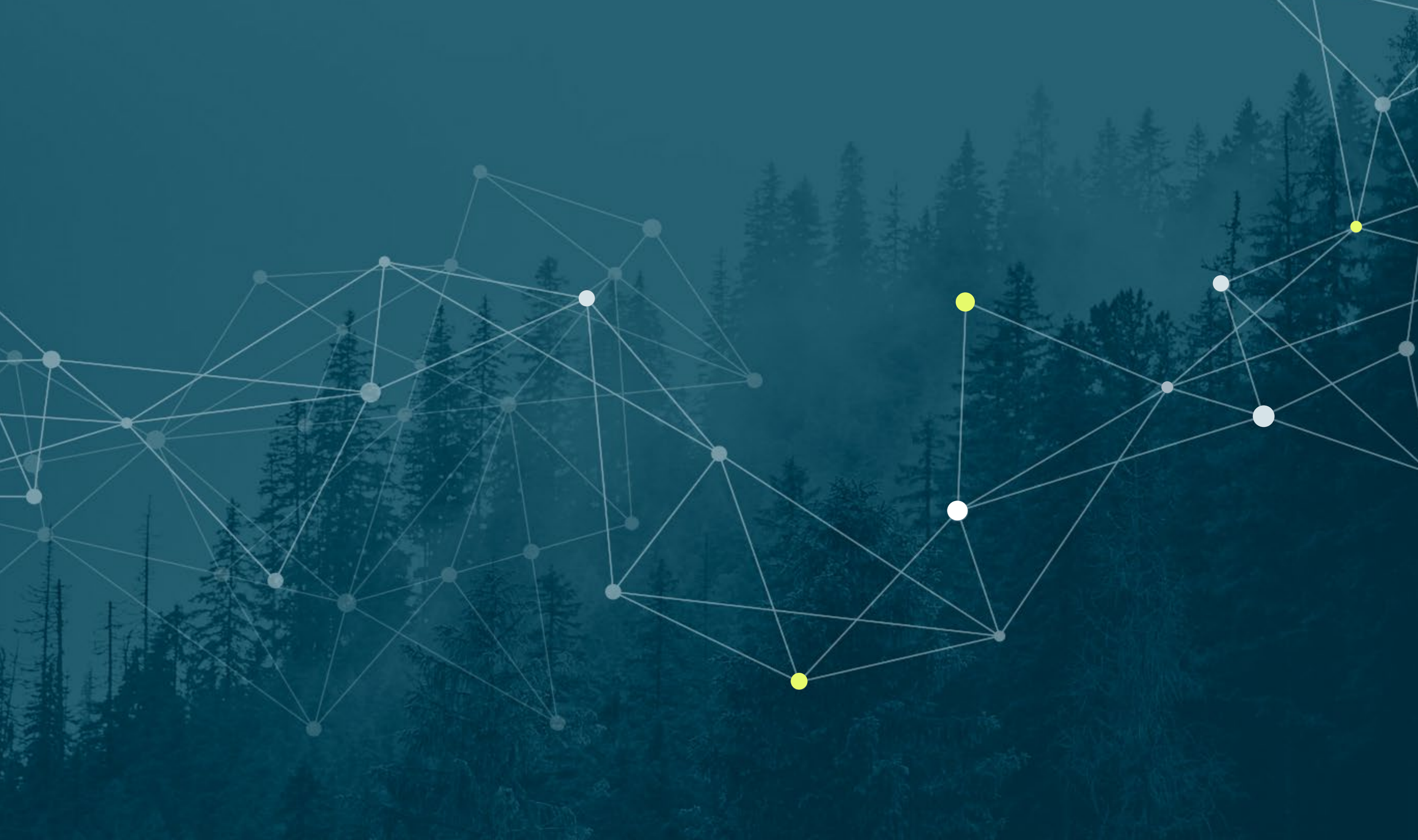
Ground Truth: An Assessment of Forest Carbon Credit Protocols

A CATF REPORT



CLEAN AIR TASK FORCE

Forest Carbon Protocols

forestcarbonprotocols.org

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CATF's Land Systems Program combines analysis, policy advocacy, and communication to understand trade-offs and synergies among competing land uses and to advance policies and practices that best mitigate climate change while supporting livelihoods worldwide.

This report is based on a detailed technical assessment of forest carbon credit protocols conducted by a team of leading forest scientists and published in *Earth's Future*.

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Executive Summary

Forests hold enormous potential to help mitigate climate change by absorbing massive amounts of carbon dioxide through the leaves of trees and storing it away in trunks, branches, and soils. Private finance channeled through carbon markets is one way to fund management activities that boost forest carbon storage.

Today, forest carbon credits make up roughly 40% of the global voluntary carbon market. The voluntary market peaked at $2 billion in 2022 and has contracted since then due to concerns about the integrity of carbon credits. Market predictions suggest it could continue to shrink or could grow to $1 trillion by 2050 depending on credit quality and emerging national and international carbon markets. However, the existing systems of certifying, selling, and retiring forest carbon credits as offsets for ongoing emissions are fraught with controversy. **Many forest carbon projects fall short of delivering the climate benefits they promise, raising critical questions around credibility.**

Clean Air Task Force convened a team of leading forest scientists to evaluate the protocols for certifying forest carbon credits and determine whether these existing carbon market guidelines are strong enough to ensure high-quality credits. This report provides a summary of the Ground-Truth assessment results, along with additional policy context and recommendations based on our analysis. The project team scored 20 forest carbon credit protocols representing technical guidance for carbon credit certification in both voluntary and compliance carbon markets in North America.

The evaluation revealed that existing carbon market protocols are not sufficiently robust to guarantee that certified credits deliver their promised climate benefits.

Key Findings:

1. **Existing forest carbon protocols are too weak to ensure high-quality credits.** On a scale[a] from fundamentally flawed to exemplary, all but one evaluated protocol scored "weak" or lower. This result indicates that existing forest carbon credits used to offset emissions cannot be assumed to be climate beneficial, and the volume of unused credits available for this purpose is a serious concern. Until protocols are improved, it is crucial that buyers have access to detailed technical information about the underlying project, as well as the technical expertise to accurately assess the quality of any given credit. Careful evaluation of specific credits, project-level transparency, and technical expertise are essential for effectively using carbon credits today.

2. **Key concerns relate to non-permanence risk reduction, additionality and baselines, and leakage.** Most protocols inadequately account for risks to carbon storage over time such as wildfires, pests, and land use change, allow for too much developer discretion in claims about what would have happened in the absence of the project and/or do not robustly account for how project development could affect forest carbon storage in other locations. Since protocols are weak in different ways, credits can be low-quality for different reasons – making a single simple fix elusive. To ensure credits are consistently high-quality, all protocols need to be strong in all the components evaluated in this assessment.

3. **Protocol improvements are needed to deliver reliably high-quality forest carbon credits.** The assessment results highlight the need to design protocols that are benchmarked against independent regional datasets, implement more prescriptive processes to reduce reliance on individual developer discretion, and are adaptable to changing conditions and knowledge. In addition, carbon markets should radically improve transparency while removing verifier conflicts of interest and ultimately, integrate developing science on non-greenhouse gas feedbacks between forests and climate.

4. **Non-offsetting approaches are also needed to enhance forest carbon storage.** Given the results of this assessment and the high bar needed to ensure quality credits, implementing the recommended improvements may constrict supply and raise credit prices. Financial incentives that do not rely on a carbon credit for offsetting model will be needed to capitalize on the full potential for forests to contribute to climate change mitigation.

Carbon markets are at a crossroads and their future trajectory is highly uncertain. Although the system has faced significant criticism and widespread recognition of its shortcomings to date, there is a groundswell of interest and activity in reforming and expanding carbon markets. The results of the Ground-Truth assessment demonstrate that **it is crucial to enhance the protocols for quantifying and certifying forest carbon credits to avoid repeating past mistakes and ensure that new compliance systems and expanding voluntary markets are effective.**

[a] Approaches were scored on a seven-point Likert scale: fundamentally flawed, very weak, weak, satisfactory, robust, very robust, exemplary. The project team was instructed to assess the approaches relative to their view of an ideal approach given the state of science, and not relative to one another.

Section I

What are forest carbon credits, markets, and protocols?

KEY MESSAGE

The certification and sale of forest carbon credits, which each represent one additional tonne of carbon stored in a forest due to an intentional management intervention, is one way to finance activities that protect and enhance the global forest carbon sink. Markets for buying and selling carbon credits can be voluntary or compliance based. The guidelines for quantifying the additional carbon stored are known as protocols.

