CLIMATE CHANGE
42/2024

Interim Report

How to measure and quantify biogenic carbon removals

Requirements for a transparent monitoring system

by:

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Oeko-Institut, Berlin

publisher:

German Environment Agency

German Environment Agency

Umwelt Bundesamt

CLIMATE CHANGE 42/2024

Ressortforschungsplan of the Federal Ministry for the
Environment, Nature Conservation, Nuclear Safety and
Consumer Protection

Project No. (FKZ) 3722 42 515 0
FB001531/ENG

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On behalf of the German Environment Agency

Imprint

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Borkumstr. 2
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Germany

Report completed in:
April 2024

Edited by:
Section V.1.2 Strategies and Scenarios for Climate Protection and Energy; Section V 2.6 Climate Protection Projects – Market Mechanisms UNFCCC
Judith Voß-Stemping, Marcel Kruse

Publication as pdf:
http://www.umweltbundesamt.de/publikationen

ISSN 1862-4359

Dessau-Roßlau, October 2024

Abstract: How to measure and quantify biogenic carbon removals

Robust quantification of carbon dioxide removals (CDR) lies at the heart of any certification mechanism and is central for their functionality and environmental integrity. For the establishment of a Carbon Removal Certification Framework (CRCF) that was recently adopted, the EU Commission is currently conducting an inventory of the existing knowledge base. The objective of most certification mechanisms is to turn greenhouse gas emission reductions or removals into tradable commodities. To achieve this, each certificate issued by a mechanism must reliably represent the same amount of greenhouse gas reduced or removed from the atmosphere. The report compares selected standards to work out advantages and disadvantages of existing monitoring methods for an EU certification of carbon removals.

The paper scrutinises the reviewed crediting methodologies for biogenic removals with regard to central aspects that impact the environmental integrity of these methodologies. A focus is put on the rules and requirements of these methodologies for quantifying and monitoring biogenic carbon removals. Other essential design elements are also touched upon but not considered in detail.

Robust quantification methodologies are a key pillar for ensuring the environmental integrity of removals certified under the CRCF. The report shows that existing methodologies for quantifying removals used on the voluntary carbon markets have shortcomings that involve overestimating risks when determining the net-removal impacts of project activities.

Kurzbeschreibung: Wie misst und quantifiziert man den biogenen Kohlenbindungen?

Eine solide Quantifizierung von Kohlenstoffbindungen (CDR) ist das Herzstück eines jeden Zertifizierungsmechanismus und von zentraler Bedeutung für dessen Funktionalität und ökologische Integrität. Im Hinblick auf die Schaffung eines Zertifizierungsrahmens für Kohlenstoffbindungen (Carbon Removal Certification Framework, CRCF), der kürzlich angenommen wurde, führt die EU-Kommission derzeit eine Bestandsaufnahme der vorhandenen Wissensbasis durch. Das Ziel der meisten Zertifizierungsmechanismen besteht darin, die Verringerung oder den Abbau von Treibhausgasemissionen in handelbare Güter umzuwandeln. Um dies zu erreichen, muss jedes von einem Mechanismus ausgestellte Zertifikat verlässlich die gleiche Menge an Treibhausgasen repräsentieren, die reduziert oder aus der Atmosphäre entfernt wurden. Der Bericht vergleicht ausgewählte Standards, um die Vor- und Nachteile der bestehenden Überwachungsmethoden für eine EU-Zertifizierung des Kohlenstoffabbaus herauszuarbeiten.

Der Bericht diskutiert die untersuchten Anrechnungsmethoden für biogenen Kohlenstoffabbau im Hinblick auf zentrale Aspekte, die die Umweltintegrität dieser Methoden beeinflussen. Ein Schwerpunkt liegt dabei auf den Regeln und Anforderungen dieser Methoden zur Quantifizierung und Überwachung des biogenen Kohlenstoffabbaus. Andere wesentliche Gestaltungselemente werden ebenfalls betrachtet, aber nicht im Detail untersucht.

Robuste Quantifizierungsmethoden sind eine wichtige Voraussetzung für die Gewährleistung der Umweltintegrität der im Rahmen des CRCF zertifizierten Kohlenstoffbindungen. Der Bericht zeigt, dass die bestehenden Methoden zur Quantifizierung, die auf den freiwilligen Kohlenstoffmärkten verwendet werden, Mängel aufweisen, die dazu führen, dass bei der Erfassung der Wirkungen von Projekten Risiken der Überschätzung von Kohlenstoffbindungen entstehen.

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1 Introduction

Robust quantification of emission reductions and removals lies at the heart of any certification mechanism and is central for their functionality and environmental integrity. The objective of most certification mechanisms is to turn greenhouse gas emission reductions or removals into tradable commodities. To achieve this, each certificate issued by a mechanism must reliably represent the same amount of greenhouse gas reduced or removed from the atmosphere.

In the context of establishing a Carbon Removal Certification Framework (CRCF) that was recently adopted[1], the EU Commission is currently conducting an inventory of the existing knowledge base. The development of a competitive carbon removal market requires in particular an efficient, transparent, and robust monitoring system for the traceability of sequestered CO_2 that can track how much fossil, biogenic or atmospheric CO_2 is transported, processed, stored and possibly released back into the atmosphere each year. The system must also be able to distinguish between solutions that permanently remove carbon dioxide and those that store carbon or CO_2 for shorter periods of time and that are therefore no contribution to a required net decrease in atmospheric CO_2 concentration.

While the EU regulatory framework governing the use of CRCF certificates is still evolving[2], work is already underway to adopt delegated acts, which will contain the first certification methodologies for eligibly project types under the CRCF. What can be considered as a robust monitoring system might depend in parts on the use case for the certificates e.g., whether they are used as offsets or for underpinning contribution claims. The CRCF however already enshrines a few core principles such as the principle of conservativeness that must be applied for all certification methodologies.

How these principles will be operationalized in certification methodologies will ultimately define the robustness and environmental integrity of the CRCF. The development of certification methodologies should therefore be informed by the lessons learned from voluntary carbon markets. In the past two decades certification methodologies have been developed for many different carbon market project types and researchers and practitioners alike have scrutinized their scientific robustness and practicability in the field. This includes methodologies for the quantification of removal impacts e.g., for project types such as afforestation/reforestation and improved forest management (IFM).

This paper will compare quantification approaches applied by carbon crediting programs on the voluntary carbon markets for selected project types that focus on removals of greenhouse gas emissions. It identifies strength and weaknesses of different approaches and synthesizes the key findings to derive recommendations for the development of certification methodologies under the CRCF.

[1] 2022/0394 (COD) Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing a Union certification framework for permanent carbon removals, carbon farming and carbon storage in products.

[2] Central parts of the regulatory framework will be the Directive for Empowering Consumers for the Green Transition and the Green Claims Directive.

2 Methodological approach

This paper scrutinises a number of selected crediting methodologies for biogenic removals with regard to central aspects that impact the environmental integrity of these methodologies. A focus is put on the rules and requirements of these methodologies for quantifying and monitoring biogenic carbon removals. Other essential design elements are also touched upon but not considered in detail.

A set of criteria/guiding questions was developed for the analysis of the selected methodologies that draws upon extensive preliminary work and knowledge of the opportunities and risks of the methods of existing certification standards, particularly in previous research projects for the German Environmental Agency (e.g. Böttcher et al. 2022; Reise et al. 2022) and the detailed evaluation of existing certification standards under the Carbon Credit Quality Initiative.[3]

The following criteria/guiding questions guide the analysis of the selected methodologies:

- Description of the methodology and the related crediting programme;
- Approaches to quantifying and monitoring carbon removals, including requirement level of the approved methods in terms of accuracy and uncertainties of the methods for quantifying carbon removals, how baselines are calculated and past management practices taken into account;
- Further aspects related to monitoring and reporting requirements and implications for environmental integrity, including consideration of leakage effects, project additionality, approaches to address non-permanence and avoid double counting, as well as the consideration of environmental and social safeguards;

The following crediting methodologies were selected for the analysis:

- Methodologies for the quantification of afforestation activities for which a detailed analysis has already been carried out under the Carbon Credit Quality Initiative (including Gold Standard, CDM, ACR, CAR);
- Methodologies for the quantification of improved forest management for which a detailed analysis has been carried out under the Carbon Credit Quality Initiative. In this paper, a synthesis of the following three crediting methodologies is presented (including ACR IFM on non-federal US forestlands, CAR US forest/Mexico forest, VM003, VM005, VM0010, and VM0012);
- The German Wald-Klimastandard; and
- Methodologies for the quantification of removals through biochar, (including Puro.earth and VCS).

[3] See https://carboncreditquality.org/ for further information on the Carbon Credit Quality Initiative which Öko-Institut is part of.

3 Analysis of selected crediting methodologies

3.1 Methodologies for the quantification of afforestation activities

3.1.1 Description

Afforestation and reforestation (AR) is a popular project type on the voluntary carbon market that aims at removing greenhouse gases by planting trees on ecologically appropriate non-forest land areas. Activities implemented under the label of this project type include the establishment of both, natural forests, and forests, which owners use for commercial purposes such as timber harvesting.

Most of the major carbon crediting programs offer registration for afforestation projects. Most afforestation carbon credits have been issued under the Verified Carbon Standard (VCS), with about 80 per cent of afforestation certificates being issued under this program. There are a few small, specialized carbon crediting programs focusing on nature-based carbon crediting approaches that offer registration as well (see Table 1).

