NET RAPIDO

perspectives climate research

Tracking greenhouse gas removals

Baseline and monitoring methodologies, additionality testing, and accounting

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Perspectives Climate Research

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Disclaimer

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Key messages and recommendations

While the main focus of climate change mitigation efforts rightly remains on cutting greenhouse gas (GHG) emissions, aiming at net-zero emissions requires to engage strongly in GHG removals from the atmosphere and their permanent storage. Compared to emissions reductions, the policy infrastructures for this new type of climate change mitigation are still in their infancy, especially regarding the development of monitoring, reporting and verification methodologies in order to track mitigation results credibly and reliably – both in the context of carbon markets and results-based finance. Such methodologies assess the baseline situation and use measured and standardized data to track results from mitigation activities. They need to cover the entire carbon dioxide removal ecosystem (comprising generally of a combination of capture, transport and sequestration elements) in a consistent and transparent manner. While complete methodologies have been developed for the mechanisms of the Kyoto Protocol and for voluntary carbon markets for purely land-use-based approaches, for other removal approaches only some methodology elements exist. They include notably some forms of the capture, transport and underground storage of CO_2, as well as some aspects of biogenic carbon removal. Other removal approaches, however, have not been addressed at all or in ways that are inconsistent with one-another and thus require new methodologies.

There is also the need to distinguish between projects that take place also without further support, and therefore should not be eligible to generate emission credits or receive results-based finance, and those that need carbon revenue to be attractive – and which thus represent additional efforts.

This report maps existing methodology elements, offers specific proposals for refining and revising them and points to gaps requiring development of new ones altogether.

Our main recommendations to carbon market activity developers, administrators, and negotiators include:

→ Develop baseline and monitoring methodologies for

  — Industrial direct air capture (DAC), whose characteristics must include: i) adequate description of the baseline considering the volume and concentration of gas in a suitable place for its processing, ii) adequate guidelines for the measurement of emissions of the materials necessary for the production and operation of DAC equipment, iii) adequate and conservative measurements for DAC, and iv) Monitoring risk of non-permanence.

- Energy-, waste treatment, and industrial plants utilizing biomass and capturing CO_2 (known as BECCS). The methodologies should i) distinguish carbon removals from emission reductions, ii) account associated upstream and downstream emissions, including emissions in the sector of land use, land use change and forestry (LULUCF), iii) ensure that biomass used must be sustainable.

→ Clarify provisions regarding storage permanence to differentiate between processes resulting in

- capture and re-release of CO_2 (no removal); or
- capture and durable storage (removal), where differences in durability may exist depending on the characteristics of the technology.

These provisions need to define clearly what duration is required for a storage to be deemed as "permanent" and how liability for reversals is allocated.

→ Clarify fungibility of emissions reductions and carbon dioxide removal in carbon markets. While enhance liquidity and economic efficiency would call for full fungibility, the interest to enable a price differentiation for the initially highly costly technological removal options would call for a separation of markets.

→ Formulate guidance regarding the appropriate form of additionality testing for mitigation technologies including in particular for measures involving carbon capture and utilisation (CCU) and carbon capture and storage (CCS).

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Acronyms

A/R	Afforestation/Reforestation
BAT	Best available technology
BAU	Business as usual
BECCS	Bio-energy with carbon capture and storage
CBDR-RC	Common but Differentiated Responsibilities and Respective Capabilities
CCS	Carbon capture and storage
CCU	Carbon capture and use
CDM	Clean development mechanism
CDR	Carbon dioxide removal
CO_2	Carbon dioxide
DAC	Direct air carbon capture
DACCS	Direct air carbon capture and storage
ERF	Emissions Reduction Fund (of Australia)
GGR	Greenhouse gas removal
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land use, land-use change and forestry
MDB	Multilateral development bank
MRV	Monitoring, reporting and verification
NDC	Nationally determined contribution
NET	Negative emissions technology
PA	Paris Agreement
PMR	Partnership for Market Readiness
REDD+	Reducing emissions from deforestation and forest degradation
UNFCCC	United Nations Framework Convention on Climate Change
VCS	Verified Carbon Standard

01

Introduction

This report examines the design of methodologies to determine the mitigation contribution of technologies to remove GHGs[1] from the atmosphere. Such methodologies are highly relevant for designing policy instruments to promote such removals, and thus will be decisive regarding the contribution removals can make to meaningful climate change mitigation. Understanding carbon dioxide removal (CDR) as a form of the 'mitigation of climate change' (Honegger et al. 2021) has repercussions for its governance and notably clarifies that Parties' have an obligation of conduct (to pursue mitigation) which extends to CDR.

We want to address two target groups: experts on methodologies to anticipate and track mitigation results for whom we outline the particular challenges posed by CDR, and practitioners working on the implementation of CDR activities whom we want to alert to policy design challenges ahead and methodology requirements.

CDR comes in many different shades and can be pursued in various sectors, industries and social contexts – ranging from ecosystem restoration to high-tech black-box engineering solutions drawing carbon from ambient air and variously involving storage in biomass, geological reservoirs or even in form of basaltic rock. The actors involved in the emerging CDR ecosystem are accordingly diverse and – due to their differing starting points – come with various visions for policy. What they share – as rooted in the notion of CO_2 removal itself – is the objective of permanently removing CO_2 that had previously already been emitted, in order to mitigate climate change. To fill the Paris Agreement with life, all these actors and technologies need to work in a concerted manner. The credible and long-term viable pursuit of relevant activities hinges on the design and implementation of a comprehensive policy toolbox.

1 In practice, currently only CO_2 removal is possible in relevant quantities. Therefore, in the remainder of the report we speak of CO_2 / carbon dioxide removal (CDR) only.

The design of this toolbox requires building on a diverse policy, technical, and practical expertise but needs to be credible. Ultimately the ensemble of applied policy instruments needs to ensure what is commonly referred to as environmental integrity: The notion that the claimed mitigation results correspond to the physical outcome for the atmosphere and that they contribute to global mitigation efforts accordingly. Otherwise, the novel field of CDR could face the same fate as "classical" carbon capture and storage (CCS) from fossil fuels which during the early 2000s was seen as a key solution to the climate change problem but since then has struggled to overcome popular opposition.

Over the last two decades, methodologies relevant to the tracking of mitigation results have generally not been designed with CDR in mind, but for reductions in emissions. This means that lessons can be drawn from existing methodology elements, but they need to also be modified and expanded upon in order to do justice to the particularities of CDR.

1.1 The role(s) of GHG removals for mitigating climate change

CDR may fulfil three slightly different purposes for the mitigation of climate change, listed in increasing order of stringency:

i. *temporarily* balancing out (neutralizing) residual emissions while solutions for their full decarbonization are being developed, and

ii. balancing out residual emissions *in the long term* for achieving net-zero global emissions, and

iii. achieving a *global reduction in atmospheric CO_2 concentration* to return to previous levels through a phase of global net-negative emissions (during which the level of global residual emissions is smaller than the level of CDR).

There is also a slowly recognized need for industrialized nations (with large historic emissions) to achieve net-zero and net-negative emissions early, in order to compensate for the remaining emissions of poorer, developing countries who are expected to achieve net zero only at a later point in time.

Ultimately, a risk-management approach anticipates that full decarbonization of human activities is highly uncertain (if not impossible). Therefore, the mitigation portfolio needs to be developed as broadly as possible including CDR approaches at various stages of development. Meanwhile research, development and deployment of CDR must not serve as a distraction from indispensable emissions reductions.

Expected performance and maturity of CDR approaches varies widely. For policy to be credible and aligned with the objectives of the Paris Agreement at least six functions need to be jointly fulfilled (Honegger et al. 2021). This report examines how one of the six – proper measuring, reporting, verification and accounting of results – may be achieved, which will allow tracking domestic and global progress toward net-zero emissions. Full understanding of the provisions of the Paris Agreement as well as pre-existing provisions set within the United Nations Framework Convention on Climate Change (UNFCCC) is required as a basis for gradually transitioning from piloting to effective continuous, scaled operation of CDR in a way that is compatible with mitigation pathways toward stabilization of the climate system (no matter the temperature level) with results being assessed in a transparent and credible way.

In order to do this, some areas fraught with misunderstandings or differences in interpretation need to be addressed methodologically in a consistent and conservative way in order to allow CDR to play a key role in contributing to the ambitious Paris Agreement targets, especially in international cooperation).

The primary distinction of relevance compared to classical emission reduction in the context of CDR is the permanence with which CO_2 is removed (stored) from the atmosphere. Rather than utilizing arbitrary delineations such as 'technological' versus 'nature-based' CDR, we will distinguish between approaches with high inherent permanence versus approaches with limited inherent permanence. Both can – under the right circumstances – offer important contributions, but policy design needs to anticipate reversal risks and address them in the monitoring methodologies.

CDR is defined by a net-flow of a GHG from the atmosphere into 'durable' or permanent storage. Because CDR is often achieved through a value-chain that involves geological storage also referred to as carbon capture and storage, CDR and emissions reductions are often confused. A removal is achieved if the origin of (at least some of) the CO_2 stored is atmospheric or biogenic (indirectly atmospheric). If the origin of the CO_2 is fossil (or from the mineral transformation in cement production), then any storage thereof results in a reduction of emissions (and not a removal). Future policies, monitoring methodologies and accounting practices must apply this distinction without failure (or else they undermine climate change mitigation).

1.2 The function of baseline and monitoring methodologies

In this section, we discuss the role of baseline setting, monitoring and additionality determination methodologies in climate change mitigation and map what methodologies exist for various CDR approaches.

The first type of methodologies is used for **baseline setting**, i.e. defining reference scenarios / counterfactuals for GHG emissions, removals and storage at various activity levels (e.g. at the project, programme, policy instrument, sector, company, jurisdiction or national level). Baselines are needed for baseline-and-credit policy instruments and results-based finance, but not for national GHG inventories. The determination of a conservative baseline is critical for safeguarding the environmental integrity of market-based approaches (i.e. ensuring that the market cooperation is in line with increased climate ambition and does not lead to higher global emissions), as well as the effectiveness of non-market policies. Regarding the latter, weak methodologies lead to the wasteful use of resources which, in turn, could undermine the achievement of targets and the willingness to raise ambition, thereby indirectly undermining environmental integrity (i.e. leading to higher global emissions).

In general, baseline methodologies for removals will have to include the following building blocks:

i. Defining boundaries of an activity or sector,

ii. Calculating the reference scenario, e.g. projecting future emission and removal levels in the absence of an activity,

iii. Ex-ante projecting and ex-post calculating amount of removals/storage in relation to the reference scenario,

iv. Estimating leakage risks and proposing safeguards/discount options, and
v. Estimating uncertainty in the determination of the reference scenario and the calculation of removals and storage

The second type of methodologies is needed for **calculating and monitoring** GHG emissions, removals and storage achieved at different activity levels. Calculation of these parameters is relevant at all levels, particularly for national GHG inventories, whereas monitoring is mostly deployed at lower levels of aggregation. With regard to CDR, consistent approaches are needed for considering different time-horizons of storage – across very different technologies and activity types including specification of long-term monitoring and measures taken in case leakage is detected.

Thirdly, **additionality** testing is needed to assess whether an activity seeking support through a market instrument or results-based finance would without such carbon-revenue have occurred anyway or be mobilized by specific policies. Additionality tests check financial characteristics of activities, whether they are required or mobilized by specific policies, or assess technology or other barriers. Credits from non-additional activities would lead to an increase in global emissions and thus additionality testing plays also a central role in (inter-)national carbon markets (Gold Standard 2020). For activities supported by public finance the same considerations apply as discussed above in the context of baseline methodologies. The requirements placed on the additionality test are higher for international carbon markets where additionality compared to the (unconditional) NDC needs to be shown while for climate finance and domestic carbon markets only financial and regulatory additionality are relevant.

These methodologies need to be applied as a package to understand the performance of mitigation action: they allow activity-specific monitoring of mitigation compared to an activity-specific baseline scenario and thus to identify the result of an activity over a discrete amount of time (as a mitigation return to a particular investment). Thereby, they inform the design of effective policy instruments: While initially research and development specifically need to pursue high-cost and immature mitigation technology approaches, gradually mitigation needs to (also) be guided by efficiency as technologies mature. Many CDR approaches are still situated in the former category.

1.3 Interplay of baseline and monitoring methodologies and accounting

Countries that are party to the Paris Agreement are to keep track of the emissions and the removals that take place in their territory. They do so via a national inventory of GHGs. There are rules and guidance that indicate how GHG flows are to be accounted for in order for countries to do this consistently including to avoid double counting of the same flows in two countries and transparently to allow the international community to track progress toward temperature targets.

Accounting at national level through national greenhouse gas inventories does not apply the same level of specificity as monitoring for specific activities. Yet the two intersect, when activities lead to internationally transferred mitigation outcomes (ITMOs), where the results are deducted in one country and added in another in order to allow tracking progress at the international level. Without such 'corresponding adjustment' both countries would report the same results twice and create an upwardly biased picture of global progress.

Therefore, it is critical that monitoring methodologies follow common standards and allow a sufficient level of reliable comparability between activity types internationally.

