (Gross *et al.*, 2025; Palviainen, Hanssen and Laurén, 2025). Due to the technological readiness and comparable low costs, biochar production and use projects are currently the most attractive activity category for removals (CDR.fyi, 2025). Thus, all of the major carbon market programmes are developing or have already approved biochar methodologies. The most common production technology for biochar is the controlled pyrolysis of biomass (Meyer, Glaser and Quicker, 2011).

Generally, feedstock selection and pyrolysis temperature affect the biochar structure and thereby the durability of biochar (Singh, Cowie and Smernik, 2012; Zhang, Ayyub and Fung, 2022), which can range from decades to millennia (Lehmann & Joseph 2015, Budai et al. 2018). But also the soil type, climate, agricultural management and bioactivity on the site where it is distributed can impact biochar mineralization (Fang, Singh and Singh, 2014; Lehmann and Joseph, 2015; Wang, Xiong and Kuzyakov, 2016; Schmidt, Abiven and Hagemann, 2022; Zhang, Ayyub and Fung, 2022; Azzi *et al.*, 2024; Chiaramonti *et al.*, 2024; Schmidt *et al.*, 2025). By analysing the structure of the biochar in laboratory settings and taking into account the average soil temperature of the area where soil incorporation will take place, the permanence of biochar can be calculated.

Both, the random reflectance R_0 (measuring the inertinite maceral) (Sanei et al. 2024, 2025) and the Hydrogen-to-Carbon (H/C) ratio can be used to determine the permanence of biochar by laboratory analysis. Azzi et al. (2024) find that the H/C ratio indicating the structure of biochar is the best predictor for its durability, while soil temperature appears to be less relevant but should still be considered. Woolf *et al.* (2021) provide decay data for biochar based on the H/C ratio, pyrolysis temperature and the soil temperature at application site. The range of the estimated permanence fraction for 100 years is 0.54 to 0.89, while high pyrolysis temperature and low soil temperature positively affect the permanence fraction. This data is applied in the decay function in the biochar CRCF methodology and also used in the methodologies of VCS, Puro and CAR.

A direct reversal of biochar can occur if a wildfire leads to burning of the biochar in the soil. Such risk is relevant in savanna-type environments with regular fires or in situations where agricultural residues are burned on the fields. However, in general biochar has a low flammability (Zhao, Enders and Lehmann, 2014; Das *et al.*, 2017) which is decreasing with increasing pyrolysis temperature (Das *et al.*, 2021; Shanmugam *et al.*, 2022). Combustion risk can be further reduced by ensuring a minimum depth of biochar disposal in the soil. Also flooding can wash out the biochar, which can lead to a reversal by accelerated mineralisation when ending up in the hydrosphere (Fang et al. 2020).

All VCM methodologies and the CRCF methodology consider reversal risks of verified biochar projects as negligible. Only Isometric requests a buffer pool contribution of 2% as this is their mandated contribution value for any “Very Low Risk of Reversal” activity, as which biochar is categorised. All other programmes require no compensation measures or post-application monitoring.

Key considerations for reversal risk assessment for SOC

- **SOC reversal risk should be assessed at project level**, regularly re-evaluated due to high spatial variability, and accompanied by site-specific mitigation measures to enhance SOC stability (e.g. flood barriers, drought tolerant irrigation). Also, SOC reversal risks should be spatially coupled with erosion and landslide susceptibility models (e.g., slope, soil texture, and land cover) (Dialynas *et al.*, 2016).
- **Risk assessments for droughts must include soil moisture regimes, drought duration and frequency, and observed SOC stock trends under prolonged water deficits** (Liang *et al.*, 2021).
- **Assessments should integrate flood and waterlogging hazard layers with site-level soil data to estimate SOC loss through erosion, oxidation, or sediment export** (Ran *et al.*, 2023). Saltwater intrusion in coastal zones must be explicitly considered.
- **Risk scoring should account for temperature-driven SOC decomposition rates calibrated to projected climate shifts rather than historical baselines** (Wang *et al.*, 2023).
- **There are no risk specific datasets available for SOC reversals on a larger scale (i.e. regional or country-level).** Hence, without further research, data on overall SOC changes in the project area would need to be combined with databases on historic hazards and coupled with future climate projections.

- Substantial SOC stock datasets exist for certain countries and regions (e.g. FAO's Soils Portal[7] or the International Soil Reference and Information Centre (ISCRIC[8])) but their suitability for tracking SOC changes remains uncertain. To improve their credibility, updated sampling designs, refined measurement protocols, and improved remote sensing and field data are required (Lorenz and Lal, 2016). Recently published studies provide approaches that could be adapted for other countries and regions to improve risk assessment, e.g.:
    - (Breure *et al.*, 2025) developed the SOC risk index that helps assess EU-wide SOC risk by using pedo-climatic clustering into 16 local zones (climate, productivity, pH, terrain).
    - Aiteew *et al.* (2024) present an approach for predicting SOC changes by testing and refining the MONICA (Model of Nitrogen and Carbon dynamics on Agro-ecosystems) model, which is a process-based simulation tool for agro-ecosystems.
- Biochar production characteristics affecting risk mitigation, such as biochar structure and pyrolysis temperature, should be monitored to ensure low flammability and sufficient permanence (Shanmugam *et al.*, 2022).
- An increasing number of studies analyse the benefits of biochar distribution in forests (Li *et al.*, 2018; Johanis, Lehejček and Tejnecký, 2022; Palviainen, Hanssen and Laurén, 2025) and on grassland (Ohsowski *et al.*, 2012). Compared to incorporation in soils, biochar distributed on surface is less protected and more prone to reversal risks. While fire on grassland and cropland has a short duration but can have high peak temperature, forests fire can have lower peak temperature but are lasting longer, leading to a longer ignition duration for the distributed biochar particles and more severely affected soil properties (Gomes *et al.*, 2020; Cheng *et al.*, 2025). Biochar on uncovered and dry soils has a high risk of being subject to wind erosion, leading to a transportation of biochar outside the project boundary (Silva *et al.*, 2015). To mitigate reversal risks, biochar should be incorporated into soils at a minimum depth. Monitoring must ensure that the minimum depth of incorporation is applied. The determination of a minimum depth that protects biochar from combustion for over 100 years requires further research.
- A risk assessment should be applied on the projected area for biochar incorporation into soils. Biochar should not be distributed in areas with significant risk of high temperature combustion (e.g. volcano eruption) or with high likelihood that the biochar is washed-out over time and transported to the hydrosphere (e.g. flood areas).

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[7] https://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/regional-and-national-soil34

[8] https://isric.org/explore/

Harvested wood products (HWP)

The IPCC defines the carbon pool HWP to account for CO_2 emission and removals arising from i) wood utilisation in products, ii) wood biomass used for energy purposes, and iii) wood biomass in solide waste disposal sites (Rüter *et al.*, 2019). Several studies have developed approaches to measure HWP carbon balance (Skog, 2003; Cláudia Dias *et al.*, 2009) and to estimate HWP removal potentials (Chen *et al.*, 2008; Pilli, Fiorese and Grassi, 2015; Johnston and Radeloff, 2019; Matsumoto and Kayo, 2022; Trauner, Asada and Stern, 2025). For carbon market activities currently the focus lies on the use of HWP as construction material, classified as bio-based building materials.

Besides HWP, bio-based building materials also include products from agricultural feedstocks such as bamboo, hemp or straw that store biogenic carbon in buildings (Yadav and Agarwal, 2021). Such activities contribute both to an emission reduction (replacing emissions-intensive materials) and a temporary storage that lasts as long as the infrastructure persists (Churkina *et al.*, 2020; Priore *et al.*, 2026). Reversal risks are linked to the deliberate or unintended destruction of the building through extreme weather events, geological catastrophes or human intervention (Priore *et al.*, 2026).

None of the major VCM programmes has yet published a methodology on the use of bio-based building materials. However, two small European crediting programs have already published methodologies for such activities: The Climate Cleanup Foundation has developed a methodology for using bio-based materials in the building sector in the Netherlands (Climate Cleanup Initiative, 2024). The Rainbow Standard has developed a methodology for crediting the production of bio-based construction material and its use (Rainbow Standard, 2025). While the former counts storage of over 35 years as removal, the latter requires 100 years. The average lifespan of a building in Europe, 65 years (Berglund-Brown *et al.*, 2025), would be consistent with the average of the two.

The Rainbow Standard requires project developers to fill a risk evaluation template that assesses the risk of reversal based on likelihood and severity of certain risks factors. This includes the natural risks: fire, flooding, extreme temperature, earthquake. Both, likelihood and severity, have values on a scale of 1 to 5 assigned. Thus, buildings in high-risk areas for any of those natural hazards receive a corresponding high-risk score. If a certain risk level is reached the project developer needs to submit a mitigation plan and the contribution to the buffer pool is increased.

Key considerations for reversal risk assessment for HWP

- Methodologies for activities generating biospheric or geospheric carbon pools in **buildings** need to consider the specific average expected lifetime of buildings in the activity area.

Activities should be ineligible in areas showing high risks of destruction as per jurisdictional natural hazard maps.

- For each project a risk assessment should be conducted evaluating the risk of unintended deconstruction.

3.2.2. Geosphere

Table 6 summarises the reversal risk approaches of key carbon crediting programmes for geospheric storage, including their risk taxonomy, carbon-pool differentiation, assessment methods, and conservativeness provisions. There are two overarching types of geospheric carbon pools: (1) CO_2 storage in geological formations and (2) CO_2 storage via mineralisation. The key difference between reversal risks associated with the two types lies in the different underlying trapping mechanisms. Key risks for CO_2 storage in geological fomations are understanding the characteristics of the geological site and (legacy) wellbore integrity, in addition to regulatory, political, financial and monitoring requirements. More detailed information per programme can be found in ANNEX 1, Table A3. Comparative overview of individual reversal risk factors are assessed across major carbon crediting programmes for geospheric carbon pools.

Table 6: Overview of reversal risk assessment approaches adopted by private carbon crediting programmes in the geosphere

Parameter	Description
Risk scope and taxonomy	How many reversal risk categories are defined and what types of risks are covered: i) Activity finance / management; ii) regulatory/political/governance; iii) naturally induced; iv) human induced
Differentiation by activity type and geospheric carbon pool	All the carbon crediting programmes distinguishes risks for different CDR activity types (e.g. DACCS, BECCS, ERW) and different geological storage pools (formations, mineralisation, products).
Assessment of reversal risk	How each programme approaches the actual evaluation of reversal risk: Using dedicated tools (Verra, GS4GG), questionnaires (ISO), or methodology-level freedom (Puro).
Assessment of reversal risk likelihood, magnitude and spatial scale	Whether carbon crediting programmes require characterisation of how likely a reversal is, how severe it would be, and how geographically extensive. All programmes are required to do a risk assessment, only Puro indicates a matrix of severity scoring.
Transparency and documentation requirements	All programmes require disclosing reversal risk assessments and pre-emptive and post reversal mitigation measures as per their methodologies.
Minimum time series requirements	The minimum durability horizon over which carbon storage must be assured or modelled. The timing differs per programme but are not required as monitoring periods. 100 years (GS4GG, Puro), 1000+ years (Verra, ISO, Puro)
Conservativeness and treatment of uncertainty	How each programme handles quantification uncertainty: Via uncertainty discounts (ISO (ERW)), conservative default assumptions (Puro), or prescribed analytical steps (Verra, ISO, GS4GG).
Identification of risk-specific mitigation measures	Whether the programme specifies concrete mitigation measures that PPs must put in place to address reversal risks. All programmes set pre-emptive risk mitigation measures in their respective methodologies to lower the risk of reversal.
Aggregation rules and overall risk rating	How individual risk sub-scores are combined into a single rating, which then determines the contribution to the buffer/insurance pool. Aggregated (GS4GG, Verra) or fixed (ISO)
Climate change risk amplification / consideration	Whether and how increasing climate risks (more frequent extreme events, changing environmental conditions) are factored into reversal risk assessments. Less applicable to geospheric carbon pools. A reversal will increase CO_2 in the atmosphere, adding to further climate change.
Risk thresholds or pass/fail gates	Whether specific quantitative thresholds exist that render a project ineligible or trigger disqualification. Ocean storage is ineligible (GS4GG), maximum risk rating values make projects ineligible (6.7% GS4GG, 7% Verra), if a reversal exceeds 10% of the injected CO_2 volume for storage the project becomes ineligible.
Periodic review and update	How often risk assessments must be reviewed and under what circumstances they must be revised. Reviewed at every verification (GS4GG), every 5 years (ISO), periodically (Puro, Verra). Revised every 5 years (GS4GG), with every renewal (all programmes), after reversal occurred (all programmes).

Reversal pathways in geospheric CO_2 storage

Carbon pools in the geosphere include **saline aquifers**, **depleted hydrocarbon formations**[9], 'unmineable' **coal seams** and **(ultra)mafic**[10] **rock** - basalts or peridotites - where CO_2 reacts with naturally occurring iron (Fe), magnesium (Mg) and, calcium (Ca)) - in **porous rock below ground** or in **crushed form above ground**. Biomass buried in the geosphere also constitutes a (solid) carbon pool, akin to naturally occurring processes of biomass burial in anaerobic conditions that in geological timeframes generates coal. Non-biological building materials like **concrete** and **cement** can also be deemed a geospheric carbon pool. For completeness, the hydrosphere also contains various carbon pools related to activities associated with geospheric CO_2 storage, namely **carbon dissolved in the water building corals**, and **carbon contained in sediments on the seafloor**. These are not discussed further in this study. Activity types usually address one of these pools. DACCS and BECCS fill one of the four first described pools as well as buildings materials, whereas crushed minerals are targeted by ERW. Before any risk assessment can be performed, it is imperative to understand the different geological CO_2 trap mechanisms which influence the level of risk. The CO_2 trap mechanisms are categorised into **physical**, **residual**, **solution**, and **mineral** traps. Physical trapping happens when the CO_2 is injected into a physically distinct porous and permeable subsurface storage site, either saline aquifer or depleted hydrocarbon formations and the CO_2 is trapped **structurally** (by fault sealing or rock deformation (folds)). Residual trapping occurs where the capillary pressure of the rock constituting the formation is significantly different from the overlying formation, which **prevents the CO_2 from moving upwards** in the geological sequence of rocks (stratigraphy). Solution trapping happens when the CO_2 is dissolved into the formation fluid creating a new stable fluid equilibrium between the formation minerals and its pores. Finally, mineral trapping occurs when the dissolved CO_2 reacts with (in)organic elements existing in the subsurface environment and **solidifies** (Massarweh and Abushaikha, 2024).

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[9] We note that geologists usually use the term "reservoir" but want to prevent an overlap of terminology between higher level "reservoirs" as defined in section 3.1 above and more distinct geological "reservoirs".

[10] (Ultra-)mafic minerals are silicate minerals or igneous rock rich in magnesium and iron. Their silicate content classifies them into mafic ($45\% < SiO_2 < 52\%$) and ultramafic ($SiO_2 <45\%$) minerals (as opposed to intermediate and felsic minerals characterized by higher SiO_2 contents).

Figure 3 shows the trapping processes as a trapping versus time for injection of CO_2 into subsurface formations (A) and dissolved CO_2 for mineralisation (B). Mineralisation will cause the most stable and permanent solution. If injected into formations like saline aquifers and/or depleted hydrocarbon fields, mineralisation only happens after thousands of years, while for injection into calcium, iron and/or magnesium rich ((ultra-)mafic) rocks this takes just months (Matter *et al.*, 2025).

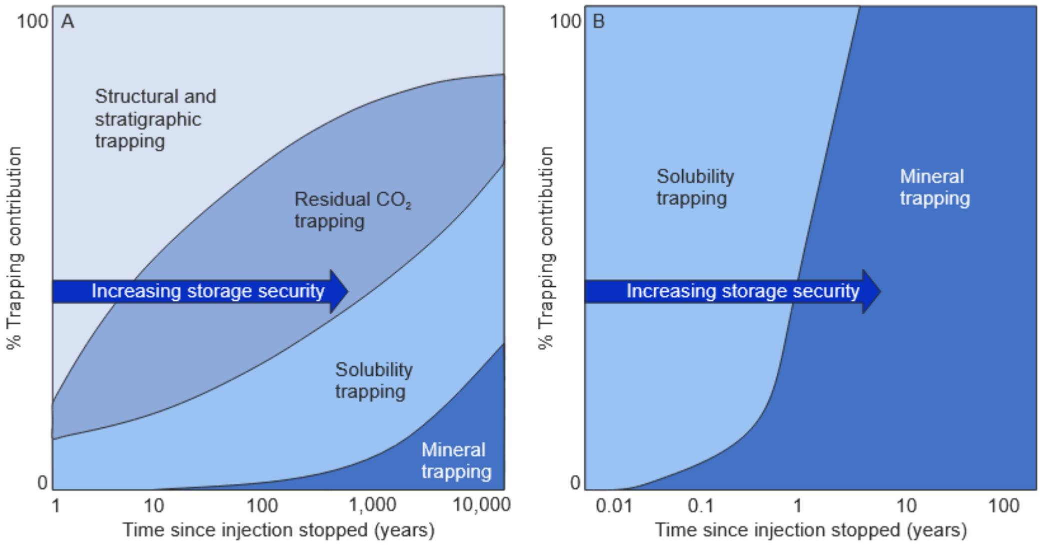

Figure 3: Share of CO2 trapping mechanisms over time for direct injection into geological formations (A) and for water-dissolved CO_2 for mineralisation after injection (B) (Source: puro.earth, 2024)

Geospheric storage pools can thus be grouped those based on **structural** trapping (e.g. in saline aquifers or depleted hydrocarbon formations; we use the term "**(geological) formation**" for the remainder of this chapter) and those based on **mineral** trapping (e.g. via injection into deep (ultra-)mafic rock formations, in durable materials like concrete, or crushed materials dispersed at the surface) we use the term "**mineralisation**" for the remainder of this chapter). The chemical process of mineralisation can be used with different activity types and CO_2 storage options, which may bring specific risks. We cover the following storage options, which are reflected in carbon market methodologies:

In-situ mineralisation in (ultra-)mafic geological formations

Captured CO_2 is dissolved in water (solubility trapping) and pressed into sub-surface (ultra-)mafic geological formations (typically basalt), where it reacts with the rock and is chemically bound in a stable carbonate mineral (mineral trapping) (Ernest Ansah Owusu *et al.*, 2025). Technological methods to accelerate the natural mineralisation processes enable 95% mineralisation of injected carbonated water within two years. (Snæbjörnsdóttir *et al.*, 2020) consider the risk of reversal from mineralised CO_2 negligible.

Ex-situ mineralization for CO_2 utilization and storage in concrete

Mineralisation is used to bind CO_2 in stable carbonate ($CaCO_3$) and utilise it within cementitious materials, typically as a building material. When used e.g. as construction fillers, the carbonate remains stable and is neither thermally nor chemically decomposed. Storage may become non-permanent only under extreme conditions, e.g. in fires or during the product's end of life. Peer-reviewed studies confirm that $CaCO_3$ in concrete remains stable over millennia (pH 12+, <600°C) (MRÓZ et al., 2025), with negligible reversal risk under typical operational scenarios.

Ex-situ mineralisation via Enhanced Rock Weathering (ERW)

Enhanced Rock Weathering (ERW) utilises a sped-up natural process, which binds atmospheric CO_2 in (ultra-)mafic minerals. Naturally, rain reacts with atmospheric CO_2, forming carbonic acid. When reaching the earth, this acid reacts with the surface of (ultra-)mafic minerals on the ground to bind the CO_2 as bicarbonate, a durable mineral. Eventually, the bicarbonate is washed to the seas and stored there permanently. This natural process takes millennia due to the slow weathering of minerals, which is required to create new surfaces to react with the carbonic acid from rain. ERW drastically decreases the time required for the process: Suitable minerals are grinded into a fine powder, thereby maximising the surface for the aspired chemical reaction (see Don MacElroy, 2025). Silicate powder is often applied to agricultural soils, where conditions for carbonation are optimal (Levy *et al.*, 2024).

Ex-situ mineralisation in mineral waste

In some activities (e.g. mining, waste storage) waste minerals accrue which can react with atmospheric CO_2 and permanently store it in mineralised form. The processes relevant for this activity type are basically the same as for ERW projects, with the difference that the materials reacting with CO_2 are not applied to e.g. soils as in ERW, but stored in open or closed systems or used as a raw material. The durability of geospheric carbon pools is generally much higher than that of biological ones. However, reversal risks are not absent and differ significantly between pools and activity types. Note that Table 7 provides a high-level overview only; specific risks are covered in the sections on specific activity types, where applicable.

Table 7: Key reversal risks in geospheric CO_2 storage pools

Risk Type	Geological formation (Reservoirs)		Mineralisation	
		In-situ	Utilisation (concrete)	Minerals on surface
Storage/design risks	Well design risks: • Use of corrosive material in well design • Cement type and volume Legacy wells: • Number of wells above/perforating storage complex • Level of plugging and abandonment	Fracture propagation or micro fracturing during injection	Destruction of buildings	
Natural risks	(Re)activation of faults or fractures due to pressure increase in the formation or earthquake	Changes in geochemical parameters in contact with acidic subsurface fluids	Destruction of buildings through natural hazards (earthquake, volcanic eruptions, windstorm, flooding, landslide, …)	Changes in geochemical parameters through interaction with bio- or hydrosphere (e.g., low pH fluids, degassing, biological processes, …)
	CO_2 Migration along stratigraphic layers	Temperature increases due to magma displacement	High temperatures above 30°C when mixing, placing and curing or above 150°C when in place.	