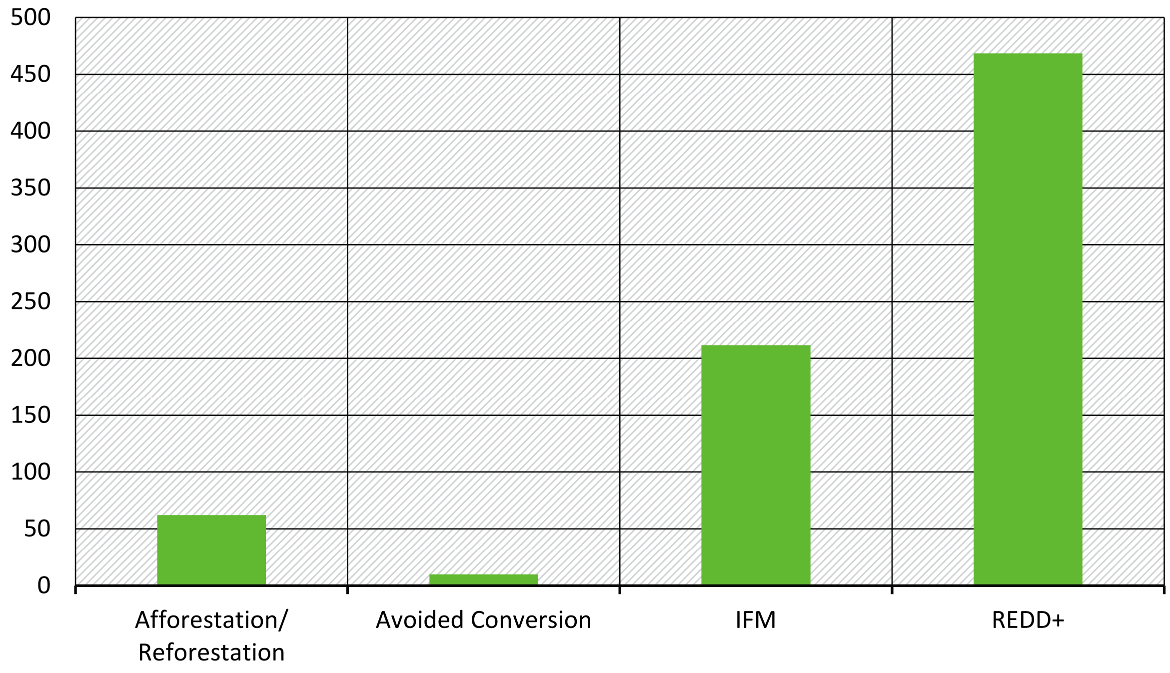
Table 1: Carbon crediting programs offering registration for afforestation projects (selection)

Program	Regional Focus	Eligible quantification methodologies
ACR	U.S.	ACR Afforestation and Reforestation of Degraded Lands
Climate Action Reserve	U.S. Mexico	U.S. Forest Protocol Mexico Forest Protocol
Clean Development Mechanism	Global	Various, mainly CDM AR-ACM0003
Gold Standard	Global	GS Methodology for Afforestation/Reforestation GHGs Emission Reduction & Sequestration
Plan Vivo	Global	Modular quantification approach
UK Woodland Carbon Code	UK	Modular quantification approach
Verified Carbon Standard	Global	Various, mainly CDM AR-ACM0003
Wald-Klimastandard	Germany	Forest restoration (Forest conversion is under development)

Source: Own compilation, Oeko-Institut.

While planting new trees is likely the image that most consumers have in mind when thinking about forest-based carbon removals, afforestation currently only holds a comparatively small market share among forest carbon credit types. Until today, projects that implement Improved Forest Management (IFM) or Avoided Deforestation (REDD+) activities have issued a substantially larger number of credits (see Figure 1). Most afforestation projects registered under voluntary offset registries take place in Latin America and the Caribbean, followed by Southern Asia, Sub-Saharan Africa and East Asia (Haya et al. 2023).

Figure 1: Volume of certificates issued for selected forest carbon credit types until 31 December 2023 (million) under voluntary registries (does not include CDM)



Source: Haya et al. 2023

3.1.2 Approaches to quantifying and monitoring carbon removals

Afforestation projects involve accounting for many carbon pools and emission sources (see Table 2). Determining how project activities affect each of them is important to robustly quantify the net removal impact of an afforestation project. While growing, each newly planted tree removes carbon dioxide from the atmosphere and stores it in its above (i.e. trunk and branches) and below ground (i.e. roots) biomass. Tree growth is a dynamic process, and over time new trees lose some of their biomass in form of deadwood and litter. Some of the lost biomass will enter the soil organic pool, an effect that also needs to be accounted for. Where afforestation projects entail commercial timber harvesting, project owners must account for the effect of harvesting on forest carbon stocks. An important carbon pool in this context is harvested wood products, which may store carbon for long periods of time. The implementation of commercial afforestation projects is associated with emissions that must be accounted for to robustly quantify their net removal effect. Most of them are only relevant for cases where project owners use the forest for commercial timber production. Relevant emission sources include forest management practices such as prescribed burns on the forest area, the application of nutrients to facilitate tree growth, as well as preparation and maintenance of the project site. Timber harvesting is associated with transport emissions. Where accounting includes harvested wood products, emissions associated with their decomposition must be considered.

Table 2: Carbon pools and emission sources in afforestation projects

Carbon pool	Emission source
Above-ground biomass Trees and shrubs	Forest management activities (e.g. prescribed burns)
Below ground biomass Roots	Decomposition of harvested wood products
Deadwood	Nutrient application
Litter	Site preparation
Soil organic carbon	Maintenance of the project site
Slash deadwood	Transport and manufacturing of harvested wood products
Harvested wood products	Decay of harvested wood products

Source: Own compilation, Oeko-Institut

Project developers must apply an eligible quantification methodology to estimate the net removal impact of their project. Considering volume of credits issued, the dominant methodology for the project type is the CDM afforestation methodology AR-ACM0003. Most projects registered with the CDM and VCS use a version of this methodology to quantify their removal impact. Credits issued by projects taking place in the U.S. have mainly been certified by applying the ACR methodology "Afforestation and Reforestation of Degraded Lands". Comparatively low volumes are issued under the methodologies by the Gold Standard and Climate Action Reserve.

Determining the removal impact of an afforestation activity is a challenging task for the following reasons:

- The removal impact of a project activity must be measured against a counter-factual baseline scenario. This scenario is inherently unknown and project proponents must make assumptions about how certain parameters such as timber demand and prices evolve in the future. These assumptions are often associated with considerable uncertainty. This is especially relevant for forestry projects, which often have very long crediting periods of sometimes up to 100 years.
- Implementing an afforestation project might result in emission changes upstream or downstream the removal activity. For example, the conversion of agricultural land to forest land might lead to a displacement of agricultural production to other forest land (i.e. forest land is cleared elsewhere to compensate for the loss of agricultural land in the project area).

Robust quantification methodologies address these issues by prescribing a conservative approach to estimating the removal impact of a project activity. This means that quantification approaches are designed in such a way that they rather lead to an underestimation than an overestimation of removals to appropriately account for uncertainty.

There are five aspects in removal quantification that are relevant for the overall robustness and conservativeness of afforestation methodologies:

1. Selection of the greenhouse gas assessment boundary for the project,
2. The approach to determining baseline removals,
3. The approach to determining project emissions,

4. The approach to determination of net carbon storage in wood products,
5. The approach to determining leakage emissions.

All assessed afforestation methodologies define a reasonable comprehensive **greenhouse gas assessment boundary**, with the Climate Action Reserve's U.S. Forest Protocol being the most comprehensive (see Table 2 above for an overview of relevant carbon pools and emissions sources). The other three methodologies exclude some emission sources, such as mobile combustion emissions from road buildings or emissions from the burning of litter and laying deadwood biomass during site preparation. This however is likely only associated with a limited risk to overestimate the net removal effect of project activities as these emissions sources are comparatively small.

The biggest overestimation risk applying to all assessed afforestation methodologies is the lack of requirements to account for changes in legal requirements, incentives, or common practice in **determining baseline emissions** (CCQI 2024j). This means that baselines only reflect legal requirements and relevant policy support at the time a project is initiated. Changes in the regulatory environment of the project will not be reflected, because there are no requirements to update the baseline. As crediting periods extend to up to 100 years, this is associated with a potentially high overestimation risk. An exception is the methodology by ACR that contains a requirement for project developers to establish so-called "regeneration monitoring areas". These areas must be used as a control area to validate on an ongoing basis the validity of baseline assumptions about tree growth and regeneration in the absence of the project activity. If the observed values in the monitoring area deviate from the baseline assumptions, project developers must modify the baseline. The methodology lacks however prescriptive requirements on how the monitoring areas should be selected. Further, re-assessment of these areas must only happen every 10 years, meaning that over-crediting could occur before it is detected that the baseline assumptions are not accurate.

Other elements that can lead to overestimation of net removals are the omission of relevant sources for **project emissions** such as fertilizer use or mobile combustion emissions during site preparation. This is an issue observed for all methodologies.

Afforestation methodologies use different approaches to account for **net carbon storage in wood products**. The CDM and Gold Standard methodologies treat all carbon stocks lost due to harvesting as emissions. This is a conservative approach, as some carbon may be stored in wood products for a long time (CCQI 2024j). Under the Climate Action Reserve's U.S. Forest Protocol and ACR's methodology, project owners can account for such storage. The approaches used by these methodologies likely lead to overestimation of net removals as they do not account for potential displacement of wood production from other forest lands.