Boosting forest carbon storage can **help slow climate change**

Forests remove massive amounts of carbon from the atmosphere, storing it away and helping counteract the effects of global emissions. Trees use their leaves to turn sunlight and carbon dioxide into sugars that power their growth and contribute to the 870 gigatons[1] of carbon stored in trunks, branches, roots, and soils in forests across the globe. Each year Earth's forests remove another 13 gigatons of carbon dioxide[1] from the atmosphere—roughly half of annual global fossil fuel emissions. Yet forests are always both a source and sink for carbon, losing carbon to the atmosphere as trees die and decompose. The balance of forest carbon sources and sinks, and the durability of stored carbon depend on many factors including risk of fire, drought, and deforestation. But healthy and protected forests can maintain carbon storage for centuries.[2] This makes forests a key ally in mitigating the effects of climate change.

Boosting forest carbon storage requires the adoption and implementation of new management approaches, whether they involve conserving standing forests, planting new ones, or changing harvest practices. Such concerted efforts to enhance forest carbon storage currently contribute roughly 2 gigatons carbon dioxide to the annual global forest carbon sink each year.[3] But global forests also face a range of challenges, including both legal and illegal deforestation, fire, climate change, disease, and invasive species.[4] By expanding efforts to enhance and protect the global carbon sink through deliberate management of forests and other natural ecosystems, we could store an additional 100-1,000 gigatons of carbon dioxide by late-century, with cost and resource constraints pointing towards the lower 20% of that range.[5] In the United States alone, regionally tailored, cost-effective forest management strategies could remove over 1.5 gigatons of carbon dioxide equivalents by 2050.[6]

Carbon markets allow additional forest carbon storage to be certified according to protocols and sold as carbon credits

Carbon markets are a large and possibly growing mechanism to unlock funds to implement forest solutions that benefit the Earth's climate. These markets center on carbon credits, which are tradable certificates that each represent one metric tonne of carbon dioxide equivalent emissions reduced, avoided, or removed from the atmosphere. Forest carbon credits are minted based on the additional carbon that is stored in a forest ecosystem because of an intervention made possible by finance from promised sale of those credits. Buyers are motivated by an obligation and/or desire to help mitigate climate change. But many forest carbon projects fall short of delivering the climate benefits they promise,[7-14] raising critical questions around credibility.

For a forest carbon credit to accurately represent the carbon stored from a given project, and therefore a real climate benefit, the rules for how to measure the change in forest carbon must be clear, robust, and verifiable. These key rules are laid out by credit certification bodies in one or more complex technical documents known as protocols, standards and/or methodologies. In this report, we hereafter use the term 'protocol' to refer to the full set of rules for credit certification.

In North America, the primary focus of the Ground Truth assessment, forest projects to protect and enhance carbon storage fall into three primary categories: avoided conversion (AC), afforestation/reforestation (AR), and improved forest management (IFM).

Figure 1: **Types of forest carbon projects**

AVOIDED CONVERSION (AC)

Prevent deforestation for legally permissible* alternative uses of land, like agriculture or commercial development.

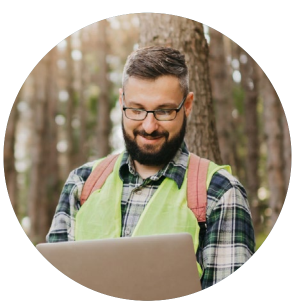
The climate benefit of avoided conversion derives from preserving both the standing stock of forest carbon and new carbon that will be stored from ongoing forest growth over time and is considered an avoided emission.

** Note that projects aiming to avoid illegal, unplanned deforestation are not considered in this report, but are a major proportion of REDD+ projects, which have been assessed in detail elsewhere.[11-14]*

AFFORESTATION/REFORESTATION (AR)

Tree planting or natural/managed regeneration on lands that were either previously forested (reforestation), or on lands that were not recently forested but could support forest ecosystems (afforestation).

The climate value of AR projects comes from the additional sequestration capacity associated with new forest growth and is therefore considered carbon removal.



IMPROVED FOREST MANAGEMENT (IFM)

A range of management practices designed to increase carbon sequestration in managed forests. Examples of IFM practices include extending rotational age between harvests and logging practices that reduce negative impacts on the unlogged portions of the forest.

The climate benefit of IFM varies by management practice but may include both the preservation of existing carbon in the forest, for example when logging is reduced, and the addition of new carbon storage capacity if the management change involves more trees growing on the landscape. Therefore, IFM can be considered a reduced emission or carbon removal.

Carbon markets are **complex** and are largely **unregulated**

Carbon markets can operate in voluntary systems or under compliance systems that may be underpinned by regulations from state, regional, national, and multi-national jurisdictions. The voluntary carbon market is centered around independent registries that set guidelines for credit quantification and track verified carbon credits for buyers who seek carbon credits to meet self-imposed obligations for reducing their carbon footprint. Compliance markets allow entities subject to regulatory emissions caps or other legally binding targets to purchase qualifying carbon credits that represent removals or reductions by others to fulfill (or partially fulfill) their obligations. At present, most forest carbon credits are traded in voluntary markets that lack a centralized oversight system.[15, 16]

The driving force of carbon markets since their outset has been the purchase and use of carbon credits to offset emissions, making the reliability of credits a necessity – one that has not always been met. In 2022, total issuance of credits in voluntary carbon markets was ~274 million, including 87 million from forest projects making the voluntary carbon market the primary market for forest carbon credits.[15] Corporate buyers seeking credits to fulfill their voluntary pledges for climate neutrality targets are the primary consumers in the market. If credits are available for purchase at a lower cost than implementing real emissions reductions within a company's supply chain, there is a significant risk that the availability of such cheap, often low-quality credits will detract from investments in decarbonization.[17]

Carbon markets are comprised of supply-side actors, including registries, project developers, and verification and validation bodies (VVBs); and demand-side interests, consisting primarily of buyers who purchase, retire, and make claims based on carbon credits.

Project developers typically generate carbon credits by following registry protocols and paying registry fees to track their credits. Registries require project developers to hire a VVB to assure compliance with protocols. Recently, ratings agencies and consulting firms have emerged to provide both buyers and sellers with information for evaluating carbon credits. Credits can be sold directly to buyers or marketed through brokers who often aggregate carbon credits.

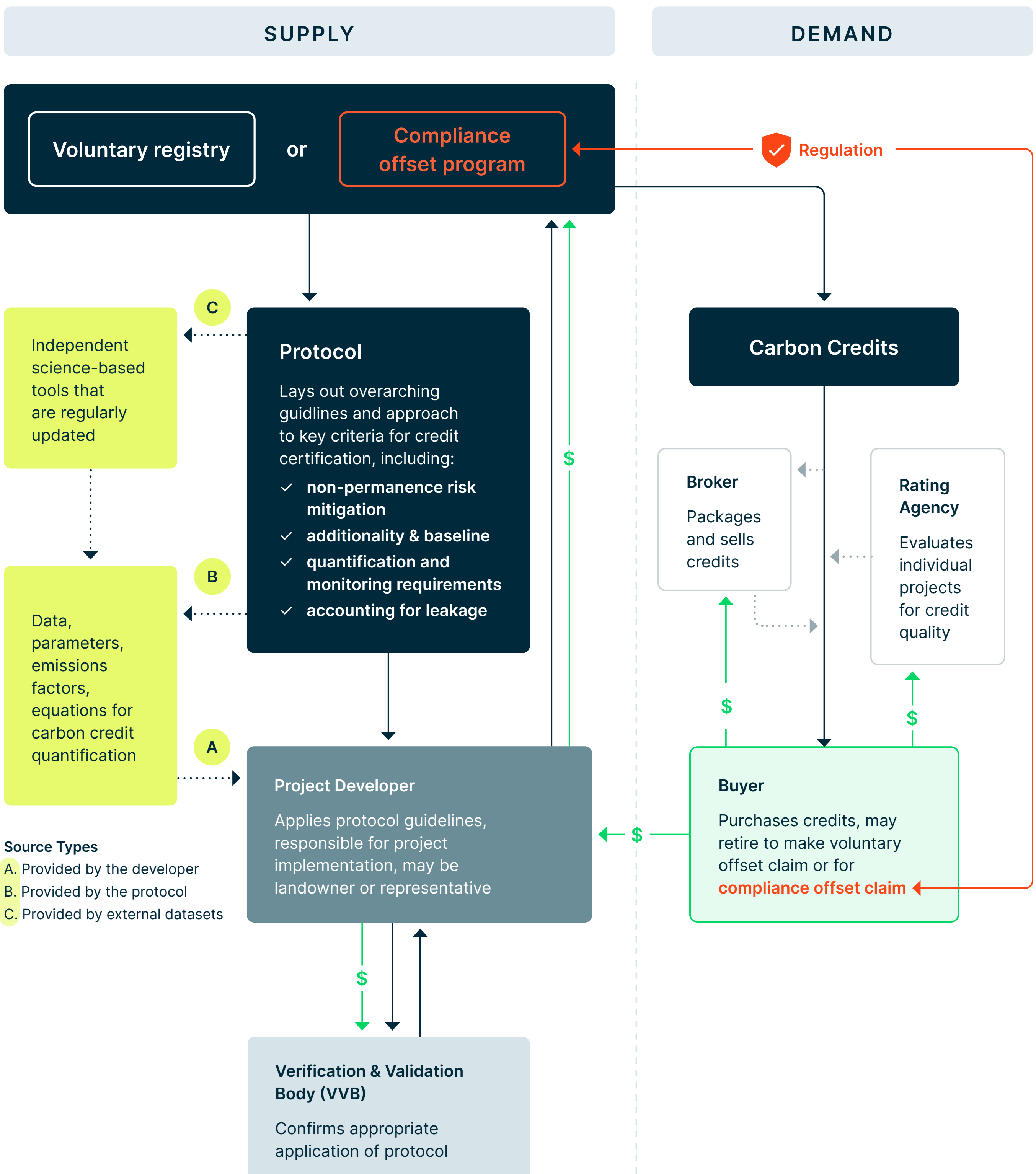
Compliance markets have a similar architecture to the voluntary market and may even rely on voluntary registries to manage credit issuance, but they can have distinct requirements and are underpinned by regulatory obligations that often dictate how the protocols are designed and how credits can be used.