Risk assessment specific to storage in Geological formations

Saline aquifers and **depleted hydrocarbon formations** are constituted by porous and permeable formation covered by an impermeable formation and bordered by sealing faults. Reversal risks can be differentiated into **seepage/leakage along well bores** and through **weak spots/faults** in the otherwise impermeable caprock/fault seal (Figure 4).

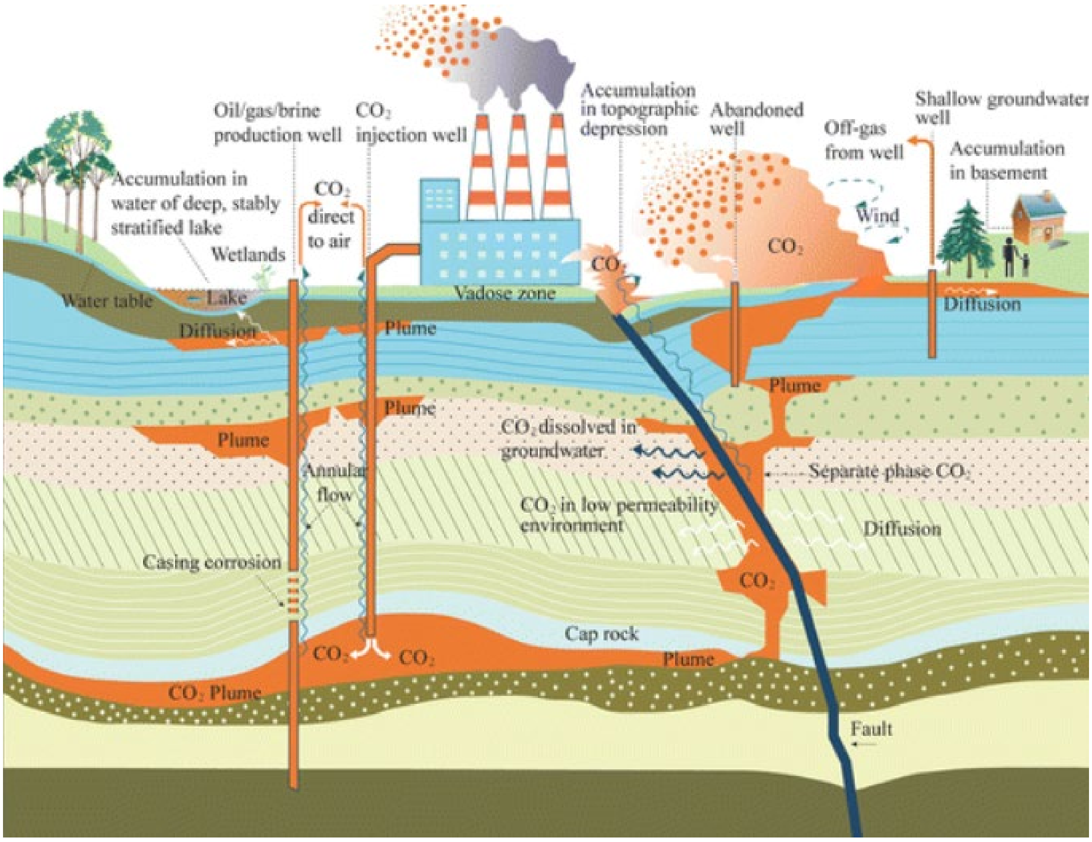

Figure 4: Reversal risks of depleted hydrocarbon formations and saline aquifers (Li and Liu, 2016)

Geological site/formation characterisation

A geological model is a static 3D representation of the subsurface built from processed seismic data and well information (Lobasov and Khrushchov, 2021), gridded along interpreted faults and populated with petrophysical properties such as facies, porosity and permeability. It is used for volumetric calculations and well placement and is typically validated through uncertainty analysis (low/base/high cases).

This static model is coupled with a dynamic model that updates as new data become available and simulates CO_2 plume migration using numerical flow algorithms. Uncertainties arise from seismic processing, grid discretisation and upscaling, which can amplify error in final predictions. To improve confidence in post-injection behaviour and decisions on site closure and liability transfer, models increasingly use higher-resolution grids and frequent time-lapse (4D) seismic, include thermal effects on CO_2 properties, and incorporate reactive geochemistry to capture dissolution and salt precipitation effects on fluid–rock interactions and plume movement (Ringrose *et al.*, 2022).

Faults and stratigraphic migration

Reversal risks through faults in the caprock are defined by vertical and horizontal movement of tCO_2 in the formation. Studies on the CO_2 migration in the Sleipner field offshore Norway, which has been injecting CO_2 since 1996 in the Utsira sandstone, shows that the CO_2 moves both vertically and horizontally in the more porous and permeable intervals of the sandstone, formed by channel fill sediments (Martinez *et al.*, 2026). **Old faults can be re-activated and microfractures initiated through pressure increase from injection**. **Tectonic events like earthquakes and volcanic eruptions** can happen and are **classified as catastrophic events**: While the **risk is assumed low, the impact is high**. The volcanic and earthquake activity concentrates along the edges of plate boundaries, which should be part of the site characterisation.

Risks related to caprock

A good understanding of the geological history of the basin, tectonic setting, its formations, its pressure and temperature curves and the geochemical nature of the formation and caprock can help to mitigate this type of reversal risk. Geological modelling, especially regarding the formation's pressure, is the basis for assessing this reversal risk type. Careful site selection informed by modelling is key for mitigation. Under Verra (Verra, 2025b), the GCS requirements state that all criteria for geological carbon storage are under regulatory control, including site selection with multiple confining layers, formation characterisation, and well design. Under Gold Standard (Gold Standard, 2025e), the CO_2 plume area-to-mass ratio will be used for risk scoring. If this ratio is higher than 1, than more CO_2 is to be stored than the space available which can result in over pressuring the reservoir and breaking the caprock. Under (puro.earth, 2024) formations need to have multiple confining layers, low permeability caprock, and minimal natural faulting. Isometric (Isometric, 2026) requires careful site selection with low permeability caprock and multiple confining layers.

Well density and well design

(Alcalde et al., 2018) summarise leakage estimates over a period of 10,000 years from models calibrated using historical data from the oil and gas industry, natural gas storage, and natural CO_2 and methane seepage. **Discharge through or along wells** can occur at injection wells or any other operational or abandoned well in the vicinity of the storage complex. The associated risks can be divided into **well density** (i.e., number of relevant wells above or perforating the storage complex) and **well design**. Low well density limits **potential leakage pathways from legacy wells**, while abandoned wells, specifically those not properly plugged (orphaned wells), are associated with higher risk unless well-managed. Most reversal occurs early through human-made pathways, with abandoned wells posing the greatest risk ("straw effect"), but **reversal rates decline over time as CO_2 becomes immobilised through self-correcting processes** (Figure 5).

Well-related reversal risks can be mitigated through proper well design according to state of the art regulations (e.g., Class VI wells in the USA (EPA, 2025)). Measures include corrosion resistant alloys for tubulars and casings, CO_2 resistant cement blends, a dual barrier system, a downhole safety valve, zonal isolation systems and selective perforation intervals, amongst others. Verra (Verra, 2025b) requires maintaining wellbore integrity for the lifetime of the project, where wells are designed following the EPA Class VI well standards (40 CFR §146.86) (EPA, 2025), as detailed in Appendix 1 of the GCS non-permanent risk tool (Verra, 2025a). In addition, the integrity of legacy wells that penetrate the storage complex is to be determined. Reservoir management demands for the injection pressure to stay below the original caprock fracture pressure, except close to the injection well, where the injection point is not directly under the caprock.

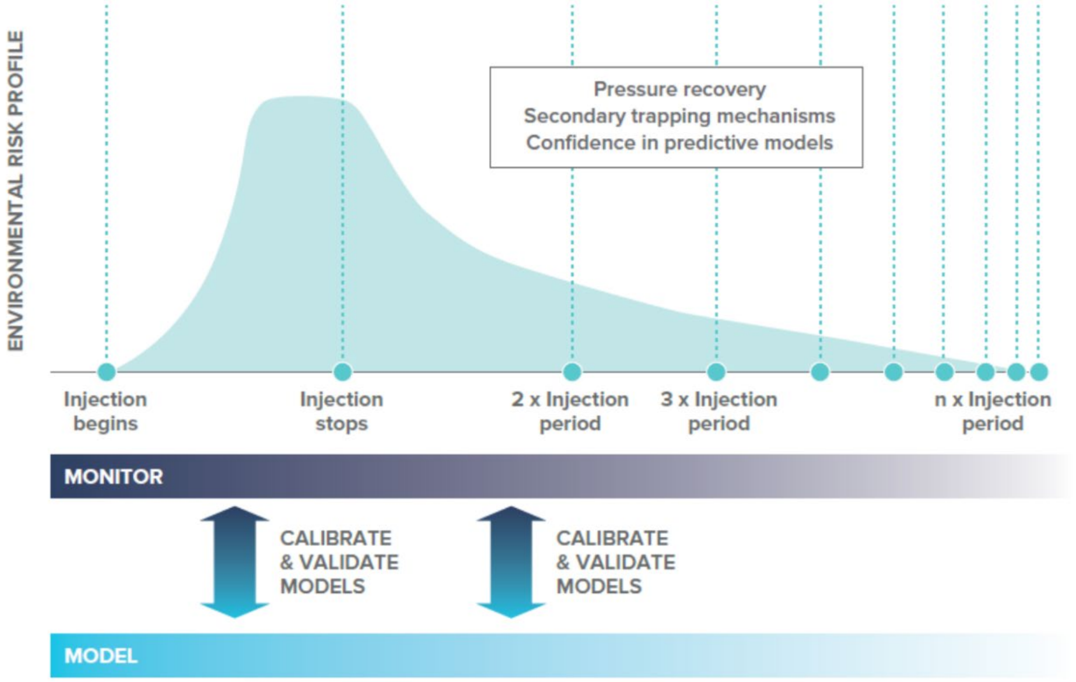

Figure 5: Lifespan risk profile for storage in geological formations (Cames *et al.*, 2024)

Under (puro.earth, 2024) the storage provider needs to show proof of legacy wells having been plugged and abandoned or converted into CO_2 injection wells. The pressure in the formation must not exceed the virgin pressure of the formation, except locally around injectors. The well design is to follow the regulatory requirements of the jurisdiction where CO_2 will be stored. Isometric

(Isometric, 2026) requires assessment of legacy wells, and those that pose risk need to be plugged prior to injection. The design of the wells must have sufficient structural strength for the life of the project. All surface casing must be below the potable groundwater level and cemented to surface. Pressure must remain below caprock fracture pressure.

Key considerations for reversal risk assessment for CO_2 storage in geological formations

The migration along wells or geological pathways (stratigraphically or structurally) to the surface equals a reversal. The risk can be assessed as follows:

- **Geological static modelling of site and basin must include:**
  - The geological setting of the reservoir and caprock
    The depth of the reservoir and if it is sufficient for CO_2 to remain in supercritical phase
  - The petrophysical characterisation of the formation (facies, porosity and permeability)
  - The geochemical signature of the reservoir and the caprock
  - The geomechanical parameters (pressure and temperature) of the reservoir and caprock
  - The volume of the CO_2 that can be stored in the model
  - Assumptions and uncertainties of the model
- **Dynamic reservoir model (applying the static geologic model as input) must include:**
  - Flow behaviour
  - Connectivity in the formation
  - Where are baffles (flow interruptions)
  - Pressure changes
  - Fluid saturation
  - Change (from timelapse (4D) seismic imaging) matching against a fixed baseline of initial pressure and fluid saturation
  - Assumptions and uncertainties of the model
- **Well planning (as described above) must include:**
  - Identification of legacy wells above and crossing the reservoir, and if they are properly plugged and abandoned
  - Well design
    - Well location
    - Depth of well
    - Drill bits and casing sizes
    - Depth of casing point

        - Material of casing (corrosive proof)
        - Cement type (non-reactive to CO_2 or formation chemistry)
        - Drilling mud (non-reactive to formation chemistry)
        - Injection point (best in low part of reservoir, for it to move easily away from the wellbore)

To decrease the risk of reversal further, the following is to be considered:

- **Regulatory framework**
    - Permitting of subsurface pore space during exploration, operation and post closure period
    - Permitting of storage surface facilities
    - Well design (e.g., licensing, closure of wells, material to be used)
    - Liability during operations and liability transfer after closure
- **Political stability of the jurisdiction where GCS is planned**
- **Sufficient financial means to cover for a reversal**
    - By the operator during operation and post-closure intervals.
    - By the state in case of liability transfer post closure
- **Monitoring plan, including post-closure monitoring, for identifying reversals**
    - Seismic 3D and 4D imaging (4D include the movement in time, which can identify if the modelled geological and formation predictions were correct or need to be adjusted)
    - Surface seismic or satellite remote sensing for early leak detection
    - Well pressure and temperature gauges to identify injection plugging or mineralisation causing an injection barrier close to the well.

Risk assessment specific to mineralisation

In mineralisation, the storage durability depends on CO_2 mobility: converting CO_2 into solid minerals greatly reduces leakage risk compared to fluid-phase storage in geological formations. However, while CO_2 storage in carbonates is widely considered permanent (i.e., durability of millennia), decarbonation and reversal can occur under specific circumstances. The key risk types are heat and acidity (low pH). The probability of these key risk types may differ based on CO_2 storage option.

For **in-situ mineralisation**, risks related to high temperature and (low) pH occur only in the period in which the mineralisation has not yet been achieved (Kim et al., 2023). Given that full mineralisation in basalt takes less than two years (Snæbjörnsdóttir *et al.*, 2020), this reversal risk is not relevant in the long term. Short term reversal risk can be reduced by keeping injection pressure balanced for controlled fracture propagation. (Carbfix, 2022) requires comprehensive site characterisation (porosity, permeability, reactive minerals) to minimise reversal risk and then sees reversal risk <0.1% per year.

Reversal risks for **ex-situ mineralisation** in grained rock, mine tailings and other waste minerals, concrete and cement mainly relate to incineration (>800°C), exposure to strong acids (pH <4) (MRÓZ et al., 2025), fires in the built environment, or high-temperature closed-loop recycling of concrete that compromises product integrity. In addition to reversal risks related to mineralisation in general (i.e., extreme heat and low pH), if applied to soils, carbonates may be exposed to natural biological and chemical processes. Thus, ERW and carbonated materials can lead to CO_2 being stored not only in the geosphere (as carbonate), but also in the bio- and (when washed out) hydrosphere. Reversals can occur in the soil (via cation retention, carbonate uptake, plant uptake of cations, and secondary mineral formation); after run-off in rivers (via degassing and calcite precipitation); and eventually in oceanic processes (via degassing, calcite precipitation and authigenic clay formation) (puro.earth, 2022b; Beerling *et al.*, 2025). The programmes vary in their coverage of the four storage options described above (sub-surface mineralisation, utilization in concrete, ERW, waste minerals).

In-situ mineralisation

GS4GG does not have a specific tool or methodology specifically targeting in-situ mineralisation. The same applies to Verra. Isometric has a protocol dedicated to in-situ mineralisation (Isometric, 2025c). The risk of reversals is assumed to be very low based on the standard's questionnaire. Reversal risks due to high temperature and low pH are not mentioned. Instead, reversal risk is linked to caprock, well stability and a very low possibility of methane production inside the storage reservoir, without further assessing these risks.

Puro.earth's "Methodology for geologically stored carbon" (puro.earth, 2024) covers both storage in formations and via in-situ mineralisation without disaggregating the specific risks. The focus lies on careful site selection (namely oversimplified modelling and potential chemical reactions) and operational risks related to CO_2 migration, wellbore and seal integrity, induced seismicity, fracture and fault development and propagation, and unwanted chemical reactions affecting reservoir properties. The methodology suggests developing a project specific risk matrix based on risk severity and likelihood. Project proponents are required to create, maintain and periodically update a comprehensive, scientifically justifiable risk assessment that is in line with puro´s general rules and standard. There is, however, no mention of risks specific to in-situ mineralisation, neither on high temperatures nor acidity.

Ex-situ mineralisation for utilisation in concrete

GS4GG's approach to risk assessment in CO_2 stored in carbon excludes risky applications and/or life cycles. This applies also to end-of-life (EoL) scenarios such as road use, landfilling, or reuse, which must be shown to avoid CO_2 re-release (Gold Standard, 2024b). If permanence cannot be demonstrated, the activity is discounted or excluded from permanent crediting.

Isometric (Isometric, 2024) applies conservative modelling approaches, which assumes worst case scenarios (including extreme scenarios on fires, acid exposure and material transport), to ensure a conservative approach. Operational monitoring ensures that full CO_2 mineralisation occurs during production of cement. Project-specific data including regional exposure, asset types, groundwater pH, and end-of-life pathways are assessed to justify CO_2 permanence. Puro.earth (puro.earth, 2022a) treats carbonated materials as permanent storage if they remain solid and chemically stable. Proponents must ensure that this stability remains throughout the whole lifecycle by describing exposure pathways during application (e.g., construction filler, landfill, reuse) and in a statement of end use and/or disposal; mitigation plans are required for foreseeable scenarios. Verra (Verra, 2024a) focusses on mineralisation efficiency during the production phase by crediting only the mineralised share of CO_2. Reversal risks after mineralisation, including at end of life, are assumed negligible.

Ex-situ mineralisation in grained rock (ERW)

Isometric (Isometric, 2025d) assumes that if ERW is applied at large scale in the future, marine alkalinity may decrease as a consequence of increased carbonation, and residence time of dissolved inorganic carbon (DIC) may be decreased, thereby elevating the risk of reversal. Currently, the reversal risk is deemed very small. However, as the activity is associated with high uncertainty, the number of issued credits is decreased for conservativeness. Puro.earth (puro.earth, 2022b) requires proponents to assess potential reversal risks arising from natural processes leading to reacidification of soils or water (i.e., a reversal risk based on acidity) and from anthropogenic interference, including land use changes inducing ammonium-based fertiliser use, and industrial spills or mine drainage, that lead to soil acidification. The identification of further reversal risks is left to proponents.

Ex-situ mineralisation in waste materials

Under Gold Standard, potential CO_2 losses and reversals from carbonated waste materials are monitored via a combination of direct measurement (where possible) and modelling approaches. In addition, GS4GG requires the project developer to "document and include, as part of the PDD, appropriate evidence for all probable end-of-life scenarios of the carbonated product." (Gold Standard, 2025b). This is to proof that there will be no significant risk for reversals at the end of the product's life. Unless this is proven, the CO_2 storage is considered non-durable. For a detailed reversal risk assessment, GS4GG uses tool 6, which is also used to determine the buffer pool percentage at project level. The default for this activity type is 2.5%; the tests in the reversal risk tool may require a higher buffer pool share.

While reversal risks are generally considered low or very low for carbonated waste materials, high temperatures (> 300 °C) and exposure to low pH fluids can cause reversals (Isometric, 2025a). Isometric's approach to reversal risks is based on an evaluation of the carbonated material´s storage site. Their methodology defines three classes. For closed storage systems, reversal risk is deemed negligible, and only the 2% buffer pool contribution is required. Open storage systems exposed to environmental conditions are subject to an uncertainty discount determined on project level, in addition to the 2% buffer pool. The same applies for storage sites associated with a high risk of exposure to high temperatures and/or acidic solutions, namely in mine tailings. This third storage category is subject to stringent and detailed MRV requirements, too (Isometric, 2025a, Appendix I).

Key considerations for CO_2 mineralisation

The key reversal risks for underground storage (i.e., in formations and via **in-situ mineralisation**) are related to **caprock stability and wellbore integrity**, as well as to potentially catastrophic events like earthquakes or volcanic eruptions. To mitigate these risks, three aspects are critical: First, **careful site selection** that avoids areas of increased seismic or volcanic activity and of vulnerable and/or overly permeable caprock. Site-specific, detailed and conservative geological modelling of caprock and formations must be applied to ensure the best possible reversal risk mitigation. Second, **wells must be managed and monitored** with great care, including reliable oversight and regulation by authorities to avoid orphaned wells and insufficient plugging of wells after injection. Measures to ensure sufficiently long monitoring even after injection should be applied, although reversal risks decrease with time. Third, **the injection pressure must be managed** well to avoid that rock is cracked, opening cracks through which already stored CO_2 (which is in fluid state, i.e., prior to mineral trapping) may re-emit. Again, a good understanding of site characteristics, including modelling of initial pressure of the storage rock, must be ensured.

Ex-situ mineralisation comprises a different risk portfolio: **High temperatures and low pH** can cause reversals. Thus, programmes aim to avoid situations in which these conditions can be met. Good practices involve the **exclusion of risky life cycle pathways** (e.g., certain end-of-life uses for concrete based on mineralisation) from certification and **avoidance and/or conservative treatment of storage site** (e.g., larger buffer pool contributions required for open storage site in areas prone to contact with low pH fluids). However, best practice would be to credit only storage sites that are closed and not at risk of being contaminated with acids or high temperatures. As an example, waste minerals from mine tailings should not be stored openly directly in the mining area, where acids and high temperatures may occur. Some activities, namely related to spreading carbonated materials in the environment (e.g., **ERW applications on soils**) are subject to **low MRV ability and high uncertainty**, with a multitude of known reversal risks along the pathway from application to final storage in the ocean. Current approaches aim at either **applying uncertainty discounts** (Isometric) or **assessing a sub-set of risks** that are related to low pH (puro.earth). Given the low control on the carbonated materials pathway and life cycle, these approaches seem insufficient. Both Isometric and puro.earth aim at quantifying "losses" caused e.g. by plant uptake or precipitation of secondary carbonates and incorporate these into their removal calculations. However, challenges related to these losses' monitoring and reliable quantification are large. **Good practice calls either for very strict conservativeness in the issuance of credits, or for excluding ERW until uncertainties of reversal risks are reduced**.