All methodologies mandate **accounting for leakage emissions** due to projects replacing other land uses such as agricultural production. They sometimes lack specificity and prescriptive approaches, which could lead to overestimation of net removals.

3.1.3 Further aspects related to monitoring and reporting requirements and implications for environmental integrity

3.1.3.1 Additionality

There are several factors that impact the likelihood of additionality for afforestation projects. A key factor is whether the project involves commercial timber harvesting. If this is the case, forest owners likely have substantial revenues from timber harvesting. If revenues from carbon credits are required to make projects financially viable, in these cases depends on the financial attractiveness of investments in a particular timber species in the respective geographic region. Assessments of the attractiveness of global timber investments suggests that afforestation activities are likely financially attractive (Cubbage et al. 2022; Cubbage et al. 2020). Projects that establish natural forests without timber harvest typically do not have any other revenues than those from the sale of carbon credits. This means that it is very likely that the existence of carbon markets is the decisive factor to implement these projects (CCQI 2022). Next to the financial attractiveness of a project activity, additionality hinges on other factors such as the stringency of the rules of carbon crediting programs for project proponents to demonstrate that project go beyond legal requirements.

3.1.3.2 Addressing non-permanence

Afforestation projects are associated with non-permanence risks as removals achieved by a project activity might be reversed if forests are lost to natural disturbances such as wildfires or if there is mismanagement in the project. Carbon crediting programs apply different approaches to address non-permanence risks. The predominant approach is to compensate for reversals using pooled buffer reserves that are structured as an insurance mechanism for reversal events. A key shortcoming of these buffers is that they may contain carbon credits from project types that have a reversal risk themselves. The pooled buffer reserve of CAR and the VCS for example are only composed of carbon credits from projects that do have a material non-permanence risk. The pools of ACR and the Gold Standard contain 78% (ACR) and 71% (GS) credits that do not have non-permanence risks. This is achieved by allowing project owners to deposit carbon credits from other project type into the buffer (CCQI 2024d, 2024f, 2024e, 2024g). Ensuring a forest project with forestry carbon credits for example may be risky, as credits in the buffer pool might need to be canceled in case these projects are subject to a reversal themselves. Prescribing a ceiling to credits with reversal risks in the buffer pool could be a remedy for this (Schneider et al. 2022). A key difference in the rules of carbon crediting programs is the duration of time for which reversals must be monitored and compensated. This varies between 20 and 100 or more years. CAR for example has a provision that requires to monitor the project area for reversals 100 years after any issuance of a credit. This means that if a credit is issued in year 99 of a project with a crediting period of 100 years, the project area must be monitored until year 199 after the start of the project. The Gold Standard requires monitoring and reversals only through the end of a project's crediting period which can between 30-50 years for forestry projects.

Table 3: Time horizon for monitoring reversal

Carbon crediting program	Required minimum periods for addressing reversals
ACR	40 years
Climate Action Reserve	100 years and more*
Gold Standard	30-50 years*
Plan Vivo	At least 50 years
UK Woodland Carbon Code	Until the end of the project duration
Verified Carbon Standard	20-100 years*
Wald-Klimastandard	20-30 years

*Depending on crediting period, methodology and/or credit vintage. Sources: (ACR 2023; Climate Action Reserve 2024; Gold Standard 2020; Plan Vivo 2023; Woodland Carbon Code (WCC) 2022; VCS 2024; EVA 2023)

3.1.3.3 Avoiding double counting

Afforestation projects have a risk of double issuance due to indirect overlaps between projects. This risk is currently not addressed by any of the carbon crediting programs offering the project type. Double issuance can happen when an afforestation project and a project reducing firewood consumption take place in the same area. The latter could for example be efficient cookstove or household biodigester projects. If an afforestation project is implemented in the same forest area, it might claim the same removals or emission reductions. This risk could be addressed by systematic checks during the project appraisal process whether the project area overlaps with that of other carbon market projects. Currently none of the carbon crediting programs is conducting such checks.

This risk is however only relevant for countries where cooking with non-renewable biomass is likely. This is not the case for countries like the U.S., for example.

3.1.3.4 Environmental and social impacts

Afforestation projects can contribute to several sustainable development goals (SDGs). They have a positive impact on water and soil retention and can improve water quality in the project area. They also have a positive effect on biodiversity, providing support and services for many different species. Planting trees and maintaining a healthy forest requires further supports job in the project area.

Projects that involve commercial timber harvest might however also be associated with risks for sustainable development goals. They can have negative impacts on biodiversity if projects are designed as monocultures using fast growing-species to maximize timber returns. Where projects apply fertilizer, this might negatively impact water quality. Project also might exacerbate water shortages if implemented in areas where water is scarce or that are prone to droughts (CCQI 2024i)

3.2 Methodologies for the quantification of improved forest management

3.2.1 Description

Improved forest management (IFM) is an umbrella term for a broad array of forest management practices that aim at increasing or maintaining forest carbon stocks. The German Wald-Klimastandard has recently published a method for forest restoration that is already being applied. However, among the major established carbon crediting programs only the three U.S.-based voluntary registries *American Carbon Registry*, *Climate Action Reserve* and *Verified Carbon Standard* offer registration for this project type. Registration is also possible under the California Air Resources Board (CARB). Carbon credits certified under CARB can be used by entities to comply with their obligations under the California Cap-and-Trade Program.

Table 4: Carbon crediting programs offering registration for IFM-projects (selection)

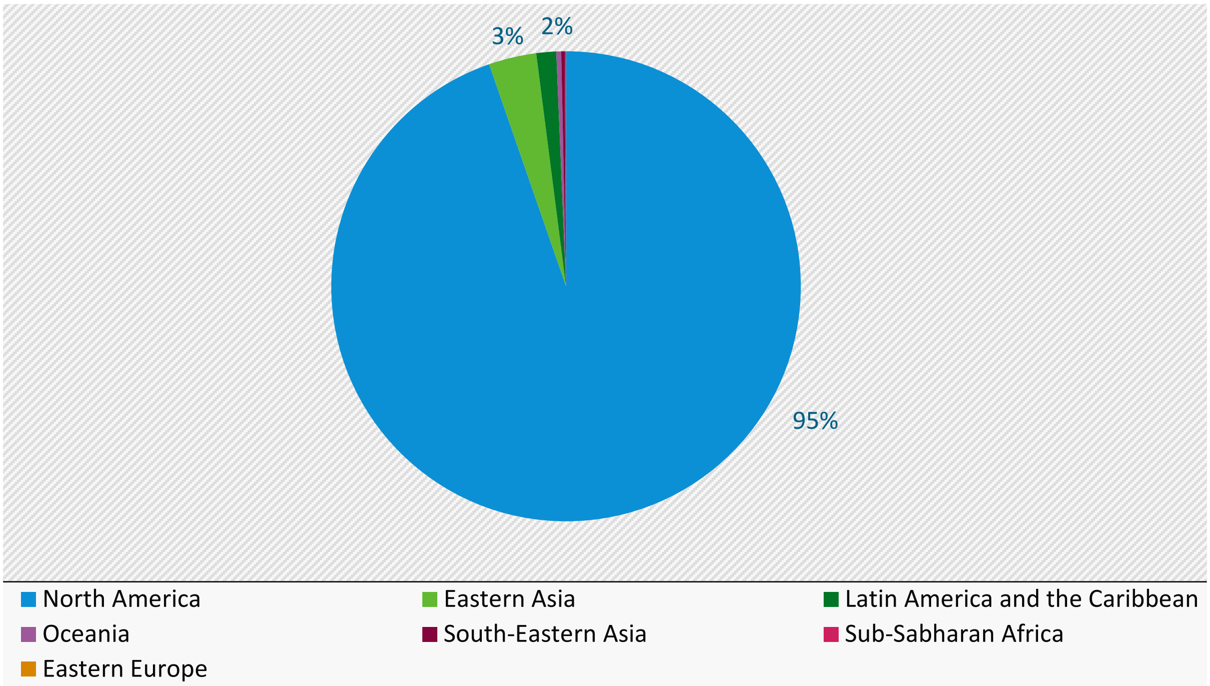
Program	Regional Focus	Eligible quantification methodologies
ACR	U.S.	IFM in non-Federal U.S. Forestlands
California Air Resources Board	U.S.	Compliance Offset Protocol U.S. Forest Projects
Climate Action Reserve	U.S. Mexico	U.S. Forest Protocol Mexico Forest Protocol

Program	Regional Focus	Eligible quantification methodologies
Verified Carbon Standard	**Global**	**VM0003; VM0005; VM0010; VM0012**

Source: Own compilation, Oeko-Institut

Until December 2023, 211.5 million IFM-credits have been issued under the four carbon crediting programs listed in Table 4 above (Haya et al. 2023). Almost 90 per cent of IFM-credits originate from projects in the United States. Other countries with notable shares of IFM projects include Mexico and China. The prevalence of the project type in the U.S. is a legacy of the California Emission Trading Program that allows regulated entities to meet a certain fraction of their obligations through retiring certain carbon credits from projects registered with the California Air Resource Board. Among the different carbon credit types that are eligible for this purpose, IFM-credits make up more than half of eligible offsets (Stapp et al. 2023).