Summarising, mitigation progress needs to be tracked at three levels: at the level of specific project activities, at the nationally aggregated level (in GHG inventories), and ultimately at the level of the international community (through taking stock of governments' respective achievements toward implementing NDCs). While there will never be full consistency between the three levels, material inconsistencies should be avoided as far as possible.

We now discuss key definitions needed in the context of development of methodologies for assessing the mitigation achieved by CDR.

02

Definitions

Given the relatively recent emergence of the CDR field, terminologies are often unclear. Therefore, we embark on a series of definitions.

2.1 Climate change mitigation covers GHG removal and thus CDR

International climate policy focusses on two primary categories of action: *mitigation (of climate change) and adaptation (to climate change)*[2]. This report does not address adaptation. Mitigation encompasses emissions reductions and GHG removals (Honegger et al. 2021), of which CDR currently is the only relevant type.

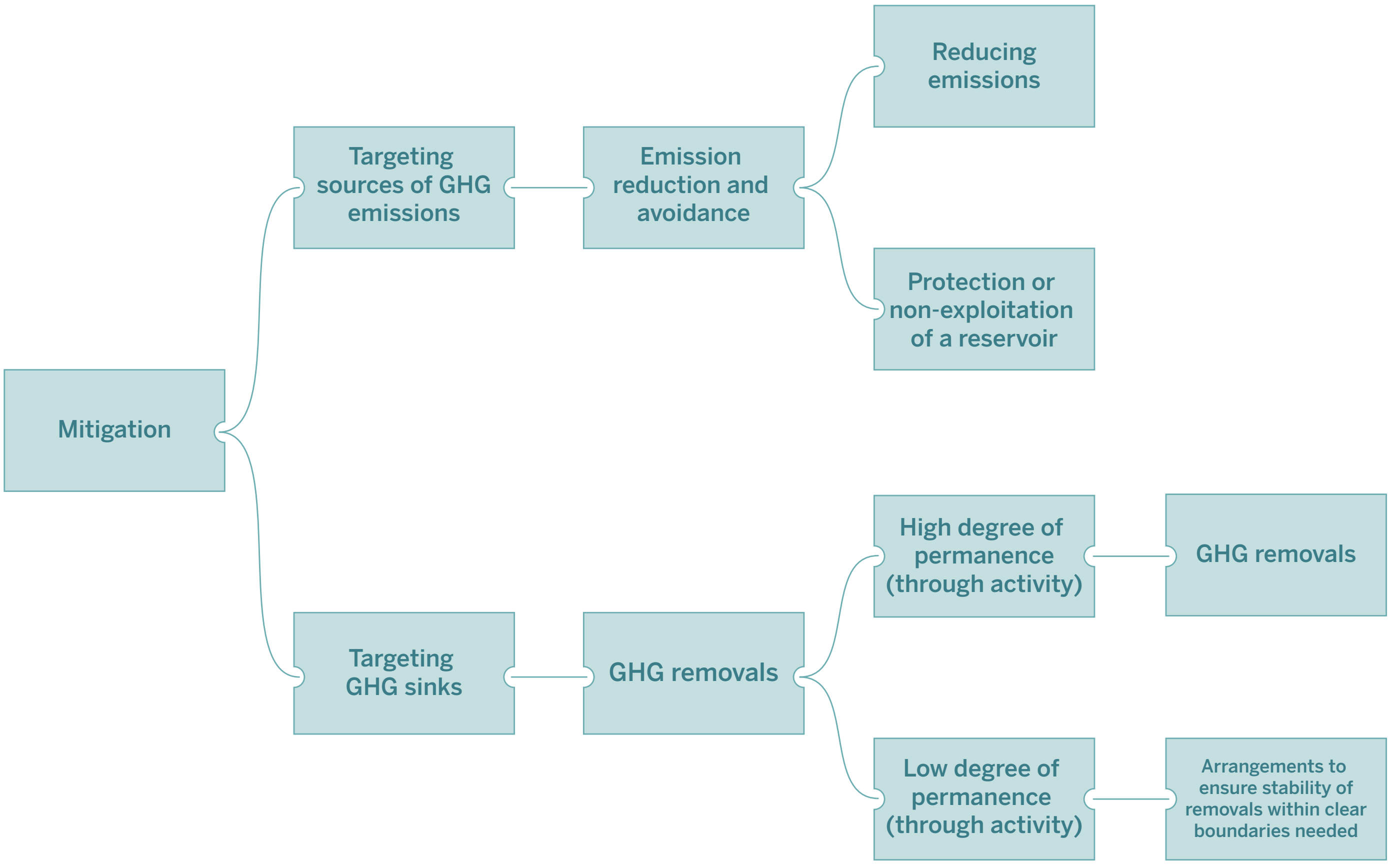
From a global perspective – balancing GHG sources and sinks requires addressing not only emission reductions but also removals. Yet the Paris Agreement gives no clear indication of priority of one over the other. Nonetheless, it is critically important to define the boundaries of emission reduction and removal activities, especially in those cases which address both sources and sinks (see Figure 1).

An emission reduction means a reduction of emissions below a reference scenario (see discussion in section 1.2 above).

2 Besides mitigation and adaptation some scholars also propose to broaden the climate policy toolkit even more and add "amelioration" (or solar radiation modification) as a third pillar (Aldy and Zeckhauser 2020).

FIGURE 1

The mitigation definition tree



Source: authors

An emission avoidance is associated with the protection or the non-exploitation of a carbon reservoir (either a (forest) ecosystem[3] or a fossil fuel reserve[4]). We will not further address 'avoidance' in this report.

GHG removal (anthropogenic) – is achieved through negative emissions technologies and is defined as (based on IPCC 2018, 2019):

A technology or practice which results in an overall removal of CO_2 (or other GHG) from the atmosphere into durable (i.e. over a climate-relevant time horizon) storage (away from the atmosphere). In practice this involves at least two steps: Capture of biogenic or atmospheric CO_2 (or other GHG) and storage. Most cases also involve transport of the CO_2 (or other GHG).

3 Reducing emissions from deforestation and forest degradation (REDD+) is often used synonymously with the term 'avoidance' or 'emission reduction through avoided deforestation'. It should be noted here, that REDD+ is an international policy framework that aims to create financial incentives for developing countries to undertake actions to protect and sustainably manage forests. These actions are not limited to reducing emissions from deforestation but also include reducing emissions from forest degradation, conservation of forest carbon stocks, sustainable management of forests, and enhancement of forest carbon stocks.

4 This was for example proposed by Ecuador's president Correa in 2003 for protecting the oil reservoir under the Yasuni national park, see Köhler and Michaelowa (2014).

2.2 Carbon (dioxide) capture and storage (CCS)

Carbon dioxide capture and storage (CCS) can be used to achieve emissions reductions or CO_2-removals as explained in the following based on the CCS definition by IPCC (2018):

> *A process in which a relatively pure stream of CO_2 from industrial and energy-related sources is separated (captured), conditioned, compressed and transported to a storage location for durable (i.e. over a climate-relevant time horizon) isolation from the atmosphere …*

CO_2 can thus be captured at different (industrial or energy-related) sources for storage. This is not limited to instances of fossil fuel- or geogenic point sources, but this also includes other industrial or energy-related sources such as industrial processes directly capturing CO_2 from ambient air or biomass-based energy-transformation (CCS is constituent of "BECCS" and "DACCS"). Two principal types of CCS-applications can thus be distinguished based on their potential mitigation result (see also Tamme 2021):

a) Capturing CO_2 from a fossil (e.g. fossil fuel combustion) or geogenic (e.g. cement production) point source and storing it durably prevents CO_2 from entering the atmosphere and thus constitutes an emissions reduction.

b) Capturing CO_2 from a biological source (e.g. bioenergy combustion) or directly from the atmosphere (direct air capture) and storing it durably can result in negative emissions and thus can constitute a negative emissions technology (NET).

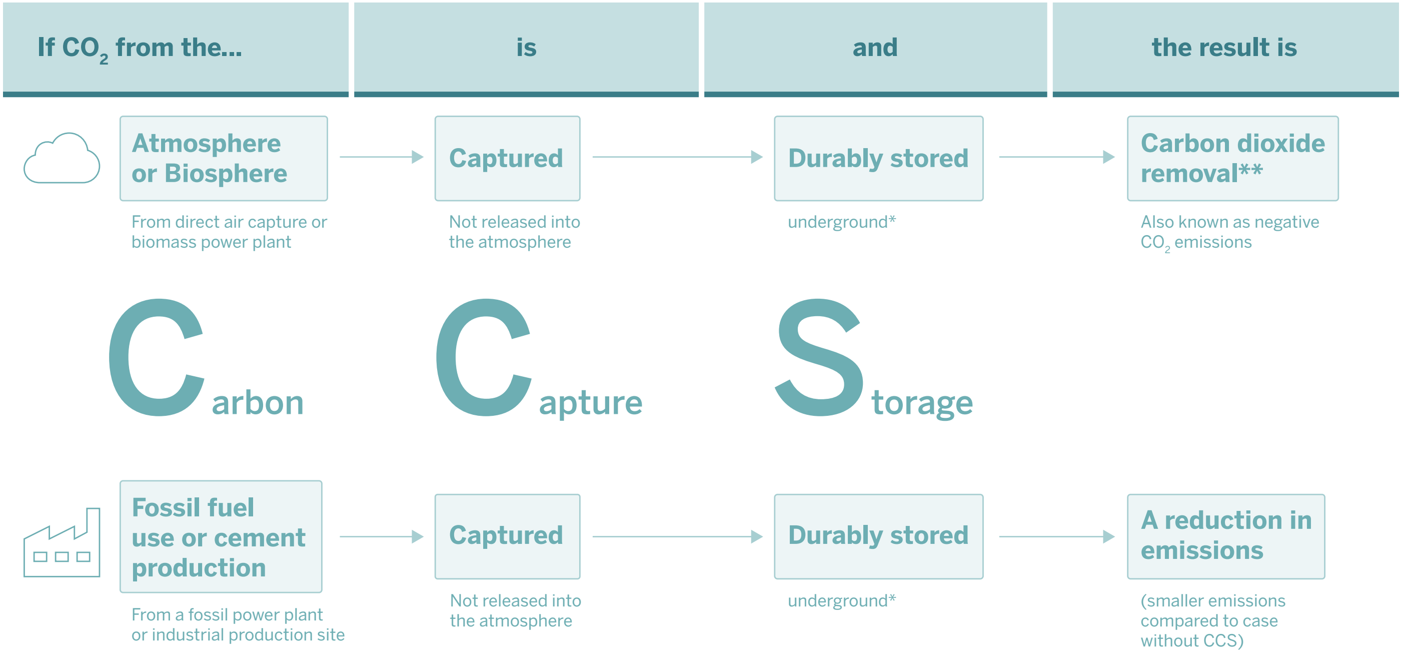
BOX 1

The ambiguous concept of carbon capture, utilisation and storage (CCUS)

CCS or carbon capture and utilisation (CCU) are terms that describe two different carbon flows. However, the term carbon capture, utilisation and storage (CCUS) has also been used – sometimes interchangeably – to describe combinations of both or ambiguous cases in which the carbon flow is not specified. The perhaps most common form of CCU is the production of alternative fuels. This 'utilisation' of the captured carbon is directly linked to emissions once the resulting product is used i.e. burned. This thus – at best – achieves a relative reduction in emissions (if the fuel is based on carbon captured from the atmosphere or biomass and displaces fossil fuels). At worst it could even increase emissions due to inefficiency. Where CCU results in durable storage, such CCUS can result in emissions reductions as well as in CDR (if the captured carbon comes from the atmosphere or the biosphere). Disambiguation is thus paramount in the context of any results-based activities.

FIGURE 2

Two possible results from CCS – depending on the source of carbon



* production of inherently durable, long-lived products may be considered storage under particular circumstances

** carbon dioxide removal can also be achieved through other means (such as afforestation, ecosystem restoration, enhanced weathering and more)

Source: authors

2.3 Durable storage or "permanence"

The definitions of CDR and CCS both raise the question: What constitutes a 'climate-relevant time horizon' or 'durable" storage? No consensus exists on this question. Proposals include:

→ 'Permanent' storage for 1000 years or more (Carbon Plan 2021)

→ A 100-year period derived from durability assessment of the IPCC (2005) and the use of 100-year global warming potentials for GHGs under the Kyoto Protocol and Paris Agreement

→ An 'equivalence period' of 55 years (Moura Costa and Wilson 2000). This would roughly mean that after this period the reversal of the storage would be considered to no longer have a negative effect on the climate.

→ A length of the period dependent on the availability and costs of a backstop technology. If a general backstop mitigation technology becomes available (a technology that offers infinite mitigation potential), then any reversals thereafter are acceptable (at the price level of the backstop) (Herzog et al. 2003).

We would like to note that the average lifetime of companies on the US Standards and Poors S&P 500 stock exchange index has oscillated between 15 and 35 years in the last half century (Statista 2022). Only about 0.5% of companies in the US exist for over 100 years (Bain 2021). The oldest company still existing in the world is 1440 years old, and only about 15 companies exceed 1000 years of age (World Atlas 2022).

This means that even the lower end of period lengths discussed in the literature, huge challenges regarding responsibilities will arise, and the higher ends will be unmanageable for any human organization.