Table 8: Reversal risk for crushed material spread on soil (ERW)

Risk Type	Sub-Risk	puro.earth	Isometric
Increased acidity (lower pH)	Increased acidity due to feedstock containing sulphide group elements	no	yes[11]
	Neutralisation of acids other than carbonic acids	yes	yes
Plant uptake of cations	-	yes	yes
Secondary silicate mineral formation	-	yes	
Precipitation of secondary carbonates	-	yes	yes
Losses from water systems (re-equilibration of carbonate system)	Rivers and lakes	yes	yes
	Ocean	yes	yes

3.3. Guiding principles for PACM reversal risk assessment

PACM's reversal risk assessment procedures should build on lessons from private carbon crediting programmes but go beyond them by requiring a more science- and evidence-based framework that builds on **activity type-specific and, where feasible, carbon pool specific** assessments that

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[11] The Isometric ERW protocol references a module on „Rock and Mineral Feedstock Characterization" (Isometric, 2025e), in which this risk type is addressed.

reflect the distinct risk profiles of biosphere and geosphere storage. The same applies for the hydrosphere which has not been a subject of this report. In the following, we outline some guiding principles for the PACM reversal risk assessment both in the respective tool and in mechanism methodologies.

- **Carbon pool-level specification within activity types:** PACM's reversal risk assessment tool will provide separate risk components for distinct activity types, reflecting their characteristic hazard profiles, management regimes and monitoring options. Within each activity type, the tool should provide guidance on identifying all carbon pools that are materially affected. Additional reversal risk factors, i.e. those going beyond common financial, management and social risks applicable across activity types, should be defined, to the extent feasible, at the level of individual carbon pools, or at least be explicitly informed by pool-specific evidence (e.g., separate treatment of AGB disturbance risk vs SOC erosion and land-use change risk).
- **No undifferentiated activity-level scoring where pools diverge:** Where carbon pools within an activity type face clearly different hazard types, magnitudes or timescales, the tool should not rely solely on a single undifferentiated activity-level risk score. In such cases, pool-specific risk factors must either be quantified or, at a minimum, be reflected through differentiated qualitative ratings and conservative aggregation procedures that prevent high-risk pools from being masked by low-risk pools.
- **Use of transparent, standardised scientific datasets and/or models:** Additional reversal risk factors should be anchored, wherever possible, in transparent and publicly accessible scientific datasets and/or models. The tool should base hazard probabilities and potential loss magnitudes on scientifically credible, spatially standardised data sources (e.g., global or regional biomass datasets, fire probability models, flood and landslide layers, windthrow risk maps, climate projections). Resorting to default values should be allowed only where such data are unavailable or clearly inadequate.
- **Risk mitigation-linked, conservatively credited risk reductions:** Risk mitigation measures should only lower assessed reversal risk where they are clearly defined for the specific hazard or activity type, meet evidence-based design criteria and their implementation and performance are independently verified over time. Any resulting risk reductions should be parameterised (e.g., within quantified adjustment ranges) and applied conservatively, avoiding large downward adjustments based on untested or weakly evidenced measures.
- **Conservativeness as a core principle:** Where data are incomplete, heterogeneous or uncertain, the tool's guidance should require conservative assumptions, transparently documented extrapolations and lower-bound durability estimates, rather than optimistic values. Any use of default parameters must be clearly justified, based on the best available evidence,

and demonstrably conservative. The same should also be enshrined in the tool as guidance to define “negligible risk” at the methodology-level.

- **Application of proportionality and tiered methods:** The reversal risk assessment framework should apply a tiered approach that matches methodological complexity to risk level and scale. For high-risk activities, more data-rich, probabilistic methods should be expected, whereas for lower-risk activities, simplified approaches may be acceptable, provided that overall stringency is not relaxed below the “negligible risk” benchmark. To balance affordability and robustness, the tool should (i) define minimum information requirements and reference datasets or models that lower transaction costs, (ii) allow the use of standardised hazard layers and pre-calculated regional risk factors where these are demonstrably conservative, and (iii) link any reductions in buffer contributions to objectively verifiable mitigation measures rather than bespoke modelling for each individual activity. This principle implies that the tool itself must first assess the relevant risk level and scale for each activity at the reservoir level.
- **Transparent and non-diluting aggregation of risks:** Aggregation of individual reversal risk factors should follow clear, transparent formulas that reflect potential interactions between hazards (for example, drought amplifying fire risk) and avoid assuming full diversification where hazards are correlated. Climate-related amplification factors should be applied where multiple climate-sensitive hazards affect the same reservoir and activity type.
- **Differentiated definition of “negligible reversal risk”:** The reversal risk assessment tool should provide indicative parameter ranges or reference values for this maximum percentage, differentiated by reservoir and activity type. Negligible risk must be underpinned by robust evidence that stored GHGs are stable or in a steady state over at least 100 years from the time it is claimed, consistent with the Non-Permanence Standard: for biosphere reservoirs this includes explicit treatment of slow-onset processes (such as drought-related mortality, gradual degradation and regeneration failure) alongside acute events, and for geosphere reservoirs, careful analysis of site integrity, leakage pathways and monitoring confidence.

Whilst these guidelines are important to be discussed, it will be important for all stakeholders involved to also remain pragmatic. Overly stringent rules and requirements can affect the financial viability of projects and could turn project developers away from the path of highest integrity. The reflections in Box A2 on the value of temporal removals in regard to climate change amplification factors and tipping points emphasise the need for strong benchmarks for permanence thresholds and monitoring timelines over pragmatism.

4. The role of insurance policies in addressing reversal risks

The analysis in this section synthesizes available documentation as well as interviews conducted with insurance industry stakeholders active in the carbon market.

Against the backdrop of ongoing discussion about the effectiveness and design of buffer pools – particularly regarding their capital adequacy and the calibration of risk-based contributions – interest is growing among carbon market stakeholders in exploring insurance as a complementary or alternative mechanism to manage reversal risks. As outlined in section 2.5, in the context of PACM, a concept note is exploring the alternative measures to compensate reversals. This will most likely also include insurance policies and comparable guarantees.

Buffer pool challenges

Insurers note that severe or regionally clustered reversal events, such as large-scale wildfires, may challenge the resilience of pooled systems by drawing down reserves faster than they can be replenished, especially in areas already facing accelerating climate impacts. Buffer pools can also entail opportunity costs for project developers, as a portion of credits must be set aside rather than sold, which can weigh more heavily on smaller or early-stage projects with limited liquidity. Furthermore, the requirement to hold credits in reserve over long periods may create continuing liability exposure while constraining the financial flexibility needed for project reinvestment or scale-up. Finally, because buffer pools operate on standardised parameters, they allow only limited tailoring to individual buyer risk preferences or the diverse profiles of different project types and market participants – highlighting the potential value of more adaptive and risk-responsive instruments within the broader market architecture.

Insurance as a potential complement to buffer pools

The insurance sector has begun exploring ways to complement existing market compensation mechanisms by introducing approaches to assessing and pricing reversal risks. In recent years, a growing number of specialised start-ups and smaller insurers have entered this space, offering pilot products designed to evaluate, price, and transfer various forms of risk. These instruments can, in some cases, operate alongside or partially substitute for buffer pools, providing coverage for risks such as reversal, invalidation, non-delivery or market volatility. However, these offerings remain at an early stage, and their scalability and long-term integration into carbon market infrastructure are still being tested.

As in mainstream insurance markets, carbon market-related insurance operates in a highly regulated environment where insurers must maintain sufficient capital reserves to reliably pay claims, helping build market confidence in their ability to manage large-scale reversal events. Underwriting relies on actuarially grounded analysis: insurers evaluate political and natural-catastrophe exposures using established market databases, while specialised datasets assess carbon market-specific dimensions such as host country regulatory frameworks, historical credit delivery profiles, methodologies, and crediting programme rules. This generates project-specific risk ratings that determine coverage terms and premiums, enabling a pricing structure far more closely aligned with the underlying risk of each project taking into account its location.

Because premiums directly reflect underlying risk factors, insurance also incentivises project developers to implement risk mitigation measures. Developers can reduce premiums by improving fire management, enhancing monitoring, or selecting less risk-exposed geographies, thereby encouraging higher-quality project design and execution. Furthermore, availability of well-structured insurance products can strengthen investor and lender confidence, reduce loan interest rates and thereby helping mobilise capital for new projects and improving the financial viability of carbon credit generation, particularly for projects requiring upfront investment or facing long development periods before revenues start to accrue.

Insurance products in carbon markets are typically short-term instruments – often spanning one to three years with renewal options – reflecting the need for regular reassessment of evolving hazard conditions, regulatory contexts, and project performance. This approach mirrors conventional insurance practice, where long-term exposures are managed through a sequence of annually renewed contracts rather than single, multi-decadal policies. While such flexibility allows insurers to adapt coverage to changing risk profiles, it offers less long-term certainty for project developers, who tend to value the stability that current buffer pool arrangements provide.

4.1. Mapping of existing insurance products

A range of insurance products exists across the carbon market value chain to address different carbon credit-related risks:

- **Delivery** insurance protects developers, investors, and lenders against under-delivery or non-delivery of credits, including risks linked to monitoring or verification failures.
- **Cancellation** insurance protects developers and buyers against the loss of issued credits due to reversal events or certain forms of invalidation.

- **Buffer-depletion** insurance provides programme-level protection when buffer pools experience large or unexpected losses, helping ensure the continuity of remedial capacity at the programme level.

While most policies pay out in cash, some insurers also offer in-kind coverage by replacing credits directly, according to the requirements of the programme. Under cash-settlement options, the payout price is fixed upfront when the policy is bound, whereas under credit-settlement options for the insured defines quality criteria that ensure "like-for-like" replacement (See box A4), meaning that regardless of the activity type, one reversed unit is replaced by one unit of the similar characteristics. Each approach has its practical advantages: cash payouts offer financial certainty to buyers, investors and lenders and gives them the flexibility to procure replacement credits themselves, whereas in-kind settlements provide environmental integrity certainty by guaranteeing direct, like-for-like replacement when required.

Table 9 below provides a brief overview of the emerging ecosystem of carbon credit insurance, with a focus on reversal risk insurance:

Table 9: Overview of emerging carbon credit insurance ecosystem

Organisation	Organisation type	Stakeholders targeted	Product name	Key features
CarbonPool (CarbonPool, no date)	Insurer	Activity participants, buyers, investors	• **Carbon Reversal Insurance** • Carbon Shortfall Insurance • Planting Insurance	• In-kind payouts via 1:1 replacement credits; recently expanded to cash payout due to liquidity constraints in high quality units • Uses advanced environmental and weather modelling and actuarial methods to create tailor-made risk models • Offers monitoring for reversal events on a regular basis • Estimates reversal insurance will have an annual premium of <1% of the value of the insured carbon credits. • Participates in Verra's durability pilot
Kita (Kita, 2026)	Insurer	Activity participants, buyers investors, lenders	• **Buffer Depletion Insurance** • Non-Delivery Insurance • Non-Payment Insurance • Counterparty Insurance • Political risk Insurance	• Protects the established buffers and buffers being established in the instance of unexpectedly high loss levels that might lead to a buffer depletion past comfortable levels. • Both in-kind and cash payouts • Uses risk modelling, data analysis and MRV • Offer other bespoke products for managing reversal risks • Participates in Verra's durability pilot
Oka (Oka, 2026)	Insurer	Activity participants, buyers, investors, crediting programmes	• **Carbon Protect Insurance** • **Buffer Pool Risk Solutions** • Corresponding Adjustment Protect Insurance • Contract Risk Solutions • Financial Risk Solutions	• Carbon Protect Insurance provides cash payout to buyers in the event of unforeseeable and unavoidable post-issuance risks, including reversal • Offers bespoke products tailored to preferences of the insured and can be tweaked to cater to activity participants • Uses subject matter expertise, AI-enabled actuarial modelling • Backed by Lloyd's

Organisation	Organisation type	Stakeholders targeted	Product name	Key features
Cfc (Cfc, 2025, 2026, 2026)	Insurer	Activity participants, buyers, investors, lenders	• **Carbon Delivery Insurance** • **Carbon Cancellation Insurance** • Carbon Lender Insurance • CORSIA Guarantee	• Carbon Delivery Insurance caters to companies purchasing NbS credits on forward basis to mitigate non-delivery from any cause o Policy period: 36 months maximum, to capture maturity month o Policy limit: 100% of investment – capped at USD 25 million per project • Carbon Cancellation Insurance safeguards purchased credits against credit invalidation or reversal. o Policy period: 12 months maximum, annually renewable o Policy limit: 100% of investment – capped at USD 25 million per project • Underwriting based on open-source information; selection criteria ranges across several factors: reliability, additionality and location • Ability to create bespoke products for activity participants
Howden (Howden, no date)	Broker	Activity participants, buyers, investors	• Carbon Insurance • Carbon Capture and Storage Leakage Risk insurance	• Carbon insurance covers reversal risk. Howden provides bespoke solutions for client tailored to client exposure, risk appetite and broader risk management and financing strategy • First-of-its-kind insurance facility covering the leakage of CO_2 from commercial-scale CCS facilities o Designed by Howden, led by SCOR's syndicate at Lloyd's o Provides cover for environmental damage and loss of revenue arising from sudden or gradual CO2 leakage
WTW (WTW, 2026)	Broker	Buyers, investors, lenders	• **Post-delivery risk insurance** • Credit non-payment insurance & carbon non-delivery insurance	• Post-delivery risk insurance provides financial protection against invalidation of carbon credits, non-permanence and reversal events. • Ability to provide tailored support to clients to manage carbon credit risks and opportunities

Organisation	Organisation type	Stakeholders targeted	Product name	Key features
			• Political risk insurance • EU ETS & Fuel EU protect	
AON (AON, 2024)	Insurer/Broker	Activity participant	Carbon Capture and Storage insurance	• Provides capacity for physical risks, loss of revenue and general liabilities for large-scale projects; • Bespoke coverage that responds to issues with storage reservoir integrity, including loss of revenue; • Indemnity for loss of tax credits or requirements to purchase carbon credits associated with a leak of CO_2 from the carbon storage facility; • Placement with A- or higher-rated insurers, predominantly in the London market.

4.2. Enabling environment for insurance products

Current conditions only partially support the scaling of insurance and guarantee products. Insurers **cannot underwrite contracts for several decades** – as would be required to cover reversal risks for durations of 40 to 100 years, due to capital reserve requirements and the inherent uncertainty of long-term risks. Therefore, most insurance contracts **are annual**, or at **best run for a few years**, with premiums adjusted regularly as underlying risks change. In contrast, the ICVCM's work on permanence has highlighted that credible management of non-permanence would require products with tenors of 40 years or more, a duration that is not common in insurance markets today. This **misalignment between permanence expectations and actuarial feasibility** restricts the supply of insurance products and discourages both insurers and project developers from relying solely on insurance as a risk management tool.

In this context, a **central design question** for programmes and regulators is whether a **sequence of shorter term, renewable insurance contracts** can be regarded as an acceptable way to manage long term reversal risk, and under which conditions such an approach might be preferable to, or complementary with, buffer pools. Short term contracts renewed on a rolling basis offer flexibility and allow premiums and coverage to be updated as science, data and climate impacts evolve. However, they also expose projects to renewal risk (e.g., rapid premium increases or withdrawal of coverage in response to climate driven loss trends), similar to what is observed in high-risk property insurance markets. This argues for a cautious, incremental approach: frameworks should acknowledge the current limitations of insurance policies, allow space for the sector to develop, and start with combinations of tools that are workable now, while planning to raise ambition as markets, data and regulatory experience deepen.

Another major consideration is **moral hazard**. Insurance can only function if it does not undermine the incentives of PPs and other actors to minimise reversals. In practice, this means that policies held by project developers typically cannot cover losses that arise from their own negligence or intentional misconduct and must instead focus on **unavoidable risks**. Experience from other insurance lines shows that contract design is critical to mitigating moral hazard, but these lessons have not yet been fully translated into the carbon market context. Before embedding insurance more deeply into permanence frameworks, there is a need to learn from this broader body of practice, and to analyse how different insurance designs affect behaviour and incentives across project developers, buyers, intermediaries, and host governments.

Market demand conditions and regulatory signals will strongly influence whether such products emerge at scale. Carbon insurance is a very new segment: policies have only been broadly available since around 2023, providers are still predominantly specialised startups, and large incumbents or reinsurers are not really engaging. Demand is currently concentrated in the VCM and in specific niches, such as transactions linked to large institutional investors or schemes like CORSIA. To create a stable demand base, carbon crediting programmes and regulators can: (i) integrate insurance into their rules in ways that are codeveloped with insurers; (ii) avoid overly prescriptive criteria that are incompatible with insurance regulation or business models; and (iii) gradually expand the range of eligible tools (e.g. buffer-plus-insurance, permanence funds) within clear, predictable guardrails.

Early observations from stakeholders in the insurance market indicate that demand from project developers is nascent and concentrated among mid-sized projects. Larger projects have shown limited interest as the cost of insuring high issuance volumes is significant, while smaller projects, which are already financially stretched, struggle to justify the additional premium expense. Looking ahead, demand is likely to grow as compliance mechanisms such as CORSIA and PACM formalise insurance as an eligible tool, but without a clear regulatory signal requiring or incentivising its use, uptake is likely to remain modest. A deliberate policy push, such as requiring insurance as a condition of credit issuance within clear guardrails or offering premium subsidies for smaller projects, may be needed to move the market beyond its current niche.

Liability structures pose another major obstacle. Most carbon crediting programmes assign long-term liability almost entirely to project developers, despite the fact that developers may not exist for the full duration of the commitment and that buyers, investors, registries, and host governments also benefit from credited mitigation outcomes. Such misallocation complicates underwriting and heightens the likelihood of coverage gaps, making insurance less attractive and less scalable as a standalone mechanism.

Institutional infrastructure also remains a barrier. Insurers require **high-quality, accessible, and standardised data** for underwriting, such as MRV outputs, hazard information, project documentation, and historical reversal records. Yet carbon crediting programmes have not yet systematically collected such data or if they have not make them available to third parties. The absence of open, standardised and advanced depositories of such data linked to carbon market registries slows underwriting processes and restricts insurers' ability to scale capacity across diverse geographies and project types, increasing both friction and cost in the market. Relatedly, transparency around reversals and applied remedies remains uneven. Without consistent histories of past loss events or clarity on how standards have previously handled them, insurers find it difficult to accurately determine risk ratings, which could potentially raise premiums or deter the development of novel activity types.

4.3. Reflections and recommendations

The insurance sector brings **substantial analytical capability to reversal risk assessment**, leveraging high resolution hazard modelling long used in property markets to evaluate localized fire, drought, storm, and geological risks with greater precision than generic approaches. This enables more accurate and equitable allocation of reversal liabilities to specific projects and locations, and the **same actuarial methods can inform risk-based buffer pool contributions**, not just insurance pricing.

Experiences from the property insurance sector, particularly recent wildfire events in California, demonstrate that hazard conditions can shift rapidly and dramatically. As climate change-related impacts intensify, insurers have **raised premiums** sharply or **withdrawn entirely** from high-risk regions. The same dynamics could affect carbon market projects, especially forestry projects exposed to increasing fire, drought, or pest risk. Climate change may outpace underwriting models and capital reserves, rendering premiums volatile and, if climate change impacts accelerate further, making certain regions effectively uninsurable. Obviously, buffer pools would face the same challenge – they would be rapidly exhausted in the face of accelerating climate change impacts. Smaller, specialist carbon insurers stress their ability to adjust more quickly than traditional insurers (e.g., by updating risk models or reshaping covered perils at policy renewal), but long-term ability to offer contracts still hinges on **whether risk can be repriced as fast as climate change impacts rise**.

Short policy durations also pose a challenge. Most carbon market policies sit in the 1–3-year range (often renewed annually). Multi-year policies beyond this range are rare because insurers cannot lock capital to back claims for decades, nor can they reliably forecast reversal risks over such time horizons. Unlike the property-insurance and life insurance sector, which benefit from deep historical datasets, stable actuarial assumptions built up over generations and large, diversified pools of capital, carbon-market insurance remains far less mature and currently lacks the scale needed to guarantee long-term continuity.

Affordability remains a persistent challenge. Premiums, although risk-based and more economically rational than buffer contributions, may still be unaffordable for smaller or high-risk projects. Rising climate hazards could accelerate premium increases, potentially rendering insurance inaccessible in certain regions. These dynamics indicate that insurance might be more viable for larger, well-capitalised activity developers, who can absorb volatility, invest in mitigation to lower premiums, and commit to renewal programmes while smaller or community-based projects will struggle with upfront costs and maintaining continuous cover. **Support measures**, such as government subsidies, or hybrid models, may be required for such projects to be able to secure continuous coverage.

Where premiums exceed project margins, insurers may also carve out perils or narrow scope to keep costs viable, eschewing “full-coverage” policies.

Market participants also highlight the issue of **selection effects**. If low-risk projects disproportionately choose insurance while high-risk projects remain in pooled buffer systems, pressure will grow on buffer fungibility, solvency and fairness. This reinforces the case for updating buffer pool design to include improved activity-specific risk-based contributions and for specifying clear interaction rules between insurance and buffer systems within hybrid permanence frameworks.