Figure 2: Share of IFM-credit issuances by region (in %)



Source: Haya et al. 2023

IFM-projects might involve several activities and carbon crediting programs typically do not restrict project proponents to a selection of a defined set of activities as long as they increase or maintain carbon stocks. Instead, quantification methodologies provide non-exclusive lists what type of activities might be implemented under an IFM-project. This approach promotes inclusivity as it accommodates different stakeholders such as timber companies and small forest-owners alike. At the same time it makes it more challenging to monitor what exact activities are implemented in a project. Activities that can be typically identified in project design documents of IFM-projects include the following (CCQI 2024k):

- Extended rotation: the time of harvesting is delayed beyond the calculated economic optimum for the forest.
- Increased productivity: forest growth is increased by applying enrichment planting or other practices that increase carbon stocks.

- Production to conservation: management of a forest shifts from timber production to conservation purposes.
- Reduced impact logging: applying improved logging practices to reduce the impact of wood harvesting on above- and below-ground biomass.
- Avoiding degradation: avoiding the start of or an increase in harvesting that is assumed to occur on a forest patch in the baseline scenario.

For all activities except for increasing productivity the main factor for achieving removals is to reduce harvesting levels compared to the baseline.

3.2.2 Approaches to quantifying and monitoring carbon removals

The carbon pools and emission sources that must be monitored for IFM-projects are largely the same than those for afforestation projects (see section above). In general, quantification also faces similar issues related to baseline setting. In contrast to afforestation projects, the effect of IFM-projects on upstream or downstream emissions is however a much larger issue.

All assessed methodologies exclude some carbon pools and emission sources from the **greenhouse gas assessment boundary**. Exclusion is a conservative approach, where these pools and sources have a negligible effect on the net removal impact of a project activity. If major sources are excluded this can however lead to overestimation of removals. Pools that are excluded by some methodologies for which exclusion might lead to overestimation are natural deadwood, soil organic carbon and harvested wood products. For example, only the Climate Action Reserve's U.S. Forest Protocol requires the inclusion of soil organic carbon, while under all other methodologies this is not mandatory (CCQI 2024k).

All methodologies require project developers to **estimate carbon stocks** of a forest before start of the project activities. The most common approaches are direct measurements, remote sensing and modelling approaches. All methodologies allow considerable flexibility to pick and choose between sampling design, data sources, models, and parameters for the quantification of carbon stocks. Such flexibility creates overestimation risks as project proponents might chose those that are most beneficial in terms of volume of credits generated by a project. An exception is the Climate Action Reserve's U.S. Forest Protocol that includes comparably stringent requirements for parameter selection (CCQI 2024k).

Due to long crediting periods and exposure of input variables to many external factors that might drive evolvement of carbon stocks, **baseline scenarios** for IFM-projects are associated with an inherent uncertainty. In establishing baseline scenarios, project proponents must make assumptions about how many different parameters such as timber prices, forest ownership and forest management regulations evolve over long periods of time, typically 20-100 years. For any such predictions there is a high level of uncertainty and methodologies often do not prescribe updating the baseline during project implementation. This creates uncertainty around removal estimates as it is difficult to establish causality between the activities implemented in the framework of the IFM projects and removals achieved on a forest patch. If, for example timber prices are very low at the calculated optimal time for harvesting a forest stand, project owners might decide to postpone harvesting regardless of the additional income this might generate through selling carbon credits.

Many IFM projects generate removals by reducing timber harvest levels in a forest patch compared to the baseline scenario. This means that these projects have a high risk of **leakage** as harvest levels might increase outside the project area to compensate for the reduction in timber supply from the project area. All quantification methodologies require project developers to account for leakage risks by applying a fixed rate leakage deduction (CCQI 2024k). Such deductions account for all leakage that might occur under the project. Whether or not such an approach is robust, depends on whether the selected rates are sufficiently closed to observed leakage rates for the region where the project is implemented. The leakage rates in the methodologies range from 10-70% and are applied at different stages of the quantification. The ACR methodology and VM0012 for example require applying a deduction on the total number of removals achieved in a reporting period. Under other methodologies, project developers must apply it to the estimated difference between project and baseline carbon stocks. The leakage rates that methodologies prescribe are lower than those identified in scientific studies (CCQI 2024k). For the United States, which by far is the most relevant country for IFM-projects, studies estimate leakage rate to be between 42-95% (Gan und McCarl 2007; Wear und Murray 2004). At the same time the most heavily used methodologies for projects in the U.S. only prescribe deductions between 10-30%. This potential difference in leakage rates creates a high risk to overestimate the removal impact of IFM-projects.

3.2.3 Further aspects related to monitoring and reporting requirements and implications for environmental integrity

3.2.3.1 Additionality

As many IFM-projects continue to harvest timber, they have revenue streams other than those from selling carbon credits. Some activities like increasing productivity might even increase harvesting levels, and hence abilities to monetize timber (CCQI 2024c). For other activities, like extending the rotation age, additionality risks might be more differentiated. If forest owners commit to postponing harvesting for several years beyond the economically optimal harvesting time, there are less risks that the activity is not additional. Forest owners forgo revenues by harvesting less timber than the forest patch might produce over a given period. In addition, keeping trees growing beyond their optimal harvest time, increases risks to lose the forest to wildfires or pests. On the other hand, extending rotation by just a few years might involve higher non-additionality risks as it is more difficult to determine whether revenues from carbon credits are the decisive factor, or whether the postponement decision is driven by external factors such as a temporary slump in timber prices (CCQI 2024a).

Other activities, such as shifting a forest management regime from timber production to conservation will involve that forest owners forgo significant revenues compared to the baseline scenario. In addition, managing a forest for conservation involves costs such as maintaining forest health. These activities likely have few non-additionality risks as long as baseline harvest assumptions are plausible (CCQI 2024b).

3.2.3.2 Addressing non-permanence

The same non-permanence risks apply for IFM-projects as those that have been discussed above for afforestation. Most carbon crediting programs make no distinction between forestry projects when it comes to rules to minimize non-permanence risk.

3.2.3.3 Avoiding double counting

Like for afforestation projects, there is a risk of overlapping claims for IFM-projects in countries where cooking with non-renewable biomass is widespread. As most IFM-projects take place in the U.S., the risk is less relevant for most carbon credits issues from these projects.

3.2.3.4 Environmental and social impacts

Like for additionality, the environmental and social impacts of IFM-projects depend on the activity that is being implemented. Projects that focus on increasing the productivity of an existing forest might have negative interactions with some sustainable development goals. Management approaches such as thinning or removing less productive trees might negatively impact soil and water quality in a forest and reduce biodiversity. Other activities such as shifting from timber production to conservation or extending the rotation age on a forest patch can have positive impacts on forest ecosystems by increasing overall forest health (CCQI 2024h).

3.3 Methodologies under the German Wald-Klimastandard

3.3.1 Description

The Wald-Klimastandard (WKS, Forest Climate Standard) is a voluntary carbon market standard for quantifying ecosystem services of privately and publicly owned forests in Germany. In the following, we analyze methodologies adopted under the standard in more detail. This focus on methodologies under a specific standard has been chosen because the WKS is currently the largest national standard applied in Germany. Moreover, it has been set up with the aim to provide carbon credits of high quality and has been established with a broad involvement of stakeholders.

The WKS is being developed by the private association Ecosystem Value Association (eva)[4]. Under WKS, three methodologies are currently being applied or developed, including for **forest restoration** on climate-induced calamity areas, **forest conversion** of monocultures to climate-resilient mixed forests, and **extended rotation**. The methodology for forest restoration has been published in October 2023 and is the only one currently applied (May 2024). The methodology on forest conversion is in a pilot phase. The analysis of WKS methodologies presented here focuses on forest restoration and forest conversion only. It is based on documentation of Wald-Klimastandard – Version 1.0[5] and underlying assessments, info sheets and tools.

Project activities that are eligible under the forest restoration and forest conversion methodologies include assisted natural regeneration, tree planting and sowing of tree seeds, as well as supporting measures such as prevention of damage caused by game (e.g. fencing, hunting), removal of competing vegetation, silvicultural measures (e.g. thinning), or forest fire prevention measures.

Despite references to the broad term of “ecosystem services” in its description, when it comes to quantification, WKS only addresses **carbon stock changes** of above- and below-ground tree biomass.

Crediting is applied based on an **ex-ante approach**. This means that credits are issued for expected future emission reductions or removals that are yet to occur. If the monitoring reveals that the issued credits exceed the actual emission reductions or removals, the excess issuance is compensated through cancellation of credits. This feature is distinct from all major international carbon crediting programs that only issue carbon credits ex-post, i.e. after verification that the emission reductions or removals have actually occurred.

[4] https://www.ecosystemvalue.org/

[5] Wald-Klimastandard – Version 1.0, 15. Februar 2024, Revisionsnummer: 1.0.04, available at https://version.waldklimastandard.de/1-0/standard/

The **length of the crediting period** for forest restoration projects can be set by project developers to 20, 25 or 30 years. Forest conversion projects have a fixed crediting period of 30 years.

Certificates generated by a validated and verified project can be utilized by the owner on the voluntary market without restrictions. Within the voluntary market certificates can be transferred or retired but they are excluded from any regulated markets. Transfers are tracked by an **Impact Registry** that serves as proof of ownership and status of certificates and ensures traceability. Instead of a transfer, certificates can also be retired by the holder with the purpose to offset emissions to achieve individual targets or to compensate for the shortfall of projects that may arise due to the ex-ante approach.