This simplified diagram of carbon markets displays the flow of information, guidance, and carbon credits among key players on both the supply and demand sides in gray arrows. The flow of finance through the forest carbon market is shown in green arrows. Solid arrows represent consistent relationships, and dotted arrows represent relationships that are optional or vary. The key data, parameters, emissions factors, and equations required for credit quantification may come from various sources:

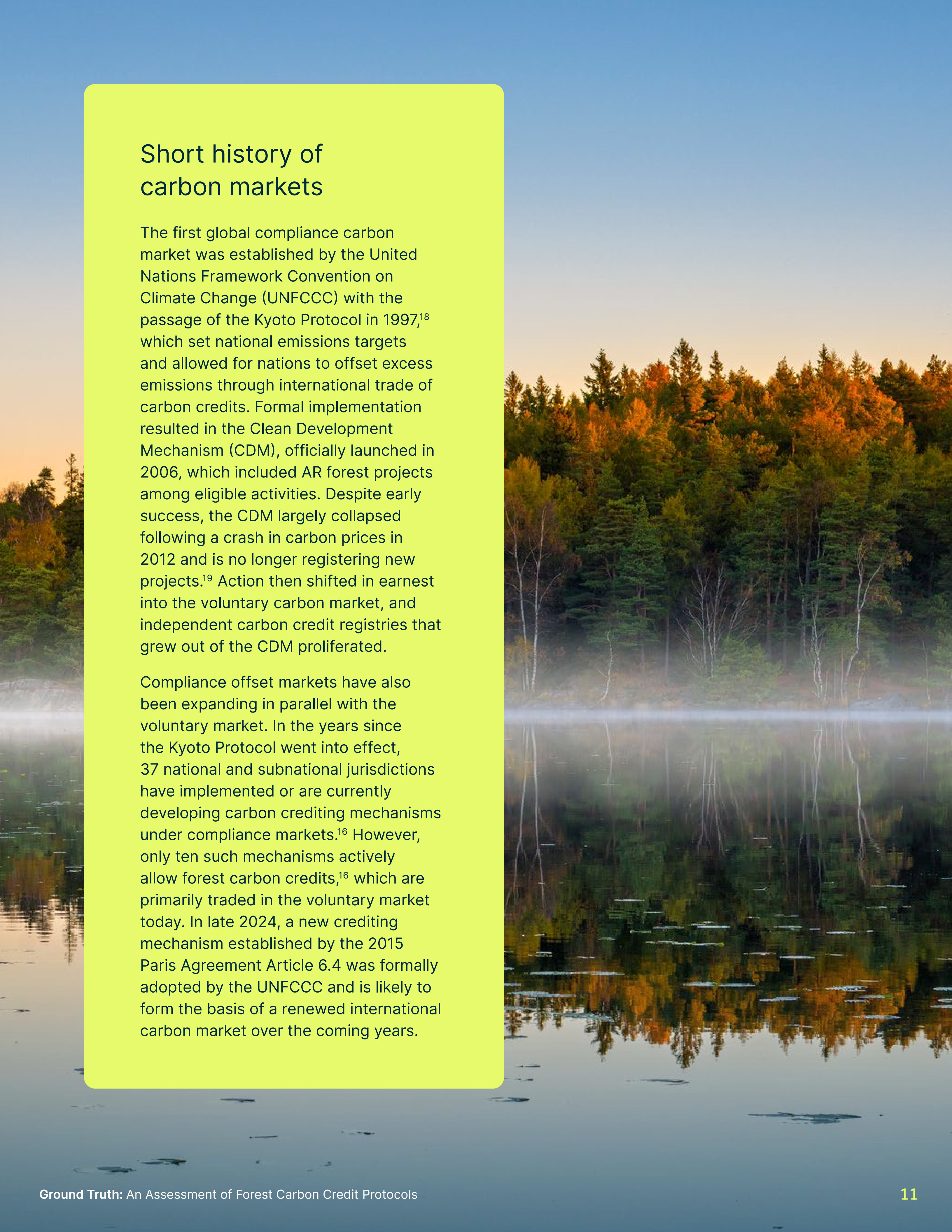
A. Provided by the developer
B. Provided by the protocol
C. Provided by external datasets

Regulations underlying compliance offset systems provide additional requirements (shown with orange arrows), that can inform the guidelines for protocols and the use of carbon credits in offsetting contexts.

Figure 2: **Carbon market architecture**



Source Types
A. Provided by the developer
B. Provided by the protocol
C. Provided by external datasets



Short history of carbon markets

The first global compliance carbon market was established by the United Nations Framework Convention on Climate Change (UNFCCC) with the passage of the Kyoto Protocol in 1997,[18] which set national emissions targets and allowed for nations to offset excess emissions through international trade of carbon credits. Formal implementation resulted in the Clean Development Mechanism (CDM), officially launched in 2006, which included AR forest projects among eligible activities. Despite early success, the CDM largely collapsed following a crash in carbon prices in 2012 and is no longer registering new projects.[19] Action then shifted in earnest into the voluntary carbon market, and independent carbon credit registries that grew out of the CDM proliferated.

Compliance offset markets have also been expanding in parallel with the voluntary market. In the years since the Kyoto Protocol went into effect, 37 national and subnational jurisdictions have implemented or are currently developing carbon crediting mechanisms under compliance markets.[16] However, only ten such mechanisms actively allow forest carbon credits,[16] which are primarily traded in the voluntary market today. In late 2024, a new crediting mechanism established by the 2015 Paris Agreement Article 6.4 was formally adopted by the UNFCCC and is likely to form the basis of a renewed international carbon market over the coming years.

Section II

What makes a high-quality forest carbon credit?

KEY MESSAGE

Four components of certification necessary for a forest carbon project to deliver high quality credits with real and durable climate benefits are:

1. *Non-permanence risk reduction*
2. *Additionality and proper baseline establishment*
3. *Quantification and monitoring requirements for carbon*
4. *Accounting for indirect leakage emissions*

Protocols contain the rules and requirements for quantifying and certifying carbon credits for sale, and thus are critical to ensuring quality.

A **high-quality forest carbon credit** is one that represents a real, accurately measured tonne of carbon emissions avoided or removed that will remain out of the atmosphere for decades or more and that doesn't cause indirect emissions elsewhere.

Guidelines for certifying carbon credits, provided through carbon credit protocols, attempt to ensure high quality through four key components of quantification:

1. Non-permanence risk reduction
2. Additionality and proper baseline establishment
3. Quantification and monitoring requirements for carbon
4. Accounting for indirect leakage emissions

To provide a real climate benefit, forest carbon projects must not cause net climate warming due to non-greenhouse gas feedbacks. While scientific understanding of how forests influence climate beyond carbon storage and emission is still developing, these feedbacks could be important in some locations. For example, when afforestation or reforestation projects involve planting dark colored trees on a relatively bright colored land cover, like a grassland, more heat could be absorbed by the Earth's surface and counteract some of the climate cooling effect of tree carbon storage. This change in surface reflectivity, known as albedo, is becoming well enough understood to be integrated into carbon project planning.[20] But at present not a single forest carbon protocol that was evaluated accounts for potential non-greenhouse gas impacts so this was not part of the evaluation.

It is also important that forest carbon projects are environmentally sound and sustainable and that they respect human rights and self-determination of local communities. However, the Ground Truth assessment is focused on the technical quantification of carbon benefit, rather than environmental and social aspects of forest carbon projects, and does not evaluate environmental and social safeguards.

Figure 3: **Key components of high-quality credits**

NON-PERMANENCE RISK REDUCTION

Addresses vulnerability of carbon re-release to the atmosphere through human activities like deforestation or disturbances like fire or insect outbreaks.