A number of cross-cutting considerations shape the feasibility of expanding insurance use. Relying on **regulated insurers** helps build trust, as these entities must hold sufficient capital to pay claims and comply with prudential standards. Equally important is the need for **clear operational definitions**, including what constitutes a loss/reversal, which events trigger a payout, and how avoidable versus unavoidable risks are distinguished. These elements are essential both for underwriting integrity and for maintaining environmental credibility, ensuring that insurance does not inadvertently weaken project developer incentives to minimise avoidable reversal risks. At the same time, the carbon insurance ecosystem is still young. A pragmatic approach is therefore to begin with workable, narrowly scoped coverage, and gradually expand as data quality improves, actuarial confidence grows, and overall market capacity matures.

To sum up, insurance offers precision, incentives, and regulated capacity for well defined, time-bound reversal risks. However, given the shortcomings of existing insurance policies for reversal risks, many stakeholders view hybrid **architecture** as the more feasible and preferred approach. Under such a model, **insurance would cover specific, short-term, unavoidable risks**, given insurers’ inability to insure avoidable or negligence-related reversals or to offer very long-term guarantees, while **buffer pools and government guarantees would cover broader or long-tail risks that fall outside insurers’ underwriting capacity**. With clearer liability rules, better data infrastructure, calibrated buffer design, and affordability measures, the combined system can deliver higher integrity and more stable investment conditions than any single tool alone. Care should be taken to prevent an adverse selection dynamic, in which lower-risk projects opt for relatively inexpensive insurance coverage while higher-risk projects remain concentrated in buffer pools. Over time, both instruments may face growing strain as reversal risks increase due to accelerating climate impacts.

5. Deep dive: Permanence requirements in the EU

5.1. Assessment of CRCF certification methodologies

The EU CRCF sets up a framework to certify carbon removal and carbon farming activities in the EU. It distinguishes between three categories: permanent removals, carbon farming activities, and carbon storage in products. Activity types ex ante categorised as permanent removals are: DACCS, BioCCS, biochar, Enhanced rock weathering (ERW), ocean alkalinity enhancement, direct ocean capture with carbon storage and other solutions that lead to permanent storage of carbon.

Carbon farming activity types realising removals include:

- Rewetting and restoring peatlands and wetlands to reduce carbon oxidation and increase carbon sequestration,
- Agroforestry and mixed farming, integrating trees or shrubs with crop and/or livestock management,
- Implementing soil protection measures like catch crops, cover crops, conservation tillage, and hedgerows,
- Reforestation respecting ecological principles for biodiversity and sustainable forest management.

Examples for carbon storage in products under the CRCF include:

- Durable wood-based construction materials,
- Durable carbonated in products, e.g. concrete.

In the following, we discuss the approaches to reversal risks as formulated in the methodologies. Note that the analysis is based on currently available draft versions, as neither of the Delegated Acts (and, thus, the methodologies) are operational as of March 2026.

5.1.1. DACCS and BioCCS

For DACCS and BioCCS, the methodology (European Parliament, 2026) refers to the CCS Directive: “The CO_2 captured by the activity shall be injected in an operational geological storage site permitted under Directive 2009/31/EC and operators of storage sites used by DACCS and BioCCS activities are liable for any release of CO_2 from permanent geological storage under the rules set out in Article 16 of Directive 2009/31/EC.” ((European Parliament and European Council, 2009), p. 69). Key aspects governing reversal risks in this Directive are covered below and summarised in Table 10.

In the CCS Directive, reversals are covered in Article 16 on “Measures in case of leakages or significant irregularities”. It states that the operator of a storage site must notify the competent authority (i.e., member states and/or sub-national administration) and apply "the necessary corrective measures"[12] if leakage[13] or significant irregularities[14] (i.e., reversal or increased risk thereof) occur. A plan containing those measures is to be submitted during application for a storage permit (Article 7(7)) and included in the permit itself (Article 9(6)), along with the obligations to (1) notify authorities and (2) apply the corrective measures plan in case of a reversal or significant irregularities. Requirements regarding the monitoring plan (referred to in Article 13(2)) are formulated in the CCS Directive's Annex II, including on leakage detection (Annex II, 1.1 l).

With the reference to "competent authorities", the CCS Directive puts the responsibility regarding details on measures to be taken, if reversals occur, onto member states and their national legislation. The European Commission may review permit applications (including the corrective measures plan) and issue a non-binding opinion. The final decision on permitting storage is taken by the competent authority (Article 10).

In addition to notifying the competent authority pursuant to the CCS Directive, the storage site operator must also notify the competent authority pursuant to the ETS Directive (European Union, 2024) in case of leakages or significant irregularities (Article 16(1)). As CO_2 storage operators are regulated under the ETS Directive, they must surrender allowances for any leakage emissions of undetermined or fossil fuel origin.

Once a storage site is closed, operator liability persists for a minimum of 20 years before it may be transferred to the competent authority (Article 18). Transfer requires evidence that "all available evidence indicates that the stored CO2 will be completely and permanently contained", proof of site sealing, and a financial contribution sufficient to cover at least 30 years of post-closure monitoring.

To ensure consistent implementation across Member States, a set of Commission Guidance Documents (European Commission, 2025c, 2025d, 2025e, 2025f) further specifies how competent authorities should apply the Directive. Guidance Document 1 introduces an as-low-as-reasonably-practicable (ALARP) risk management framework: operators must submit a site-specific risk matrix classifying all identified risks by likelihood and impact, and the aggregate risk profile must not outweigh project benefits. The risk assessment proceeds through three sequential steps — hazard

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[12] Corrective measures are defined as „any measures taken to correct significant irregularities or to close leakages in order to prevent or stop the release of CO_2 from the storage complex" (Article 3(19)).
[13] Leakage is defined as „any release of CO2 from the storage complex" (Article 3(5)).
[14] Significant irregularities are defined as „any irregularity in the injection or storage operations or in the condition of the storage complex itself, which implies the risk of a leakage or risk to the environment or human health" (Article 3(17)).

characterisation (identifying leakage pathways such as caprock failure, well integrity loss, and fault reactivation), exposure and effects assessment (determining the extent to which people, ecosystems, and the environment could be affected), and risk characterisation (integrating hazard and exposure findings into an overall risk profile) — and must be updated iteratively as monitoring data evolve. Guidance Document 2 requires site characterisation through three-dimensional geological modelling, dynamic injection simulation, and hydrogeological analysis, and mandates a corrective measures plan covering key failure scenarios (CO2 migration outside the storage zone, pressure build-up, groundwater contamination, and legacy well integrity) with identified responsible parties and intervention methods. Documentation of all corrective actions must be reported to the competent authority, and both the monitoring plan and the corrective measures plan must be updated on an ongoing basis The draft CRCF methodology relies heavily on the existing EU CCS Directive framework for managing permanence including permitting, monitoring, reporting obligations, corrective measures, and operator liability. Long-term responsibility transfer to the competent authority is possible only after a minimum monitoring period and proof of stable containment.

Our assessment highlights that reversal governance for geological storage is relatively robust compared to other CRCF methodologies because it builds on a well-established regulatory system around the CCS Directive. However, it depends strongly on consistent implementation by national competent authorities. Differences in monitoring rigor or enforcement could introduce unintended variability and quality criteria across Member States. Moreover, the CRCF itself adds limited harmonised rules on how leakage events affect certified removal units.

5.1.2. Biochar

The CRCF methodology classifies biochar as having a low reversal risk and no buffer pool contribution or other remediation liability is requested. Moreover, it only mandates monitoring until the end use of biochar is verified. By verifying that the biochar has been incorporated into cement, concrete or asphalt, or has been applied to soils compliant to the regulation, the monitoring responsibilities are satisfied. In case the application to soils cannot be supervised by a representative of the certification body, site access must be granted for one year to monitor the biochar application.

This approach is criticised by NGOs and think tanks (Bellona, 2025; Fallasch *et al.*, 2025; Hernández, 2025) as soil type, temperature, moisture, and agricultural management affect the stability and permanence of biochar applied to soils, and that significant reversal risks exist, see discussion in section 3 above. While the stopping of monitoring is also proposed in the Isometric biochar methodology which states that "*based on present understanding, reversals in Biochar storage will not be directly observable with measurements and attributable to a particular project*", and there is agreement that long term monitoring of biochar permanence in soils is complex and costly for each individual project (de la Rosa *et al.*, 2018; Chiaramonti *et al.*, 2024; Schmidt *et al.*, 2025), this is no valid reason to just ignore these reversal risks. The permanence fraction of biochar as percentage F_{Perm} in the CRCF methodology can be calculated by applying the decay function assessing the hydrogen to carbon ratio (Azzi *et al.*, 2024) and the random reflectance R_0 (also called "inertinite benchmark") (Sanei *et al.*, 2024, 2025). While calculating F_{Perm} by the hydrogen to carbon ratio is already considered conservative and is valued 0 in the uncertainty assessment, the random reflectance approach needs to apply a conservativeness factor of 2.5% when calculating uncertainty. However, both of the CRCF methodology's approaches to measure whether stable forms of biochar are produced are unable to address actual reversal risks in the activity. Overall, it seems that the biochar methodology is not addressing reversal risks properly.

Besides the application of biochar in soils, the CRCF methodology allows the incorporation into cement, concrete or asphalt. Also, for these applications no monitoring is required after the building material has been produced, which again is not state of the art. As a benchmark case, the Isometric biochar methodology explicitly emphasizes the high uncertainty in locating construction materials as they can run through many different use cases throughout their life cycle and requires application of uncertainty discounts that account for degradation of biochar in construction materials throughout their life cycle (e.g. abrasion from asphalt). Reversal risk might increase in future if closed loop recycling under high temperature, in which biochar particles in construction materials would be combusted, becomes a more common technology.

Biochar stability varies depending on feedstock, pyrolysis temperature, and environmental context (e.g. priming effects). In soils, degradation rates can differ substantially and mineralisation of a fraction of carbon may occur over years or millennia. However, stability of carbon in biochar can be affected by the production process, and production and monitoring requirements shall ensure that biochar stability is guaranteed for a certain time period. In case the production requirements are fulfilled, biochar is a material with low flammability. Thus, the current draft methodology classifies the credited stable fraction of biochar as having negligible reversal risk and therefore does not require buffer pool contributions. Monitoring is limited to verifying the end use of the biochar (e.g., soil application or incorporation into materials) and ending afterwards.

The lack of post-application monitoring means that biochar permanence must be verified ex-ante. Without continued monitoring, underestimation of biochar mineralisation or reversals resulting from natural hazards after application will not be observable. This seems not aligned with a precautionary approach, given that uncertainty and research needs on the impacts of environmental conditions on biochar permanence remain. These issues could be addressed by introducing risk-based monitoring frequencies and establishing liability or buffer mechanisms for post-crediting reversals.

Table 10: Assessment of DACCS, BECCS and Biochar

Field	Aspect	DACCS and BECCS	Biochar
Reversal risk assessment	Risks covered in application of methodology	Yes	No formal risk assessment is required because biochar is deemed to be inert and stable once applied
	Risk quantification method (e.g., qualitative/quantitative model, resources, evidence) → please describe it in detail	Three-dimensional static geological earth model of the storage site, its surroundings, connection to transport infrastructure is mandated. Site characterisation and modelling of plume behaviour including leakage, plume migration, well failure and external disturbances are used to quantify storage risks and buffer requirements.	Not applicable; biochar is considered low risk for reversal.
	Risk eligibility threshold (if applicable)	Principle-based approach, activities that cannot demonstrate compliance with the required principles shall be ineligible for certification	Carbon quality checked via inertinite assessment (reflectance ≥ 2%) and decay function (H/Corg ≤ 0.7) to ensure it is resistant to decomposition
	Risk mitigation measures	Careful site selection, plume modelling, continuous monitoring, and corrective actions. Activity developers must provide financial security and buffers with credit cancellation if reversal occurs. Responsibility stays with developer until long-term stability is proven	Total biochar application capped at 50 t/ha cumulatively over time
Monitoring (during and after crediting period)	Parameters monitored (carbon pools, performance indicators)	Minimum requirements relevant for reversal risks: reservoir temperature and pressure (to determine CO_2 phase behaviour and state) in CRCF methodology, however stringent monitoring requirements in the CCS directive.	Monitoring must follow EU soil health and monitoring legislation
	Monitoring frequency	Intermittent (not specified) for certain parameters (e.g., 4D seismic), and continuous for others (e.g., temperature and pressure on the wellbore)	Soil carbon content, biochar decay indicators, and biochar quality.
	Duration of post-crediting monitoring	Required for at least 20 years	Monitoring of biochar required for one year after it being applied to soils or

			until being incorporated in products
Conservativeness and uncertainty	Uncertainty treatment (deductions, discounting)	The conservatism factor (CF) is applied to reduce the total credited CO_2 to account for quantitative uncertainty. Uncertainty from measured, estimated, or default data for CO_2 captured, transported, and stored.	The random reflectance method requires an uncertainty calculation applying a conservatism factor (2.5%).
	Liability mechanism (Y/N)	Yes	No
Reversal management and compensation	Temporary crediting (Y/N)	No	No
	Insurance or buffer pool mechanism	No	No
	Baseline updating after reversal	No	No

5.1.3. Carbon farming methodologies

The CRCF methodology includes requirements for three carbon farming activity types, namely: peatland restoration through rewetting, planting of trees and agroforestry and soil management of agricultural mineral soils including improved fertiliser use. For each of them, different reversal risk assessment, monitoring and liability requirements are stipulated (see Table 11).

The CRCF risk rate calculation, which determines the share of buffer pool credits to allocate to the buffer pool, primarily focuses on specific climatic and management risks triggering reversals. This approach overlooks political, project management, financial and market risks, crucial for accurately identifying high-risk projects and required under most carbon crediting programmes. The parent regulation EU2024/3012 has a strong quantification element, everything in the methodologies needs to be measurable, verifiable and consistent across member states. Non-physical risks are qualitative rather than quantitative. The regulation explicitly states the minimisation of administrative and financial burden on operators (Art8.3.h 2024/3012), where non-physical risk (mitigation) can cause small farmer projects to become financially unviable (EU, 2024).

While disturbance events like wildfires; storms; biological and insect outbreaks; and extreme climate events are explicitly mentioned in the methodology, other significant risks, such as landslides and volcanic eruptions, are not mentioned, potentially leaving them unaccounted for in reversal risk calculations and buffer pool credit allocations. On activity type level requirements, the risk assessment uses a binary hazard-vulnerability framework approach, where relevant factors (e.g. disturbance events of the past 30 years combined with the water exploitation index (peatlands) or species suitability for afforestation/agroforestry are included. However, critical information on climate change projections is not consequently taken into account, which can significantly exacerbate reversal risks. This aspect is only considered for tree species in agroforestry and afforestation activities. Further, the magnitude of past carbon losses is not considered, except for activities covered under agriculture on mineral soils, where soil organic carbon (SOC) change has to be estimated for the past 10 years and combined with carbon saturation, is used to calculate the overall risk level. This is also the only activity type, for which a carbon pool specific risk (i.e. solely SOC) is assessed.

A risk eligibility threshold for high-risk projects (according to the risk assessment) is only defined for afforestation, peatland rewetting and conservation and agroforestry, with no such thresholds established for other agricultural activities. This approach is not aligned with conservative approaches under carbon crediting programmes. Moreover, the mitigation measures are described using vague “factors” such as reduction multipliers ranging from 0.8 to 1.0, yet these lack a clear causal basis or empirical validation. Additionally, there is no requirement to demonstrate how a mitigation measure alters the frequency or severity of a reversal hazard. Mitigation measures are only required for medium risk for rewetting of peatlands and other soil restoration projects, exhibiting inconsistency and missing an opportunity to not only require but stipulated mitigation measures, proven to reduce risk.

The draft also includes more information on monitoring requirements, modelling, and remote sensing, including minimum resolution, scientific credibility, and calibration compared to the previous draft. However, multiple options for data sources are still permitted, and peer-reviewed data is not consistently required. The spatial scale used for risk assessment in afforestation and agroforestry projects, relying on NUTS1/2-level (i.e. major socio-economic regions/basic regions for regional policies) statistics for disturbance returns (see risk quantification method in Table 11), might be too coarse and risks overlooking local variations that could significantly influence reversal risk for trees in areas with high hazard levels or older stands with high biomass (Haya *et al.*, 2023).

A monitoring report is required every five years, which is aligned with the maximum interval under PACM. However, this frequency may prove insufficient, particularly for monitoring highly variable SOC levels. As for post-crediting, there is no post-crediting period specified for peatland rewetting projects, since they are considered to result in irreversible emission reductions by preventing emissions that would otherwise be released into the atmosphere. This assumption relies on sustained water table elevation, despite potential reversals from re-drainage or disturbances. Yet irreversibility requires that the benefit cannot be undone, not merely that it avoids emissions at certification time. This approach is, hence, not only in stark contrast to most carbon crediting programmes, but also conflicts with the EU Regulation 2024/3012, which acknowledges that carbon farming and carbon storage in products face a higher risk of voluntary or involuntary carbon release into the atmosphere. In contrast, afforestation projects are required to be monitored for a total of 40 years (with an activity period of 30 years), aligning with many carbon crediting programmes but not with best practices (i.e. 100 years).

Regarding liability, there is no requirement for a liability mechanism for soil emission reductions, except for the case of early project termination. This approach is not aligned with the VCM or PACM programme requirements. Additionally, there are no provisions for compensating post-crediting reversals. Buffer credits, which are meant to account for potential reversals, expire after the monitoring period, yet future major reversals can easily exceed the contributions made to the buffer pool. While the expiration of buffered units after the monitoring period is required by the carbon farming methodology, best-practice systems require mandatory buffer contributions from all projects, with dynamic adjustments based on quantified risks, to ensure adequate coverage for reversals.

The methodology might aim to compensate weak risk assessment and post-crediting requirements by applying temporary crediting to removals but relying solely on temporary credits for removals does not adequately address the broader risks involved in such projects. Moreover, the methodology does not include any provision specified for emission reductions. In addition, the methodology shows a degree of reliance on certification schemes for potential additional guidance on risk mitigation practices and their corresponding factors as well as monitoring requirements, which undermines its own accountability and shifts responsibility to external bodies.

Finally, the methodology offers several options for the liability mechanism, including a buffer pool, insurance policy, or a comparable guarantee product. After a reversal event, credits must be replaced with an equal number from the buffer or unit pool. If an insurance policy or similar guarantee product is used, the replacement may not be in the form of monetary compensation. In the case of avoidable reversals, replenishment is required with an equivalent number of credits of the same duration as those that were cancelled, which is aligned with carbon market requirements. In terms of operational details and enforcement, the methodologies lack clarity. For example, a stress test is required to assess the resilience of the buffer pool against a range of reversal risk scenarios. This is to be based on, inter alia, the range of risk ratings and significant loss events. No further details are provided, e.g. thresholds or standardised approach. There is also no information on the consequences of non-compliance (e.g. non-replenishment after reversal event) or failure of the stress test, undermining environmental integrity. Furthermore, buffer pools by carbon crediting programmes such as VCS have been proven insufficient to account for reversal risks such as wildfires and drought (Badgley *et al.*, 2022; Anderegg *et al.*, 2025b).

Overall, CRCF's reversal risk framework for carbon farming activities is less stringent than private carbon market programmes. It omits relevant risks and relies on binary hazard-vulnerability assessment (high/medium/low) rather than on dynamic, probabilistic models. Mitigation measures result in "reduction factors" (0.8–1.0 multipliers) without empirical validation, causal demonstration of risk reduction, or universal mandates across activity types. Coarse spatial data undermines accuracy and monitoring gaps compound this: 5-year reporting intervals for volatile SOC dynamics and no post-crediting liability for soil emission reductions or peatland "irreversible" claims, despite Reg. 2024/3012 explicitly warning of reversal risks in carbon farming. Buffer pools requirements lack robustness, especially regarding enforcement. Pooled units expire post-monitoring, leaving tail risks. Hence, the methodology does not provide sufficiently robust and long-term reversal risk treatment and requires significant improvements.