3.3.2 Approaches to quantifying and monitoring carbon removals

The WKS **excludes many emission sources and carbon pools** from its quantification method, namely soil organic carbon, shrub biomass, deadwood, non-tree biomass, emissions from combustion of fossil fuels for project realization, emissions from synthetic fertilizer application and biomass burning. For these emission sources and carbon pools it is assumed that they will not develop negatively in the project scenario, that they do not differ significantly from the reference scenario, or that their total amount is not considered significant. Moreover, wood products are considered outside the system boundaries and therefore not included in the quantification. Thus, in contrary to other standards certifying forest management activities for voluntary carbon markets (see 3.2), the WKS applies a rather narrow scope. This is justified by standard developers by referring to studies that demonstrated no significant changes on carbon pools other than above- and below-ground biomass over the relative short time horizon of 30 years that the standard applies. Thus, **negative impacts from projects on any carbon pools in the longer term are ignored** by both methodologies with implications for environmental integrity. Moreover, the methodology excludes emission sources and carbon pools for which emissions could be significant during project implementation. This includes emissions from site preparation, planting, fencing etc. that do not occur in the baseline but in the project scenario. A critical assumption is that projects are considered to start after disturbed forest areas have been cleared from deadwood and damaged trees. This leaves **considerable amounts of carbon in this biomass unaccounted**. This is despite positive effects that the retention of deadwood and remaining trees can have for biodiversity but also for improving conditions for the regeneration of trees, e.g. through shade and cooling effects.

The **baseline scenario** for the forest restoration method corresponds to the **natural development** of the project area without additional protection and planting activities. However, it is assumed that management, like thinning and harvest activities, is carried out as recommended by forest management guidelines. The projection of carbon stocks accumulated in above- and belowground tree biomass in the baseline scenario considers specific influencing factors and risks for trees potentially regenerating on the project area without human intervention. These are:

- the natural regeneration potential of the area;
- the mortality of young trees due to ground vegetation, browsing and other tree species;
- the site-related mortality due to nutrient availability and the influence of damming and groundwater;
- the climate-related mortality due to drought stress, windthrow, snow break, late frost and forest fire events.

A central assumption is the potential for natural regeneration. The WKS requires a detailed stratification of the project area according to influencing factors that affect the potential for natural generation. These include the occurrence of pioneer tree species, mixture and structure of previous as well as residual and neighboring stands, and the fruiting cycle of residual trees.

For forest conversion activities the baseline estimation is more complex. The WKS assumes that forestry activities are continued (business as usual). The current management is derived from the most recent National Forest Inventory (NFI) data that provide information on average target diameters for harvest, harvest intensity as well as thinning intervals and intensity. In the baseline scenario it is assumed that species composition does not change over time. This is a critical assumption as there are clearly trends of species change that can be observed from the NFI data and can be considered business as usual. Moreover, similarly to assumptions on natural regeneration for forest restoration activities, it can be assumed that some species change occurs naturally in forests targeted for forest conversion. Assuming no species changes may thus not be an appropriate assumption. It could lead to overestimation of removals because the shift in the type of wood products produced (e.g. from construction wood to firewood) could reduce the residence of carbon in products.

The **project scenario** is determined by the planned measures defined by the forest owners as part of the project activities. For forest restoration activities, project induced carbon stock changes are estimated by a specific project scenario tool including site- and tree species-specific data derived from NFI data. For forest conversion, estimates for the project scenario are based on functions for simulating forest growth and mapping of forestry interventions using an established tree growth model.

Five years after the start of project activities, areas on which WKS certificates have been claimed will be **monitored** for the first time. The monitoring will be repeated every three to five years, depending on the availability of remote sensing data. The monitoring concept is currently only considering forest restoration activities.

3.3.3 Further aspects related to monitoring and reporting requirements and implications for environmental integrity

3.3.3.1 Ensuring additionality

WKS takes a standardized approach and addresses **additionality** at three levels: legally, financially and at the level of ecosystem service. The **legal analysis** assesses the impact of the existing legal framework in Germany on national climate policy goals. Legal additionality needs to take into account that there is an obligation for reforestation. According to the standard, the legal framework conditions provide too little incentives for activities of forest owners in Germany to achieve these goals. Concretely, national authorities estimate that annually 95,000 ha of forests that are found to be not sufficiently adapted to climate change impacts need to be regenerated after calamities or should be actively converted from monocultures to mixed forests.

Currently, publicly observed rates of forest restoration and conversion are well below the recommended rate despite the legal framework that requires forest restoration. WKS concludes that legal additionality of their forest restoration and conversion projects is therefore given as long as observed rates of restoration are below the recommended annual area. The low rate of forest restoration, according to WKS, is due to the management of extreme events and early proactive intervention requiring a high demand for resources, which often exceed the capabilities of forest owners of any property type (public or private).

Financial additionality can be proven by testing if the project would also be implemented without the carbon credits. The profitability risks need to be assessed to what degree they impede forest owners to invest into reforestation. Despite existing funding through subsidies there are, according to WKS, still bureaucratic hurdles, especially for very small and small private forests (<200 ha), remaining own contributions that are required and de-minimis constraints that can be considered for proofing financial additionality of projects.

Still, this approach to defining additionality can be debated. The standard claims that financial constraints are the main reason for the inadequate rate of forest restoration. In fact there can be other than financial reasons like lack of capacities, lack of plant and seeding material, and uncertainty of forest owners regarding choice of species etc. that can play a role. The approach to defining additionality is not only assumed for private forest owners, in fact public forests are not explicitly excluded from the approach. Indeed also publicly owned forest enterprises suffer from insufficient funds for forest restoration, especially in municipal forests. However, assuming that the Federal law for forest restoration can be followed by Federal state authorities only with additional funds overstretches the definition of additionality considerably. In general, standardized approaches to additionality bear the risk for adverse selection, where only those forest owners engage in projects which had anyway planned to diversify their forests while others may not register under WKS.

3.3.3.2 Addressing leakage

Negative effects on carbon pools and GHG emissions due to **activity-shifting leakage** and market leakage are not considered relevant and are therefore not included in the quantification. For the current application of WKS, it is assumed that projects are subject to European and German law that prohibit deforestation. WKS assumes that this assumption eliminates the risk of regional relocation of activities that lead to deforestation or unsustainable timber utilization on other areas. **Market leakage** is assumed to not occur because there are currently no projects under the WKS that lead to a reduced timber supply.

Leakage can be expected to become an issue for both, the methodology for forest restoration and forest conversion. The activities involve a change in tree species from coniferous to broadleaved and mixed forests that are expected to be more resilient to climate change impacts. However, such a change has also implications for the supply of timber. Wood from conifers in Germany is mostly used as material for construction, furniture and pulp and paper. Only 10 % is used directly for energy (Hennenberg et al. 2022). Instead, 70% of the harvested wood from broadleaved trees is energy wood. Consequently, leakage effects can be expected in the medium- to long-term future if no changes in the structure of wood use occur.

3.3.3.3 Addressing non-permanence

To address the risk of non-permanence, WKS installs a **buffer** to which projects must contribute 15% of the amount of issued certificates. In addition, the buffer is filled by “positive deviation”, i.e. whenever projects overperform compared to the ex-ante issued carbon credits. For a standard operating only in one region, here Germany, such an approach bears the risk of insufficient supply to the buffer. This is especially the case if larger areas and therefore number of projects are suffering from natural disturbances and climate change impacts, such a s drought. The buffer might be quickly used due to underperforming projects and a simultaneous reduction in credit generation and no further input from overperforming projects.

If monitoring reveals that projects under the WKS are not developing in line with the ex-ante assumed project scenario and the anticipated amount of certificates is not achieved, such a **shortfall** needs to be compensated within a period of six months. The compensation is required by forest owners in case the shortfalls is caused by an influenceable factor, i.e. in case of breach of the provisions of the standard, or damage caused by game browsing. Shortfalls caused by a non-influenceable factor are to be compensated by the permanence buffer. This is particularly the case for changes of calculation models used for project and baseline scenario calculation as well as natural disturbances such as forest fires, pest outbreaks, extreme weather events that are affecting the project area. In case the amount of certificates in the permanence buffer is reduced to less than 50% of the total number of certificates contributed by projects to the buffer, the contribution share of 15% can be increased for new projects.

Another measure for addressing non-permanence risk is the exclusion of areas with high forest fire risk. Projects on areas with a projected risk level of five for more than 40 days per year cannot be used to generate certificates. Basis for this assessment are estimates for the climate scenario RCP 8.5 in the period from 2021 to 2050. However, this constraint currently does not exclude any areas in Germany[6].

An issue for environmental integrity is the relatively short monitoring period of maximum 30 years (down to 20 years for forest restoration projects). Longer-term changes to carbon pools due to project activities but also due to management changes after the monitoring period are not reflected in the credits that are issued and reversals do not need to be compensated. This implies that emissions from any harvesting and use of the biomass are not accounted for. Extending monitoring also beyond the implementation period is a critical prerequisite for further liabilities. However, for achieving the goals of the Paris Agreement, it is critical that any future reversals are fully compensated for.

3.3.3.4 Avoiding double counting

The risk of **double issuance** and **double use** of certificates is avoided by the Impact Registry. WKS is also planning to annually report to the authorities of the national inventory register.