ADDITIONALITY & PROPER BASELINE ESTABLISHMENT

Involves demonstrating that the carbon stored by the forest project would have ended up in the atmosphere without the carbon credit incentive and developing a realistic assessment of what would have occurred in the absence of the intervention.

QUANTIFICATION & MONITORING REQUIREMENTS FOR CARBON

Specify the relevant carbon pools and emissions sources and are central to ensuring the accuracy and continued presence of the carbon sequestered by the project over time.

ACCOUNTING FOR INDIRECT LEAKAGE EMISSIONS

Entails assessing whether and to what extent implementing the carbon project impacts land use activities and markets outside of the project boundary in ways that increase emissions elsewhere.

Section III

How do current forest carbon credit protocols score?

KEY MESSAGE

The evaluation of 20 forest carbon credit protocols determined that most protocols score poorly. Consequently, the project team concluded that these protocols are not robust enough to guarantee that associated forest carbon credits are consistently real, high-quality, and fungible with fossil carbon emissions for offsetting.

Existing forest carbon credit protocols relevant to North America were evaluated for their ability to guarantee high-quality credits.

Specifically, the team of forest scientists used a detailed rubric based on 18 individual features across four key components that are common to all forest carbon credit protocols (see Sanders DeMott et al (2025) for details). Each expert scored 126 separate approaches to implementing these protocol features on a seven-point Likert scale,[a] allowing a detailed evaluation of specific features rather than simply a high-level review of the protocol as a whole. The overall protocol scores based on the individual features were consistently low with most ranging between very weak and weak and just one protocol scoring satisfactory. None of the 30 protocol-project type combinations received a median score of robust or higher.

Based on the assessment, these protocols cannot guarantee that forest carbon credits are sufficiently high quality to be fungible with one tonne of fossil emissions in an offsetting context.

Most forest protocols perform poorly in three of the four components used to define high-quality forest carbon credits: non-permanence risk reduction, additionality and baseline estimation, and accounting for leakage. Although most protocols do a better job of quantifying and monitoring carbon stored by projects by using science-based approaches, they are currently not designed to easily integrate new breakthroughs in forest carbon monitoring. While certain protocols may score well in one or two components, substantial inconsistencies across the evaluated protocols can lead to low-quality credits. It is critical that protocols be strong in all four components to generate reliably high-quality credits.

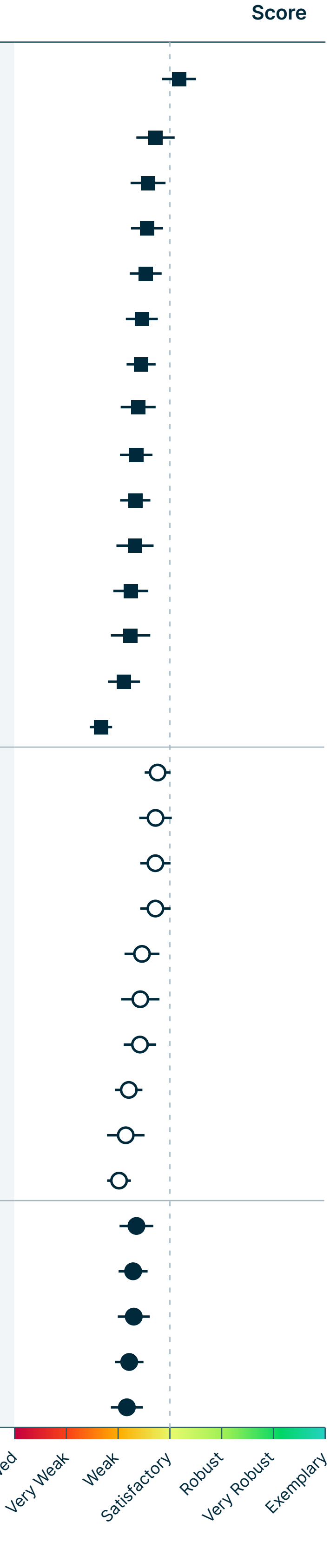
[a] Approaches were scored on a seven-point Likert scale:

- Fundamentally Flawed
- Very Weak
- Weak
- Satisfactory
- Robust
- Very Robust
- Exemplary

The project team was instructed to assess the approaches relative to their view of an ideal approach given the state of science, and not relative to one another.

Figure 4: **Ranked forest carbon credit protocols**

Protocol	Program	
VM0045 IFM Using Dynamic Matched Baselines from National Forest Inventories, V1.0*	Verra	Improved Forest Management (IFM)
VM0035 IFM through Reduced Impact Logging, V1.0	Verra	Improved Forest Management (IFM)
VM0005 Conversion of Low-Productive Forest to High-Productive Forest, V1.2	Verra	Improved Forest Management (IFM)
VM0012 IFM in Temperate and Boreal Forests (LtPF), V1.2	Verra	Improved Forest Management (IFM)
VM0034 Canadian Forest Carbon Offset Methodology, V2.0	Verra	Improved Forest Management (IFM)
VM0010 IFM: Conversion from Logged to Protected Forest, V1.3*	Verra	Improved Forest Management (IFM)
VM0003 IFM through Extension of Rotation Age, V1.3	Verra	Improved Forest Management (IFM)
U.S. Forest Protocol, V5.1	Climate Action Reserve	Improved Forest Management (IFM)
IFM on Non-Federal U.S. Forestlands, V2.0*	American Carbon Registry	Improved Forest Management (IFM)
IFM on Small Non-Industrial Private Forestlands, V1.0*	American Carbon Registry	Improved Forest Management (IFM)
U.S. Forest Projects – June 25, 2015	California	Improved Forest Management (IFM)
IFM on Canadian Forestlands, V1.0	American Carbon Registry	Improved Forest Management (IFM)
Forest Carbon Offset Protocol, V2.0	British Columbia	Improved Forest Management (IFM)
Mexico Forest Protocol, V3.0	Climate Action Reserve	Improved Forest Management (IFM)
PM 001 Agriculture and Forestry Carbon Benefit Assessment Methodology, V1.0	Plan Vivo	Improved Forest Management (IFM)
U.S. Forest Protocol, V5.1	Climate Action Reserve	Afforestation/Reforestation (AR)
Afforestation and Reforestation of Degraded Lands, V1.2	American Carbon Registry	Afforestation/Reforestation (AR)
U.S. Forest Projects – June 25, 2015	California	Afforestation/Reforestation (AR)
VM0047 Afforestation, Reforestation, and Revegetation, V1.0	Verra	Afforestation/Reforestation (AR)
Forest Carbon Offset Protocol, V2.0	British Columbia	Afforestation/Reforestation (AR)
VM0034 Canadian Forest Carbon Offset Methodology, V2.0	Verra	Afforestation/Reforestation (AR)
Mexico Forest Protocol, V3.0	Climate Action Reserve	Afforestation/Reforestation (AR)
Afforestation/Reforestation (A/R) GHGs Emissions Reduction & Sequestration, V2.0*	Gold Standard	Afforestation/Reforestation (AR)
Carbon sequestration through AR on private lands – September 2023	Quebec	Afforestation/Reforestation (AR)
PM 001 Agriculture and Forestry Carbon Benefit Assessment Methodology, V1.0	Plan Vivo	Afforestation/Reforestation (AR)
Active Conservation and Sustainable Management on U.S. Forestlands, V1.0	American Carbon Registry	Avoided Conversion (AC)
Forest Carbon Offset Protocol, V2.0	British Columbia	Avoided Conversion (AC)
VM0034 Canadian Forest Carbon Offset Methodology, V2.0	Verra	Avoided Conversion (AC)
U.S. Forest Protocol, V5.1	Climate Action Reserve	Avoided Conversion (AC)
U.S. Forest Projects – June 25, 2015	California	Avoided Conversion (AC)



**An updated version of this protocol with moderate changes is now available.*

Non-permanence risk reduction

All protocols scored between very weak and satisfactory for this component; no protocols scored as robust or stronger although the 100-year monitoring period scored as very robust. Protocols were evaluated for their approaches to monitoring period length, the structure of risk assessment and accounting, determining overall buffer pool contribution, identifying risk from wildfire and insect or disease, and if and how often risk rating is revisited. All but one protocol used a buffer pool for risk management and the outlier used a tonne-year accounting[21] approach.