Table 11: Risk Permanence, Risk approach, and Risk for Carbon Farming Methodology under CRCF (Source: (European Parliament, 2026))

	Aspect	Rewetting and restoration of peatlands and of other organic soils	Agriculture and agroforestry on mineral soils	Afforestation
Reversal risk assessment	Risks covered in methodology	Yes	Yes	Yes
	Risk quantification method (e.g., qualitative/quantitative model, resources, evidence) please describe it in detail	Quantitative: Disturbance regime (Low: return period ≥ 30 years, Medium: return period 15-30 years, High: return period < 15 years) vs. Water exploitation Index: (Low: WEI+ < 20%, Medium: WEI+ 20-40%, High: WEI+ > 40%) Combination of the two factors results in either low, medium or high-risk level, according to Table 5 in the Annex of the DA. Evidence: For disturbance regime: Option 1: EU-provided return period dataset Option 2: Statistics from 30+ years of disturbance events (e.g. wildfires, storms, extreme climate events, biological and insect outbreaks) to calculate the ratio, using empirical records, surveys, Earth data, or literature. The area for calculation is	For agriculture: Quantitative: Hazard (no change, decrease (high) or increase (low climatic conditions and land management in past 10 years driving SOC changes proxied by recent SOC changes vs. Vulnerability (low: carbon saturation < 68%, high: carbon saturation ≥ 68%) Combination of the two factors results in a 2-10% risk rating, according to Table 6 in the Annex of the DA. Risk mitigation practices beyond eligibility and sustainability requirements may reduce the risk rate by a factor of 0.8 to 1. Certification schemes may offer further guidance. Evidence: For Hazard change: SOC changes in project area over the past 10 using own data, national	Species suitability: Suitability of species/composition in conservative climate projections vs. Disturbance risk: Return period of hazards (average interval between natural disturbances (mandatory: fires, windthrows, pests/insects)). Risk mitigation practices beyond eligibility and sustainability requirements may reduce the risk rate by a factor of 0.8 to 1. Certification schemes may offer further guidance. Evidence: For suitability of species: Commission's estimates, national datasets or peer-reviewed data. For disturbance regime: Option 1: EU-provided return period dataset. Option 2: Statistics from 30+ years of disturbance events to calculate the ratio, using empirical records,

		required to be "large enough" for robust regional statistics (NUTS2 or NUTS1). For water exploitation: WEI+ by Eurostat	surveys, or the Commission's estimates. For saturation: own data, or the Commission's estimates For Agroforestry: see Afforestation requirements.	surveys, Earth data, or literature. The area for calculation is required to be "large enough" for robust regional statistics (NUTS2 or NUTS1).
	Risk eligibility threshold (if applicable)	Activities deemed high-risk following risk assessment are ineligible.	For agroforestry and afforestation: Tree species deemed unsuitable via risk assessment are ineligible, unless historical or experimental success and future suitability are demonstrated in the activity plan. For agriculture: No requirements.	
	Risk mitigation measures	Medium-risk activities require enhanced mitigation beyond baseline requirements (e.g., boosting vegetation cover to raise humidity against fires, or curbing river basin water extraction for sustainable freshwater use). Certification schemes to offer further guidance	Not required	Not required
Monitoring (during crediting period)	Monitoring plan (mandatory components)	Description of carbon pools/emission sources (below), with their quantification/monitoring methods and frequencies; relevant documentation, description of how the risks of reversals and the reversals are monitored		
	Parameters monitored (carbon pools, performance indicators)	Living biomass (CO_2, mineral soils (CO_2), organic soils (CO_2, CH_4, N_2O), direct N_2O emissions from managed non-agricultural soils (N_2O)	Living biomass (CO_2), mineral soils (CO_2)	Living biomass (CO_2), mineral soils (CO_2), direct N_2O emissions from managed non-agricultural soils (N_2O)
	Monitoring frequency	At least every five years and within one year after reversal event		
	Eligible data collection method and sources	Options: 1. Modelling (calibrated with direct measurements), 2. direct measurements or 3. default factors. Approach must be used consistently per carbon pool/emission source.		

		Detailed requirements for transparency, Scientific credibility, suitability and accuracy are stipulated.		
Monitoring (post-crediting)	Duration of post-crediting monitoring	Not required	At least 10 years, except for practices that reduce direct and indirect N_2O emissions from managed agricultural soils, which does not required post-crediting period monitoring.	Monitoring period must begin with the activity period and last at least 40 years
	Incentives for post-crediting monitoring	Activity period renewal up to 2x (30 years in total)	Agriculture and agroforestry practices that reduce N_2O emissions and increase carbon removals OR agriculture that reduces CO_2 emissions from soils: Activity period renewal up to 2x (15 years in total) Agroforestry: Activity period renewal up to 1x (30 years in total)	No renewal after 30-year activity period, requirement to monitor for at least 40 years
Conservativeness and uncertainty	Conservative estimates	Use of conservative estimates are required		
	Uncertainty treatment (deductions, discounting)	Uncertainty reduction required		
Reversal Management and Compensation	Liability mechanism (Y/N)	No	For Soil ERs: Required only to prevent early termination. For removals: Yes	Yes

5.2. Case studies

5.2.1. Triple liability for reversals: Ørsted - Northern Lights Joint Venture BECCS case

Ørsted Bioenergy and Thermal Power A/S (Ørsted) is developing a bio-energy with carbon capture and storage (BECCS) project, including capture from two bioenergy installations (Avedøre-verket (AVV) and Asnæs-verket (ASV)) in Denmark, and transport from Kalundborg port to the CO_2 storage facilities in Øygarden, Norway. The transport and storage activities are operated by Northern Lights Joint Venture DA (NLJV) in Norway. The business model of this large-scale BECCS project combines subsidies with carbon credit sales in the VCM. Ørsted secured the public funding component in 2023 by submitting a competitive bid in Denmark's first CCUS tender. This tender shall ensure that at least a minimum of 400,000 tonnes of CO_2 will be stored annually starting from 2026 until 2045. Ørsted will capture a total of 430,000 tonnes of CO_2 annually from their two sites in Denmark.

This project must comply with a complex mix of EU ETS rules, EU CCS Directive obligations, Danish tender conditions and VCM methodology requirements. This creates challenges related to "double penalisation" of emissions, overlapping liability provisions and potentially excessive penalties for reversals. The latter is examined in detail below.

EU requirements for CCS activities

The Ørsted facilities exceed the 20 MW thermal input threshold for coverage under the EU ETS (European Parliament and European Council, 2005). Over 95% of the facilities' fuel use is from sustainable biomass, with an emission factor of zero. However, other parts of the value chain remain covered by the EU ETS: i) Truck and vessel emissions transporting CO_2 to Norway[15]; ii) Energy use throughout the value chain; and iii) (Re-) emissions from CO_2 storage site in Norway.

The interaction between the EU ETS and EU CCS Directive are described in Section 5.1. To account for the (re)-emissions the Operator must follow the Implementing Regulation 2018/2066 (European Union, 2018) on the monitoring requirements and reporting (MRR). The MRR is detailed on the differentiation of biomass and fossil origin of the source material.

Article 38 specifies the treatment of biomass, Article 39 the determination of biomass and fossil fraction, Article 43 the determination of emissions, Article 48 inherent CO_2[16] and Article 49 the transfer

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[15] This includes emissions from transport fuel use AND leakage of CO_2 transported where applicable

[16] Inherent CO_2 is CO_2 contained in a fuel or material and released as part of the normal process (rather than being produced by combustion

of CO_2[17]. **If the origin can be tracked throughout the CCS value chain**, the MMR rules can be interpreted as: **CO_2 leakage from transport and storage, sourced from biomass or the atmosphere, is to be accounted for as zero emissions at the point of emission accounting**. **The CCS and EU ETS directives as primary legislation,** on the contrary, **do not differentiate between atmosphere, biogenic or fossil origin passed capture,** and require operators to surrender allowances for leaked CO_2 during transport or from storage. This discrepancy between MRR on the one hand, and CCS and ETS directives on the other, leads to confusion for operators along the value chain. Project developers operate on the basis that they will have to surrender allowances no matter the source after a discharge or reversal event.

Danish state subsidy

Ørsted needs to abide by the "Contract on subsidy for carbon capture, transport and storage" (Energistyrelsen, 2024) as per the Danish Energy Agency (DEA). Article 1.3 states that "*the Parties have entered into **the Contract pursuant to which the Operator shall ensure capture, transportation and permanent storage of CO_2** […]. **The Subsidies will be paid per ton CO_2 captured and permanently stored.***"

The Contract doesn't mention reversals or re-emissions, however, it speaks of:

- **"Delivered Quantity"** (Article 14);
    - Article 14.2 allows for a temporary storage site if there are unplanned defects or failure at the original storage site for no longer than six months. If the DEA does not approve this temporary storage site "*the CO_2 stored will not be considered Delivered Quantity and the Operator shall immediately stop the permanent storage*" at this site. The DEA can claim repayment and/or penalties from the Operator.
- **Penalties**, material breach or termination for non-performance (Articles 15.3 and 15.5)
    - According to Appendix 6, Subsidy and economy scheme, penalties are due if the Delivered Quantity is lower than the Contracted Quantity and only applies during the operational phase.
- **Liability** in connection to the (non)-performance (Article 16.1)
    - The Operator shall be fully liable for any act or omission of its Sub-Suppliers, of which one is interpreted as the transport and storage operator.

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[17] 43(4) states that biomass and fossil emissions must be quantified individually. Article 49(3) applies to transport of the CO_2, and biomass and fossil emissions are still separated. Article 49(1) states that transported or stored CO_2 can ONLY be deducted from fossil emissions (biomass = 0). In case of re-emissions the same should apply.

- Operator's failure to perform due to **failure by a third party** engaged by the Operator to perform whole or a part of the Contract (Article 18.1.4)
    - It is unclear from the documentation if a third party is defined differently from a Sub-Supplier.

The **Operator's obligation to ensure permanent storage of the CO_2 captured**, shall survive the expiry or termination of the Contract and **remain in force indefinitely**. Article 5.9.1 of the Contract states that **the Operator shall ensure that the CCS Activities are in compliance with applicable law, including the CCS directive**. Meaning that **reversals are to be handled in accordance** with the Directive as described above. It is deemed there are **no immediate repercussions for the Operator to the DEA for reversals** through either penalties or repayment of the Subsidy.

VCM requirements

Ørsted is using the VM0049 framework methodology for CCS. Figure 6 below shows the different documentation the project is obliged to follow.

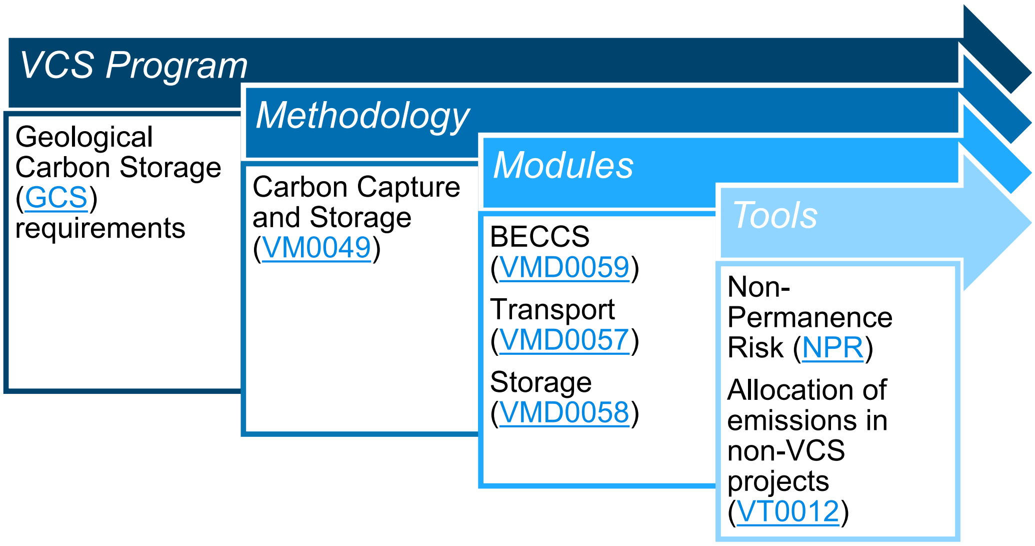

Figure 6: Project-relevant documentation for registering a BECCS project under Verra

According to VCS rules, the risk assessment to determine reversals is deemed low and the NPR tool calculates 1%[18] of generated credits towards the buffer pool, which would be maximum 4300 credits annually. However, the risk of reversal ramps up during operation (e.g., injection pressure can induce (micro)fracturing creating a reversal pathway). The reversal risk then plateaus

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[18] The online draft PDD for validation states 2.575%, the NPR has been updated from version 4 to 4.1 and the update resulted in a lowering of the percentage to 1%.

and decreases after injection stops[19] . If a reversal occurs from the storage complex it will be indicated by the seismic interpretation planned every 5-7 years. The detectability of the seismic imaging is 100,000 tonnes CO_2 (Verra, 2025f) which becomes the minimum value of the reversal. The storage site offshore Norway can store maximum 1.5 million tonnes of CO_2 per year and 5 million tonnes annually from 2028 (Northern Lights JV DA, 2025). Any lost CO_2 from Ørsted will apply its buffer pool proportionally to the total amount stored.

Northern Lights JV DA has performed a containment risk assessment over 45 years of operation (25 years injection and 20 years post-injection) and again over 125 years. The assessment identified a chance of 0.05% CO_2 leakage from the reservoir after 125 years (Verra, 2025f). Only a proportion will be released at surface, with the remaining CO_2 being retained within other stratigraphic layers as described in Section 3.2.2.

A loss of containment as per Verra definition occurs where the injected CO_2 migrates out of the storage complex (Verra, 2024b), either in another subsurface layer or directly to the surface. If a loss of containment is detected, **the project proponent must halt injection**, quantify the loss, and determine whether it can be repaired. Injection can only resume when containment is re-established. **Even if the CO_2 does not reach the surface but entered outside the defined storage complex, the loss needs to be covered by the buffer pool**.

Projects are no longer eligible for crediting when the quantity of CO_2 lost is more than 10% of the total CO_2 injected in the project.

Interaction between the different market-based instruments

While operational project and leakage emissions from removal activities within the EU can be “double” penalised both under EU ETS and the VCM (or CRCF), the above case shows that if the sustainable biomass is properly traced the reversal should only lead to VCM buffer pool decrease during a loss of containment event/reversal, while in practice, the same event continues to trigger allowance surrender obligations under the EU ETS. This is correct from an accounting point of view, as the EU ETS is primarily an emission reporting approach, while the VCM is a carbon accounting approach. And a reversal of removals will therefore be identified as zero emissions in emission reporting but needs to be compensated regarding issued carbon credits. However, mixed streams or untraceable

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[19] Note that injection losses are not the same as reversals during injection: the former describes a loss of CO_2 „on its way“ to the storage site and is addressed when calculating project emissions; the latter describes re-emission of formerly stored CO_2 as a consequence of (increased pressure and resulting rock fracturing) ongoing injection and is treated as a reversal.

biomass, will lead to multiple reversal liability, both under the EU ETS and the VCM. Should the VCM in such cases accept ETS coverage as sufficient? The landscape across VCM programmes is mixed: Verra, Gold Standard, Isometric, and including CRCF, do not recognise ETS coverage and require full accounting for emissions even when ETS obligations apply. Puro.earth is the only programme that explicitly recognises ETS coverage, but only for power and heat use (puro.earth, 2024).

The EU ETS Directive does allow for other GHG emission trading schemes in its Article 25, only referring to the Kyoto Protocol. If an agreement is concluded, the Commission shall draw up provisions to the mutual recognition of allowances under that agreement.

As it is likely that the combination of different regulatory systems will be frequently used for removals projects, a rule of "single reversal liability" would be appropriate. It could be designed in a way comparable to treaties to avoid double taxation.

5.2.2. Bilateral Agreement signed between Switzerland and Norway

In June 2025, the Governments of Switzerland and Norway signed a bilateral agreement under Article 6.2 of the Paris Agreement establishing one of the first sovereign frameworks for cross-border cooperation on both geospheric removals and CCS (Energidepartementet, 2025). The agreement creates the legal, accounting and regulatory conditions for enabling (i) transfers of ITMOs under Article 6.2 and (ii) cross-border transport of CO_2 from Switzerland to Norway for permanent geological storage. First pilot activities under this bilateral agreement have already been launched, with Swiss company Neustark and Norwegian company SpareBank 1 Sør-Norge agreeing on the transfer of a symbolic amount of removals through CO_2 carbonation in concrete, ash or slag (Neustark, 2025).

While the agreement does not establish a formal buffer pool reversal risk mitigation is embedded structurally through several approaches:

1. Permanent storage requirement reduces the likelihood of reversals: Only removals with permanent geological or mineral storage qualify, materially lowering reversal risk relative to less permanent biospheric carbon pools.
2. Regulatory oversight of storage sites facilitates reversal detection: Norwegian CCS operations are subject to stringent environmental regulation and long-term monitoring, aligning with the EU' CCS Directive. This ensures that reversals are detected in a timely fashion.
3. Inventory-based accountability for reversals: Because ITMOs are integrated into national greenhouse gas inventories with corresponding adjustments, any reversal will have to be

accounted for in the Norwegian inventory as an emission, creating strong incentives for environmental integrity.

The absence of a dedicated Article 6 buffer pool to cover reversal risks suggests a strong belief of both governments that technology choice (mineralisation), regulatory liability frameworks, and sovereign accounting discipline solve the reversal risk problem. It however becomes very risky if there is “bad luck” where a reversal event occurs even if it has been deemed highly unlikely. The agreement does not provide any coverage for such an event.

In future bilateral agreements, governments might consider requirement for insurance in the case of an (unlikely) reversal event. If the probability of such an event is very low, the premium for such an insurance should be affordable.

6. Discussion

In this section, we synthesise the key findings presented throughout the report. We begin by examining the cross-cutting insights on permanence requirements, followed by a discussion of the role and limitations of the proposed reversal risk framework. We then consider how insurance mechanisms could contribute to managing reversal risks and conclude with a reflection on recent developments in the EU context.

6.1. Key cross-cutting findings on permanence requirements

Across schemes, initiatives and carbon crediting programmes, permanence requirements are gradually converging on **a common architecture built around four elements: explicit assessment of reversal risk, minimum monitoring and compensation periods, use of buffer pools for compensation of reversals and clear allocation of liability for reversals.** CORSIA, the EU CRCF, the ICVCM, the UK ETS Authority and major private carbon crediting programmes as well as the newly operationalised PACM all require some form of risk assessment, mitigation, monitoring and compensation mechanism, even if the details differ substantially.

With regard to the **storage period which is deemed to represent permanence**, the UK ETS Authority and the EU CRCF apply a 200 year period, CAR and Verra 40-100 years – which can increase to 1000 years for geological storage - whereas ICVCM applies 40 years from the start of the first crediting period (AFOLU), and CORSIA accepts 20 years, the shortest period of any programme. This means that definitions of “permanence” or “durability” of credits **differ by centuries** between programmes, creating inconsistent permanence expectations across schemes. A visual of this patchwork of requirements is shown in Figure 7. **Similar activities face very different permanence expectations depending on the programme they are registered in**, with **project economics being more attractive for programmes with lenient requirements**, in case credit revenues are similar across programmes. This risks leading to **activity developers “shopping” for the least demanding interpretation of permanence**, unless **credits with higher permanence are priced higher than those with lower permanence**.

With regard to the **percentages of credits allocated to buffer pools** an equally wide variation can be observed between low-single digit percentages and 20-30% for biospheric pools. Many programmes apply **fixed percentages**, which are not based on science or derived by empirical evidence.

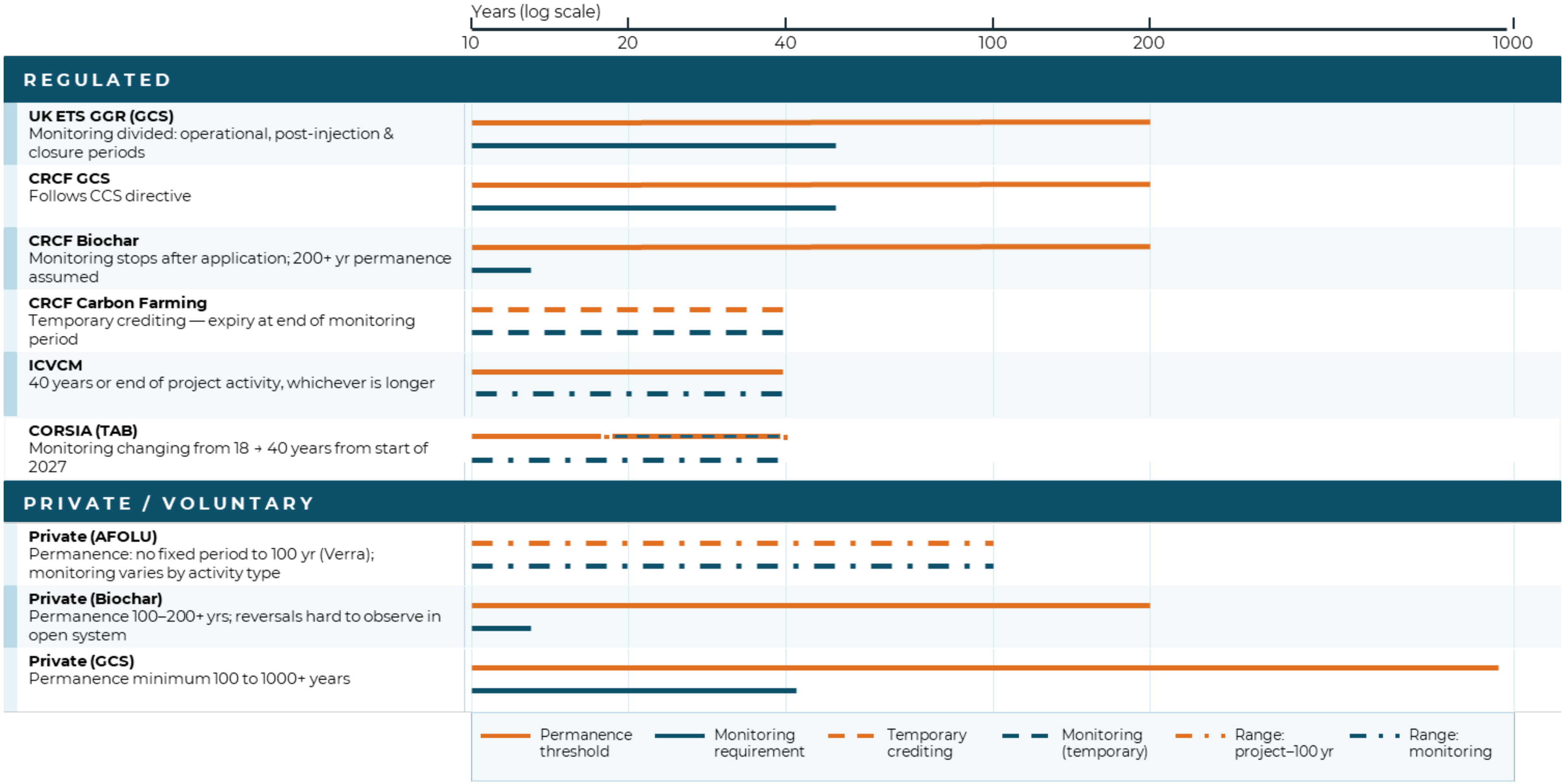

Figure 7: Permanence versus monitoring timelines for different carbon market mechanisms, carbon pool and project activities

Due to the **short period of existence of most buffer pools**, the risk of **undercapitalisation** can only be assessed for a small share of pools with a history of more than a decade. Undercapitalisation risk is **higher for buffer pools covering similar activity types, or focused on a small geographical region**. Regarding the latter, Badgley *et al.* (2022) found that for California's forest offsets programme's buffer pool in the period 2013–2021 wildfire losses consumed 95% of contributions for the two projects CAR1046 (Trinity Timberlands, 2015: 847,895 tCO_2e) and CAR1174 (Eddie Ranch, 2018: 276,867 tCO_2e), with smaller losses for the projects ACR260, ACR273, CAR1102, and ACR255. The authors estimated that the single disease "sudden oak death" alone could exhaust all disease-risk reserves of that buffer pool. For the global buffer pool of Verra which covers all VCS activity types and has been filled with 77 million credits (6.3% of total credits issued), MacDonald (2025) found relatively few instances where the pool has been drawn on and deems the risk of exhaustion as low. Due to these research results, there is broad recognition that **buffer pool management needs to be improved through maximisation of pool diversification (ICVCM and CORSIA)** and **regular stress tests** (ICVCM, PACM).