To address the risk of **double claiming**, the WKS provides recommendations for the use of certificates by companies to increase transparency. Validated certificates may immediately be used by companies for **contribution**claims. Such claims may also include statements on how much CO_2 has been saved through the commitment in a specific project. **Compensation claims** are allowed only for verified certificates. However, buyers of certificates should clearly communicate the origin of the certificates and that the performance of the German forest is counted towards Germany's climate targets and reported and accounted under the UNFCCC and EU.

3.3.3.5 Environmental and social safeguards

WKS broadly addresses social and environmental safeguards by requiring **FSC- or PEFC-certification** for the project areas included. The standard also requires that the project activities pursue "the long-term goal of the silvicultural model of a 'climate-resilient mixed forest'". It includes practical guidelines for the selection of climate-adapted tree species and a corresponding silvicultural plan. However, tree species from natural regeneration should be integrated into the project as part of close-to-nature forestry.

At least three tree species are required by WKS that each account for at least 10% and at most 50% of the area. Naturally regenerating species considered not adapted to site conditions can only account for a maximum of 20% of the area, as well as species new to the area. There is no requirement to use native plant material. Moreover, trees can be planted as pure stands on areas

[6] https://kfo.pik-potsdam.de/static/countries/ger/tool.html?sector_id=2&language_id=de&p_id=wbc5&timeframe=30&hist=0&futscen=2&season=0&diagram=0&displayed=0,1&absrel=abs&expert=0&year=2020&zoom=1&difference=false

up to 0.5 ha. The WKS thus falls behind the certification criteria set by FSC regarding species composition of forest restoration that constraints the share of non-native trees to 20% and requires mixing of tree species within the area.

3.4 Methodologies for the quantification of removals through biochar

3.4.1 Description

Biochar is biomass transformed in such a way that the carbon it contains is converted to stable compounds that do not decompose over a long period of time because they are more resistant to biotic and abiotic degradation. The conversion processes can be classified as either pyrolysis, gasification, or torrefaction. The process of pyrolysis is a thermochemical conversion of biomass under conditions of oxygen being excluded at temperatures between 400°C and 650°C. Gasification requires temperatures > 700°C. Here, oxygen is only reduced to a level that combustion will not occur resulting in the release of syngas (a mixture of carbon monoxide, hydrogen, and carbon dioxide). Torrefaction is a similar process but at temperatures only between 200°C and 350°C. Products from these processes are biogas, bio-oil and biochar that can potentially replace fossil fuels. The energy requirements for biochar production vary based on the specific production method and the type of biomass used. Incorporated into soils biochar can improve soil properties and potentially reduce energy consumption for fertilizers. However, such effects vary greatly with different soil types and environmental conditions; thus net positive effects for soils cannot always be achieved (Fuss et al. 2018).Klicken oder tippen Sie hier, um Text einzugeben.

Biomass for biochar is either directly produced by agriculture or forestry or recovered from waste streams. It therefore does not constitute a carbon removal process in itself, but is a form of storage, as the removal has occurred during the period of biomass growth (Siemons et al. 2023).

Methodologies for the certification of biochar for the voluntary carbon market have been developed over the last decade. Puro.earth introduced its methodology for biochar in 2019. VCS published its methodology for biochar utilization in soil and non-soil applications in 2021. In the following both methods are analyzed regarding their approaches to quantifying and monitoring carbon removals. We base the analysis on the puro.earth Biochar methodology, Edition 2022[7] and VCS Methodology for biochar utilization in soil and non-soil applications, Version 1.0[8]. Both methodologies show a number of commonalities but also differences (see Table 5).

Table 5: Comparison of puro.earth and VCS biochar methodologies

	Puro.earth	VCS
Types of biochar applications	Soil or non-soil applications, examples: soil additive, greenhouse substrate, surface water barrier, animal feed additive, wastewater treatment, insulation material, landfill/mine absorber	Soil or non-soil applications, examples: soil amendment on land other than wetlands, cement, asphalt, plastics
Geographical coverage	Global	Global

[7] Puro.earth Biochar methodology, Edition 2022 V3, available at https://7518557.fs1.hubspotusercontent-na1.net/hubfs/7518557/Supplier%20Documents/Puro.earth%20Biochar%20Methodology.pdf

[8] VCS Methodology for biochar utilization in soil and non-soil applications, Version 1.0, available at https://verra.org/wp-content/uploads/imported/methodologies/210803_VCS-Biochar-Methodology-v1.0-.pdf

	Puro.earth	VCS
Technical biochar definition	molar $H\ Corg/$ ratio lower than 0.7	-
Type of feedstocks allowed	Sustainably sourced biomass, or waste biomass such as agricultural waste, biodegradable waste, urban wood waste or food waste	Agricultural waste biomass, forestry and other wood processing, recycling economy, aquaculture plants, animal manure, High-Carbon Fly Ash
Emissions sources and pools included		
Biomass production	Included, including direct land use changes	Excluded, emissions directly from cultivating and harvesting biomass for production of biochar are set as zero
Combustion/Anaerobic /Aerobic decomposition of feedstocks	Conditional, zero by default	Conditional, zero by default
Biochar production, (pre-)treatment, transport, and application	Included	Included, methodology for estimating production emission differentiated by high and low technology production facilities
Baseline scenario	zero	zero
Use of certificates	Compensation	Compensation
Crediting period	Not applied	Not applied
Addressing double counting	avoided by the use of the Puro Registry	final location of the site of biochar application "should be registered, where possible"
Additionality	Assumed to be default (new activity)	Assumed to be default (new activity)
Addressing leakage	Not addressed	Emissions due to activity shifting leakage or biomass diversion are considered zero, as currently only waste biomass is eligible for biochar production
Addressing non-permanence	LCA data and proof for the biochar use, amount of biochar ending up in waste incineration to be excluded, no consideration of natural risks	If net GHG benefit in verification period is negative for soil applications, no credits issued. Natural risks associated with non-soil applications considered negligible.
Environmental and social safeguards	Certification of forest-based biomass, max 70% extraction of residues, Social safeguards	Certification of forest-based biomass, max 70% extraction of residues, no decrease of carbon pools

Source: Own compilation, Oeko-Institut

3.4.2 Approaches to quantifying and monitoring carbon removals

The **system boundary** of the puro.earth methodology is "cradle-to-grave" and includes emissions from production and supply of the biomass, from biomass conversion to biochar, and from biochar distribution and use. Also VCS covers in its project boundaries the area where the initial waste biomass is sourced, treated for the purpose of production of biochar, and the final application.

Included uses for puro.earth are, e.g. greenhouse substrates, surface water barrier, animal feed additive, wastewater treatment, insulation material, landfill/mine absorber, and soil additive. VCS similarly certifies the use of biochar for a variety of soil or non-soil applications, including soil amendment on land other than wetlands, cement, asphalt, and even plastics.

Biochar under the puro.earth methodology must be produced from **biomass feedstocks** presented by IPCC Appendix 4 - Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments[9]. The list includes animal manure, wood, herbaceous biomass (grasses, forbs, leaves, excluding rice husks and rice straw), nut shells, pits and stones, and biosolids (paper sludge, sewage sludge). In addition, the methodology constrains biomass sources to the positive list of biomass feedstocks of the European Biochar Certificate[10]. For wood the list allows only biomass from certified, sustainable forestry.

Also VCS formulates in its methodology **requirements for feedstocks**. Eligible feedstocks include agricultural waste biomass, forestry and other wood processing, recycling economy, aquaculture plants, animal manure, and High-Carbon Fly Ash. Besides wood from pruning and thinning the methodology allows the use of "diseased trees felled in the course of plantation or woodland management" as well as bark and wood chips with little commercial value. More sustainability constraints on feedstocks are discussed below in section 3.4.3.5.

The default **baseline scenario** for the project activity within both methodologies is zero, which is considered a conservative assumption since GHG emissions from decomposition or combustion of biomass without the project are excluded. However, this assumes no utilization of the biomass feedstock at all as the business as usual. This cannot be considered conservative in cases where biogenic waste is being used for compost, or bioenergy with potential fossil fuel substitution effects.

There are considerable differences between the methodologies analyzed regarding emissions sources and pools included. Puro.earth requires a comprehensive life cycle analysis (LCA) of biomass production and supply that includes important terms.

- Biomass production and transport, including GHG emissions arising from all activities involved in the biomass cultivation and harvesting process and
- Direct land use changes related to a change in land cover or land management, including emissions from reforestation but also the loss of carbon when harvesting forest residues or agricultural residues. Setting these emissions to zero must be justified adequately with an explicit reference situation.

The VCS methodology excludes emissions directly from cultivating and harvesting biomass for production of biochar as it allows only the use of waste biomass. This assumption ignores direct and indirect effects of residue biomass use. These are effects occurring in ecosystems from

[9] https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch02_Ap4_Biochar.pdf

[10] https://www.european-biochar.org/media/doc/2/positive-list_en_v10_3.pdf

where residues are extracted or indirect effects due to a diversion of biomass streams from existing uses to biochar production.

The methodologies for estimating emissions associated with the production and, treatment, transport, and application of biochar in the **project scenario** are similar and based on IPCC methods and default factors for carbon content and 100-year decay rates. VCS applies differentiated methods for estimating production emission from high and low technology production facilities.

3.4.3 Further aspects related to monitoring and reporting requirements and implications for environmental integrity

3.4.3.1 Ensuring additionality

The VCS methodology uses a standardized approach for the demonstration of additionality assuming that only five percent or less of waste biomass available worldwide are currently used for biochar. Projects producing biochar are thus automatically considered additional and do not need to demonstrate additionality. The methodology under puro.earth instead requires an assessment of additionality at project level. Project proponents must provide full project financials and counterfactual analysis demonstrating that the project is not required by existing laws, regulations, or other binding obligations.