Figure 5: **Component: Non-permanence risk reduction**

Feature	Approach	Score	
How long is project carbon monitored for reversal?	100 years monitoring after credit issued	Very Robust	5.5
	40-100 years combined credit issuance and monitoring period	Satisfactory	3.0
	30-100 years combined credit issuance and monitoring period	Satisfactory	3.0
	30-100 years monitoring after credit issued, based on tonne year accounting	Weak	2.0
	10-50 years combined credit issuance and monitoring period	Very Weak	1.0
	None, tonne-year accounting	Very Weak	1.0
How is approach to account for risk of reversal structured?	Risk analysis and project-based buffer pool	Satisfactory	3.0
	Tonne-year accounting with buffer pool	Weak	2.0
	Project-based buffer pool contribution	Weak	2.0
	Risk analysis with fixed buffer pool contribution	Weak	2.0
	Risk mitigation plan and a project-based buffer pool	Weak	2.0
	Tonne-year accounting	Very Weak	1.0
What is the approach to determining buffer pool contribution?	Project-specific, default values assigned by specified datasets	Satisfactory	3.0
	Project-specific, default values selected and justified by project	Weak	2.0
	Project-specific, default values provided	Weak	2.0
	Fixed contribution	Very Weak	1.5

Feature	Approach	Score	
How is risk of fire accounted for the buffer pool?	Assigned as default by narrow eco-region	Satisfactory	3.0
	Assigned based on specified external dataset	Weak	2.0
	Categorical risk selected and justified at project-level	Weak	2.0
	Part of fixed buffer pool contribution	Very Weak	1.0
	Assigned as default by broad eco-region	Very Weak	1.0
	Assigned as default 4% or 6% across all projects	Very Weak	1.0
How is risk of insect and disease outbreak accounted for the buffer pool?	Combined with fire risk, assigned as default by narrow eco-region	Satisfactory	3.0
	Assigned based on specified external dataset	Weak	2.0
	Categorical risk selected and justified at project-level	Weak	2.0
	Assigned as default by broad eco-region	Very Weak	1.5
	Combined with fire risk, assigned as default	Very Weak	1.0
	Part of fixed buffer pool contribution	Very Weak	1.0
	Assigned as default at 3% across all projects	Fund. Flawed	0.5
How frequently is risk assessment revisited?	Revisited upon verification, updates are retroactive	Satisfactory	3.0
	Revisited upon each verification, buffer credits may be released over time	Weak	2.0
	Revisited upon verification or in the event of a reversal, updates not retroactive	Weak	2.0
	Revisited upon verification, updates not retroactive	Weak	2.0
	Fixed for project life	Fund. Flawed	0.0

Additionality and baseline estimation

Overall scores for the protocols were weak on average, ranging between very weak and robust, although individual elements of some protocols were scored as robust including the use of empirical observations to set a dynamic baseline. Protocols were assessed based on their approach to demonstrating additionality, establishing and then forecasting the baseline scenario through time, the frequency of baseline reassessment, and if and how uncertainty in measurements and models are handled.

Figure 6: **Component: Additionality and baseline estimation**

Feature	Approach	Score	
What are the requirements for demonstrating additionality?	Moderately flexible, project-justified with narrow qualitative eligibility requirements	Weak	2.0
	Prescriptive, based on quantitative performance test against protocol-specified baseline[1]	Weak	2.0
	Flexible, project-justified	Very Weak	1.0
How is the baseline scenario established?	Based on empirical observations of reference areas from specified external dataset	Robust	4.0
	Dictated by eligibility requirement that project area be deforested for sufficient time period	Satisfactory	3.0
	Set by observed revegetation rate of reference area from external data source	Satisfactory	3.0
	Set at initial carbon stocking levels based on eligibility that area be deforested for sufficient time period	Weak	2.5
	Dictated by eligibility requirement that project area be at risk of conversion	Weak	2.0
	Specified as harvest scenario that maximizes net present value (NPV)	Weak	2.0
	Harvest scenario to maintain carbon stocks at/above a specified regional level	Weak	2.0
	Based on specified measurable proxies for reduced impact logging practices	Weak	2.0
	Preferred baseline scenario is specified, but project selected and justified	Very Weak	1.5
	Identified and justified by project using range of possible data sources	Very Weak	1.0
	Based on highest value alternate land use from certified real estate assessment	Very Weak	1.0
	Set as initial carbon stocking levels	Very Weak	1.0

[1] Given the reliance of baseline scenario for demonstrating additionality, we used the score for 'Establishing baseline scenario' to also represent 'Demonstrating additionality' for any protocol using this approach.

Feature	Approach	Score	
How is the baseline scenario forecasted over time?	No forecasting; baseline vegetation establishment set by observing references areas (AR only)	Robust	4.0
	No forecasting; baseline set by observing reference areas from external dataset (IFM only)	Satisfactory	3.5
	No forecasting; common practice values provided by measured impact parameters (IFM only)	Satisfactory	3.0
	Required models and conversion factors specified (AC only)	Satisfactory	3.0
	Required models are specified	Weak	2.5
	Modeling required but model choice optional and conversion factors specified (AC only)	Weak	2.5
	No forecasting as baseline is fully accounted for in year 1 (AR only)	Weak	2.0
	Project-justified and may be based on measurements in reference areas or models	Weak	2.0
	Modeling required but models are unspecified or only recommended	Weak	2.0
	Prescribed model or biomass increment tables until steady state (AR only)	Weak	2.0
	Forecast via historical management or reference areas and specified equations (IFM only)	Weak	2.0
	No forecasting required; fixed at initial onsite carbon stocking level for project duration	Very Weak	1.0
What are the requirements for reassessing the baseline over time?	Dynamic and based on observations over time	Robust	4.0
	Fixed for project duration, with scheduled reassessment	Satisfactory	3.0
	Fixed for project duration, with scheduled reassessment based on reference areas (AR only)	Satisfactory	3.0
	Fixed for project duration, with criteria to trigger reassessment	Weak	2.0
	Fixed for project duration	Very Weak	1.0
What are the requirements for incorporating uncertainty into the baseline scenario?	Adjusted for conversion risk, measurement and project uncertainty combined (AC only)	Satisfactory	3.0
	Baseline uncertainty is pooled with project uncertainty and may be deducted from net credits	Weak	2.5
	Measurement uncertainty over threshold is added to baseline model inputs	Weak	2.0
	Uncertainty is factored into provided performance standard values (IFM only)	Weak	2.0
	Adjusted for conversion risk, no measurement uncertainty deduction in baseline (AC only)	Weak	2.0
	No uncertainty adjustment for baseline or project scenario	Very Weak	1.0
	No uncertainty adjustment for baseline scenario measurements	Very Weak	1.0
	No mention of uncertainty	Fund. Flawed	0.5

Quantification and monitoring requirements for carbon

Protocols generally scored higher for this component than the others and fell between very weak and robust, with the four highest-scoring protocols exceeding satisfactory. Frequent field sampling requirements and field data for monitoring were scored robust. Requirements for carbon pools and emissions sources that must be quantified and monitored vary by project type and specific project activity. The assessment focused on features related to tree biomass, harvested wood products, and soil carbon, as approaches to these pools are quite variable across protocols. Required sampling frequency, reliance on empirical data versus models, and the treatment of uncertainty in measurements and models were also assessed.

Figure 7: **Component: Quantification and monitoring requirements for carbon**

Feature	Approach	Score	
Tree biomass storage estimation	Field measurements required, biomass estimation values regionally specified	Satisfactory	3.5
	Inventory data or field measurements, biomass estimation values regionally specified	Satisfactory	3.0
	Based on measurable proxies (IFM only)	Satisfactory	3.0
	Field measurements required, biomass estimation approach flexible	Weak	2.0
	Inventory data with field validation, biomass estimation approach and values by project	Weak	2.0
	Field measurements required, broad default biomass estimation values permitted	Weak	2.0
	Based on flexible approaches to field measurement, biomass estimation approach (AR only)	Very Weak	1.5
Required sampling frequency	6 years or less	Robust	4.0
	Minimum 7-15 years	Weak	2.5
	Unspecified, measured at each issuance	Weak	2.5
	Unspecified, measured at each harvest	Weak	2.0
	Minimum 15+ years	Very Weak	1.5
	Unspecified, determined by project	Very Weak	1.0

Feature	Approach	Score	
Harvested wood products storage estimation	Based on mill reports and/or regional parameters when available	Satisfactory	3.0
	Regional values provided, project-specific calculations permitted	Satisfactory	3.0
	Based on mill reports and/or regional parameters	Satisfactory	3.0
	Based on protocol-prescribed regional values	Satisfactory	3.0
	Excluded due to insignificance, conservativeness, and/or lack of credible data	Satisfactory	3.0
	Intermediate and long-term storage based on global default values	Weak	2.0
Soil carbon storage	Excluded, limitations on soil disturbance for site preparation	Satisfactory	3.0
	Excluded for carbon benefit, required above disturbance threshold, no measurement required	Satisfactory	3.0
	Optional for carbon benefit, required for disturbance (AC only)	Satisfactory	3.0
	Excluded, potential changes considered insignificant (IFM only)	Satisfactory	3.0
	Optional for carbon benefit, no measurement required (AC only)	Weak	2.0
	Optional for carbon benefit, required if above disturbance threshold	Weak	2.0
	Optional for carbon benefit, required if above disturbance threshold, no measurement required	Weak	2.0
	Optional for emissions and/or carbon benefit	Very Weak	1.0
Data sources for issuance	Field measurement only	Robust	4.0
	Modeling periodically updated with measurements, models specified	Weak	2.0
	Modeling periodically updated with inventories, models unspecified	Weak	2.0
	Modeling periodically updated with other data sources, models open-ended	Weak	2.0
Treatment of uncertainty	Uncertainty deduction always required	Satisfactory	3.5
	Uncertainty deduction required over threshold	Satisfactory	3.0
	Uncertainty deduction included in prescribed common practice value	Weak	2.5
	Sampling precision requirement only	Very Weak	1.5
	Uncertainty should be reduced to extent possible, no adjustment	Very Weak	1.0

Indirect leakage emissions accounting

Leakage assessment approaches were evaluated separately for each project type. For IFM projects, scores ranged from very weak to satisfactory while AR projects ranged from weak to satisfactory, and AC projects ranged from very weak to weak. Leakage accounting is regarded as one of the most fraught and difficult to estimate facets of carbon credit markets.[37] Estimation methods are highly uncertain, counterfactuals are difficult, and leakage is context specific and not necessarily easily transferable.[40] Rather than evaluate multiple features of leakage assessment, the general approach laid out by protocols according to project type was scored.