Depending on what time period is chosen in order for storage of captured CO_2 to qualify as a removal, some instances of wood utilization as well as some instances of soil carbon enhancement, including through biochar application, may be – if left alone – too short-lived to constitute a removal. Dedicated policies may thus be required to achieve "durable storage" for those activities that do not result in inherently permanent storage.

2.4 Storage-inherent permanence

Some have proposed a differentiation between nature-based and technological removals. Such differentiation is, however ambiguous and not suitable for the purpose of ensuring environmental integrity. The more important differentiation for ensuring environmental integrity is between technologies or practices where storage is of high inherent permanence (e.g. CO_2 mineralized to stone represents an inert and thus inherently permanent form of storage), and technologies or approaches, where storage is highly unstable or might even have an inherent "expiry date" (e.g. enhanced soil carbon or reforestation).

Permanence is a continuum and there are no universally agreed-upon time-periods that would determine a particular percentage-probability of permanence over a specific time-window to be permanent or not.

FIGURE 3

'Permanence ladder' of different CDR types

Source: Poralla et al. (2021)

Rather, there is a continuum – expressed in the 'permanence ladder' – of the inherent permanence of different forms of storage. Finally, permanence is understood as the storage effectiveness that would result from optimal management of a storage site. This indicates that mismanagement or inadequate site selection can result in lower storage permanence.

Reversal corresponds to an emission from a reservoir that was previously increased through anthropogenic storage. Reversal makes a reservoir smaller and undoes a previous storage process.

2.5 Governance-based permanence

Where permanence is not inherent to a storage type, the objective of permanence can potentially be achieved through institutional and policy arrangements (governance) that address the potential for reversal and eliminate their threat to environmental integrity.

The simplest form in which (non-)permanence can be addressed is for those cases, where the physical durability of storage can be influenced through appropriate site selection or appropriate handling of a product (in which CO_2 is stored) such as in case of using wood in construction or in the case of using biochar to enhance soil carbon contents (whereby durability may be subject to subsequent soil management). Storage site selection is in particular relevant for CCS (geological storage), where in the most extremely durable case CO_2 mineralizes and literally turns into (chemically inert) rock. However, only storage sites in basaltic rock achieve this outcome while other storage locations like aquifers or empty oil and gas reservoirs indicate less certain storage durability.

Where storage site selection is not the main driver of (non-)permanence, measures in the realm of policy instruments may help. Market-based instruments can for example increase the likelihood of permanence by requiring a buffer (a reserve of credits). The credits in the buffer cannot be traded and will be retired if a project developer incurs reversals to balance the resulting emissions. Under normal circumstances the reserve thus results in overperformance. Even the strongest buffers can, however, in extreme cases prove insufficient – if for example entire regions experience a wave of deforestation or disruptive weather extremes.

An alternative form of ensuring – on aggregate – that removals do not result in exaggerated results claims – for cases where some steady reversal is expected – is to apply conservative baselines. Such baselines can be defined in anticipation of a particular rate of reversal in order to correct for them as they arise. Such an approach is however at risk if there are no reliable experiences to approximate future reversal rates, or if reversal rates themselves are not as steady as expected. For non-steady reversal risks such as those that might accelerate under influence of a changing climate (increased frequency of drought, forest fires and other disruptive events) conservative baseline setting is inadequate.

Another way to deal with the threat of reversals that stems from not-inherently durable forms of storage (see Figure 3) is to limit the fungibility of credits. A major way in which this can be done is by limiting the use of removals achieved in agriculture and forestry solely to the land-use-change sector, so as to solely allow these results to be counted against emissions from land-use and land-use change elsewhere. This can work to the extent that countries have sectoral LULUCF targets that are consistent with an economy-wide ecosystem of targets and policies toward a national mitigation contribution. Limiting fungibility does, however, not reduce the risk of reversal. It solely increases accountability for entire sectors.

By reducing the risk of conflating reduction and removal targets as well as conflating sector-specific mitigation targets it allows responding to reversals within the LULUCF sector through policy adaptation and – perhaps – overachievement in another sector while also limiting ex-ante the risk of delaying necessary decarbonization in other sectors. Hence, limiting fungibility could increase the transparency and allow to credibly track mitigation efforts and potential reversals sector-specifically (but it would also not directly counter reversal risks).

Different types of CDR thus have different reversal risks to be considered in the monitoring methodologies, which take into account the physical and chemical properties of storage as well as the socio-political factors that could affect reversals (including e.g. deforestation rates or other land-use change related pressures).

03

Different types of baseline and monitoring methodologies and additionality tests and their relevance for CDR

Over the last 20 years, rich experience with baseline and monitoring methodologies as well as additionality tests has accumulated and can inform the development of such methodologies for CDR. The following section offers an overview of key existing elements and the challenges encountered in their development and application.

3.1 Typology of baselines

"The baseline (...) is the state against which change is measured" (IPCC n.d.).

Baselines define the reference level / scenario[5] of emissions against which the emissions level achieved by a mitigation activity is measured during the crediting period (for baseline and credit systems) or otherwise the lifetime of a mitigation activity. The **baseline scenario** describes **what would have most likely occurred** in the absence of the mitigation action. In other words, "a non-intervention scenario is used as a reference in the analysis of intervention scenarios" (IPCC 2007, p. 810). The baseline scenario is used to estimate or project the net emissions (the balance of emissions and removals) for each year of the crediting period in the absence of the activity.

As stated by Michaelowa et al. (2021b, p. 2), "[b]aselines are 'counterfactuals' by nature and therefore there is no single 'true' approach to setting a baseline. The further we look into the future; the more diverse possible baselines can become. This uncertainty should be taken into account. In the case of high uncertainty, baselines should be set using **conservative** assumptions, values, and procedures. Conservative assumptions, values, and procedures are more likely to underestimate than overestimate emission reductions.

5 The term reference level is often used synonymously with the term baseline, in particular in the context of activities in the LULUCF sector.

Various approaches have been used in the past to define baselines, starting with the approaches defined for the Clean Development Mechanism (CDM) under the Marrakech Accords in 2001, and most recently in the context of the Article 6.4 Mechanism (UNFCCC 2021). It should be noted that generally, baselines are expressed in intensity terms, i.e. per unit of production of a good or service. The approaches can be grouped into the following overarching types (see also discussion in PMR 2013).:

1. **Historical baseline:** The emissions / removal level of a historical period serves as the baseline.
2. **Business-as-usual (BAU) baseline.** The baseline represents a projection of emissions that would occur in the absence of the mitigation action, assuming that future emissions trends follow those of the past and no further action is taken (i.e., no changes in policies will take place and no new policies will be adopted) (PMR 2013). BAU baselines are typically set on a case-by-case (project-by-project) level. Most baseline methodologies developed under the CDM have applied a BAU concept. The Article 6.4 decision (UNFCCC 2021) requires explicitly that baselines need to be set below BAU.
3. **Performance standard / BAT / benchmark baseline.** The baseline reflects a performance level that the mitigation action is expected to exceed. A performance standard can be based on a statistical analysis of the emission rates of baseline activities/practices/technologies, on the emission rate of a single generic reference activity/practice/technology – often referred to as best available technology (BAT), or on a specific percentile of the performance distribution curve that serves as a benchmark.

   Performance standard baselines have often been seen as more conservative than BAU baselines and a panacea to solve challenges in baseline setting, but their promise has so far not really materialised due to problems in choosing the appropriate level of aggregation and getting robust data (see Schneider et al. 2012). They have only been applied in a few CDM methodologies (Hayashi and Michaelowa 2013; UNFCCC 2020), whereas the Joint Crediting Mechanism (JCM) promoted by the government of Japan has used them widely (Michaelowa et al. (2021a)). The Article 6.4 decision of COP26 lists both BAT and benchmark baselines as eligible approaches (UNFCCC 2021).
4. **Net mitigation baseline.** The baseline is intentionally more ambitious than a BAU baseline i.e., it represents a level of emissions that is below the level projected for a BAU baseline. Under the CDM, such baselines have been applied for industrial gas projects.

The four baseline types are described in greater detail below.

3.1.1 BAU baselines

BAU baselines can be developed through historical trends-based projection, model-based projection or a (retrospective) comparison approach.

Projection based on (adjusted) historical trends.

BAU baseline is set by extrapolating historical emissions into the future. This can be done in one of three ways: The first option is to construct the baseline as a linear extrapolation of historic emissions. The second is to calculate the baseline is calculated as a (rolling) average of historic emissions.

In this case the baseline is set based on historical average of emissions over a certain period but recalculated in regular intervals. The third option is to set the baseline on adjusted historical trends. For this there are no common approaches that would specify which factors to include. One particular way of doing this is to have the baseline initially reflect historical emissions but then decline in order to require higher ambition of the host country over time.

Model-based projection.

In such cases the BAU baseline is set through simulation models. The models allow controlling for variables that may affect emissions, and thus these model-based approaches predict emission trends more precisely. The Partnership for Market Readiness (PMR 2013) lists four general types of simulation models that are relevant for baseline setting (see Table 1).

Comparison or control group approach

In a comparison – or control group – approach, the BAU baseline is set retroactively by tracking and measuring the characteristics of emissions in a similar area unaffected by the intervention activity. This requires measuring key variables in both the intervention (project) area and the comparison area that has similar socio-economic and geographical properties.

The method works best if "the contextual characteristics of the control area are close to those of the intervention area, except for the intervention itself" (UNFCCC 2018, p. 24)

3.1.2 Performance standard / BAT / benchmark baselines

Performance-based approaches to baseline setting have been discussed since the early days of carbon crediting and trading. The 2001 Marrakech Accords – which set, inter alia, the rules, modalities and procedures for the CDM – mention performance-based approaches as one of three options to choose a baseline methodology for a project activity. The performance-based approach is defined as follows: "The average emissions of similar project activities undertaken in the previous five years, in similar social, economic, environmental and technological circumstances, and whose performance is among the top 20 per cent of their category" (UNFCCC 2005, para 48).

Using standardized baselines – i.e., performance benchmarks or default values – has reduced transaction costs and increased the transparency of CDM project activities: baselines are not set on a project-by-project level but can be determined for entire project types and sectors (Schneider et al. 2012).

TABLE 1

Technology readiness levels and long-term cost estimates of different CDR types

Model Type	General Description
Engineering / System Optimization Models (Bottom Up)	Used to simulate how a system (e.g., a building system, power grid, or national energy system) will behave and/or develop given a range of inputs and constraints.
Economic / Computable General Equilibrium Models (Top Down)	Used to simulate supply and demand of goods and services in an economy under various policy and macroeconomic conditions
Hybrid Models	Combine bottom-up and top-down models to comprehensively simulate how systems may respond under varying economic conditions
Physical Process Models	Used to simulate physical systems that give rise to GHG emissions

Source: authors based on PMR (2013, p. 74)

Benchmarks have earlier been seen to be a solution to the problems of historical baselines, but over the years, it has become clear that they are only appropriate for certain sectors, and certain levels of aggregation (Michaelowa et al. (2021a), Füssler et al. 2019). Best available technology (BAT) approaches have been pushed by the EU but have not yet been tested under international carbon markets.

3.1.3 Net mitigation baseline

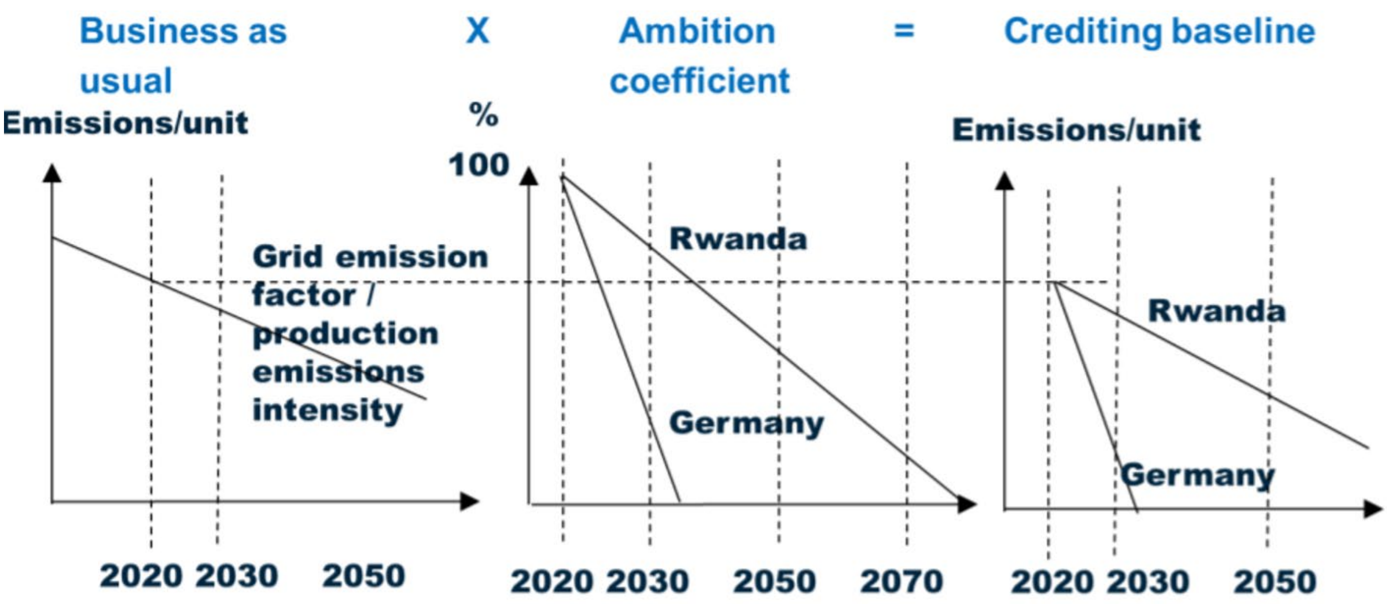
The concept of net-mitigation baselines is premised on setting an "ambitious" baseline to achieve net mitigation benefits. For example, the PMR (2013) states that "by establishing a crediting baseline demonstrably below the BAU, a crediting mechanism would issue fewer credits than the total number of tons of CO_2 equivalent emissions achieved relative to the BAU". This leads to a lower credit volume than the level of mitigation that has actually been achieved.