A further point of emerging convergence is that **reversal risk should be addressed in proportion to the underlying risk profile which differs by activity type**. CORSIA's TAB, ICVCM and the EU CRCF all distinguish between **activities with material reversal risk including AFOLU and some biomass-based activities** and **structurally low reversal risk engineered removals with geological or mineral storage**, and they generally impose **longer monitoring and stronger compensation and liability provisions on the former**. However, programmes are not consistent within these categories; for example ICVCM and CORSIA **treat jurisdictional REDD+ less stringently than project level AFOLU, assuming that governments can address reversal risks more consistently than private sector entities**. This assumption however only holds true if there is not a generally bad governance. This assumption depends on the quality of governance; where governance is weak, jurisdictional approaches may not offer the assumed advantage.

IV. Programmes differ significantly in their treatment of temporary storage, which could be formally done through temporary crediting or tonne-year accounting. Theoretically, temporary crediting has the highest degree of robustness, but due to its limited temporal validity it is relatively unattractive to activity developers and buyers. The CRCF explicitly uses temporary crediting for carbon farming and storage in products, with credits expiring at the end of the monitoring period and stored carbon deemed as released unless monitoring is extended, while leaving replacement obligations for buyers largely undefined. Tonne-year accounting or temporary crediting is not applied under CORSIA, ICVCM or the PACM, while CORSIA's TAB has left the door open to tonne-year accounting. Given that tonne year accounting could be a pragmatic solution to the permanence conundrum if the equivalence period is long enough, its prohibition warrants further examination: It is based on incompatibility between the programmes´ permanence and integrity requirements as well as definitions regarding “actual” (full) tonnes on the one hand, and the approach allowing for reversals and crediting fractions of tonnes on the other hand. If buffer pools fail widely, tonne-year accounting should be reconsidered. (More details on this approach can be found in

V. Box A2: Is there a value in temporary storage?

There is a vivid academic debate whether **storage with low durability has a value in addressing climate change or not**. There are **two conceptual arguments why such a value exists**: **reducing the rate of climate change (e.g. the temperature increase per decade) reduces climate change damages** and **preventing that temperature exceeds tipping points that lead to irreversible and large climate change impacts**.

The first argument is intuitively appealing. A rapid temperature increase, and the impacts linked to it leave less time to adapt and thus generate higher adaptation costs. A slow rate of change allows autonomous adaptation, whereas a high rate of change requires planning and generates more "surprises" regarding impacts. There is evidence that the rate of temperature increase has accelerated significantly in the last decade (Foster and Rahmstorf, 2026), and that the frequency and severity of climate change-related events causing damages has increased as well (World Meteorological Organization (WMO), 2026). However, this topic has been researched to a very limited extent. (Pinsky *et al.*, 2025) and (Visser, 2008) find that impacts of climate change on biodiversity are positively related to the rate of change. **More research is needed to calculate the benefits of reducing the rate of temperature increase.**

There is a scientific consensus that several temperature-increase-related "tipping points" exist where specific climate change impacts become irreversible. (Lenton *et al.*, 2025) summarise current knowledge on tipping points and find that we may already have exceeded the temperature levels that trigger general coral reef dieback, whereas we are getting close to the temperature triggering collapse of land permafrost, the Greenland ice sheet, the West Antarctic ice sheet and the Southern Ocean sub-polar gyre. In that context, high volumes of **temporary storage could "buy time" to keep us from crossing the tipping points**. During this time, permanent storage technologies could be developed to the extent that they would be available at a scale large enough to ensure the tipping points are never crossed. Countries could point to temporary storage in their NDC, buying time until future, permanent CDR becomes available at attractive conditions (Beyer, 2025). But if the time is not used wisely and we get into a situation where massive reversals happen without alternative mitigation being available, then temperature increase would accelerate, and we would exceed multiple tipping points very quickly. Therefore, research is needed to assess the conditions under which temporary storage could successfully "buy time", including the policy instruments required.

An approach that **attributes value to the temporary storage for each year of effective storage** is the so-called **"tonne year" approach**, explained in Box 3 below. Many researchers continue to

emphasise that temporary storage does not contribute to limiting cumulative emissions, which is necessary to meet the Paris Agreement's temperature goal and thus the **value of temporary storage cannot be equivalent to an emissions reduction** (the effect of which is inherently permanent; Brander and Broekhoff, 2023; Cullenward, 2023; Watson and Bui, 2026).

I.

And Box A3: Alternative approaches to addressing non-permanence)

6.2. Advantages and disadvantages of the proposed reversal risk framework

The reversal risk framework developed in chapter 3 in order to operationalise the PACM reversal risk assessment procedure **systematically differentiates risks at carbon-pool level within activity types** and applies **explicit links between risk factors, mitigation measures and buffer pool contributions**. It improves on current practice by **requiring transparent, standardised datasets and models, probabilistic risk quantification**, and aggregation that avoids a cumulation of high climate change-related risks.

However, there are various challenges in applying the framework. Its pool-specific design builds on the **broad availability of disaggregated, robust hazard and GHG store datasets**. Currently, these are incomplete. **Probabilistic and multi-hazard assessment is methodologically complex and generates significant computational demands**. Smaller activities will struggle to apply these approaches unless **reservoir-specific simplifications are possible**. Differences in practical implementation between activity types will be significant.

The framework will only be feasible if its **elements are introduced over time** according to a **prioritisation commensurate with the risk level**. One should start with "**no-regret" and easily implementable elements** – such as a common risk taxonomy, explicit reservoir and pool identification, basic likelihood–magnitude–spatial scale structuring (for the biosphere), conservative treatment of data gaps, and the rule that risk mitigation needs to be evidenced and verifiable. **More complicated elements requiring significant investment by both regulators and activity developers**, notably systematic probabilistic modelling, multi-hazard interaction treatment and the use of advanced global datasets, should **first be applied for higher-risk or large-volume activities** and expanded to other activity categories over time.

6.3. Role of insurance policies to address reversal risks

Insurance for reversal risk in carbon markets is **still in its infancy**, both in terms of product design and institutional embedding. The landscape described in Chapter 4 above shows a small number of specialised providers experimenting with products addressing credit delivery, credit cancellation and buffer-depletion risks. Carbon market programmes such as Verra, ICVCM and PACM have just started to think about integrating insurance in their regulatory toolbox.

Researchers and practitioners converge on one point: **insurance cannot credibly serve as a standalone instrument for managing non-permanence**. Structural constraints in insurance markets are **not aligned with the need to cover multiple decades or even centuries**; insurance providers usually work with **one- to three-year policies** and **rely on frequent repricing** as hazard conditions and data evolve. This means that **“rolling” sequences of short-term insurance policies** are more realistic than long-term policies. In that context, lessons from property insurance, including **recent sharp premium increases in or withdrawal of insurance providers from high-risk regions**, suggest that **long term insurance coverage and affordability are likely to be absent where climate impacts become most severe**. Private insurers cannot or will not underwrite such spiralling risks at acceptable cost, but **alternative solutions such as buffer pools will also fail unless contributions are increased in line with the risks, which may bankrupt activity developers**.

There is an emerging consensus to develop **hybrid architectures in which multiple tools are combined** in ways that strengthen, rather than dilute, overall environmental integrity. **Insurance can add value where risks are well defined and time-bound**, for example, by protecting buffer pools against rare, outsized depletion events or covering specific categories of unavoidable reversal risk during the crediting period. Buffer pools, permanence funds and, in some contexts, public guarantees can, in turn, provide backstops for longer-term and more diffuse risks that are hard to price or diversify. For this layering to enhance integrity, two conditions are crucial. First, the regulatory regime must **avoid adverse selection and cherry-picking**, where **low-risk projects take up cheap insurance and are no longer required to contribute to the buffer pool** while **high-risk projects feed the buffer without the contribution level being adjusted for the increase of average risk**. Second, insurance must not weaken incentives for prevention: carve-outs for avoidable reversals, calibrated deductibles, and clear trigger definitions are needed so that **insurance coverage does not reward negligence or underinvestment in risk mitigation**.

6.4. Implications for the EU context

The EU CRCF applies a **permanence architecture differentiated by storage type** as it distinguishes between permanent carbon removals (e.g. DACCS, BioCCS), carbon storage in products, and carbon farming activities. Geological storage is subject to the **regulatory safeguards of the CCS Directive**, which establishes robust monitoring requirements and operator liability for seepage. Biospheric removals are treated as temporary or medium-durability storage, where credits expire at the end of the monitoring period unless monitoring is extended, effectively treating stored carbon as released thereafter. **Biochar only requires limited post-application monitoring, which may not fully address potential reversal risks**.

CRCF faces challenges regarding overlaps with other policy instruments. **Duplicated liabilities** could emerge if CRCF credits are accepted under the EU ETS where a **reversal could lead to both allowance surrender under the ETS and reversal compensation under the CRCF**. CRCF provisions **are not aligned with ICVCM, CORSIA and the PACM**, particularly regarding monitoring periods and reversal compensation approaches. If the EU wants to generate credits aligned with these programmes under CRCF, a strengthening of the CRCF rules would be necessary.

7. Recommendations

7.1. Strive for agreement on minimum reversal risk requirements across all international carbon market regulators and programmes

The rapidly evolving and **highly diverse landscape** of how **public and private international carbon market programme administrators assess and mitigate reversal risks, and compensate for reversals that have actually occurred** is likely to lead to a **loss of trust of key stakeholders** that reversal risks are dealt with properly. Therefore, **PACM regulators, intergovernmental organisations** (ICAO, in the context of CORSIA), **governments** regulating their Article 6.2 and other carbon market approaches (e.g. the EU regarding CRCF) as well as **private programme administrators** (Verra, Gold Standard, Isometric etc.) and **initiatives to enhance the environmental integrity of voluntary carbon markets** (ICVCM, VCMI) should agree on minimum requirements to deal with reversal risks, covering

- **Quantitative assessment of reversal risks**, differentiated by **activity type** (e.g. forestry, direct air capture with geological storage, etc). Where empirical evidence is unavailable, default parameters should be set conservatively rather than at central estimates, and the conservatism should be documented and revisited as evidence accumulates. Risk reductions claimed by **jurisdictional approaches** (in comparison to single activities) need to be empirically validated. Quantitative values of risk should **reward pre-emptive reversal risk mitigation** like thorough site selection and geological modelling for geological storage; species, age-class and spatial diversification for AFOLU; cover-cropping and tillage practices for soil carbon.
- **Liability** for reversals. Liability allocation along the value chain (project developer, host government, buyer, programme administrator) needs to be specified for the full duration of the permanence period. Differences between overlapping frameworks (e.g. EU CRCF and EU ETS; domestic schemes and Article 6 cooperative approaches) should be eliminated to avoid duplicated or unclear liability.
- **Duration of monitoring periods** for reversals
- **Design of buffer pools**, including the coverage of different activity types, the **contribution rates**, the **change** of contribution rates due to trends in actual reversals or projected changes in reversal risks and the access to the buffer pool once a reversal has been detected. Contribution rates need to reflect **the actual quantitative risk** and its **projected development over time**. Ad hoc, fixed and undifferentiated contribution rates as currently applied by the majority of programmes should no longer be applied. It needs to be clearly specified what happens if the buffer pool is exhausted.

- Requirements for **insurance contracts** that could **replace buffer pool contributions**. Implement a clear policy **regarding the minimum duration** of insurance contracts, considering the unwillingness of insurers to offer long-term contracts. Governments should use convening capacity in international financial hubs to **stimulate development of long-duration permanence insurance products**; through clarifying which reversal risks are insurable and developing multi-decadal pricing approaches.
- Reconsideration of **the role of temporary crediting and tonne-year accounting as a complement to (not a substitute for) permanent compensation**, particularly for activity types where long-term permanence is genuinely uncertain. The EU CRCF's use of temporary units for carbon farming is one precedent worth evaluating empirically.

These minimum requirements should be specified in a way that they **enable trust of key stakeholders**, including **civil society organisations and media**, in the permanence of carbon stores protected through emission reductions or accumulated through removals under international carbon markets. The development of the requirements could be orchestrated through international initiatives and build on work undertaken by initiatives (like the coalition to Grow Carbon Markets (CGCM) aiming to achieve integrity in international carbon markets to date.

7.2. Work with PACM regulators to develop and implement "best of class" approaches

PACM regulators should go beyond the minimum requirements and develop "best of the class" approaches. Governments and other stakeholders should make submissions to the PACM pushing such approaches, which should include:

Quantitative assessment of reversal risks

Differentiation of assessments by reservoir and pools that could be materially affected by reversals, reflecting the activity type specific hazard profiles, taking into account multiple pools covered by a single activity type.

Application of probabilistic approaches requiring significant data input **for pools with high reversal risks**, while for pools with low reversal risks simplified approaches could be used. Review the classification every three years.

Considering climate-change-triggered increase of reversal risk for biospheric activities, extrapolated into the future.

Aggregation of individual reversal risk factors through clear, transparent formulas that reflect potential interactions between hazards.

Use of transparent, standardised, publicly available scientific datasets and/or models to determine the pool-specific risk factors. If data are incomplete, application of conservative assumptions to identify default parameters.

Reduction of risk factors due to risk mitigation measures only if these measures satisfy evidence-based design criteria and their implementation and performance are independently verified over time.

Declaration of negligible risk only if robust evidence has been provided that stored GHGs are stable or in a steady state over at least 100 years.

Governments should fund and maintain public hazard datasets for implementation of a robust quantitative risk assessment.

Liability for reversals

Allocation of liability to the activity developer(s) for the entire reversal risk monitoring period.

Duration of the monitoring period for reversals

Requirement for monitoring until a negligible level of reversal risk has been reached, with the monitoring period ending 100 years after start of the activity if a negligible level has not been attained.

Specification of monitoring requirements proportionate to reservoir- and activity-specific risk profiles. As enabling activity for implementation of monitoring, governments should fund and maintain monitoring tools for above-ground biomass and soil organic carbon monitoring.

Design of buffer pools

Administration of a single, global buffer pool covering all activity types with a material reversal risk.

Specification of requirements for the vintages of A6.4ERs **and activity types** they have been generated from in the pool that are cancelled once a reversal has been monitored and communicated to the buffer pool administrator. **Activity types and vintage should be as similar as possible to those of the A6.4ERs invalidated by the reversal**.

Conservative specification, and sufficient activity type and sub-type-differentiation of buffer pool contribution rates, taking into account the current projections of reversal risks over 100 years. **A default-zero buffer pool contribution (mainly for geosphere reservoirs) is not consistent with good practice**.

Commissioning of empirical stress-testing of buffer pools at least every three years applying observed and projected loss rates (including climate-change-triggered increase of reversal risk) to current pool balances to determine whether contributions remain adequate, with publication of the results.

Requirements for insurance contracts

Permission for activity developers to not having to contribute to the buffer pool if they can prove an insurance contract that provides full replacement of issued A6.4ERs for which a reversal has been identified in line with the procedures for replacement from the buffer pool. Such contracts should include (i) **a carve-out excluding avoidable reversals** (negligence, non-compliance, fraud) from coverage; (ii) **deductibles and coverage limits** calibrated to the activity's risk profile, not to the policyholder's commercial preferences; (iii) **pre-agreed, objective trigger definitions** for claims; and (iv) **annual confirmation that the policy remains in force**, with automatic reversion to buffer-pool-only coverage if the policy lapses or is materially amended.

Governments should support a structured evaluation of the Verra durability pilot (and other emerging durability-insurance products) after three years of operation regarding their effectiveness.

Proactive engagement of non-government stakeholders to minimise reversals

Non-government stakeholders can contribute meaningfully to minimise reversals through:

Activity developers planning for the full permanence horizon, including management transitions, beneficiary changes and policy shifts that may occur over decades. **Maintain transparent reversal-monitoring and reporting** throughout the permanence period and **disclose buffer pool contributions and insurance coverage** to buyers and registries.

Credit buyers using risk-assessment and mitigation quality beyond price as a procurement criterion. Credits with stronger and transparent underlying risk mitigation practices and issued by a programme with science-based buffer pool design should be preferred. If engaging under the VCM or Article 6.2, credit buyers should require transparency on how reversals will be compensated, including the seniority of buffer pool claims, any insurance coverage in place, and replacement-credit obligations. They should **build replacement-credit clauses into purchase agreements** where appropriate.

Insurance companies could engage in development of longer-term insurance contracts, clearly specifying the conditions and impacts on premium levels, and potential government support. Their work also should address affordability and access barriers for small-scale and community-led projects, including through pooled or aggregated insurance structures and partnerships with development finance institutions.

Design of a domestic removals framework

When incentivising domestic removals, governments should consider combining buffer pools, insurance and liability rules as follows:

Application of permanence periods differentiated by reservoir, anchored in a 100-year minimum storage period for durable removals.

If biospheric removals are added to a removal-only regime at a later stage, **treat biospheric and geospheric reservoirs separately** and align buffer pool requirements with the lower-permanence reservoir's risk profile.

Reduction of buffer pool contributions to zero only where activity-specific evidence shows the reversal risk is 'negligible' as defined in international guidance.

Further research needs

Important research gaps limit the evidence base for reversal risk management. Governments thus should support research:

- to **empirically validate the assumption that jurisdictional approaches carry systematically lower reversal risk than project-level activities**;
- on **long-term biochar stability and soil organic carbon dynamics under changing climate conditions**;
- on **treatment of compounding climate hazards** (e.g. concurrent drought–fire–pest events) over multi-decadal permanence horizons;.
- On the **effectiveness of specific reversal risk mitigation measures**, such as fuel-load management in AFOLU or well integrity protocols in geological storage, in reducing observed reversal frequency;
- on **loss-performance data** for permanence-related insurance claims;
  on **how compensation responsibilities should be allocated under Article 6 in cases of host-country triggered reversals**, such as government changes in forest protection policies (see e.g. Brazilian rise in deforestation triggered by Bolsonaro’s policies).
  on **how reversals that occur beyond formal permanence periods but within climate-relevant timescales should be compensated.**

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ANNEX 1

VII. Box A1: Jurisdictional versus Project REDD+ reversal considerations

The distinction between project-based and jurisdictional REDD+ reflects a fundamental shift in carbon market thinking over the past decade. Early REDD+ projects (2007–2015) focused on community/Natura-protected areas scale, typically implemented by private entities or NGOs. In the past with little coordination/oversight from the government. This has improved due to, e.g., enacted laws, a bigger emphasis on the baseline setting, and benefit sharing aspects. Jurisdictional approaches, emerged from the Warsaw Framework for REDD+ and cemented in the Article 5 of the 2015 Paris Agreement framework, operate at national or subnational administrative scale with governments as the primary legal entities and formal accountable actors for programme implementation.

The theory underlying **differential treatment of non-permanence risk between scales posits that geographic and institutional diversification provides structural advantages**. A project-level reversal, whether from fire, illegal logging, policy change, or economic shifts, can eliminate all credited forest conservation within a discrete area, potentially wiping out the entire project's conservation gains. By contrast, jurisdictional programs operate across **large territories where risks are spatially distributed**. A single fire, flood, or localized policy shock in one district should be unlikely to significantly reverse forest conservation across an entire nation or subnational jurisdiction. **This geographic diversification means that reversals at jurisdictional scale should require widespread, coordinated loss of forest cover,** a much rarer and more identifiable event than project-level reversals. Additionally, national forest monitoring systems and multiple enforcement agencies should create institutional redundancy, that isolated projects cannot achieve, theoretically reducing the risk that a single governance failure triggers system-wide collapse.

However, **empirical evidence increasingly challenges this theoretical advantage**. Large-scale jurisdictional reversals have occurred: **Brazil achieved substantial jurisdictional-level emission reductions in the early 2010s, only to experience dramatic reversals due to political policy shifts that reversed forest protection nationwide**. Similarly, **the Zambezia Integrated Landscape Management Program (ZILMP) in Mozambique achieved verified emission reductions under the Forest Carbon Partnership Facility, but all gains were subsequently reversed due to widespread slash-and-burn agriculture expansion**. These cases demonstrate that jurisdictional-scale reversals, while potentially less frequent than project-level ones, can be systemic and comprehensive, sometimes exceeding the magnitude of project-level reversals.