3.4.3.2 Addressing leakage

Leakage is not addressed by the puro.earth biochar methodology. VCS assumes emissions due to activity shifting leakage or biomass diversion to be zero, as only waste biomass is eligible for biochar production. As discussed above, this assumption ignores direct and indirect effects of residue biomass use that are caused by the diversion of biomass streams from existing uses to biochar production.

3.4.3.3 Addressing non-permanence

Under the puro.earth methodology non-permanence is addressed by LCA data and proof for the biochar use. Moreover, the amount of biochar ending up in waste incineration to be excluded. Beyond that there is no consideration of natural risks.

The VCS methodology instead considers the risk of reversal. If net GHG benefit in the verification period is negative for soil applications, no credits will be issued. Natural risks associated with biochar non-soil applications are, however, considered negligible. In general it is assumed that non-permanence issues are not likely to occur as “biochar applied to agricultural soils will continue to act as a carbon sink irrespective of the fate of the project”.

3.4.3.4 Avoiding double counting

To avoid double counting, puro.earth refers to the Puro Registry. No other measures against double counting are mentioned. The VCS methodology states that the final location of the site of biochar application “should be registered, where possible” to avoid that double issuing occurs.

3.4.3.5 Environmental and social safeguards

The methodology provided by puro.earth requires that biomass feedstocks are sustainability sourced. For forest biomass sustainability can be proven by certificates of the Forest Stewardship Council (FSC), Sustainable Forestry Initiative (SFI), or the Programme for the Endorsement of Forest Certification (PEFC). Alternatively evidence of forest management plans approved by a government, state or regional authority or other “*reputable sustainable forest* *certification programs with high scientific standards and market recognition*" are accepted. For the use of non-forest waste biomass as feedstock for biochar no certificates are needed.

The methodology allows the use of timber "*that has been damaged by a natural disaster (e.g. fire, pests, flood) and cannot be economically recovered or used as originally intended*". Thus stem wood is not excluded per se. For agricultural waste it is required that 30% of residues are left to the field to avoid decreasing soil health and crop levels. The use of invasive species is constrained to species that are recognized by state authorities and only if procedures for clearing the land of the invasive plant avoid unintended clearing of existing native vegetation. Moreover, production facilities must comply with local environmental regulations, regarding air, water, and soil pollution, including compliance with Industrial Emissions Directive (2010/75/EU). It also has to be ensured that the production does no significant harm to local communities. For biochar production and application life cycle assessment data must be provided and documented.

Also VCS formulates in its methodology sustainability requirements for feedstocks**.** For primary wood originating from forests a proof of sustainable sources needs to be provided documenting also that extraction did not lead to deforestation or degradation. Such proof can be management plans approved by a relevant state or regional authority, forestry certification including but limited to PEFC and FSC. Besides wood from pruning and thinning the methodology allows the use of "diseased trees felled in the course of plantation or woodland management" as well as bark and wood chips with little commercial value. Similarly to puro.earth, the removal of agricultural residues as feedstock is limited to no more than 70% of total residues. The methodology excludes projects that lead to a decrease of carbon pools, in particular, soil organic carbon on agricultural lands, or reduction in carbon stocks in forest dead wood and litter pools.

4 Discussion and conclusions

Robust quantification methodologies are a key pillar for ensuring the environmental integrity of removals certified under the new European CRCF Framework in preparation. The assessment shows that existing methodologies for quantifying removals used on the voluntary carbon markets have shortcomings that involve overestimating risks when determining the net-removal impacts of project activities. It further provides important insights on how quantification approaches must be structured to result in conservative estimates on the net-removal impact of project activities. The main conclusions include the following:

- Certification schemes should only offer registration for those removal activities that do not generate credits through stopping the core activity of a project type. For example, most IFM-projects generate credits by stopping or reducing timber harvesting levels. This is associated with high leakage risks, as timber demand may remain the same, resulting in increased harvesting levels in other areas. Whether the CRCF will include certification methodologies for project types such as IFM is still unclear. The Commission should, however, conduct a thorough assessment of leakage risks for each project type and carefully weighing these risks against the potential benefits of allowing such project types under the CRCF. Categorization of leakage risks can be used for excluding projects, demand counteractive measures or updated leakage risks assessments.

- Certification schemes should prescribe in their general program provisions that removals should be determined in a conservative manner, rather than using the most accurate estimate. The degree of conservativeness should be based on the magnitude of uncertainty associated with estimating removals (i.e. in cases of high uncertainty, approaches should be more conservative). The CRCF enshrines the principle of conservativeness and requires that each certification methodology will include rules to address uncertainties in the quantification of carbon credits in a conservative manner. This provides an opportunity to further detail and operationalize this general principle by incentivizing improvements over time e.g. by applying discounts for high uncertainties.

- Certification schemes should require project developers to periodically update the baseline and include such requirement in each quantification methodology. The CRCF includes a requirement for the Commission to review and update standardized baselines every five years, however with a qualifier that this should be done "as appropriate". For activity-specific baselines the CRCF requires that they are updated "at the beginning of each activity period, unless otherwise stated in the applicable certification methodology". A requirement to update baselines at the beginning of each activity period might not be sufficient for project types with very long crediting periods. For example, for some existing IFM-quantification methodologies, crediting periods are up to 100 years. To be robust, each methodology adopted under the CRCF should therefore include a mandatory review and update clause that requires updating both, standardized and activity-specific baselines, at least every five years without allowing any exceptions to this rule.

- Certification schemes should require project owners to demonstrate that additionality of their activities continues to uphold if external factors, such as regulatory frameworks change. To be robust, methodologies should include provisions that require reconfirming legal additionality on an ongoing basis and ceasing issuances of carbon credits, beginning with the date that new legal requirements enter into force that mandate the removal activity. Such an approach is best practice on the voluntary carbon market.

- Methodologies should be prescriptive in defining greenhouse gas emission boundaries for removal projects. Excluding carbon pools and emissions sources from project boundaries can be conservative if they have a negligible impact on the net removal effect. This should however be determined top-down through the methodology and not be left at the discretion of each individual project developer.
- Methodologies that allow for activity-specific baselines should contain prescriptive approaches for estimating baseline carbon stocks. There should be no flexibility for project developers to pick and choose from different options as this introduces over-crediting risks by project developers always choosing the option that generates most credits.
- Methodologies should base default values for key parameter and variables on latest scientific research.
- Methodologies should conservatively account for leakage emissions. This should include all forms of leakage, including activity and market leakage. Leakage deductions should be based on scientific literature or modelling results and be conservatively set.
- Methodologies should be periodically reviewed and updated to ensure that they reflect new findings and scientific evidence. Certification schemes should have procedures in place for suspending a new methodology if new scientific evidence suggest that removals are over-estimated, or additionality is not ensured.
- New methodologies should be vetted through expert review by an appointed body of experts (e.g., technical advisory panel or expert working group), before being adopted. Appointment of experts should be governed through a merit-based process, including publicly available selection criteria that ensure that experts have the respective technical and sectoral expertise that is required for assessing the robustness of new methodologies.
- Removal activities might have negative interactions with some sustainable development goals, such as water, biodiversity, and soil quality, depending on the activity that is being implemented. Robust environmental and social safeguards play a key role in identifying potential risks and adopting design measure for projects that minimize negative impacts. It is important that certification schemes adopt environmental and social safeguard requirements that meet international best-practices, such as the Performance Standards of the International Finance Corporation (IFC).
- Monitoring and compensating for reversals is particularly relevant for carbon removal project types. A critical factor is the time horizon for how long the occurrence of any reversals must be monitored and compensated for. Minimum time periods should match the specific activity implemented by the project. For permanent removals a time period of 100 years can be considered as best practice, as some programs like the Climate Action Reserve already does this for some project types.

When considering the suitability of these methodologies under the CRCF it will be important to scrutinize them in detail to minimize overestimating risks.

5 List of references

ACR (2023): The ACR Standard - Version 8.0. Requirements and Specifications for the Quantification, Monitoring, Reporting, Verification and Registration of Project-Based GHG Emissions Reductions and Removals. Online verfügbar unter https://acrcarbon.org/wp-content/uploads/2023/10/ACR-Standard-v8.0.pdf.

Böttcher, H.; Schneider, L.; Urrutia, C.; Siemons, A.; Fallasch, F. (2022): Land use as a sector for market mechanisms under Article 6 of the Paris Agreement. Hg. v. Umweltbundesamt (UBA). Dessau-Roßlau (Climate Change, 49/2022). Online verfügbar unter https://www.umweltbundesamt.de/publikationen/land-use-as-a-sector-for-market-mechanisms-under, zuletzt geprüft am 28.08.2023.

CCQI (2022): Application of the Oeko-Institut/WWF-US/EDF methodology for assessing the quality of carbon credits. Online verfügbar unter https://carboncreditquality.org/download/Assessments/1.1.3%20Establishment%20of%20Natural%20Forest%20%2831%20May%202022%29.pdf.

CCQI (2024a): Application of the CCQI methodology for assessing the quality of carbon credits. 1.1.3 Financial attractiveness - Improved forest management - Extended rotation age. Online verfügbar unter https://carboncreditquality.org/download/Assessments/1.1.3%20IFM-Extended%20rotation%20%2821%20February%202024%29.pdf.