Although a conservative BAU baseline, in itself, does not represent an ambitious or net mitigation baseline, conservativeness in CDM projects has been viewed as bringing uncredited emission reductions – important mitigation benefits beyond the number of CERs issued (Spalding-Fecher et al. 2012).

In addition to the three types of baselines setting mentioned above, Michaelowa et al. (2021c) proposed dynamic baselines that change over time by applying an "ambition coefficient" to the emission intensities of BAU technologies, which decreases over time to zero when a country is to have reached zero net emissions. The "ambition coefficient" is to be derived top-down from country level zero emissions pathways. For each country, a trajectory towards net zero emissions is defined. At the date when the trajectory reaches net zero, the baseline of all emission reduction activities is set to zero, meaning that thereafter only CDR would generate emission credits.

FIGURE 4

Application of the ambition coefficient to the BAU to derive a dynamic crediting baseline



Source: Michaelowa et al. (2021c, p. 10)

Following the Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC), which expects less developed countries may reach net-zero later than developed nations (Romdhane 2021), rich countries have to reach the net zero level earlier than poor countries as shown in Figure 4.

The baseline is determined by multiplying BAU emissions with the national ambition coefficient. This approach allows poorer countries the ability to participate in market transactions for emissions reductions credits for a longer period. Michaelowa et al. (2021c) suggest the ambition coefficient to be updated every NDC cycle (5 years). Eventually the net-mitigation baseline could even go into net-negative territory, upon which the country could solely purchase removal units. As more and more countries would reach net-zero or even net-negative baselines the market would eventually be dominated by removal units.

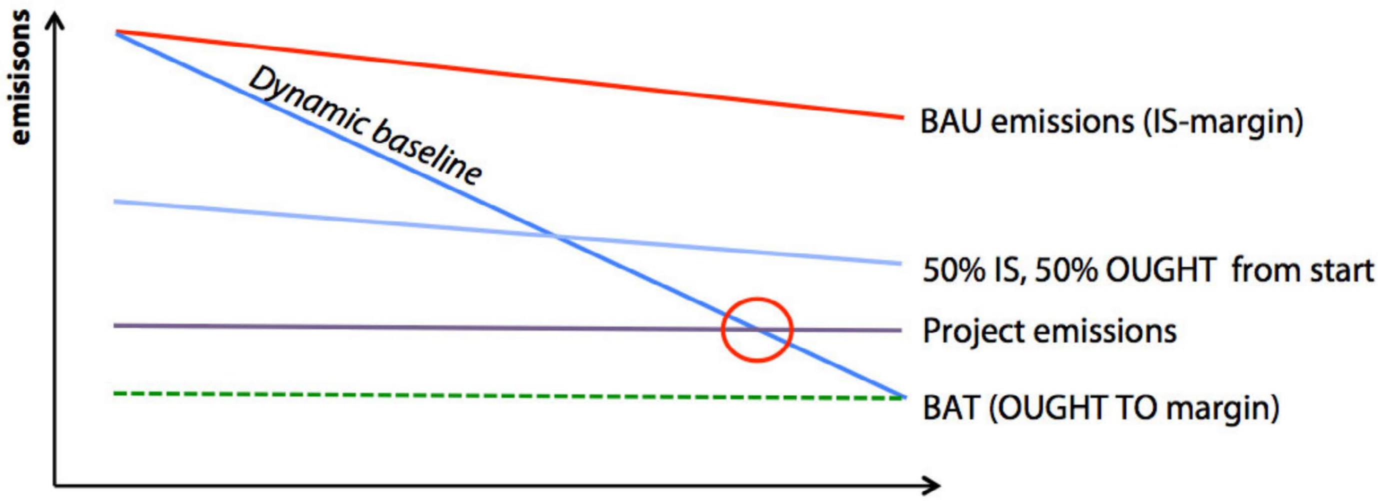
An alternative approach would be to stop the decline of the baseline at a normative reference or "ought margin" that may be a BAT (Hermwille 2020).

In this approach, the baseline is calculated as a weighted average of BAU and "ought margin", with weights changing over time from 100% of BAU and 0% of "ought margin" to 0% of BAU and 100% of "ought margin" (see Figure 5).

Both approaches – with the ambition coefficient being more stringent than the "ought margin" – seek to align with the long-term objectives of the Paris Agreement. Given their stringency, the ambition coefficient and ought margin and resulting transition period will be highly contentious.

FIGURE 5

Transition from a BAU to an 'ought margin' defined by best available technology through a dynamic baseline



Source: Hermwille (2020, p. 12)

3.1.4 A way forward: setting baselines for CDR

Current situation

Currently baseline setting is a rather exotic topic in context of CDR.

In a situation where countries have no "net negative" emission targets, approaches such as bioenergy use with carbon capture and storage (BECCS) as well as waste-biomass incineration with CCS have a "natural" baseline whereby no CCS is undertaken, but the same volumes of biomass are used for energy production. Currently bioenergy is widely accounted for as essentially climate neutral given that the carbon embodied in the biomass had previously been taken up from the atmosphere by the growing plant. This assumption is increasingly being questioned as inaccurate due to potential land-use emissions associated with dedicated plantations displacing other land-use or unmanaged forests representing a degradation in standing biomass carbon stocks. This notwithstanding, for the time being the baseline for BECCS remains climate-neutral energy production (despite very real smokestack CO_2-emissions).

For the purest-form CDR technology – all value-chain elements of which purely exist for the purpose of removing CO_2 from the atmosphere into durable storage – Direct Air Carbon Capture and Storage (DACCS) the baseline is no activity whatsoever.

This means that tracking the results achieved through either BECCS or DACCS activities involves solely subtracting the monitored carbon flows (emissions during capture, transport and storage and storage volumes) from zero, which ought to yield a negative emissions value.

There are other negative emissions technologies, for which this might not be quite as simple, given that they represent processes that are being combined with existing activities such as cement production (whereby CO_2 can be deliberately bound into the material), or production of durable materials form atmospherically or captured or biogenic CO_2. In those cases, the baseline ought to represent the processes that would take place without the additional efforts required to achieve removals.

Future developments

If the net-mitigation baseline setting approach is used – e.g., applying the ambition coefficient – to ensure a contribution to global mitigation efforts in line with global net-zero ambition, then gradually there will have to be a shift towards only permitting crediting of removals.

Once CDR measures have become widely established common practice, included in unconditional nationally determined mitigation contributions (NDCs) or required through regulation, baselines will have to be adapted to reflect for that new reality. This would then mean that in the corresponding sectors, a certain amount of removals will have to become the new normal and thus the baseline. Against this baseline only more effective forms of removal could be deemed worthy of crediting.

A simple approach for applying an ambition coefficient for countries with net removal targets (meaning a negative balance of emissions from sources and sequestration and storage in sinks) would require a country's net removal target to be denominated as a percentage of base year emissions. The ambition coefficient value would be the higher, the higher the net removal target. Let us assume a country with 100 million t CO_2eq. base year emissions. It takes up a net removal target of 10 million t CO_2eq per year, i.e. 10% of base year emissions.

Now the ambition coefficient to calculate removal credits from that country would be set at 10% for the period in which the target applies. For an ambitious target of 50% the coefficient would be set at 50%, and reach 100% if the country annually removes a GHG volume equivalent to the base year emissions level. This approach could be refined by deducting an amount commensurate to the global natural carbon sequestration which is not allocated to countries, such as the ocean carbon sink. If this natural sequestration would reach 20% of total global base year emissions, the ambition coefficient could be adjusted by this value, meaning that a country with a removal target of 80% would get an ambition coefficient of 100%, and the country with a removal target of 10% a coefficient of 12.5%

3.2 Monitoring methodologies

Monitoring at project-level – under the CDM and voluntary carbon markets – tends to be more detailed compared to the aggregate national inventory-level monitoring. For CCS-based activities, however, reporting is expected to be done at a project-level too. However, there are a few particularities for inventory reporting (see Textbox 2). Monitoring of land-use and forestry related sinks has some further complexities (see Textbox 3).

Monitoring requirements under the CDM

The CDM provides a series of guidelines and requirements for monitoring methodologies. The guidelines are differentiated for large- and small-scale methodologies, afforestation and reforestation as well as CCS methodologies. In general, monitoring methodologies should include the following elements (CDM 2014):

→ Description of the data and information that will be collected to monitor and calculate the GHG mitigation results generated by the implementation of project activity including baseline emissions, the project emissions and leakage. Project proponents should also include information on algorithms and formula used.

→ Definition of variables that will impact the GHG mitigation results of the project activity continuously and variables that are generally constant during the crediting period.

→ Measurement and calibration requirements and procedures of the variables that shall be continuously measured and for the variables that can be measured or calculated at the beginning of the crediting period or once a year. These methods and procedures could include accepted industry standards as well as national or international standards.

→ Procedures on Quality Assurance and Quality control (QA/QC)

→ Uncertainty and accuracy measurement levels of the equipment and instruments used to measure various parameters. It is required that measured data with high levels of uncertainty is compared with other sources of information to guarantee consistency.

For CCS-based mitigation activities, project participants are to demonstrate that the project activity does not involve: (i) The transport of carbon dioxide from one country to another; and/or (ii) A geological storage site that is located in more than one country.

The project participants shall clearly document in the PDD how the liability obligations arising from the proposed CCS CDM project activity or its geological storage site are allocated during the operational phase, closure phase and post-closure phase.

Furthermore, under the CDM project standard for project activities, there are specific design requirements for the monitoring plan for CCS) project activities. that are described in greater detail in Section 4.1.2.

BOX 2

Monitoring and reporting of CCS-related activities in GHG inventories

Volume 2 – Energy of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (notably Chapter 2 and 5), provides guidance for estimating GHG emissions from CO_2 capture associated with combustion activities, particularly those relative to power plants, transport, injection and storage systems. Guidelines in Chapter 2 for CO_2 capture indicate that plant-specific reporting at Tier 3 is required (given the technologies' novelty). Emissions from capture and compression are calculated as the difference from emissions assumed without capture minus the metered amount captured. This method thus naturally considers any rise in energy consumption at the power plant associated with the capture process. Chapter 5 provides guidance for estimating fugitive emissions during transport via pipelines and ships which are the main modes of CO_2 bulk transport, yet methods of calculating emissions from truck and rail transport are not covered as those means of transport are unlikely to be significant in most of the countries. Furthermore, under the guidance it is recommended that any emissions from compression of the stored gas at the storage site should be measured and reported and that only emissions pathways that need to be considered in the accounting are CO_2 leakage to the ground surface or seabed from the geological storage reservoir (IPCC 2006).

As a matter of principle, the GHG inventory guidelines state that the mitigation result of a CCS activity-chain is reported in the sector in which the CO_2 is being captured, whereas any emissions associated with transport and underground storage is reported in the respective countries' energy sector reporting. Where transport is across a national boundary, the territorial principle applies.

Monitoring requirements under Verra's Verified Carbon Standard

General monitoring requirements

Projects shall be monitored in accordance with the methodologies applied and shall consider two key requirements (Verra 2021):

- → Data and parameters to be provided in accordance with the selected methodology and its provisions regarding quality and treatment of uncertainty.
- → A monitoring plan is needed which considers all necessary information on how to obtain, record, compile and analyse data and information to quantify GHG emissions and removals, including leakage. This plan includes roles and responsibilities and, where monitoring equipment is used, it must be calibrated according to the equipment specifications and/or national/international standards.

Monitoring of land-use and forest activities under the VCS

For land-use and forestry activities monitoring includes field measurements after each harvest from which emission reductions can be estimated (Verra 2016). Thus, after each harvest, all parameters that cause emissions must be sampled in the field and estimated according to the different methodologies and region where the project is carried out.

For example, areas in dry forests and long regeneration time may be monitored every five years, while in tropical moist forests, every two years, due to the very fast growth rates.

In the case of A/R, Verra generally uses CDM methodologies. The methodologies used are AR-ACM0003 and AR-AM0014 for large scale, and AR-AMS0003 and AR-AMS0007 for small scale, in both cases separating the wetlands from the other forest types (CDM n.d.); and seek to verify the applicability of the regulatory conditions and definitions, the change in carbon stocks and emissions of both the project and the leakage. In this sense, precision requirements are needed and listed in the tool "Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities".