Figure 8: **Component: Leakage accounting**

Feature	Approach	Score	
Leakage accounting (IFM)	Market leakage values provided based on stocking density. Activity leakage monitored	Satisfactory	3.0
	No leakage adjustment as harvest reduction is not permitted	Satisfactory	3.0
	Default market leakage values, no activity leakage, leakage credits may be earned back	Weak	2.0
	Market leakage based on default values or project specific. Activity leakage monitored	Weak	2.0
	Both activity and market leakage must be assessed at project level	Weak	2.0
	Default market leakage value, no explicit requirements for activity leakage	Very Weak	1.5
	Multiple approaches at project discretion	Very Weak	1.0
Leakage accounting (AR)	Default leakage factors of 10-50% provided based on displaced activity	Satisfactory	3.0
	Project-specific activity shifting leakage based on displaced activity applied annually	Satisfactory	3.0
	Project-specific activity/market shifting leakage based on productivity and project term	Weak	2.5
	Project-specific activity shifting leakage calculated on operator’s displaced activity	Weak	2.5
	Project-specific or default activity shifting leakage, total value applied in year 1	Weak	2.0
	Very flexible, multiple approaches at project discretion	Weak	2.0
Leakage accounting (AC)	Activity shifting leakage deduction of 4.3%, market leakage required for reduced harvest	Weak	2.0
	Both activity and market leakage must be assessed on a project-specific basis	Weak	2.0
	Activity shifting leakage deduction of 3.5% required, no market leakage accounting	Very Weak	1.0

Section IV

How can carbon credit protocols be improved?

KEY MESSAGE

Protocols need to be significantly overhauled. They should prescribe spatially explicit, independent, and up-to-date data, reevaluate risk over time, develop dynamic baselines that evolve as conditions change, and provide regionally specific default values and parameters for estimating the actual change in carbon in the forest. They should also be structured to enable timely updates to reflect the best available science. In addition, there needs to be radical improvements in transparency and alleviation of conflicts of interest in carbon markets.

Improvements to the four evaluated components

The project team identified improvements to protocols and the carbon market system that would promote reliably high-quality forest carbon credits based on available science. Some of these improvements are straightforward to implement and may already be adopted by some protocols. Others will require building out scientific tools, governing structures, and financing and risk-sharing mechanisms necessary for implementation, but are critical to the long-term validity of the forest carbon market.

Non-permanence risk mitigation improvements

Protocols should require that risk reassessments be project-specific, rather than based on general default values, and updated at least every five years such that they incorporate the best available science to assess risk as it develops. Protocols should require the use of independent specific, spatially explicit datasets instead of allowing project developers to choose data sources. Templates and tools to incorporate site-specific information with such datasets would also help improve accuracy; for example, site-level species composition will impact the risk of disease/insect invasion. These improvements may require much larger buffer pool contributions than current protocols demand but could reduce transaction costs and increase access by shifting some of the calculation off the project developer to outside actors.

Additionality and baselines improvements

Baselines should be dynamic, transparent, and adjusted for changing ecological and socio-economic conditions during the crediting period. Dynamism can be incorporated into baselines by using empirical observations of well-matched reference areas of similar forests not enrolled in a carbon project or at minimum, requiring regular reassessment of the baseline scenario assumptions during the crediting period. Existing datasets in some forested regions could provide spatial information on rates of development and land use conversion, natural revegetation patterns, and forest management practices to inform such empirical baselines. But widespread adoption of this approach will require continued development of such high-quality forest inventory data streams. Ensuring that tools are used rigorously will require detailed guidelines for selecting appropriate reference sites that minimize gaming, avoid adverse selection, and are matched transparently and repeatably. Protocols should also provide a means to quantitatively account for the inherent uncertainty in applying observations from reference areas to the project area. A simple improvement in transparency would be the inclusion of a visual presentation of the estimated project carbon stocks and baseline assumptions over time, in addition to a descriptive explanation and justification.

Quantification and monitoring improvements

Regionally appropriate allometric equations (which allow for physical measurements like tree trunk diameter to be converted to mass of carbon) provided by protocols should be the minimum requirement, but rapid improvements in forest measurement tools will continue to increase the accuracy and precision of biomass estimation. Protocols must be constructed so that improvements can be readily incorporated. Harvested wood products are very hard to estimate without mill reports; thus, the project team recommends that these be made available to verifiers. In the absence of mill reports, protocols should establish tools to make standardized region-specific values available. Awarding credits for soil carbon gains in forest projects should be excluded until methods are developed to properly account for spatial and temporal variability of this pool.[22]

Uncertainty should be clearly articulated and reported by category, not just as an overall correction, as it is critical that more work be done to understand and reduce the primary sources of uncertainty.

Leakage assessment improvements

The growing body of literature on leakage (such as 21–23) suggests that existing protocols significantly underestimate leakage and, therefore, are over-crediting. Constraining leakage is fundamental to ensuring that each carbon credit has real climate benefit. However, the tools to tackle this more robustly have yet to be developed and integrated into the carbon market system. The degree of variation in existing default values across protocols is concerning and points to a need to fundamentally overhaul leakage assessment. For US projects, it should be possible to develop more regionally representative default values that can be established and integrated into protocols based on currently available data. Furthermore, protocols for improved forest management that require no reduction in harvest could account for market leakage.[26]

General carbon market system structure improvements

In addition to these improvements to the four evaluated components, overarching structural changes to carbon markets could improve both rigor and trust in forest carbon credits:

Improve transparency

While standardization and stricter protocol criteria are important, some level of flexibility will always be necessary. Therefore, radical improvements in transparency are needed to allow for the review and comparison of individual projects and their progress. This should include information on data sources provided through detailed reporting in publicly accessible and user-friendly, machine-readable formats. Supporting data and parameters for risk, baselines, tree biomass, wood storage estimation, and leakage should come from independent sources and be prescribed by the registry, not originate from the project developer. At minimum, registries should ensure that issued carbon credits specify the protocol and version number (including any relevant modules) under which they were certified.

Address actual or perceived conflicted interest of VVBs

These key players are hired from a pre-approved list maintained by registries at the discretion of the project developer. While VVBs are not compensated per credit, because they are paid by project developers, they could face pressure to approve weak projects lest risk being passed over for projects in the future. This concern might be remedied if registries systematically manage the selection of VVBs to ensure an appropriate level of independence.

Consider non-greenhouse gas feedbacks between forests and climate, especially albedo

Non greenhouse-gas impacts of forests on climate, like albedo, are an increasing concern, particularly for afforestation, and may require further structural changes to carbon markets. Tools providing information on geographies where reductions in albedo counteract the carbon benefit of AR projects[27] are a step in this direction and make screening for regions where albedo changes are likely to counteract the climate benefit of AR projects feasible today. As scientific understanding of other non-greenhouse gas feedbacks between forests and climate, such as biological volatile organic compound production and local land-atmosphere exchange impacts on water cycles evolve, there may be cause to integrate these elements into protocols to quantify net climate impact.

Improving Compliance Carbon Market Protocols

While compliance markets, underpinned by government regulations or legally binding targets, allow for guardrails on the appropriate use of carbon credits and more oversight in certification, getting the guidelines for quantification of forest carbon credits right can be a challenge. Existing compliance-based markets may need to consider legal constraints, administrative limitations, political dynamics, market certainty dynamics, and other factors that impact adoption of these recommended improvements. Therefore, improving protocols in compliance markets may require additional design considerations or legislative updates to improve rigor.