Likewise, it is important to note that **the prominence of government as the primary actor does not automatically reduce reversal risk**. In developing countries where governance capacity is limited, institutional corruption is endemic, or political systems are unstable, centralized government control of forest conservation programs can paradoxically increase non-permanence risk. **Political shifts, changes in administrative priorities, or corruption-driven diversion of forest protection resources can trigger rapid, jurisdiction-wide reversals that exceed the magnitude of project-level failures**. The Zambezia case and recent Brazilian experience demonstrate that large-scale reversals can occur swiftly when government commitment shifts or enforcement capacity deteriorates, regardless of initial baseline robustness or monitoring infrastructure. **The theory that government involvement reduces reversal risk therefore requires substantial empirical validation**, particularly in contexts where institutional governance and anti-corruption safeguards are weak.

IX. Box A2: Is there a value in temporary storage?

There is a vivid academic debate whether **storage with low durability has a value in addressing climate change or not**. There are **two conceptual arguments why such a value exists**: **reducing the rate of climate change (e.g. the temperature increase per decade) reduces climate change damages** and **preventing that temperature exceeds tipping points that lead to irreversible and large climate change impacts**.

The first argument is intuitively appealing. A rapid temperature increase, and the impacts linked to it leave less time to adapt and thus generate higher adaptation costs. A slow rate of change allows autonomous adaptation, whereas a high rate of change requires planning and generates more "surprises" regarding impacts. There is evidence that the rate of temperature increase has accelerated significantly in the last decade (Foster and Rahmstorf, 2026), and that the frequency and severity of climate change-related events causing damages has increased as well (World Meteorological Organization (WMO), 2026). However, this topic has been researched to a very limited extent. (Pinsky *et al.*, 2025) and (Visser, 2008) find that impacts of climate change on biodiversity are positively related to the rate of change. **More research is needed to calculate the benefits of reducing the rate of temperature increase.**

There is a scientific consensus that several temperature-increase-related "tipping points" exist where specific climate change impacts become irreversible. (Lenton *et al.*, 2025) summarise current knowledge on tipping points and find that we may already have exceeded the temperature levels that trigger general coral reef dieback, whereas we are getting close to the temperature triggering collapse of land permafrost, the Greenland ice sheet, the West Antarctic ice sheet and the Southern Ocean sub-polar gyre. In that context, high volumes of **temporary storage could "buy time" to keep us from crossing the tipping points**. During this time, permanent storage technologies could be developed to the extent that they would be available at a scale large enough to ensure the tipping points are never crossed. Countries could point to temporary storage in their NDC, buying time until future, permanent CDR becomes available at attractive conditions (Beyer, 2025). But if the time is not used wisely and we get into a situation where massive reversals happen without alternative mitigation being available, then temperature increase would accelerate, and we would exceed multiple tipping points very quickly. Therefore, research is needed to assess the conditions under which temporary storage could successfully "buy time", including the policy instruments required.

An approach that **attributes value to the temporary storage for each year of effective storage** is the so-called **"tonne year" approach**, explained in Box 3 below. Many researchers continue to

emphasise that temporary storage does not contribute to limiting cumulative emissions, which is necessary to meet the Paris Agreement’s temperature goal and thus the **value of temporary storage cannot be equivalent to an emissions reduction** (the effect of which is inherently permanent; Brander and Broekhoff, 2023; Cullenward, 2023; Watson and Bui, 2026).

XI. Box A3: Alternative approaches to addressing non-permanence

Tonne-year accounting

Tonne-year accounting is a crediting approach in which mitigation outcomes are recognised incrementally over time . Under this method, credits are issued in proportion to the length of time carbon is kept in a store. After a so-called “equivalence period” the full volume of credits is reached and any reversal happening afterwards is ignored. As a result, every year, only the fraction of the achieved mitigation is credited which is covered by the share of the year in the “equivalence period”, i.e. if the equivalence period is 100 years each year 1% of credit per tonne of CO_2 reduced or removed will be granted. Rather than issuing full credits upfront, credits are thus granted progressively for each year that carbon remains stored, with the credited fraction increasing over the defined storage period. If a reversal occurs before the “equivalence period” is over, further credit issuance stops, and the credits already issued are considered to represent permanent mitigation. The key aspect regarding environmental integrity is the duration of the “equivalence period” (FAO, 2024). (Moura Costa and Wilson, 2000) had proposed 46 years, while (Herzog, Caldeira and Reilly, 2003) make it dependent on the future availability of a “backstop technology” that allows unlimited permanent removals. If one would choose 1000 or even 10,000 years, then the annual credit volume would be immaterial.

The tonne-year accounting method was considered under the PACM but following extensive debate prompted by numerous stakeholder submissions, the SBM decided at its fifth session in 2023 not to adopt it, due to negative ecological implications, unsuitability for international applications and lacking effectiveness in addressing reversals in line with the PACM mandate (UNFCCC, 2023). The removals community focusing on geosphere pools felt that tonne-year accounting would unduly favour biospheric pools with high reversal risks. Environmental NGOs criticised the short equivalence periods under consideration (50 to 100 years) as well as the inbuilt incentive to reverse the store after a short duration. To counteract this incentive, NGOs proposed minimum storage periods of 5-30 years before tonne-year accounting could be applied.

Temporary crediting

Temporary crediting is an approach under which carbon credits are issued for mitigation outcomes with reversal risks that are explicitly recognised as time-limited rather than permanent. These credits remain valid only for a defined duration and expire after a set period or once a reversal is detected during that period. Once a credit expires, it must be replaced to maintain the integrity of the original mitigation claim. This replacement can either take place by credits representing newly issued temporary credits or permanent ones. The temporary credit approach does not face any reversal risks after its expiration. By assigning value to temporary carbon storage, this approach can incentivise near-term mitigation while providing additional time for more permanent mitigation outcomes to emerge. However, the obligation to replace expired credits creates ongoing responsibility and uncertain-ty for credit holders, which has reduced its attractiveness in carbon markets and limited its up-take beyond its initial implementation. The approach was for example applied under the Clean Development Mechanism (CDM), particularly for afforestation and reforestation activities, **but it proved unattractive to buyers** (Gillenwater and Seres, 2011). The share of afforestation and reforestation credits in total CDM credits reached just 1%. Temporary crediting is currently also applied for some credit types under the European Union's (EU) Carbon Removal Certification Framework (CRCF).

Building on the CDM experience, the SBM did discuss temporary crediting (see (UNFCCC, 2023), p. 41). The argument that such credits are not attractive to buyers seems to have led to an exclusion of this approach to deal with reversal risks.

XII. Box A4: The "like-for-like" principle

The like-for-like principle holds that carbon credits should match the emissions they counterbalance not only in quantity, but also in durability (Allen *et al.*, 2022). In other words, equivalence must extend beyond tonnes of CO_2 to include the length of time the climate benefit persists. Emissions from fossil fuels – which can remain in the atmosphere for centuries to millennia – should therefore be counterbalanced either through permanent emissions reductions or through removals that ensure storage over a comparable time horizon (Streck *et al.*, 2025b). By contrast, shorter-lived GHGs may be aligned with mitigation outcomes that involve more limited durability, including certain nature-based approaches like forest conservation or soil carbon sequestration.

There is no universally agreed definition of the like-for-like principle. Some analyses, including work by the Oeko-Institut, argue that flexibility in carbon markets should not permit the substitution of permanent fossil CO_2 emissions with mitigation outcomes from land-use sectors that carry material reversal risks (Graichen *et al.*, 2025). From this perspective, credits exposed to non-permanence risk cannot be considered equivalent to mitigation outcomes without such risk. They also argue that allowing them to offset permanent emissions could undermine environmental integrity, particularly in light of growing evidence that some ecosystems are shifting from net sinks to net sources (Carle *et al.*, 2025; Li *et al.*, 2025; Rodríguez-Veiga *et al.*, 2025). It may also create distributional concerns, as host countries could ultimately bear liability for future reversals.

In policy debates, the like-for-like principle is sometimes interpreted or presented as implying that fossil emissions can only be offset through permanent, typically technical, carbon removals (e.g., direct air carbon capture with storage (DACCS)). However, there is no scientific basis for excluding permanent GHG emission reductions from serving this function. At any sub-global level, both permanent GHG emission reductions and permanent removals have the same effect on global net emissions (Möllersten *et al.*, 2024).

A strict like-for-like interpretation would favour buffers differentiated by activity types, so that non-permanent, high-risk activities do not effectively underwrite more durable mitigation outcomes. This, however, would make individual buffers more vulnerable to early depletion and increase the risk of undercapitalisation in high-risk segments. There is therefore a basic trade-off: aggregate, cross pool buffers maximise diversification and stability, while stricter like-for-like application pushes towards more segregated, activity specific buffers with higher volatility. In addition, higher buffer requirements associated with high-risk activities mean that theoretically a credit from such activities could, if no reversal occurs, yield more than one tonne of CO_2 reduced or removed.

XIII. Table A1. Private carbon crediting programmes' permanence requirements

	ACR* (ACR, 2023, 2024b, 2024a)	**ART TREES (3.0)* (ART, 2025b)**	**CAR* (CAR, 2019, 2022a, 2022b, 2023, 2024b)**	**Gold Standard* (Gold Standard, 2025c, 2025e, 2025c, 2025a, 2025d)**	**Isometric* (Isometric, 2025a, 2025e, 2026)**	**puro.earth (puro.earth, 2022a, 2024, 2026)**	**Verra VCS* (Verra, 2025c, 2025b, 2025a, 2025e, 2025d)**
Reversal risk assessment (see section 3.2 for further details)							
Assessment requirements	**AFOLU**: Dedicated tool in place providing guidance **GCS**: Specific requirements	Risk assessment results determine the buffer pool contribution %	**AFOLU:** Project operators required to identify and quantify risks based on activity-specific circumstances (protocol-specific requirements)	**AFOLU:** Dedicated guidelines in place **GCS:** Specific requirements in place	**Programme-level:** Risk reversal questionnaire provided. Relevant risk factors also specified at protocol level and included in monitoring plan	**GCS:** Methodology-specific reversal risk estimation	**AFOLU:** Dedicated tool in place **GCS**: Dedicated GCS tool in place only applicable to geological storage of CO_2 in reservoirs
Risk mitigation measures (see section 3.2 for further details)							
Mitigation requirements	**AFOLU**: Tool specifies mitigation principles for some risk types **GCS**: Storage-level and methodology specific requirements	Three different mitigation factors can be applied	**AFOLU:** Specified risk mitigation measures can lower the overall risk rating	**AFOLU**: Depending on score, risk mitigation measures must be developed and detailed in a plan **GCS:** Requirements are given in two dedicated GCS tools	**AFOLU**: Protocol-specific requirements **GCS**: Protocol-specific requirements	**GCS:** Methodology specific requirements. Pre-emptive mitigation is required where material risks are identified	**AFOLU**: Exemplary mitigation measures provided in tool **GCS:** Tool outlines well design requirements. Site characterisation is requested with high-risk sites excluded
Determination of scale and applicability of compensation mechanism requirements							

	ACR* (ACR, 2023, 2024b, 2024a)	**ART TREES (3.0)* (ART, 2025b)**	**CAR* (CAR, 2019, 2022a, 2022b, 2023, 2024b)**	**Gold Standard* (Gold Standard, 2025c, 2025e, 2025c, 2025a, 2025d)**	**Isometric* (Isometric, 2025a, 2025e, 2026)**	**puro.earth (puro.earth, 2022a, 2024, 2026)**	**Verra VCS* (Verra, 2025c, 2025b, 2025a, 2025e, 2025d)**
Buffer pool design	**AFOLU**: Pooled buffer across terrestrial sequestration projects **GCS:** Fixed % of credits in Reserve Account which exists until project term end and Risk Mitigation Covenant must be in place post-injection	Combined buffer pool that contains contribution from all participants	**AFOLU:** Buffer pool covers activity types with identified risk of unavoidable reversal with holding accounts for the different activity types	**AFOLU:** Gold Standard Compliance Buffer across LUF projects **GCS:** Standard Compliance Buffer for GCS projects. If reversal occurs after crediting period, credits held in buffer pool are cancelled to compensate	**Biosphere:** Protocol-specific buffer pools **GCS:** Protocol-specific buffer pools in accounts specific to each PP	**GCS:** No buffer pool in place	**AFOLU**: AFOLU pooled buffer account available **GCS:** GCS pooled buffer account available
Buffer pool/reserve contribution requirements incl. composition of contribution	**AFOLU:** Dependent on risk assessment. Credits may come from project itself or from any ACR-issued credits held in the PP's account (with vintages no older than five years) **GCS**: 10% of credits annually in Reserve Account,	Based on reversal risk assessment: Contribution range of 5-30%	**AFOLU**: Protocol-specific; sometimes dependent on risk assessment result or use of default parameters. Credits of the same activity type must be contributed	**AFOLU:** 20% fixed contribution. Upon written notice at/prior to issuance, credits from other GS-certified projects instead of project credits **GCS**: 2.5% fixed contribution. PPs have 3 options: Use GSVERs	**GCS:** Programme level categorised risk level with fixed % for buffer pool contribution. CO_2 storage in reservoirs is classified as very low reversal risk, 2% buffer pool contribution applied as a precaution	**GCS:** No buffer pool contribution. If the fraction of stored CO2 is <99% over the first 100 years (based on risk assessment) and cannot be mitigated the PP needs to apply a commensurate deduction to the	**AFOLU:** Dependent on risk assessment. Credits from same activity to be contributed **GCS**: Dependent on result of risk assessment. Credits from same activity to be contributed. Minimum 1% to maximum acceptable rating

	ACR* (ACR, 2023, 2024b, 2024a)	ART TREES (3.0)* (ART, 2025b)	CAR* (CAR, 2019, 2022a, 2022b, 2023, 2024b)	Gold Standard* (Gold Standard, 2025c, 2025e, 2025c, 2025a, 2025d)	Isometric* (Isometric, 2025a, 2025e, 2026)	puro.earth (puro.earth, 2022a, 2024, 2026)	Verra VCS* (Verra, 2025c, 2025b, 2025a, 2025e, 2025d)
	either from the project or any other project type or vintage			available in registry account; buy GSVERs from same project type; use GSVERs from buffer pool above min. 2.5%		reported output volume	of 7% of annual CO_2 injection goes to buffer pool. Higher than 7% are rejected
Reversal coverage	**AFOLU**: Pool compensates for unavoidable reversals **GCS**: Pool compensates for unavoidable reversals. Specific coverage of avoidable ones	Covering all reversals (no distinction made)	**AFOLU:** Buffer pool covers unavoidable reversals	**AFOLU:** Covers unavoidable reversals **GCS**: Covers unavoidable reversals	**All activities with reversal risks:** Can use buffer account credits for avoidable reversals but PPs must reimburse buffer pool account accordingly	**GCS:** No buffer pool contribution, but accounting for avoidable and unavoidable reversals	**AFOLU & GCS:** Covering unavoidable and avoidable reversals. In case of avoidable reversals, buffer must be replenished with equivalent amount
Alternative mechanisms & approaches	**Programme-level:** Permits use of ACR-approved insurance product instead of buffer pool/reserve contributions	-	**AFOLU:** Other instruments may be available in future (e.g., insurance). CAR to review and approve these	**GCS (engineered removals):** Allows for the use of insurance products and guarantees approved by Gold Standard	**Programme-level:** Permits use of third-party insurance; does not alter buffer pool size	**GCS:** Reversal quantity subtracted from output volume or credits withdrawn and invalidated from CO_2 removal supplier account (ideally same type)	**Programme-level**: For now, fully reliant on buffer pool. Currently piloting insurance and fund-based approach
Reversal risk monitoring, reporting and compensation period							

	ACR* (ACR, 2023, 2024b, 2024a)	ART TREES (3.0)* (ART, 2025b)	CAR* (CAR, 2019, 2022a, 2022b, 2023, 2024b)	Gold Standard* (Gold Standard, 2025c, 2025e, 2025c, 2025a, 2025d)	Isometric* (Isometric, 2025a, 2025e, 2026)	puro.earth (puro.earth, 2022a, 2024, 2026)	Verra VCS* (Verra, 2025c, 2025b, 2025a, 2025e, 2025d)
Frequency of monitoring for reversals (during crediting period and PCM period)	**AFOLU:** Ongoing monitoring requirements in methodologies (at verification) **GCS**: Detailed post-injection monitoring to demonstrate permanent sequestration of CO_2 captured and stored. Ongoing reversal monitoring requirements specified in meth.	Monitoring reports are due in calendar year 1, 3 and 5 of crediting period. No monitoring report in PCM period. Each monitoring to identify annual buffer contribution and all justifications	**AFOLU:** Protocol-specific rules *E.g., U.S. Forest Protocol: Annual reporting*	**AFOLU**: Annual summary of monitoring information, monitoring report at verification **GCS**: Monitoring during injection, and post injection. No single fixed frequency	**Protocol-specific** rules. Risk assessment to design monitoring plan requirements incl. extent, frequency and duration of monitoring	**GCS**: Verification and monitoring safeguards: Annual third-party audits of reported CO_2 removal outputs ensure that issued credits correspond to verified removals and allow corrections if discrepancies are found	**AFOLU:** Monitoring report to be submitted at verification. No gaps between monitoring periods allowed **GCS:** Min. once per monitoring period (not specified). Monitoring must continue for at least 10 years post-injection or longer if required and delivered annually
Length of monitoring period incl. PCM specifications	**AFOLU:** At least 40 years from start of the crediting period (minimum project term) **GCS:** Minimum post-injection period for GCS projects is 5 years, if no leakage cannot be assured the	Monitoring is not required after a participant exists the programme For CORSIA: Monitoring and reporting required for a min. of 5-year crediting periods	**AFOLU**: Depending on protocol-specific requirements *E.g., U.S. Forest Protocol: 100 years following issuance of CAR credits*	**AFOLU:** 30-50 years from start of crediting period. No PCM requirements **GCS:** Max. crediting period is 45 years. Monitoring in post injection until closure criteria are met (ISO 27914) and regulators	**AFOLU:** Methodology-specific requirements, at least 40 years from end of crediting period **GCS:** Methodology-specific requirements, project duration complemented by 50 years of post-injection	**GCS**: Methodology-specific length requirements. Post-injection monitoring is required until plume stability is demonstrated, typically for 20–50 years under applicable regulations	**AFOLU**: At least 40 years from start of crediting period. Long-term monitoring system may be leveraged (still under development) **GCS:** Post-injection monitoring until site closure, with a minimum

	ACR* (ACR, 2023, 2024b, 2024a)	ART TREES (3.0)* (ART, 2025b)	CAR* (CAR, 2019, 2022a, 2022b, 2023, 2024b)	Gold Standard* (Gold Standard, 2025c, 2025e, 2025c, 2025a, 2025d)	Isometric* (Isometric, 2025a, 2025e, 2026)	puro.earth (puro.earth, 2022a, 2024, 2026)	Verra VCS* (Verra, 2025c, 2025b, 2025a, 2025e, 2025d)
	monitoring will be extended in 2-year increments			confirm long-term containment is ensured	monitoring, unless otherwise specified		post-injection care period of seven years
Cessation of monitoring	**AFOLU:** Activities deemed to have ceased (early project termination) **GCS**: -	-	**AFOLU:** Deemed avoidable reversal, full remediation required for respective monitoring period	**Programme-level:** De-certification/-registration is considered full reversal of all GSVERs issued to project	**Programme-level:** Deemed avoidable reversal	**GCS:** Production facility deregistered	**AFOLU:** Deemed avoidable reversal **GCS**: Not indicated in documentation
Reversal notification, report and consequences							
Reversal notification	**Programme-level:** Within 10 business days after becoming aware	-	**AFOLU:** Protocol-specific requirements	**Programme-level**: Within 30 days of discovery of loss event	**Programme-level:** Within 1-3 days	**GCS**: Within 5 days of detection	**Programme-level:** Within 30 days
Consequences of reversal notification	**Programme-level:** Within 6 months, full monitoring report must be submitted	Annual buffer pool contribution increases by 5% for a 5-year period during which no mitigating factors to be claimed	**AFOLU:** Submission of detailed report within one year	**Programme-level:** Submission of detailed report within three months of initial notification	**Programme-level:** No submission deadline specified for full report	**GCS**: No additional report. Reversal must be calculated and subtracted from total removals, which is audited that year	**Programme-level:** Submission of detailed report within two years
Compensation for reversals							
Programme-	If compensation is not provided by PPs, ACR may	If reversals exceed number of credits contributed to	If avoidable reversals are not compensated by	If the developer fails to compensate the loss,	If buffer pool is depleted, additional credits	If due to the failure of the CO_2 Removal	If loss event report is not submitted in time,