BOX 3

VCS monitoring approach for forestry sector activities

The Volume 4 – Agriculture, Forestry and Other Land Use of the IPCC guidance provides methods for estimating greenhouse gas emissions and removals associated with changes in biomass, dead organic matter and soil organic carbon on Forest Land and Land Converted to Forest Land. It spans the following carbon pools:

- i) Biomass (above-ground and below-ground biomass)
- → Dead organic matter (dead wood and litter)
- ii) Soil carbon
- iii) Non-CO_2 gases (CH_4, CO, N_2O, NO_X)

Which carbon pools are reported upon will depend on their significance in national conditions.

In addition, this chapter addresses carbon stock changes on managed forests (divided into Forest Land Remaining Forest Land and Land Converted to Forest Land) from human activities; provides tier 1 methods and default values for higher tier methods; and includes methods to estimate non-CO_2 GHG emissions from biomass burning.

Carbon pools are evaluated differently depending on whether they are Forest Land Remaining Forest Land or Land Converted to Forest Land.

Forest Land Remaining Forest Land

Forest land over 20 years (or country specific). Every step considers a choice of methos, choice of emission factors and choice of activity data. The first step is to estimate biomass gains and losses, considering at the end an uncertainty assessment. Then, as a second step, methods for estimating dead organic (DOM) matter are presented. Tier 1 assumes that carbon stock changes in DOM are zero, but where countries want to quantify DOM need to go to Tier 2 or 3 methodologies, and in countries where DOM is key, they should adopt higher Tier, even. At the end, an uncertainty assessment shall be included (except for Tier 1). A thirds step is to estimate change in soil carbon stocks with separate guidance for i) mineral forest soils, and ii) organic forest soils, in both cases considering uncertainty at the end. Finally, as a last step, is to account non-CO_2 GHG from biomass burning caused by natural or controlled fires, considering a country-specific uncertainty assessment at the end of this fourth step.

Land Converted to Forest Land

Other land uses converted to forest lands (including plantations) according to definition of forest adopted by each country with a suggested period of 20 years.

Again, stratification is a good practice to reduce uncertainty. Three steps are covered, being the first calculation of emissions and removals of CO_2 by changes in biomass (above- and belowground biomass). Then, changes in carbon stocks in dead organic matter pools are assessed to finally, as the third step, emissions of carbon from mineral and organic soils is calculated.

All these steps consider an appropriate choice of method, emission factors, activity data and an uncertainty analysis. Finally, non-CO_2 GHG emissions from biomass burning is assessed.

Independently of forest type, completeness, time series, AQ/CQ and reporting and documentation is to be assessed and documented.

— Completeness: all carbon gains and losses should be covered.

— Developing a consistent time series: activity data might only be available every few years and achieving time series consistency may require longer time series. Consistent accounting should use common definition of climate and soil types.

— Quality assurance and quality control: GHG inventories may have difference accuracy and levels of bias, then expert review of emission estimation procedures is a good practice. Internal and external review should be considered, preferably by experts not directly involved in the inventory development.

— Reporting and documentation should be as detailed as possible and including definitions and evidence of the correct application of those definitions.

3.3 Additionality testing

Due to the important implications of additionality (requiring that the implemented projects indeed bring net environmental benefits), additionality testing approaches have often been scrutinized and contested since the emergence of international baseline-and-credit schemes over two decades ago (Michaelowa et al. 2019). Current methodological approaches for additionality testing are built on decades of extensive efforts by the international carbon market community, most notably the work done under the Kyoto Protocol's CDM (Ahonen et at. 2021).

3.4 Additionality testing practices for CDR

Some new CDR voluntary markets including Puro Earth do not consider additionality whatsoever based on the assertion that their project types would certainly not have happened in the absence of carbon-revenues. This assumption is, however, only true as long as the following necessary conditions are all fulfilled:

a) no regulation requires the corresponding measures,

b) the measures are not necessary for NDC achievement,

c) there is no meaningful savings potential or revenue source associated with the measure, and

d) the measure is associated with costs exceeding any carbon-pricing incentives present or there are other prohibitive barriers

As carbon prices increase, policies emerge that variously support or require certain removals (e.g. toward sectoral or national caps or targets), and as removal technologies mature and decrease in costs, the situation will change and require introduction of additionality testing for credible market-based instruments incentivizing CDR.

In the following we therefore examine existing approaches that could more generally be applied for additionality testing on CDR projects.

Additionality approaches under compliance markets (CDM)

The CDM defines additionality of non-afforestation and reforestation projects as the "The effect of the CDM project activity to reduce anthropogenic GHG emissions below the level that would have occurred in the absence of the CDM project activity" (CDM 2019). This definition, while nominally addressing the difference between emissions with or without carbon-revenue from the CDM in its operation describes the distinction (and the corresponding test for which there are rules and requirements) between activities that would have taken place without carbon-revenues and those that would not (and are thus additional).

BOX 4

CDM approach to additionality determination for A/R projects

The principle of "additionality" is at the core of the CDM (Michaelowa 2009). It seeks to ensure that CDM projects would not have occurred in the BAU scenario. For the particular case of A/R activities the CDM foresees a combined additionality and baseline scenario determination. The "combined tool to identify the baseline scenario and demonstrate additionality in A/R CDM project activities", follows five steps to assess the additionality and thus acceptability of a proposed A/R activity:

- → Step 0: Preliminary screening based on the starting date of the A/R project activity;
- → Step 1: Identification of alternative land use scenarios to the proposed A/R;
- → Step 2: Barrier analysis that would prevent the implementation of at least one alternative land use scenarios;
- → Step 3: Investment analysis (if needed) and;
- → Step 4: Common practice analysis (analysis on the extent to which forestation activity has already diffused in the geographical area).

This tool to evaluate the additionality of A/R activities is also used for A/R activities by standards such as the VCS or The Gold Standard.

VCS definition of additionality

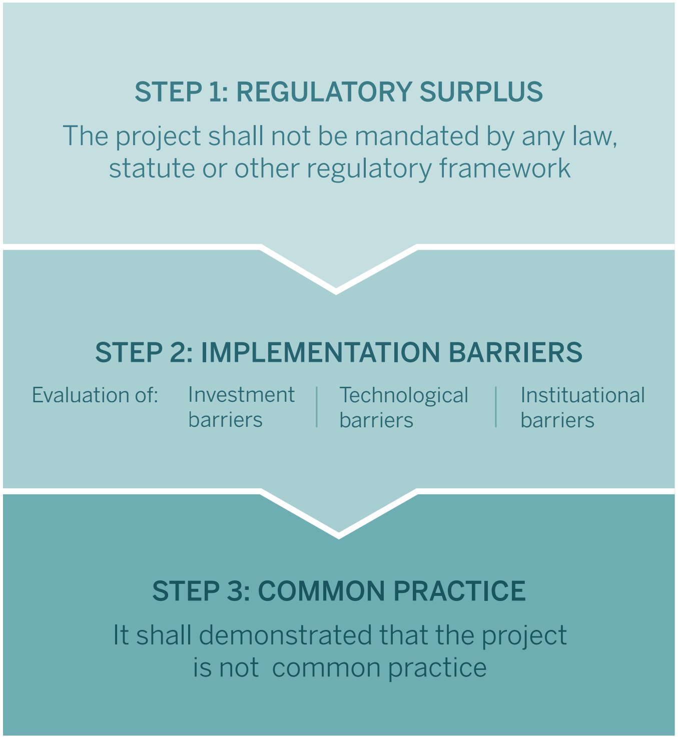
Under VCS the concept of additionality is defined as: *"A project activity is additional if it can be demonstrated that the activity results in emission reductions or removals that are in excess of what would be achieved under a "business as usual" scenario and the activity would not have occurred in the absence of the incentive provided by the carbon markets. Additionality is an important characteristic of GHG credits, including VCUs, because it indicates that they represent a net environmental benefit and a real reduction of GHG emissions, and can thus be used to offset emissions."* (Verra 2021)

Under the VCS, additionality testing procedures are included in the methodologies – either using a project method (see Figure 6) or a standardized method (see Figure 7) (Verra 2019). It should be noted that the standardized method skips the investment test and thus is not really credible. Why is that the case? Let us use the example of a performance benchmark.

The benchmark is set at the 20th percentile of performance. It however does not specify at all whether the activity is attractive or not from an investment point of view.

FIGURE 6

VCS additionality demonstration – Project Method



Source: authors

FIGURE 7

VCS additionality demonstration – Standardized Methods

Performance methods

STEP 1: REGULATORY SURPLUS

The project shall not be mandated by any law, statute or other regulatory framework

STEP 2: PERFORMANCE BENCHMARK

The GHG emissions generated (or carbon sequestered) per unit of output, unit of input or sequestration metric by the project shall be below (or above, for sequestration) the prescribed performance benchmark metric or proxy for such metric

Activity methods

STEP 1: REGULATORY SURPLUS

The project shall not be mandated by any law, statute or other regulatory framework

STEP 2: POSITIVE LIST

Option A: Activity Penetration

The methodology shall demonstrate that the project activity has achieved a low level of penetration relative to its maximum adoption potential (the level of penetration of the project activity shall be no higher than 5%)

Option B: Financial Feasibility

The methodology shall demonstrate that the project activity is less financially or economically attractive than the alternatives to the project activity

Option C: Revenue Streams

The methodology shall demonstrate that the project activity does not have any significant sources of revenue other than revenue from the sale of GHG credits (limited to 5% of the capital cost)

Source: authors

Gold Standard additionality approach

Under the Gold Standard, voluntary offset projects must "reasonably demonstrate that the emission reductions from the project are additional to what would have happened in the absence of the project". To satisfy this additionality test, project proponents need to satisfactorily demonstrate that:

- → The project would not have occurred without the project being a Gold Standard voluntary offset project; due to financial, political or other barriers;
- → The project goes beyond a `business as usual' scenario;
- → Greenhouse gas emissions are lower with the project than they would have been without the project (i.e. the baseline situation)

For this the standard sets out a specific approach for additionality testing (Figure 8).

FIGURE 8

Operationalized approach for additionality testing under the Gold Standard

Measurability of mitigation	Mitigation needs to be measurable. Results should be predictable, amenable to standarized validations and verification processes.
Introduction of technology and/or knowledge innovation to the host country	Projects should positively contribute to technology transfer
Check for public announcement	Where public announcement has been made of the project going ahead without it being a voluntary offset project, the project is not eligible
Compliance with the UNFCCC´s Additionality Tool	Projects should comply with the CDM "Tool for the demonstration and assessment of additionality"
Not employ Official Development Assitance (ODA)	The project should not employ ODA for purchasing of VER credits

Source: authors based on Gold Standard (2006)

04

Existing baseline and monitoring methodology elements for CDR

This section maps the existing frameworks, approaches and methods that (in part) apply to or offer lessons for various forms of carbon dioxide removal. The section starts by examining the approaches relevant to CCS (4.1). It then examines what approaches to direct air capture (DAC) exist (4.2) and discusses approaches to capture from biogenic sources (4.3) and finally examines the special case of various CCU applications (4.4).

4.1 Geological storage (and transport) methodology elements

To date, CCS methodology elements have been focussed on achieving emissions reductions by capturing carbon from fossil or geogenic sources. Many of these could, however, also be applied to uses that would achieve a removal of CO_2 from the atmosphere – namely if combined with DAC or if capture takes place at biogenic CO_2 sources. The following thus offers an overview concerning baseline setting, monitoring requirements, and additionality in the existing methodologies or frameworks.

4.1.1 Methodology scopes relevant to carbon dioxide transport and geological storage

Methodologies, frameworks and protocols vary in terms of their scopes and applicability to various forms of carbon dioxide transport and geological storage

→ The methodology of the **American Carbon Registry (ACR)** is only applicable to storage by way of enhanced oil recovery (EOR); carbon can be variously sourced including from DAC facilities (American Carbon Registry 2015);

→ The **Alberta protocol** is only applicable to CCS projects that inject CO_2 into saline aquifers as per the Alberta state regulations (State of Alberta 2015);

→ The **Australian Emissions Reduction Fund (ERF)** claims to cover all CCS/CCUS activities (Australian Government Department of Industry, Science, Energy and Resources 2020).

→ **Puro.earth** has a methodology applicable to activities that store CO_2 captured directly from the atmosphere or from biogenic sources geologically (Puro earth 2020).

GHGs that are covered:

→ In the **C2ES accounting framework** and **ACR** methodology, CH_4 and N_2O emissions are not calculated in baseline emissions (McCormick 2012; American Carbon Registry 2015);

→ CO_2, CH_4, and N_2O must be quantified in the **Alberta quantification protocol** (Government of Alterta, 2015);

→ In the **California CCS Protocol**, a broader spectrum of GHGs must be quantified including CO_2, CH_4, N_2O, volatile organic compound (VOC), CO (California Air Resources Board 2018);

Two options for baseline setting are commonly used in the examined standards:

→ **Projection-based baseline:** calculated based on the continued practice of GHG emissions, corresponding to BAU baseline;

→ **Standards-based baseline:** calculated based on performance standard of a certain project type or section, corresponding to performance standard baseline.