Table 1: **Recommendations for improving forest carbon protocols key components**

Component	Recommended improvements	
	Near-term Implementation	**Significant Development Required**
Non-permanence risk reduction	✓ Require risk reassessments at least every 5 years. ✓ Risk of reversal is derived from third-party best-available scientific data specified by the registry.	✓ Provide templates and methodologies for project-specific information to be combined with independent datasets to derive site-appropriate values. ✓ Buffer pool contributions must appropriately reflect observed and projected risk.
Additionality and baseline estimation	✓ Baselines should be dynamic. Assumptions should be reassessed at regular intervals. ✓ Reporting should require visual representation of baseline projection.	✓ Baselines should be derived from empirical observations over time. ✓ Detailed guidelines should be provided for selecting reference sites that minimize gaming, avoid adverse selection, and are matched transparently and repeatably. ✓ Provide means to quantitatively account and deduct for uncertainty associated with reference areas.
Quantification and monitoring requirements	✓ Regionally appropriate values for biomass estimation should be provided by protocols. ✓ Soil carbon gains should not be credited for forest projects at this time; soil carbon emissions from disturbance should be deducted.	✓ Protocols must be designed to allow for improvements in tools and techniques to be incorporated with the goal of increasing the accuracy and precision of biomass measurements over time. ✓ Uncertainty should be clearly articulated and reported by source, not just as an overall correction.
Leakage assessment	✓ Within the U.S., conservative and regionally appropriate values should be provided by protocols. ✓ Prohibiting reductions in harvest can prevent leakage for some improved forest management projects.	✓ Approaches to account for leakage need to be fundamentally overhauled to account for the reality of activity shifting and market leakage at regional, national, and global scales. ✓ Investments in research to develop better, standardized tools are needed.
General carbon market structure	✓ Improve transparency ✓ Address actual or perceived conflicted interest of VVBs. ✓ Consider non-greenhouse gas feedbacks between forests and climate, especially albedo	

Section V

What is next for forest carbon markets?

KEY MESSAGE

Achieving these improvements should promote consistent real, high-quality credits. At the same time, these changes will likely constrain supply and increase cost of credits. To fully realize the climate mitigation potential of forest ecosystems, it will also be important to expand alternate mechanisms to channel finance into forest climate solutions that do not rely on a credit sale for offsetting model.

Forest carbon offset markets are at a crossroads, **now is the time to implement change**

The future trajectory of forest carbon offset markets is highly uncertain. Despite high profile criticisms and wide recognition of the failures of this system to date, there is a groundswell of interest in reforming and expanding carbon offset markets across a range of key stakeholders. There is both an urgent need and a large appetite for information to prevent weak protocols from being integrated into future market activities.

There are ongoing activities and opportunities to raise the bar on carbon credit quality occurring in the private sector on both the supply and demand sides, and through new or updated regulatory mechanisms. Stakeholders must be prepared to meet these opportunities.

Implementing improvements will require a collaborative effort by stakeholders, and could increase cost and decrease the number of credits issued per project

Improving forest carbon crediting protocols will require substantial changes to the carbon markets, as well as significant efforts from the forest carbon research community. Scientists, governments, investors, and carbon market actors must work together to create and support the data and tools needed to improve forest carbon crediting. Strong policies that incentivize meeting these high standards are also critical. Continuing to rely on the status quo without such investments is a serious risk to climate change mitigation.

Adopting these recommendations may cause the number of carbon forest credits issued per project to decline because these improvements will lead to more conservative quantification of the carbon benefits of forestry activities. But consistent real, high-quality credits should also command a higher price.

Non-offsetting approaches are also needed to enhance forest carbon storage

Commodifying the carbon in forests for use as offsets is not and should not be the only way to finance the critical work of forest conservation, restoration, and sustainable management that enhance forest carbon storage. There are emerging models to channel private funds to forest carbon efforts, such as corporate purchasing of carbon credits to contribute to climate change mitigation without claiming offsets against emissions, enhanced conservation easements for forest carbon management, direct payments for practices that enhance carbon storage, and expanded access to low-cost or non-recourse loans to finance practice adoption. Such models could reduce the need for precision and permanence at the project-scale that are necessary for offsetting fossil emissions, while mobilizing private finance for critical forest solutions.

Implications

The general principles of structuring protocols to adopt the best available science, limit gaming of the system by using project-specific but prescribed, independent, and up-to-date data, developing dynamic baselines that evolve as conditions change, and providing for region-specific default values and parameters will help improve many forest carbon project types. Moreover, coordinated data infrastructure across jurisdictions will help harmonize protocols for international markets.

The results of the Ground-Truth assessment demonstrate that it is crucial to strengthen forest carbon credit protocols for quantifying and certifying forest carbon credits to ensure that credits issued under new compliance systems and expanding voluntary markets achieve their intended climate outcomes.

Glossary

Additionality – demonstration that the carbon stored by the forest project would have ended up in the atmosphere without the carbon credit project

Afforestation/Reforestation (AR) – refers to tree planting or natural/managed regeneration on lands that were either forested previously (reforestation) or were not but that could support forest ecosystems (afforestation)

Avoided conversion (AC) – projects that seek to prevent deforestation for other legally permissible land uses, like agriculture or commercial development

Buffer pool – a mechanism to insure the validity of carbon credits vulnerable to reversal. A certain fraction of carbon credits generated by each project are set aside into a pooled account, which can be used as insurance to cover unanticipated losses from any specific project during the contract period

Carbon credit – a market instrument in the form of a tradable certificate representing one metric ton of carbon dioxide equivalent emission reduction, avoidance, or removal that is the manifestation of a project, intervention, or activity

Carbon market registries – entities that issue credits using their own guidelines to quantify emissions reductions or removals and track their ownership over time

Carbon offset – as a verb, the compensation for one metric tonne of carbon dioxide equivalent emissions from a given source with a carbon credit representing one metric tonne of carbon dioxide equivalent emissions reductions or removal derived from another project, intervention, or activity. As a noun, a carbon credit that can be/is used for offsetting

Improved forest management (IFM) – forest management activities that decrease emissions from forests or increase carbon removal and storage when compared to business-as-usual forestry practices

Leakage accounting – assessment and correction for the extent to which implementing the carbon project impacts land use activities and markets in ways that increase emissions outside of the project boundary

Project developers – individuals or organizations who generate carbon credits by following registry protocols and paying registry fees to track their credits

Protocols – the collection of guidelines that determine how projects must calculate the number of carbon credits generated from a carbon project for certification and sale on the registry (also referred to as 'methodologies' and/or 'standards')

Reducing Emissions from Deforestation and Forest Degradation (REDD+) – reducing emissions from deforestation and forest degradation in developing countries. This includes sustainable management of forests and conservation and enhancement of forest carbon stocks*

Tonne-year accounting – a model for crediting that awards only a fraction of a credit for each tonne of carbon stored based on the time that the carbon is guaranteed to be held in storage and the climate cooling value of the storage period

United Nations Framework Convention on Climate Change (UNFCCC) – United Nations Convention formed in 1992 aiming to stabilize greenhouse gas concentrations in the atmosphere at a level that will prevent dangerous human interference with the climate system, in a time frame which allows ecosystems to adapt naturally and enables sustainable development*

Validation and verification bodies (VVBs) – qualified, independent third-party auditors of project documentation and calculations that assure compliance with the protocol guidelines

*definitions adapted directly from UNFCCC (https://unfccc.int/)

Appendix

Figure A1: **Individual protocol scorecards**

Aggregated scores for each evaluated protocol and project type. More detailed descriptions of the evaluated features are provided in Table A1 and a comprehensive list of scored approaches for each protocol is available in Sanders-DeMott et al. 2025 and forestcarbonprotocols.org.

Protocol	Program	Project Type	Score	
VM0045 IFM Using Dynamic Matched Baselines from National Forest Inventories, V1.0*	Verra	IFM	Satisfactory	3.2
VM0035 IFM through Reduced Impact Logging, V1.0	Verra	IFM	Weak	2.7
VM0005 Conversion of Low-Productive Forest to High-Productive Forest, V1.2	Verra	IFM	Weak	2.5
VM0012 IFM in Temperate and Boreal Forests (LtPF), V1.2	Verra	IFM	Weak	2.5
VM0034 Canadian Forest Carbon Offset Methodology, V2.0	Verra	IFM	Weak	2.5
VM0010 IFM: Conversion from Logged to Protected Forest, V1.3*	Verra	IFM	Weak	2.4
VM0003 IFM through Extension of Rotation Age, V1.3	Verra	IFM	Weak	2.4
U.S. Forest Protocol, V5.1	Climate Action Reserve	IFM	Weak	2.3
IFM on Non-Federal U.S. Forestlands, V2.0*	American Carbon Registry	IFM	Weak	2.3
IFM on Small Non-Industrial Private Forestlands, V1.0*	American Carbon Registry	IFM	Weak	2.2
U.S. Forest Projects – June 25, 2015	California	IFM	Weak	2.2
IFM on Canadian Forestlands, V1.0	American Carbon Registry	IFM	Weak	2.2
Forest Carbon Offset Protocol, V2.0	British Columbia	IFM	Weak	2.1
Mexico Forest Protocol, V3.0	Climate Action Reserve	IFM	Very Weak	1.9