CCQI (2024b): Application of the CCQI methodology for assessing the quality of carbon credits. 1.1.3 Financial attractiveness - Improved forest management - Production to conservation. Online verfügbar unter https://carboncreditquality.org/download/Assessments/1.1.3%20IFM-Production%20to%20conservation%20%2821%20February%202024%29.pdf.

CCQI (2024c): Application of the CCQI methodology for assessing the quality of carbon credits. 1.1.4 Barriers - Improved forest management - Increasing productivity. Online verfügbar unter https://carboncreditquality.org/download/Assessments/1.1.4%20IFM-Increasing%20productivity%20%2821%20February%202024%29.pdf.

CCQI (2024d): Application of the CCQI methodology for assessing the quality of carbon credits. 3.2.1 Approaches for accounting and compensating for reversals (Approach 1) - ACR. Carbon Credit Quality Initiative (CCQI). Online verfügbar unter https://carboncreditquality.org/download/Assessments/3.2.1%20ACR%20Forest%20activities%20%2821%20February%202024%29.pdf.

CCQI (2024e): Application of the CCQI methodology for assessing the quality of carbon credits. 3.2.1 Approaches for accounting and compensating for reversals (Approach 1) - CAR. Carbon Credit Quality Initiative (CCQI). Online verfügbar unter https://carboncreditquality.org/download/Assessments/3.2.1%20CAR%20Forest%20activities%20%2821%20February%202024%29.pdf.

CCQI (2024f): Application of the CCQI methodology for assessing the quality of carbon credits. 3.2.1 Approaches for accounting and compensating for reversals (Approach 1) - GS. Carbon Credit Quality Initiative (CCQI). Online verfügbar unter https://carboncreditquality.org/download/Assessments/3.2.1%20GS%20Forest%20activities%20%2821%20February%202024%29.pdf.

CCQI (2024g): Application of the CCQI methodology for assessing the quality of carbon credits. 3.2.1 Approaches for accounting and compensating for reversals (Approach 1) - VCS. Carbon Credit Quality Initiative (CCQI). Online verfügbar unter https://carboncreditquality.org/download/Assessments/3.2.1%20VCS%20Forest%20activities%20%2821%20February%202024%29.pdf.

CCQI (2024h): Application of the CCQI methodology for assessing the quality of carbon credits. 6.2 Sustainable development impact of the project type or projects - Improved forest management. Online verfügbar unter https://carboncreditquality.org/download/Assessments/6.2%20Improved%20forest%20management%20%2821%20February%202024%29.pdf.

CCQI (2024i): Application of the CCQI methodology for assessing the quality of carbon credits. 6.2 Sustainable development impacts of the project type or project - Commercial afforestation. Online verfügbar unter https://carboncreditquality.org/download/Assessments/6.2%20Commercial%20afforestation%20%2821%20February%202024%29.pdf.

CCQI (2024j): Commercial Afforestation. Understanding CCQI Scores. Carbon Credit Quality Initiative (CCQI). Online verfügbar unter https://carboncreditquality.org/download/Factsheets/EN/Commercial%20Afforestation.pdf.

CCQI (2024k): Improved Forest Management. Understanding CCQI Scores. Online verfügbar unter https://carboncreditquality.org/download/Factsheets/EN/Improved%20Forest%20Management.pdf.

Climate Action Reserve (2024): Reserve Offset Program Manual - Version 9.2. Climate Action Reserve. Online verfügbar unter https://www.climateactionreserve.org/wp-content/uploads/2024/04/Reserve-Program-Manual-v9.2.pdf.

Cubbage, Frederick; Kanieski, Bruno; Rubilar, Rafael; Bussoni, Adriana; Olmos, Virginia Morales; Balmelli, Gustavo et al. (2020): Global timber investments, 2005 to 2017. In: *Forest Policy and Economics* 112, S. 102082. DOI: 10.1016/j.forpol.2019.102082.

Cubbage, Frederick; Rubilar, Rafael; Mac Donagh, Patricio; Kanieski Da Silva, Bruno; Bussoni, Adriana; Morales, Virginia et al. (2022): Comparative global timber investment costs, returns, and applications, 2020. In: *J.For.Bus.Res.* 1 (1), S. 90–121. DOI: 10.62320/jfbr.v1i1.16.

EVA (2023): Wald-Klimastandard - Version 1.0. Ecosystem Value Association. Online verfügbar unter https://version.waldklimastandard.de/1-0/standard/.

Fuss, Sabine; Lamb, William F,; Callaghan, Max W.; Hilaire, Jérôme; Creutzig, Felix; Amann, Thorben et al. (2018): Negative emissions—Part 2: Costs, potentials and side effects. In: *Environ. Res. Lett.* 13 (6), S. 63002. DOI: 10.1088/1748-9326/aabf9f.

Gan, Jianbang; McCarl, Bruce A. (2007): Measuring transnational leakage of forest conservation. In: *Ecological Economics* 64 (2), S. 423–432. Online verfügbar unter https://carboncreditquality.org/download/Assessments/1.3.2%20CAR%20U.S.%20Forest%20Project%20Protocol%20-%20IFM%20%2821%20February%202024%29.pdf.

Gold Standard (2020): Land use and forest activity requirements - Version 1.2.1. Gold Standard. Online verfügbar unter https://carboncreditquality.org/download/Assessments/3.2.1%20GS%20Forest%20activities%20%2821%20February%202024%29.pdf.

Haya, Barbara K.; Abayo, Aline; So., Ivy S.; Elias, Micah (2023): Voluntary Registry Offsets Database v10. Berkeley Carbon Trading Project, University of California, Berkeley. Online verfügbar unter https://gspp.berkeley.edu/research-and-impact/centers/cepp/projects/berkeley-carbon-trading-project/offsets-database.

Hennenberg, Klaus; Böttcher, Hannes; Braungardt, Sibylle; Köhler, Benjamin; Reise, Judith; Köppen, Susanne et al. (2022): Aktuelle Nutzung und Förderung der Holzenergie - Teilbericht zu den Projekten BioSINK und BioWISE. Hg. v. Umweltbundesamt (UBA). Öko-Institut; Institut für Energie- und Umweltforschung Heidelberg (ifeu); Informationssysteme für Rohstoffe (INFRO). Dessau-Roßlau (Climate Change, 12/2022). Online verfügbar unter https://www.umweltbundesamt.de/sites/default/files/medien/479/publikationen/cc_12-2022_aktuelle_nutzung_und_foerderung_der_holzenergie.pdf, zuletzt geprüft am 29.03.2022.

Plan Vivo (2023): PV Climate Project Requirements - Version 5.1. Online verfügbar unter https://www.planvivo.org/Handlers/Download.ashx?IDMF=73de49fa-638f-4edc-b37e-6d2147b6ca3e.

Reise, Judith; Siemons, Anne; Böttcher, Hannes; Herold, Anke; Urrutia, Cristina; Schneider, Lambert et al. (2022): Nature-based solutions and global climate protection. Assessment of their global mitigation potential and recommendations for international climate policy. Hg. v. Umweltbundesamt (UBA). Öko-Institut; Ecologic Institut. Dessau-Roßlau (Climate Change, 01/2022). Online verfügbar unter https://www.umweltbundesamt.de/publikationen/nature-based-solutions-global-climate-protection, zuletzt geprüft am 19.01.2022.

Schneider, Lambert; Fallasch, Felix; De León, Felipe; Rambharos, Mandy; Wissner, Nora; Colbert-Sangree, Tani et al. (2022): CCQI - Methodology for assessing the quality of carbon credits. Version 3.0. 3. Aufl. Hg. v. Environmental Defense Fund, WWF und Oeko-Institut. Carbon Credit Quality Initiative (CCQI). Online verfügbar unter https://carboncreditquality.org/download/Methodology/CCQI%20Methodology%20-%20Version%203.0.pdf, zuletzt geprüft am 05.07.2023.

Siemons, Anne; Böttcher, H.; Liste, V.; Jörß, W. (2023): Short typology of carbon dioxide removals: How best to differentiate methods and technologies for establishing and enhancing carbon sinks? Hg. v. Umweltbundesamt (UBA). Öko-Institut. Online verfügbar unter https://www.umweltbundesamt.de/sites/default/files/medien/11850/publikationen/factsheet_short_typology_of_carbon_dioxide_removals.pdf, zuletzt geprüft am 18.09.2023.

Stapp, Jared; Nolte, Christoph; Potts, Matthew; Baumann, Matthias; Haya, Barbara K.; van Butsic (2023): Little evidence of management change in California's forest offset program. In: *Commun Earth Environ* 4 (1). DOI: 10.1038/s43247-023-00984-2.

VCS (2024): VCS Standard - Version 4.7. Online verfügbar unter https://verra.org/wp-content/uploads/2024/04/VCS-Standard-v4.7-FINAL-4.15.24.pdf.

Wear, David N.; Murray, Brian C. (2004): Federal timber restrictions, interregional spillovers, and the impact on US softwood markets. In: *Journal of Environmental Economics and Management* 47 (2). Online verfügbar unter https://carboncreditquality.org/download/Assessments/1.3.2%20CAR%20U.S.%20Forest%20Project%20Protocol%20-%20IFM%20%2821%20February%202024%29.pdf.

Woodland Carbon Code (WCC) (2022): Requirements for voluntary carbon sequestration projects. Online verfügbar unter https://woodlandcarboncode.org.uk/images/PDFs/Woodland_Carbon_Code_V2.2_April_2022.pdf.