4.1.2 Monitoring methodologies relevant to carbon dioxide transport and geological storage

Across the investigated methodologies, the requirements for monitoring can generally be classified into two separate categories:

1. Project carbon flow monitoring including emissions along the chain from capture, transport, to injection; and
2. Monitoring for storage.

Continuous measurement is normally required for project emission monitoring and well-established technical monitoring approaches are recommended, such as using shelf metering equipment, keeping all calibration and maintenance records, etc. By contrast, the monitoring of CO_2 storage is required to be site-specific as the behavior of stored CO_2 varies significantly in different geologic reservoirs. As a result, the project proponents often are expected to develop their own monitoring strategy for each project.

Furthermore, although as of the date of this report, under the **CDM** no CCS methodologies have been approved, the decision on CCS (UNFCCC 2011) as well as the project standard for project activities (CDM 2021) already provides specific design requirements for CCS project activities, including the requirements of the monitoring plan. Moreover, even though the standard defined CCS as follows: "the capture and transport of carbon dioxide from anthropogenic sources of emissions, and the injection of the captured carbon dioxide into an underground geological storage site for long-term isolation from the atmosphere" (CDM 2021), the monitoring principles and requirements defined in the standard could potentially be applicable to CDR activities that involve permanent storage at geological formations.

An overview of the monitoring requirements that the proposed CCS CDM project activity shall comply with are (UNFCCC 2011, CDM 2021):

- → Reflect the principles and criteria of international good practice for the monitoring of geological storage sites and consider the technologies described in IPCC Guidelines.
- → Transparently specify which parameters and information will be monitored and collected, as well as the location and frequency of application of different monitoring techniques during the operational phase, closure phase and post-closure phase. Including the monitoring of geological, geochemical and geomechanically parameters, as applicable, and any other relevant parameters in the overburden and surrounding domains of the geological storage site. As well as assuring the monitoring of CO_2 streams composition in various points along the value chain of the project (capture, transport, and storage).
- → Present the techniques and methods that allow to estimate the quantity of CO_2 stored in the geological storage site, and to detect potential leaks and estimate the quantity of any leak from the geological storage. As well as envisage an assessment of the efficacy of the remedial measures implemented in the event of leaks.
- → Introduce provisions to assure the recalibration of the numerical model(s) that could have been used in the geological site characterization, to ensure that the injected CO_2 is and will behave as predicted to minimize any risk of leaks or other negative impacts.

4.1.3 Additionality relevant to carbon dioxide transport and geological storage

Not all methodologies or frameworks to date include an additionality test. The **Alberta government's Quantification Protocol** and **California's CCS Protocol** do not include such a test. The accounting framework of **C2ES** also does not appear to include any specific rules with respect to testing additionality, on the basis of the framework's claim to remain policy-neutral. However, it does require that any projects using the framework provides its own additionality criteria and assessment in order to facilitate the implementation of projects.

Of the examined methodologies and protocols that include additionality tests, the **American Carbon Registry** methodology employs a two-step test (American Carbon Registry 2015, p.11f.):

- → Regulatory test
- → Exceed a performance standard, with respect to emission reductions or removals. The project developer may choose one of the following as the standard:
    1) Practice-based: evaluating the adoption rates or penetration level;
    2) Technology standard: installation of a GHG technology may be determined to be uncommon to be additional;
    3) Emissions rate or benchmark.

In comparison, the **Australian ERF** – method scoping paper (Australian Government Department of Industry, Science, Energy and Resources 2020) requires multiple measures to ensure additionality for a project:

- → Eligibility requirements
- → Crediting period
- → Baseline setting
- → Statement of activity intent

The definition of additionality in the ERF method scoping paper possesses a broader meaning. It contains the concepts of additionality, baseline scenario, monitoring, reporting, and verification that are defined in other standards and protocols. With the definitions compared between the ERF method scoping paper and other standards, the eligibility requirements of the paper are found to be in line with the additionality definitions in other standards. The eligibility requirements examine the following factors:

- → CCUS activities that are required or encouraged by a law/regulation or program of the Commonwealth, a state or a territory;
- → Commercial readiness and financial viability;
- → Types of CCS/CCUS that face significant financial

The eligibility requirements need to be supplemented by 'regulatory additionality requirement', 'newness requirement', and 'government program requirement'.

The first factor to be examined is concerning regulatory additionality. The requirement for it is however expanded in the Australian ERF and more specific compared to other methodologies. Regulatory additionality is thus considered to be met if (Australian Government Clean Energy Regulator 2020):

1. the Regulator is satisfied the activity goes beyond any existing legal requirement; or

2. the activity is covered by an 'in lieu' provision in the applicable ERF method; or

3. the Commonwealth, state or territory regulatory requirement refers to reducing or offsetting emissions, but does not specify a particular activity to do so; and to help fulfil or meet a state or territory requirement to reduce or offset emissions, the regulated entity establishes an ERF project and transfers ACCUs from that project into a specified Commonwealth holding account in the Australian National Registry of Emissions Units (ANREU).

4.2 Direct air capture methodologies

The **American Carbon Registry** claims to be applicable to DAC but provides no specific rules other than for those applicable to the sequestration employed in conventional CCS activities. The ACR suggests that DAC projects can meet the practice-based performance standard (see section 4.1) due to the low activity penetration of DAC – unless direct air capture is required by regulations. The ACR considers baseline emissions as "...determined from the volume of gas and its concentration measured at a suitable location in the capture process." Clearly this definition does not work for DAC, given that the baseline for DAC is its absence i.e. zero CO_2-flows – whereby in contrast the DAC project implementation results in a negative-emissions CO_2-flow.

Climeworks has developed its own monitoring methodology on the basis of specific project design documentation of its new plant "Orca" in Iceland that effects DAC and storage in underground basaltic rock formations, and had it independently validated per ISO 14064-2. Not many details of its methodology are public.

However, Climeworks has been adamant in its public communication that embodied carbon (emissions generated upstream in the production of materials necessary to construction and operation of the plant) are also to be included in monitoring methodologies, which suggests that their methodology is breaking new ground and establishing a step-up in stringency and environmental integrity for voluntary markets. An independent LCA study (Deutz and Bardow 2021) states that embodied carbon emissions in case of Climeworks' technology are below 10% of the overall removal volume over the plant's lifecycle.

4.3 Capture from biogenic sources

Biomass use for achieving CDR represents one of the biggest sources of uncertainty. The current approach tends to view biomass – as part of the atmospheric carbon circle – a climate-neutral carbon source. Accordingly, any use of biomass for energy coupled with capture and storage of ensuing CO_2 achieves a negative-emission in the amount of the stored CO_2. Unfortunately, however, this represents a narrow interpretation of the carbon flow involved in such activities, and might increasingly appear inadequate to the credible tracking of results from BECCS and other removal activities involving biomass and land-use. There are at least three sources of potential emissions, which – for a holistic carbon tracking approach – ought to be reflected in future methodologies for activities based on biomass and land-use related removals:

- → Direct emissions from the supply chain (e.g. fertilizers, transport emissions, pellet-production)
- → A potential imbalance of biomass growth and harvesting rates
- → Indirect emissions resulting from displacement of land-use (so-called leakage – not in the physical meaning of the word)

While we recognize these issues – sometimes described as the delineation between "sustainable biomass" and other sources of biomass – as pressing, we will not go into detail on how such differentiation may be achieved in this report.

4.4 Carbon capture and utilization methodologies

4.4.1 Biochar

Puro.earth offers a methodology for biochar. According to this methodology (Puro.earth n.d.), CO_2 removals are achieved by biochar production if the biochar is not intended for burning for energy generation. There is no additionality assessment foreseen in the Puro.earth methodology. Finally, there is no public knowledge of the actual calculation approach for the baseline and monitoring methodology; instead it is based on Life-Cycle Assessment by third party following ISO 14040 and ISO 14044 standards where applicable. It should be noted that ISO standards are process, not performance standards so they cannot guarantee the conservativeness of a calculation.

The absence of an adequate system boundary definition and of additionality determination is problematic: this is key to adequately track any carbon losses from development to end-use (Fawzy et al. 2021). And the lack of transparency goes against expectations for offsetting (World Bank 2020).

Carbonfuture is a vendor of removal certificates and describes its approach in a document named Carbonfuture C-Sink Standards. This document describes 'additionality' but not based on the same understanding as used in carbon markets, so Carbonfuture does not appear to involve an additionality test. It utilizes the European Biochar Certification (EBC) sink certification methodology to determine the sink potential from biochar production (at the production gate) and without apparent monitoring for the use of the biochar.

Requires buyers to self-declare their application of biochar (and thereby the permanence of storage) – and considers this represent verification of the carbon sink.

The **Ithaka Institute for Carbon Strategies** offers a certification method (Schmidt et al. 2021), but it does not address key aspects for crediting. In particular it sets the system boundary of a project just for production of biochar itself and does not consider any land-use related emissions (e.g. should biochar decay or be washed out).

4.4.2 Cement-replacement material

Puro.earth has a methodology for *cement-replacement material from steel-slag that binds CO_2 during the hardening phase*. It employs no additionality test and there does not seem any public record of the baseline and monitoring methodology used.

The **VCS** includes a methodology '*for project activities that capture waste* CO_2, which would *have otherwise been emitted into the atmosphere, and utilize that gas as a feedstock in the production of concrete*' (VM0043, 2021). CO_2 from DAC is also permitted under this methodology. The baseline scenario is the continuation of traditional manufacture of concrete. The method foresees use of the activity method to test for additionality and includes a positive list. The methodology does not foresee any monitoring for CO_2 re-emissions from concrete.

4.4.3 Plastics production

Verra has developed a methodology targeting plastic production (VM0040) based on CO_2 waste gas captured.

→ *Applicability condition*: This methodology is globally applicable to project activities that convert carbon dioxide and/or methane, which would have otherwise been emitted into the atmosphere, into a useful plastic material for sale into the plastics market.

→ *Baseline*: Project method; baseline emissions = 0 when the product is biodegradable

- *Component 1: Plastic production*
- *Component 2: GHG feedstock (CO_2, non-qualifying & qualifying CH_4, non-qualifying CH_4 must be attributed to resultant CO_2 emissions)*

→ Projects cannot combine CO_2 and CH_4 as feedstock as carbon footprint would be hard to trace.

→ Additionality: activity method (penetration option)

→ Leakage: one potential source: transition of CH_4 use to another more carbon-intensive fuel

4.4.4 Wood in building construction

Puro.earth has developed a methodology for wood in construction which also has several limitations for results-based transactions: It includes no additionality test, which appears particularly problematic for construction. It entails a very narrow system boundary definition which disregards emissions during transport, construction, and end-of-life. Buildings are simply declared to represent 'long-term storage' – an assumption which the standard argues is justified by the EU Standard EN 1990 that requires building designs for a 50 years lifespan. As noted above, this is below any generally accepted duration for permanence.

We view this to be an inadequate representation of carbon flows in the building sector and for CCU (with potential storage) in general. For these applications that do not come with inherent permanence of storage a special non-permanence risk tool will be needed that accounts for instances of less-than-expected permanence and includes some form of monitoring.

05

Overcoming the gaps and problems

5.1 Gaps and problems identified

The mapping of methodology elements and approaches presented in this report highlighted the following key gaps and problems for consistent and credible use of CDR in voluntary markets and toward NDC implementation.

- → Inconsistencies in the treatment of key aspects of CDR activities including pertaining to the system definition, permanence of storage, secondary emissions (leakage). Especially the lack of robust approaches to permanence determination is deeply worrying,
- → Lacking baseline and monitoring methodologies for specific CDR types including almost completely for all forms of carbon capture use and storage
- → Absence of, or inadequate, additionality testing. Given that even now many forms of CDR are non-additional due to revenues (e.g. harvest increases due to biochar use, or reduced building costs due to use of wood as building material), with proliferation of CDR supporting policies, additionality will be even more problematic
- → Lack of transparency in CDR methodology development and no access to final methodology documents. This is unusual as hitherto all relevant standards on the voluntary carbon market have had convincing approaches to transparency of methodologies.

Inconsistencies in baseline scenario, project boundary, and project emissions

One difference is identified in the quantification method for baseline and project emissions. In the ACR methodology and C2ES accounting framework, the baseline emission is determined at the capture end by accounting for the emissions from primary processes and therefore the CO_2 source is included in the project boundary. In comparison, the California CCS protocol and Alberta government's quantification protocol exclude the primary CO_2 sources from the project boundary and determine the baseline emission on the storage end by accounting for the quantity of CO_2 injected. To calculate the net emission reductions or removals, the former method needs to calculate vented and fugitive CO_2 emissions along the value chain and then deduct them from the baseline emissions. While, the latter method has intrinsically deducted the vented and fugitive emissions as the injected CO_2 is monitored. The Australian ERF method scoping paper presents both approaches and name them as 'cradle-to-well' (capture end) and 'Injection-well-focused' (storage end), respectively. It concludes that "(...) the use of the actual CO_2 injection amount as the baseline reference could potentially result in a more accurate estimation of net abatement" (Australian Government Department of Industry, Science, Energy and Resources 2020).