Protocol	Program	Project Type	Score	
PM 001 Agriculture and Forestry Carbon Benefit Assessment Methodology, V1.0	Plan Vivo	IFM	Very Weak	1.4
U.S. Forest Protocol, V5.1	Climate Action Reserve	AR	Weak	2.7
Afforestation and Reforestation of Degraded Lands, V1.2	American Carbon Registry	AR	Weak	2.7
U.S. Forest Projects – June 25, 2015	California	AR	Weak	2.7
VM0047 Afforestation, Reforestation, and Revegetation, V1.0	Verra	AR	Weak	2.7
Forest Carbon Offset Protocol, V2.0	British Columbia	AR	Weak	2.4
VM0034 Canadian Forest Carbon Offset Methodology, V2.0	Verra	AR	Weak	2.3
Mexico Forest Protocol, V3.0	Climate Action Reserve	AR	Weak	2.3
Afforestation/Reforestation (A/R) GHGs Emissions Reduction & Sequestration, V2.0*	Gold Standard	AR	Weak	2.1
Carbon Sequestration Through AR on Private Lands – September 2023	Quebec	AR	Weak	2.0
PM 001 Agriculture and Forestry Carbon Benefit Assessment Methodology, V1.0	Plan Vivo	AR	Very Weak	1.8
Active Conservation and Sustainable Management on U.S. Forestlands, V1.0	American Carbon Registry	AC	Weak	2.2
Forest Carbon Offset Protocol, V2.0	British Columbia	AC	Weak	2.2
VM0034 Canadian Forest Carbon Offset Methodology, V2.0	Verra	AC	Weak	2.2
U.S. Forest Protocol, V5.1	Climate Action Reserve	AC	Weak	2.1
U.S. Forest Projects – June 25, 2015	California	AC	Weak	2.0

**An updated version of this protocol with moderate changes is now available.*

Table A1: **The eighteen evaluated features for each protocol**

For additional detail, see Sanders-DeMott et al. 2025.

Component	Feature		Description
Non-permanence risk reduction	1.	Monitoring period	Indicates how long project developers are required to monitor for reversals of carbon storage once credits are issued. Any reversals that occur during this period are subject to compensation to maintain the integrity of the credit.
	2.	Structure of risk mitigation	May be based on a pooled risk buffer pool of credits for all but one of the evaluated protocols. Alternatively may use a tonne-year accounting approach whereby only a fraction of a credit is issued for each tonne stored based on the amount of time the carbon is guaranteed, which can be as limited as one year.
	3.	Buffer pool risk contribution	Refers to the percentage of credits that must be set aside to account for risk and may be based on project-specific assessments or default values.
	4.	Fire risk buffer pool contribution	Covers the specific risk of wildfire to forest carbon stocks and is estimated in a range of ways across current protocols.
	5.	Insect and disease buffer pool contribution	Covers the risk of tree mortality due to outbreak of disease or insect invasion.
	6.	Risk reassessment	Indicates how often, if at all, the risk rating for a given project needs to be updated over time.
Additionality and baseline assessment	7.	Demonstrating additionality	Refers to the specific requirements for projects to demonstrate that they would not occur if not for the intervention of the carbon project and the promise of carbon credit sale.
	8.	Establishing the baseline scenario	The approach that the protocol prescribes for calculating what the carbon stocks in the project area would have been without the project.
	9.	Forecasting baseline carbon stocks through time	A critical aspect to asserting how the baseline scenario would have changed over time so that the progress of the project can be compared to this counterfactual throughout the project crediting period.
	10.	Baseline reassessment	Describes if and how the baseline assumptions are reevaluated and revised over time.
	11.	Treatment of uncertainty in the baseline estimate	If and how uncertainty of measurements and models are incorporated into baseline estimates.

Component	Feature		Description
Quantification and monitoring requirements for carbon stocks and fluxes	12.	Tree biomass estimation	Guidelines for quantifying carbon in above- and below-ground components that typically use empirical parameters to convert a measurement, such as tree trunk diameter, to biomass carbon. The specificity of those parameters to the project and the degree of decision-making for the assumptions that is placed on the project developer varies widely.
	13.	Required sampling frequency	Refers to how often on-the-ground measurements of project carbon stocks are required.
	14.	Long lived wood products storage	Products made from harvested wood can be a significant storage pool in the project and/or baseline scenario but varies with wood product lifecycle, geography, and markets.
	15.	Soil carbon accounting	If and whether soil carbon change (emission and/or storage) due to forest management is included. Measurement remains a major technical challenge at this point and is treated with varying degrees of caution across protocols.
	16.	Required data sources for monitoring and credit issuance	Refers to the extent to which protocols rely on empirical data, models, or emissions factors.
	17.	Approaches to project scenario uncertainty	How measurement and model uncertainty is addressed in protocols, level of detail in accounting and correcting varies.
Leakage accounting	18.	Leakage accounting	How protocols account for the risk that new forest management approaches that enhance forest carbon storage (such as conservation or extended rotational age) indirectly cause loss of forest carbon elsewhere. Approaches to leakage were scored by project type.

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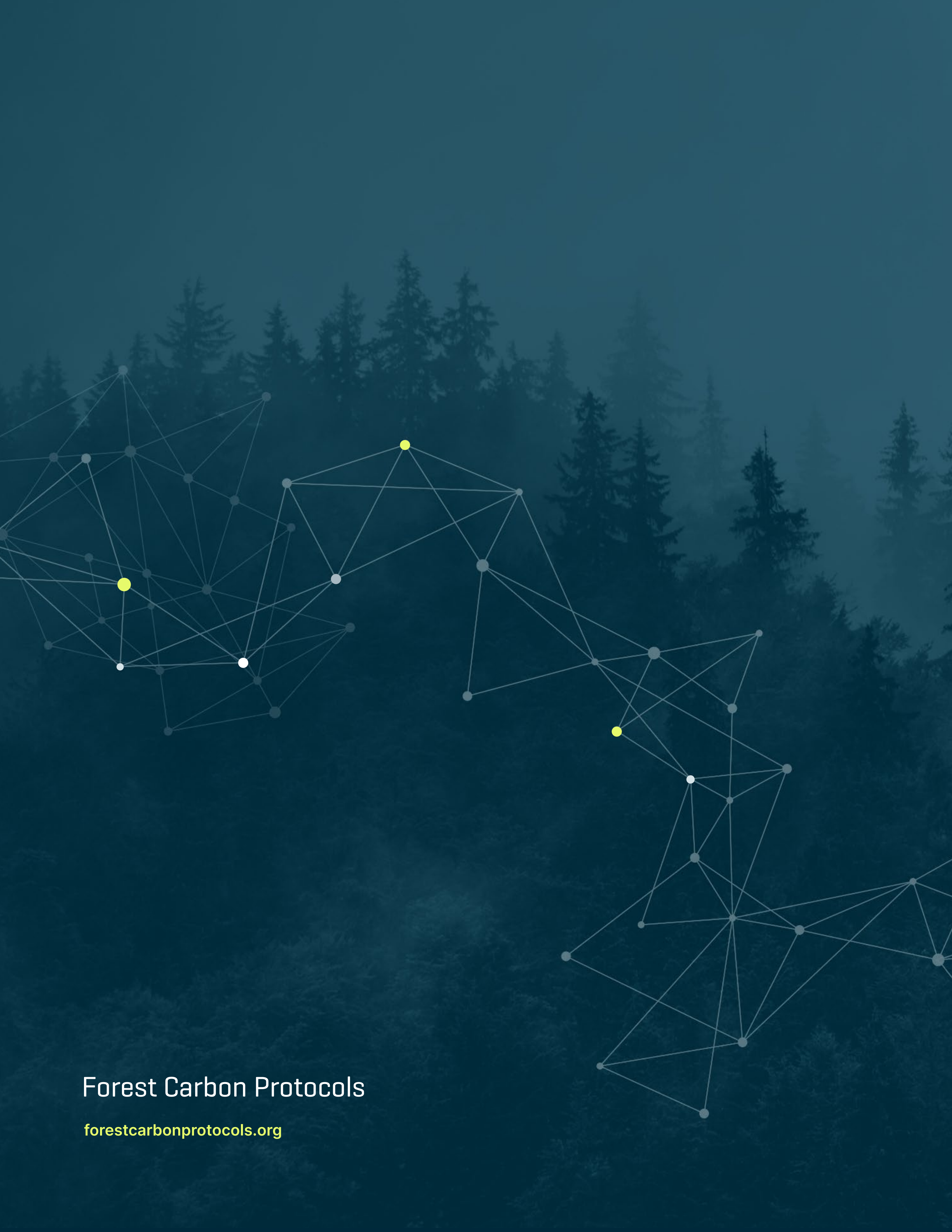

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