	ACR* (ACR, 2023, 2024b, 2024a)	**ART TREES (3.0)* (ART, 2025b)**	**CAR* (CAR, 2019, 2022a, 2022b, 2023, 2024b)**	**Gold Standard* (Gold Standard, 2025c, 2025e, 2025c, 2025a, 2025d)**	**Isometric* (Isometric, 2025a, 2025e, 2026)**	**puro.earth (puro.earth, 2022a, 2024, 2026)**	**Verra VCS* (Verra, 2025c, 2025b, 2025a, 2025e, 2025d)**
level backstop	cancel credits from the buffer pool	buffer pool, resulting deficit to be covered by participant. If participant does not have sufficient credits in account, future credits issued to be set aside or equivalent TREES credits to be purchased. After exit of a participant, ART cancels any of its unused buffer pool contribution	PPs, CAR will retire buffer pool credits. If buffer pool does not contain sufficient supply of activity type-specific credits, CAR to retire credits of another type. Further safeguards specified in case aggregate buffer pool is still not sufficient to address unavoidable reversals	Gold Standard can use credits available in the project's account to cover the reversal or introduce further options for the PP to reconciliate lost GSVERs in the future	from future removals by PP are directed to replenish the buffer until the reversal is fully compensated; the programme also commits to ensuring full compensation for reversals affecting issued credits	Supplier to perform these obligations there is a reversal event, CO_2 Removal Supplier is liable for it and is obliged to provide compensation	further VCUs not to be issued and pooled buffer account credits put on hold until report is submitted **AFOLU** pooled buffer account subject to periodic reconciliation **GCS** projects become ineligible if a reversal >10% of the injected volume of the project

XIV. Table A2. Comparative overview of individual reversal risk factors assessed across major carbon crediting programmes for biospheric carbon pools

	ACR (ACR, 2024b)	CAR (CAR, 2019, 2023, 2024a)	GS4GG (Gold Standard, 2025c)	TREES (draft 3.0)	VCS (Verra, 2025c)
Risk scope & taxonomy	Differentiating two broad categories: Management and governance risks, natural disaster risks with further sub-categories	Differentiating 4 broad risk categories across protocols: Financial, management, social & political, natural disturbance risks	Differentiation of six risks: Natural disturbance, political, project management, financial, market, other with further sub-categories	Following Cancún Safeguards VI or F: Actions to address the risks of reversals. The risk of reversals is integrated in the design, prioritization, implementation, and periodic assessments of REDD+ polices and measures.	Differentiating three broad categories: Internal, external and natural risks. These are further classified into sub-categories
Differentiation by activity type and carbon pools	Applicable to AFOLU projects with the potential for GHG emission reductions and removals to be reversed. Tool differentiates between risk categories applicable to all AFOLU projects and those applicable only to specific activity types: Illegal logging, biotic and hydrological risks to be assessed for forest projects; hydrological risks to be assessed for wetland, grassland projects	Differentiation by activity type due to protocol-specific approaches. Carbon pools are often referred to, but risk assessment does not consider carbon pools	Applicable to all agriculture and forestry activities. No further taxonomy specified, but risk factors include vulnerability of carbon pools as part of scoring.	Focus on REDD+ but no actual differentiation according to activity type and/or carbon pools	Applicable to AFOLU projects (GHG removals or avoided emissions through carbon sinks). Tool assesses risk factors that vary by activity type characteristics (e.g., forestry vs agricultural land management). No carbon pool differentiation
Risk typology	Predefined risk sub-categories → Natural disaster risks **sub-categories**: wildfire, biotic, hydrologic, other natural disaster	Predefined risk types, usually the same across different protocols → Natural disturbance risk types: wildfire, disease/insects, other episodic catastrophic events (e.g., wind, flooding event)	Predefined risk sub-categories → Natural disturbance **sub-categories**: fire damage, wind damage, temperature extremes, water extremes, climate variability, geological extreme events, animals, pest and disease outbreaks	TREES depends on the Cancún Safeguards VI or F for REDD+, where countries need to define and have verified their risk assessment and typology.	Predefined risk sub-categories → Natural risks **sub-categories**: historical natural risks including at least fire, pest and disease, extreme weather events (e.g., droughts, hurricanes), geological risks (e.g., volcanoes, earthquakes); projected future climate

	ACR (ACR, 2024b)	CAR (CAR, 2019, 2023, 2024a)	GS4GG (Gold Standard, 2025c)	TREES (draft 3.0)	VCS (Verra, 2025c)
					change & sea-level rise impact
Assessment of reversal risk likelihood, magnitude (severity) and spatial scale	Spatial hazard layers at sub-category level (e.g., Wildfire Hazard Potential), scoring reflects exposure but does not explicitly model frequency × magnitude *E.g., wildfire risk of US-based forest projects is assessed based on national digital spatial data. For forest projects outside the US, an approach can be proposed subject to verification and ACR approval.* Sometimes default values are provided for specific activity types and sub-category calculations that can be applied instead of propping a project-specific approach.	Protocol-specific but no assessment based on likelihood, magnitude or spatial scale *E.g., U.S. Forest Protocol requires use of provided Assessment Area Data File to identify specific natural disturbance risk rating. File puts an emphasis on species composition. Default values are provided for certain risk types.* *E.g., U.S. Urban Forest Management applies a 6% default contribution of issued project credits to buffer pool without any risk rating specifications* *E.g., Panama Forest Protocol: Application of differentiated default values based on land tenure categories*	Per subcategory: Overall risk is determined based on **three factors**: Project exposure (probability), vulnerability of carbon pools (inherent capacity), spatial scale (extent). *Exposure: High ≥ once in 10 years; medium = once in 20 years; low < once every 20 years* *Vulnerability: High = fully destroy GHG benefit; medium = harm to benefit but recovery in 5 years; low = harm to benefits but recovery in < 5 y* *Spatial scale: High ≥ 50% of area; medium = 10-50%; low = 5-10%*	TREES depends on the Cancún Safeguards VI or F for REDD+, where countries need to define and have verified their risk assessment including the likelihood, magnitude and spatial scale.	Historical natural risk is determined based on **likelihood** (event occurrence over 100-year period) and **significance** (% of average carbon stocks in **project area** lost in single event) *Historical likelihood (high to low): >1 per 10 years; 1 per 10–<25 years; 1 per 25–<50 years; 1 per 50–<100 years; ≤1 per 100 year* *Significance: Catastrophic (≥ 70% loss of carbon stocks); devastating (50-<70%); major (25-<50%); minor (5-<25%); insignificant (<5% loss or fully recovery within 10 y)*
Transparency and documentation requirements	Reversal risk analysis to be reported as appendix to project plan at validation, later added to monitoring report. Use of government-backed digital spatial datasets to determine wildfire, biotic and hydrological risks for US-based forest projects	Protocol-specific requirements *E.g., U.S. Forest Protocol: For mitigation measures, documentation requirements are specified*	Justification of rating of risk factors must be based on credible sources (e.g., peer-reviewed reports and studies, maps, credible websites etc.) Anecdotal evidence not accepted as primary evidence	Justification needs to be provided together with monitoring report and referencing Cancún Safeguards VI or F for REDD+	PPs must clearly document and substantiate selected risk scores. Historical event occurrence must be determined based on historical records, probabilities, remote sensing data, peer-reviewed literature, survey data, documented local knowledge

	ACR (ACR, 2024b)	**CAR (CAR, 2019, 2023, 2024a)**	**GS4GG (Gold Standard, 2025c)**	**TREES (draft 3.0)**	**VCS (Verra, 2025c)**
	In general, justification through substantiated source (clearly defined) required for natural disaster risks				
Minimum time-series requirements	Less emphasis on long historical time series in proposed concrete approaches	No fixed historical dataset length across protocols	Scores must be selected based on project's **long-term implementation risk**, which is not further specified	Monitoring under ART is not required after a Participant exits the program.	Risks to be assessed over a **100-year period** using current conditions and information
Conservativeness and treatment of uncertainty	Default scores where data incomplete Tool also accounts for other natural disaster risks that are not further specified by applying default value of 2%. No clarification on risks provided though	Not specified in any of the protocols	Scoring guidance cautions against bias, but uncertainty framework is not specified	Uncertainty framework given for activity data and emission factors to lower the risk of over-crediting. Uncertainty also captured in risk assessment on likelihood, magnitude and spatial scale following the Cancún Safeguard Vi or F for REDD+	If data over 100-year period is not available, **conservative extrapolation** or **estimates** to be used for event occurrence. No uncertainty framework
Identification of risk-specific mitigation measures	For some risks (e.g., wildfire risks), basic principles for specific mitigation measures are provided and referenced in the tool and effectiveness evidence backed up by at least one source is required	Protocol-specific mitigation measures specified. Mitigation measures often require state agency approval or oversight of professional & CAR approval *E.g., U.S. Forest Protocol: Qualified Conservation Easement, Qualified Deed Restriction. For wildfire risks, vegetation management treatments can lower rating if approved by state agency or CAR* *E.g., U.S. Urban Forest Management: Due to default contribution, no measures specified*	Depending on the actual risk score, risk mitigation measures are required. Adequacy of measures to be evaluated by VVBs	Standard (3.0) identifies three mitigating factors: legislative support REDD+ (-5%); demonstrated interannual variability of less than 15% (-10%) and demonstrated national reversal mitigation actions in line with Cancún Safeguard Vi or F (-5%)	Tool includes examples for natural risk mitigation measures regarding fire, pest/disease or extreme weather risks but no specification of mandatory measures

	ACR (ACR, 2024b)	CAR (CAR, 2019, 2023, 2024a)	GS4GG (Gold Standard, 2025c)	TREES (draft 3.0)	VCS (Verra, 2025c)
Aggregation rules and overall risk rating	Equations for each sub-category calculation are provided. Reversal risk mitigation measures may result in general risk adjustments due to conservation commitment adjustment or a diversified risk adjustment. Mitigation adjustment % are provided at sub-category level in tool Equation-based aggregation of categorical scores to determine final buffer % contribution	Protocol-specific as some require risk rating calculation and others apply default values For risk rating: Category-specific risk ratings are first summed to produce a total risk rating. That total risk rating is then subtracted from 100% to determine the project's buffer pool contribution %	Per subcategory, the risk factors are rated as high, medium, low or no impact. Scores are then multiplied to calculate the actual risk. If mitigation measures are required, a "corrected score" is to be calculated following their implementation.	Starting level of reversal risk of 25% is put forward which can be lowered by demonstrating existence of mitigating factors. Increase of 5% after reversal event.	Likelihood and significance is determined for each natural risk applicable to activity and multiplied with mitigation score (if appropriate). Subtotal risk is aggregated and multiplied with future climate change impact factor if applicable. Total natural risk equals sum of climate-related natural, non-climate natural & sea level risk Overall rating is sum of internal, external and natural risk score
Climate change risk amplification/consideration	No explicit multiplicative climate adjustment factor, risk calculations largely based on current hazard datasets	Climate-related impacts are not explicitly considered across protocols	Climate variability is subcategory and within it, separate scoring for predicted long drought period, seasonal variability in rainfall pattern, increase in extreme events and other (optional) might be required.	Consideration of climate change risks is not specified in standard, identified in country reports following Cancún Safeguard VI or F.	Projected future climate change impacts to be assessed based on climatic impact drivers which can have a positive or negative impact on project. In some cases, must be justified based on peer-reviewed or grey literature. Drivers generate an amplifying factor that increases the historic natural risk score. Sea level rise risk to be assessed in coastal zones. Risk from projected future climate change can be lowered (40% reduction of amplifying factor) if PPs demonstrate at least 5 adaptive capacity criteria

	ACR (ACR, 2024b)	CAR (CAR, 2019, 2023, 2024a)	GS4GG (Gold Standard, 2025c)	TREES (draft 3.0)	VCS (Verra, 2025c)
Risk thresholds, pass/ fail gates	No explicit fail gate specified	No risk thresholds or fail gates specified in protocols	Corrected score threshold	No thresholds or fail gates specified	Overall risk thresholds and category-level thresholds that determine project eligibility
Periodic review and update based on monitoring data	Mandatory reassessment at least every 5 years or upon material change	Protocol-specific *U.S. Forest Protocol: Risk rating to be recalculated every year project undergoes verification site visit*	Initial risk assessment and mitigation plan to be updated at time of certification renewal	No periodic review mentioned in Cancún Safeguard VI or F, time interval to be decided by country. Participants in ART are required to report following calendar years 1, 3 and 5 of each crediting period	Risk tool applied at validation, reassessment required at verification and upon significant events

XV. Table A3. Comparative overview of individual reversal risk factors are assessed across major carbon crediting programmes for geospheric carbon pools

	GS4GG (Gold Standard, 2025a, 2025e, 2025d)	Isometric (Isometric, 2024, 2025a, 2025b, 2025d, 2025c, 2026)	Puro.earth (puro.earth, 2022a, 2022b, 2024, 2024, 2026)	VCS (Verra, 2024c, 2025e, 2025a, 2025b)
Risk scope & taxonomy	Differentiation of four risks for engineered removals: 1. Activity finance and management, asset ownership, rising opportunity costs 2. Regulatory uncertainty and social instability, political, governance and legal risks, acts of terrorism, crime, and war. 3. Natural disturbances and extreme events 4. Climate change impacts exacerbating any of the above risks.	Based on the Questionnaire provided in Appendix C: 1. Natural disasters (e.g. floods, earthquakes fires; question 5) 2. Human-induced events from outside actors (e.g. change in ownership and management of project sites; question 6) The questionnaire is designed so that CO_2 storage in open systems will have lowest risk of reversal score, as an additional precaution, but the risk should be covered by the uncertainty assessment	Differentiation of four risks: 1. Nature-induced risks (e.g., flora, fauna, or climate conditions) 2. Human-induced risks (e.g., design and construction faults, operational risks) 3. Geopolitical risks (e.g., potential effects of the legal and political environment) 4. Any additional factors mentioned in the applicable Methodology	Differentiation of five risks: 1. Regulatory framework risk; 2. political risk; 3. land and resource tenure risk; 4. closure financial risk; 5. design risk
Differentiation by activity type and geospheric carbon pools	Applicable to different activity types (incl. ERW, DACCS, BECCS) and geospheric carbon pools (incl. formations, mineralisation, products). Risks further differentiated in dedicated methodologies/ tools *Methodology-specific risks (“Carbon mineralization using reactive mineral waste”)*	Specific risks differentiated in distinct protocols for four different storage pools	Specific risks addressed in distinct methodologies for three activities based on geospheric storage pools	Applicable to storage in formations. Further distinction into several storage modules (carbon pools) planned; so far, only a methodology for storage in formations is operational
Assessment of reversal risk	Refers to reversal risk assessment in the applied methodology and/or tool. A tool for “Reversal Risk Calculations for Geological	High-level questionnaire on reversal risk assessment is provided in Appendix C *Protocols for storage in saline aquifers or in situ*	Generally, reversal risks for geological storage is considered to be low or very low Standard requires quantitative estimation of	Scores are given based on the characteristics of the covered risk dimensions Risk categories have a score of 0 when stable political

	GS4GG (Gold Standard, 2025a, 2025e, 2025d)	**Isometric (Isometric, 2024, 2025a, 2025b, 2025d, 2025c, 2026)**	**Puro.earth (puro.earth, 2022a, 2022b, 2024, 2024, 2026)**	**VCS (Verra, 2024c, 2025e, 2025a, 2025b)**
	Storage" which assigns risk scores to the three covered risk types (Example for storage in formations (NPR tool): Base storage risk, closure risk and regulatory risk)	*mineralisation in (ultra)mafic rocks categorise the risk of reversal to be very low* *Storage in depleted hydrocarbon reservoirs is to be determined case by case* *Carbonation in the built environment is assessed through high temperatures and low pH* *ERW does not require risk reversal assessment*	differentiated risk types. Standard and methodologies leave freedom regarding risk assessment to PPs. Methods utilised for estimation must be scientifically justifiable and detailed in the reversal risk estimation. Further details in specific methodologies	environment is in place, that owns the pore space and favours CO_2 storage and has clear rules for transfer of liability post closure. PP has a well design fitting for CO_2 handling and access to all relevant well data Minimum score of 1 is given, when PP has secured funding for post injection site care, and maximum of 5 if no funding is secured
Assessment of reversal risk likelihood, magnitude (severity) and spatial scale	Procedure not detailed at requirement-level, but setting guardrails for assessment in applied methodologies/tools: 1. Identification, evaluation, quantification, and scoring of reversal risks 2. Evaluation nature, scale, likelihood, and duration of potential reversals 3. Prescribing percentage-based risk rating and/or default percentage	GCS (saline aquifer protocol): Key risks (most likely) are CO_2 mobility: CO_2 can migrate outside of the identified storage boundary Pressure changes: causing seal breach And chemical changes: chemical and mineral reaction can plug reservoirs preventing injection	Standard requires estimation of risk impact and likelihood of every material risk. Methods used for estimation must be scientifically justifiable and detailed. Further details in specific methodologies.	No determination of level of reversal risk
Transparency and documentation requirements	NPR results are part of the applicability conditions of the project which are to be described in the PDD	Reversal risk assessment to be included in PDD. If reversal risk of a project is higher than the one outlined in respective protocol, this must be documented and justified in PDD	Risk estimation must describe methods and values used to estimate impact and likelihood, e.g. statistical methods, peer-reviewed scientific literature or local regulations and guidelines	PPs shall document and substantiate the risk analysis covering each risk factor applicable to the project
Minimum time-series requirements	The related maximum score applied to $Risk_{Closure}$ is conservatively based on the maximum cumulative	CO_2 storage needs to be durable on geological timescales. If not explicitly	Long-term duration refers to the duration of carbon storage and is defined as a minimum length of 100 years.	The permanence of geological CO_2 storage is intended for thousands of years. It is acknowledged that

	GS4GG (Gold Standard, 2025a, 2025e, 2025d)	Isometric (Isometric, 2024, 2025a, 2025b, 2025d, 2025c, 2026)	Puro.earth (puro.earth, 2022a, 2022b, 2024, 2024, 2026)	VCS (Verra, 2024c, 2025e, 2025a, 2025b)
	leakage rates observed by EERC using statistical modelling over a 100-year horizon.	specified, the default durability threshold is 1000 years.	In the methodology 2 labels are possible, CORC100+ or CORC1000+, communicating the storage durability of the methodology.	assessment over this timescale is not feasible, hence the injection and post-injection monitoring with closure criteria based on predictive statistical modelling.
Conservativeness and treatment of uncertainty	Uncertainty determination is linked to the monitoring of stored CO_2 and is quantified in the methodology for the project activity and any dedicated tools (e.g., TOOL 3 for GCS).	Appendix A addresses the types, Appendix B the stepwise assessment of uncertainties related to removal quantification. The steps are: 1. Input parameter information; 2. Contribution analysis; 3. Sensitivity analysis. The assessment must be based on best practices. Uncertainties addressed by applying uncertainty discounts to some specific activities with open storage systems, e,g. ocean storage. Conservative assumptions to be considered in all calculations	Standard sets requirements for methodologies: Conservative assumptions must be taken throughout all calculations. Methodologies must identify and consider all material risks and establish guidelines and requirements on their assessment and documentation. Quantification must be conservative, statistical models or calibration records are preferred. If necessary, external sources (e.g. peer reviewed literature) may be used Further specific details covered in methodologies	Uncertainties are applied in the methodology and dedicated modules for capture, transport and storage
Identification of risk-specific mitigation measures	Mitigation measures for GCS are given in Annex 1 of TOOL 3: Regulatory approval of storage site, reservoir characterisation, well infrastructure design, monitoring and closure plan with secured funding for the closure period	Permitting and site characterisation of the saline aquifer protocol states key mitigation measures for GCS: Regulatory permitting, reservoir characterisation and well construction. Monitoring plan and closure plan	Pre-emptive risk mitigation, management and reporting practices required if material risks. Key mitigation measures for CO_2 storage are site selection and storage complex characterisation, well design, monitoring PPs must demonstrate ability to fulfil obligations from validated monitoring plan	NPR tool has an additional appendix with well design requirements GCS-related risks and request for assessment are included in GCS Requirements and include site selection and storage complex characterisation, well design, monitoring and closure plan with liability transfer if applicable

	GS4GG (Gold Standard, 2025a, 2025e, 2025d)	Isometric (Isometric, 2024, 2025a, 2025b, 2025d, 2025c, 2026)	Puro.earth (puro.earth, 2022a, 2022b, 2024, 2024, 2026)	VCS (Verra, 2024c, 2025e, 2025a, 2025b)
Aggregation rules and overall risk rating	Risk rating is calculated for each of the 3 risk categories. The 3 sub-scores are added up to determine buffer pool contribution. Risk rating ranges between 1-8.5%	Fixed risk rating in protocol. In some activities, risk ratings are deliberately kept low, while conservativeness is built into the uncertainty assessment (e.g., for open storage systems such as ERW)	NA	Risk rating is calculated for each of the 5 risk categories. The 5 sub-scores are added up to determine buffer pool contribution. Risk rating ranges between 1-7%
Climate change risk amplification/consideration	"Climate change impacts exacerbating any of the above risks" is one of the four risks covered, but not further specified	NA	Considered in the probability and severity of risk items. Example of risk matrix for GCS contains air/atmosphere, surface – near surface (drinkwater sources contamination), ownership and environment and community	The VCS Program sets requirements to avoid or minimize negative impacts on biodiversity and ecosystems, risk mitigation in GCS projects is also concerned with unanticipated CO_2 loss from the storage reservoir to adjacent formations impacting underground sources of drinking water and/or other subsurface resources.
Risk thresholds or pass/fail gates	Ocean fertilisation and deep ocean storage are not eligible due to uncertainties surrounding proportion of biogenic carbon transferred to deep ocean Activities rated "non-eligible" if risk assessment yields "material risk of reversal". GCS risk rating should not be above 6.7%	NA	NA	Risk ratings above 7% are ineligible and when a reversal occurs where >10% is lost compared to the total injected volume of the project will become ineligible
Periodic review and update	Reversal risk assessment to be reviewed at each verification and revised every 5 years or in case of specific circumstances	Every 5 years or in case of specific circumstances	Periodical updates of risk assessment required, but not specified	Project risk assessments are subject to periodic review by Verra, through sample review

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