While some of the investigated methodologies completely exclude upstream processes from the project boundary and therefore do not consider them in the calculation of project emissions, a few methodologies such as the Alberta quantification protocol do account for embodied CO_2 emissions generated in some of the upstream processes (e.g., production and delivery of materials, extraction/processing and transport of fuels, etc.) for the calculation of net emission reductions or removals.

The methodology issued by Puro.earth also accounts for any emissions generated solely due to the project activities, including emissions from cultivation, harvesting and transport of biomass and emissions from materials and construction.

These differences between methodologies cause differences in the quality of carbon credits generated through removals. There is urgent need for a standardization exercise which leads to a conservative approach, in order to prevent that NGOs or researchers criticize CDR to be flawed, which could lead to an evaporation of demand for removal credits and a price collapse.

Lack of methodologies for specific activities

It is evident that the existing methodologies have not covered all types of CCUS projects. Most of the existing methodologies are focused on the CCS scenarios that reduce GHG emissions by capturing CO_2 from power and industrial sectors and storing it in geological reservoirs. Methodologies for the technologies that can achieve direct CO_2 removals (e.g., DACCS, BECCS, etc.) are lacking. Although some methodologies or frameworks have recently appeared and/or claimed to be applicable to projects such as DAC or biogenic CO_2 capture processes, they do not provide as detailed methodologies for DAC or BECCS as seen in other methodologies for emission reduction project activities. For instance, the methodology of Puro.earth addresses eligibility of project types and quantification method for DAC and but not provide any information regarding additionality and monitoring strategies. The ACR methodology claims to be also applicable to DAC, nevertheless it is not treated so distinctly from other project types. Furthermore, the differentiation between GHG emission reduction and removal is not clear.
Similarly, only a few methodologies have been developed for CCU projects.

Two factors are thought to lead to the situation: 1) the majority of the CCU technologies are still at low technology readiness level (Roh et al. 2020); 2) not all CCU technologies are qualified as emission reduction or removal activities as some CCU technologies do not meet the requirement of storing CO_2 permanently (e.g., CCU-based fuels) even at very lenient definitions of permanence durations. Hence, it would make sense to develop an assessment tool of non-permanence risk for CCU instead of applying the existing tools that were in the first place developed for geological storage of CO_2.

Inadequate additionality testing

As summarized in Section 4.1.3, the assessment of additionality is lacking in many existing methodologies or framework for CCS. Of the methodologies that have included an additionality test, both differences and similarities are seen in terms of definition, available methods and assessment steps. A regulatory test is the first step for all the additionality test approaches seen in the existing methodologies. Moreover, in terms of performance test, similar standards can be found across methodologies. For example, the three options under the performance standard for additionality test in the ACR methodology correspond to the activity penetration of Verra standard, common practice analysis seen in both the Verra standard & CDM tool 01, and performance method defined in the Verra standard. However, empirical evidence shows that the penetration test is unable to credibly solve the additionality issue, as the threshold definition is generally arbitrary and not linked to the financial characteristics of the activity. Nonetheless, no financial incentive is seen in the additionality test in the ACR methodology. Of all CDR-specific additionality tests, the Australian ERF one which includes a financial and implementation barrier analysis is the most convincing one and in line with good practice under the CDM.

Lack of transparency on methodology development and final documents

Given the rapid take-off, strong demand for units, and seemingly new carbon market paradigm, many – particularly the newer – market developers and CDR offsetting platforms made only very limited efforts to transparently communicate the process through which methodologies are developed, how decisions for a particular approach (e.g. to additionality testing) were taken, and many do not seem to involve public consultations. Furthermore, the available documentation on the final methodologies is not always presented clearly or detailed enough to gain an understanding of the quality and comparability of the resulting units. Given the long experience with international compliance and voluntary carbon markets this is moving backwards and highly problematic.

Inconsistent use of key terms and arbitrary definitions

Inconsistent use of – or complete redefinitions of fundamental terms and concepts in contradiction to existing definitions provided by the UNFCCC or the IPCC including terms such as "removals" is currently posing a high risk to the development of credible mitigation through results-based CDR activities. Inconsistent definition of system boundaries similarly become problematic as this can arbitrarily change the claims of the same activity (e.g. from an emissions-reduction outcome to a "removal" outcome – if upstream or downstream emissions are cut off by the system boundary).

5.2 From Principles ....

Given the issues identified, we outline principles and steps that can be taken to address inconsistencies and gaps in a way as to ensure long-term viability and credibility of CDR as a form of climate change mitigation. Based on the authors' experience in carbon markets and climate change mitigation policy development we submit that the following principles should be applied for all removals:

1. Definitions ought to be clear, aligned with UNFCCC and IPCC definitions and used consistently
2. The mitigation targets toward which removals are used ought to be as specific as possible
3. All activity types require dedicated baseline- and monitoring methodologies that consistently address permanence, with durations for permanence being in line with scientific evidence for "equivalence periods"
4. Project system boundaries in time and space need to be set transparently and consistently
5. Baselines need to be set dynamically – in line with Paris Agreement ambition
6. Additionality testing needs to be consistent and involve financial parameters
7. Transferred mitigation units are to be correspondingly adjusted in the project-countries' inventory reporting.
8. Development, approval and final methodologies need to be transparent
9. Methodologies need to be assessed and validated by an independent party, e.g. Art 6.4 supervisory body or national regulator
10. Activity results need to be verified by an independent third Party

5.3 ...to Practice

Given the current flurry of private and public efforts toward results-based incentivization of CDR there are many opportunities to strengthen transparency, consistency, and ultimately credibility by putting the above principles into practice.

An overarching issue is to agree on a common time period for which storage needs to be guaranteed in order to be deemed "permanent". Such time period needs to be long enough to prevent a significant risk of reversals without liability, in all likelihood exceeding 50 years, better 100. The regulation needs to develop appropriate safeguards to deal with the lack of stability regarding activity developers that characterizes human activities, specifying "cascades of responsibility" when activity developers cease to exist.

For removal activity types that have inconsistent, incomplete methodologies this especially represents an expectation for consolidated efforts for transparently developing methodologies based on common and transparent definitions, assumptions, and procedures regarding permanence, system boundaries, Paris-aligned baselines, and additionality testing.

New methodologies acceptable for international market transactions are especially needed for:

→ Direct Air Capture (DAC)

→ Several forms of CO_2-transportation

→ Geological storage of CO_2 through underground mineralization in basaltic rock

→ Using wood in construction (a form of CCUS with debatable durability)

→ Enhanced weathering on land-surfaces

→ Enhanced weathering for carbon-enhanced cement production (a form of CCUS with significant inherent permanence)

For the following approaches, methodologies do exist in particular voluntary carbon markets, but they appear inadequate for use toward NDCs (transactions for compliance) per Article 6 as they do not fulfil at least one of the key principles:

- → Biochar application to soils
- → Mechanical or biological soil treatment techniques for soil carbon enhancement

For some particular activity cases, a novel approach may be needed in which methodology modules can be combined to adequately represent the GHG-flows involved in them; this includes notably:

- → BECCS with combined fossil and biogenic fuel streams,
- → Biochar application to various types of soil

The diversity of actors involved in ongoing standard developments poses a significant challenge to consistency and transparency and we see a great risk of fragmentation. Multilateral actors could once again – as previously through the CDM – serve an important role to offer an internationally accepted standard for these key issues. Most notably could the Paris Agreement's Art 6.4 mechanism as well as multilateral development banks (MDBs) and the UNFCCC's Green Climate Fund (GCF) help to avoid fragmentation by identifying and operationalizing existing definitions and provisions regarding rules modalities and procedures through which the identified inconsistencies and issues can be resolved.

At the same time, there is an important role for Paris Agreement Parties – i.e. national governments as well as the EU – to address these issues. One particular area in which they should do so is in their NDC, where they ought to specify the envisaged role of CDR, which could mean that they introduce dedicated targets or quotas for CDR (Michaelowa et al. 2020).

Another area to acknowledge the inherent differences between reductions and removals but also the differences in permanence of various CDR types could be carbon markets. In line with markets' logic of mobilizing finance and contributing to real and robust mitigation efforts, CDR types realising a high degree of permanence, respectively a long duration of storage, could reach higher prices. This would benefit the implementation and ultimately also the scale up of especially those high-permanence activities, which are still too expensive to date and are in need of additional finance flows.

So, there is a simultaneous need for both bottom-up development of potential solutions as well as top-down decision-making and consolidation across different approaches and ideas. In the following we provide a few examples for both spaces for action.

Space 1: Bottom-up development

As rules often have to partly rely on practical experience there is an urgent need for gaining experience through pioneering activities at domestic level, bilaterally between two governments or plurilaterally within clubs of willing pioneering countries. The more these activities are geared to perhaps offer an example for international best-practice the greater their value for building a basis for regional or multilateral initiatives for results-based CDR incentivization.

Some countries have already indicated their willingness to pioneer this space and further countries or groups might follow. Among the first-moving countries one can highlight Sweden (given its high level of transparency and advanced discussion of policy instruments for BECCS and Swedish-Energy-Agency led pilots) and Switzerland (through its bilateral activities implemented by KLIK).

Such first-movers may be able to shape how international cooperation on negative emissions are accounted for given the existing ambiguities in accounting and transparency related provisions for such activities: This includes in particular the definitional decision where (to which country) does an emissions reduction occur (and correspondingly whether the result is transferred to another country to be used towards its NDC or not)?

First-movers can be found in the private sector too although in some cases consistency and transparency has been lacking and standardization may be less likely to emerge from individual private-sector efforts, as seen with "wild west" type initiatives such as Puro.earth or Nori. The large-consortium effort of the CCS+ initiative toward developing an ecosystem of methodologies across different types of CDR is emerging as a possible exception, which manages to build-up a consistent and sufficiently encompassing framework for MRV of CCS-based removals and emissions reductions.

First-movers can also test methodologies through virtual simulations or case studies, in which the proposed activity type is implemented solely on paper – a dry-run so-to-speak – which can allow identifying gaps and inconsistencies e.g. between different parts of a CDR value-chain and the corresponding market actors. However, to incentivize the (often quite many) actors to engage in such activities, a credible carrot is needed, which could take the form of imminent results-based finance for CDR activities – i.e. a results-based carbon market pilot without use of units towards any NDCs – whereby the same level of stringency should be applied as for actual market-based cooperation that counts towards an NDC to test and improve on methodologies and cooperation procedures.

Space 2: Top-down development and consolidation of bottom-up methodologies

Consolidation of methodologies developed in a bottom-up fashion (i.e. across several frameworks) can be done by an international or multilateral body. This could notably be the oversight body of the Article 6.4 mechanism. Regional legislation such as the planned European carbon removal certification mechanism could also act as catalysts for greater alignment, but at the same time, such initiatives ought to be able to rely on a set of good-practice demonstrations that are emerging bottom-up. Similarly, could the GHG Protocol's Policies and Actions Standard spark action through compliance-driven crediting standards (e.g. California/Quebec) (WRI 2014). In addition, decisions by first-mover national governments might – if viewed as best-practice – feed into more formalized guidance including perhaps the IPCC guidelines for GHG inventory reporting. As shown, IPCC inventory guidelines provide only a partial guidance at this point and require further elaboration that could be based on a best-practice approach of first-mover countries. Another opportunity for specification is offered by the Initiative for Climate Action Transparency, which for example offers guidance on best-practice MRV of policy measures including for example in the forestry sector (ICAT n.d.). And finally, climate finance institutions (MDBs, the GCF and the Global Environment Facility) that act as major buyers of removals credits can also act as catalysts for greater consolidation of methodologies by selectively buying units only that fulfil a set of MRV quality criteria and additionality testing.

Critical need for learning and deliberate experimentation

It is vital to acknowledge the central role of national capacities and their need to grow gradually for policies and markets to become operational. Observations from past instances of market development including in particular in the CDM show that this learning can take a decade to build up sufficient capacities in diverse parts of the world that ought to become involved in mitigating climate change including through carbon dioxide removal activities in a consistently monitored, reported, verified and accounted for manner. The wild divergence of standards and practices we can observe at the moment remind us of the fact that consistent and credible carbon markets are not a given, but that a concerted effort is needed, which builds first and foremost on the understanding and capacity to act of many different market participants and market makers. To build up these capacities we will jointly need many years of deliberate piloting efforts in which actors remain open to learning and improvement in order to move toward a consolidated and credible market ecosystem.

06

Summary and Outlook

We have discussed the importance of consistent and transparent monitoring reporting and verification of mitigation results for results-based finance or market-based incentivization of carbon dioxide removal. And finding several challenges particular to CDR – permanence and appropriate system boundary setting, as well as challenges common to all carbon market activities such as additionality determination – we have also observed significant progress toward a joint understanding of formerly controversial issues through emergence of large-consortium initiatives and frameworks for MRV of CCS-based mitigation in the voluntary market (notably the CCS+ initiative).

Yet there still is a significant need for consolidation and development of entirely new methodology elements for several CDR types. And there is a need for several clarifications and establishment of best-practices e.g. in regards to accounting of transboundary CDR activities. There is also a need for countries to move toward greater consistency in their GHG reporting including regarding GHG metrics and net-zero targets: The transparency rules of the PA require all countries to use the same global warming potentials (GWPs) from the most recent IPCC Assessment Report from 2024 onwards. The PA text requests Parties to list emissions and removals of all GHGs in their NDCs (in as great sector-level detail as possible) and account for all in their GHG inventories, yet most countries do not yet address most types of possible CDR sinks. Furthermore, guidance is scant in regards to net-zero targets where the "balance of GHGs" can be achieved using different GWP metrics that imply very different pathways seemingly (but not actually) achieving the same net-zero milestone. The choice of metrics (GWP or global temperature potential, GTP) and time horizon has very significant consequences for the critical assessment of the amount and timing of negative emissions. It should thus become the norm that any net-zero target and policy pathway is explicit as to the metric used.

Furthermore, the strong focus on CO_2 (and not other GHGs) will need to be revisited as the relative importance of e.g. methane emissions or N_2O emissions from agriculture grows as CO_2-emissions are declining.

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Annex

TABLE 2

Baseline setting approaches under relevant existing frameworks

Methodology/ framework	Standard	Applicability conditions/ technologies covered	Baseline approach
American Carbon Registry	Based on the accounting framework developed by the Center for Climate and Energy Solutions	• *Capture*: power plant equipped with pre-, post-combustion, oxy-fuel technologies; industrial and polygeneratoin facilities; DAC facilities • *Transport*: barge, rail, truck, pipeline • *Storage*: only EOR with sequestration located in the US or Canada; utilize at minimum Class II wells in the US and similar standard in Canada • Projects that have clear and uncontested ownership of the pore space, or a filed Risk Mitigation Covenant or assurance	Business as usual • Projection-based • Standards-based
Alberta's Quantification Protocol		• CO_2 is directly captured from industrial or non-industrial facilities • Injection of CO_2 into deep saline aquifers; approved sequestration lease and approval for a storage scheme as per the regulations in Alberta • Must be in good standing with all operating permits and relevant regulations in Alberta • Achieved reductions are quantified based on actual measurements and monitoring • Metering of injected gas volumes takes place as close to the injection point as is reasonable	• Projection-based • Baseline emissions are quantified using metered quantity of CO_2 injected into the deep saline aquifer
California CCS Protocol	Low Carbon Fuel Standard	• CCS projects that capture CO_2 and sequester it in either saline or depleted oil & gas reservoirs, or reservoirs for EOR • Applies to both new and existing CCS projects provided they meet the requirements for permanence	Baseline testing (projection-based?)

Methodology/ framework	Standard	Applicability conditions/ technologies covered	Baseline approach
Center for Climate and Energy Solutions - A Greenhouse Gas Accounting Framework for Carbon Capture and Storage Projects		• CO_2 sources: 1) electric power plants equipped with pre-, post-combustion, oxy; 2) industrial facilities • Transport: only pipeline • Storage: saline aquifer, depleted oil and gas reservoir and EOR	• Projection-based • Standard-based, It also states '*Both use data from the actual CCS project to derive baseline emissions*'
Australian Emissions Reduction Fund – Method scoping paper		• CCS and CCUS projects	Design options: 1) Technology neutral and specific/ cradle-to-well CCS: baseline determined using production variables and emission intensity (standard?) 2) Technology specific/ injection-well-focused: Baseline determined by direct measurement of the amount of CO_2 injected.(projection?)
VM0040 Methodology for Greenhouse Gas Capture and Utilization in Plastic Materials	Verra Standard	This methodology is globally applicable to project activities that convert carbon dioxide and/or methane, which would have otherwise been emitted into the atmosphere, into a useful plastic material for sale into the plastics market.	Project method
AMS III.J. Avoidance of fossil fuel combustion for carbon dioxide production to be used as raw material for industrial processes	CDM	Applicable to situations where the generation of CO_2 from fossil or mineral sources in the baseline is only for the purpose of CO_2 production to be used for the production of inorganic compounds. There is no energy by-product of CO_2 production from fossil source and its consumption in the baseline	The emission baseline is the current fossil fuel based carbon dioxide production of the facility expressed as amount of CO_2 per unit of output (e.g. kg CO_2/Kg final product). IPCC default values for emission coefficients may be used in order to establish a previous indicator of kg or m3 of fuel required per kg of final product. (standard-based)
VM0043_ Methodology for CO_2 Utilization in Concrete Production	Verra	This methodology is globally applicable to project activities that capture waste CO_2, which would have otherwise been emitted into the atmosphere, and utilize that gas as a feedstock in the production of concrete. CO_2 from direct air capture is also permitted under this methodology.	Project method

Source: authors

TABLE 3

Monitoring approaches under relevant existing methodologies and frameworks

Standard / Methodology	Applicability conditions/ technologies covered
American Carbon Registry	• Based on site evaluation and geological parameters in the storage volume, simulation of potential failure scenarios that include a range of uncertainty in modelled parameters and site characteristics shall be developed • Based on the sensitivities of individual parameters to the outcomes of those simulations, the project proponent shall determine the specific monitoring parameters to be monitored, tools to be used, and the sampling frequency • Monitoring shall be designed to be sensitive to the leakage signal
Alberta's Quantification Protocol	• Two categories: 1) project emission monitoring, 2) monitoring , measurement and verification of containment • The monitoring measurement and verification include both 1) baseline monitoring tasks that are to be conducted during the pre-injection phase of the project 2) Operational monitoring tasks to be conducted periodically during the injection phase In addition, 3) monitoring will be maintained during the closure phase after injection has ceased 4) the specific monitoring technologies and activities will be determined and continuously updated and refined based on the site-specific experience
California Carbon Capture and sequestration Protocol under the Low Carbon Fuel	• Must monitor the surface, near-surface, and deep subsurface for CO_2 leakage that 1) may endanger public health or the environment 2) require reversals of the storage credits due to a failure to achieve and maintain permanence
Center for Climate and Energy Solutions - A Greenhouse Gas Accounting Framework for Carbon Capture and Storage Projects	• monitoring applies to large above ground industrial complexes and expansive subterranean geologic formations • monitoring in accordance with ISO 14064-2 principles of transparency and accuracy
Australian Emissions Reduction Fund – Method scoping paper	Not specifically addressed
VM0040 Methodology for Greenhouse Gas Capture and Utilization in Plastic Materials	• The project must monitor all key variables • The project proponent must establish, maintain and apply a monitoring plan and GHG information system that includes criteria and procedures for obtaining, recording, compiling and analyzing data, parameters and other information important for quantifying and reporting GHG emissions relevant for the project and baseline scenarios • Where measurement and monitoring equipment is used, the project proponent must ensure the equipment is calibrated according to current good practice • All data collected as part of monitoring must be archived electronically and kept at least for 2 years after the end of the last project crediting period

Standard / Methodology	Applicability conditions/ technologies covered
IPCC Guidelines for National Greenhouse Gas Inventories – Carbon Dioxide Transport, Injection and Geological	Monitoring program should include provisions for • Measurement o background fluxes of CO_2 at both the storage site and any likely emission points outside the storage site • Continuous measurement of the mass CO_2 injected at each well • Monitoring to determine any CO_2 emission from the injection system • Monitoring to determine any CO_2 fluxes through seabed or ground surface • Post-injection monitoring • Incorporating improvements in monitoring techniques/technologies over time • Periodic verification of emissions estimates
AMS III.J. Avoidance of fossil fuel combustion for carbon dioxide production to be used as raw material for industrial processes	The amount of the final product produced shall be monitored on a monthly basis and the annual production thus determined. Monitoring shall establish that there is no leakage due to the use and transportation of the renewable biomass.
VM0043_Methodology for CO_2 Utilization in Concrete Production	The project proponent must establish, maintain and apply a monitoring plan and GHG information system that includes criteria and procedures for obtaining, recording, compiling and analyzing data, parameters and other information important for quantifying and reporting GHG emissions relevant for the project and baseline scenarios

Source: authors

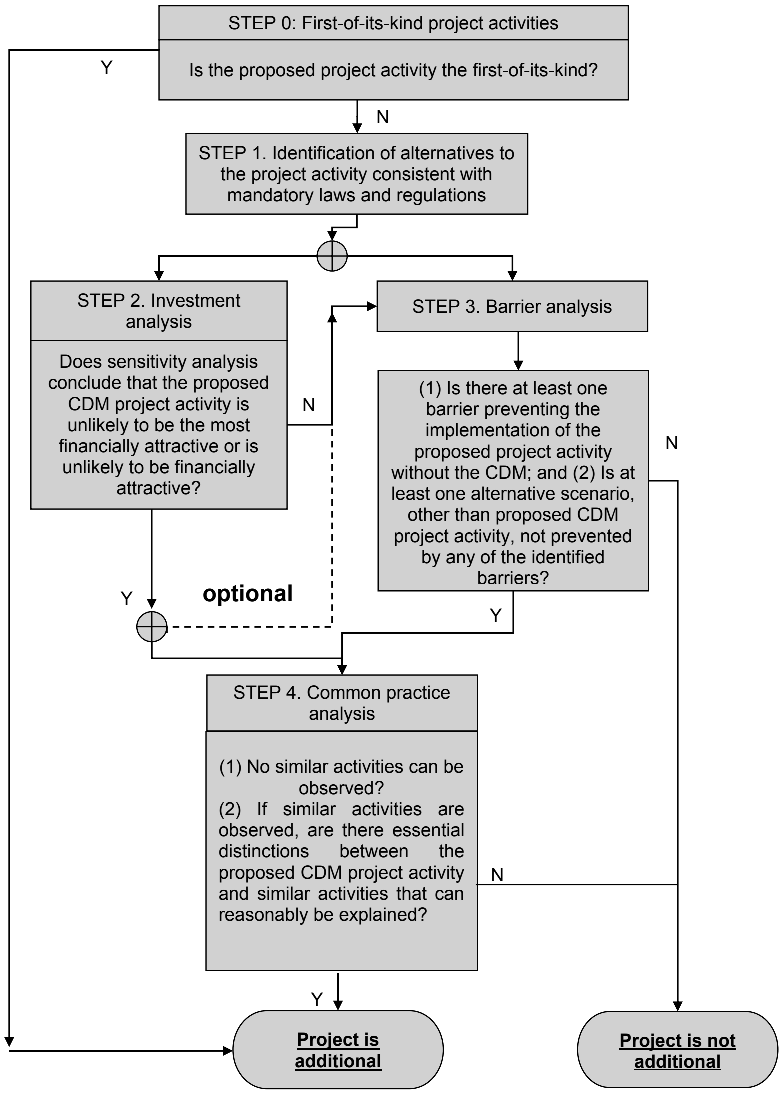
TABLE 4

Additionality testing under relevant existing frameworks

Methodology / framework	Additionality
American Carbon Registry	To qualify as additional, the project must • Pass a regulatory test; and • Exceed a performance standard (with regard to emission reduction or removal) 1. Practice-based: adoption rates or penetration level 2. Technology standard: installation of a particular GHG-reducing technology may be sufficiently uncommon 3. Emission rate or benchmark
Alberta's Quantification Protocol	Not mentioned
California CCS Protocol	Not mentioned
Center for Climate and Energy Solutions - A Greenhouse Gas Accounting Framework for Carbon Capture and Storage Projects	• Policy neutral • Determining additionality: 1. Project-specific (bottom-up) 2. Programmatic (top-down)

Methodology / framework	Additionality
Australian Emissions Reduction Fund – Method scoping paper	Eligibility requirements • CCS/CCUS activities that are required or encouraged by a law/regulation or program of the Commonwealth, a state or a territory; • Commercial readiness and financial viability of CCS/CCUS technologies in the absence of the incentive provided by the scheme, in particular for project types that would deliver material co-benefits, such as increased oil production resulting from EOR projects; • Types of CCS/CCUS projects that face significant financial or technical barriers that would not likely be overcome by the incentive provided by the ERF. Consideration would also be given to the likelihood of projects being driven by factors other than the ERF incentive, such as a company's research and development strategy or internal climate change policy.

Verra	Methodologies may use any combination of project, performance or activity methods for determining additionality
	Project method:
	• Step1: Regulatory Surplus
	• Step2: Implementation barriers
	• Step3: Common Practice
	Standardized Methods
	• *Performance method:*
	  • Step1: regulatory surplus
	  • Step2: Performance benchmark
	• *Activity method:*
	  • Step 1: Regulatory surplus
	  • Step 2: Positive list (apply one or more):
	    1) Option A: Activity Penetration
	    2) Option B: Financial Feasibility
	    3) Option C: Revenue Streams

Methodology / framework	Additionality
CDM tool for the demonstration and assessment of additionality	The use of the tool is not mandatory **Figure 1 Flowchart of the step-wise approach** 

NET-RAPIDO:

Negative emission technologies readiness assessment, policy instrument design, options for governance and dialogue aims to create a clear understanding of the opportunities, challenges and risks of negative emission technologies (NETs) for climate action to enable an objective and pragmatic consideration of this approach in policymaking. Through informed analysis and dialogue amongst relevant stakeholders, NET-RAPIDO aims to break new ground on this topic through balanced recommendations on key elements of NETs, with focus on the economic feasibility and support needs.

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