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TECHNOLOGY AND TRUST IN THE AMAZON

STRENGTHENING INTEGRITY IN ENVIRONMENTAL SERVICES MARKETS THROUGH INNOVATION: LESSONS FROM CARBON MARKETS



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ABOUT THE AUTHORS



AMAZON INVESTOR COALITION

Amazon Investor Coalition - is a global learning-and-collaboration platform fiscally sponsored by The Giving Back Fund, launched on September 16, 2020, during the United Nations 75 Global Governance Forum. AIC unites philanthropies, private investors, corporate buyers, governments, nonprofits, and local allies to reduce deforestation, promote forest-positive economies, and strengthen the rule of law across the Amazon region. Recognizing the Amazon's critical role in climate change mitigation and the global water cycle, AIC works to catalyze investment in a regenerative Amazon bioeconomy—one of the highest-leverage climate solutions of our time. Through its Nature Credit vertical, AIC advances the development of high-integrity carbon and biodiversity credit markets in the Amazon. By bridging global standards with regional realities, and fostering collaboration between Indigenous Peoples, local communities, investors, and subnational governments, AIC contributes to the creation of socially just, environmentally sound, and economically viable models for climate finance.



climate ventures

Climate Ventures - Climate Ventures (CV) works at the structural fault lines of Brazil's climate economy, where viable solutions remain invisible to capital, policy fails to reach implementation, and communities are excluded from the transitions they make possible. A think-and-do tank active since 2018, it produces and deploys applied intelligence and convenes actors across multiple sectors toward the levers that matter most. Through the Green Wave Platform, Latin America's largest green innovation registry with 1,500+ organizations, coalitions mobilizing US\$10 billion in nature finance, and publications ranging from ecosystem-wide mapping to thematic deep dives, Climate Ventures bridges the gap between climate commitments and coordinated action at scale.



Nature Tech Collective

Nature Tech Collective - Nature Tech Collective (NTC) is the connective infrastructure shaping how nature-based solutions are identified, understood, and deployed at scale. A global community of 189+ organizations, NTC connects solution-seekers with solution-builders through crowd-sourced sector intelligence, structured matchmaking, and accelerator programs, closing the gap between nature-related commitments and practical action.

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INTRODUCTION

Voluntary carbon markets are emerging as an increasingly important component of global efforts to mobilize finance for climate mitigation and nature protection. The VCMI (Voluntary Carbon Markets Integrity Initiative), through the Core Carbon Principles (CCPs), defines the fundamental pillars for the origination of high-integrity credits, among which we can highlight Additionality, Permanence, Robust Quantification, High Governance Standards, Robust Independent Third-Party Validation and Verification, Transparency, Tracking, and Benefit and Safeguard for Sustainable Development. As attention to nature-based solutions grows (the 2025 report *State of the Voluntary Carbon Market* indicates that nature-based solutions represent 45% of total transaction volume in 2024¹), these markets are attracting renewed interest as an alternative to channel investment toward high integrity forest restoration and conservation.

Nowhere is this discussion more consequential than in the Amazon. As one of the world's most critical ecosystems for climate stability and biodiversity, the region sits at the center of global debates on how nature-based solutions projects and carbon markets can support forest protection while respecting complex socio-ecological realities and overcoming financial barriers. In this context, emissions-reduction projects operate within landscapes shaped by diverse governance systems, land-tenure arrangements, and community dynamics, raising important considerations related to participation, benefit-sharing, and accountability. These governance dimensions are examined in greater detail in our *Best Practices Guide for Emissions Reduction Projects in the Brazilian Amazon*.

Many of the challenges and technical questions currently shaping debates around carbon markets are not entirely new. Since the early development of these instruments, scholars and practitioners have examined methodological questions such as baseline construction, additionality assessment, carbon stock measurement, and the ability of projects to deliver verifiable climate outcomes. What has evolved in recent years is the scale and sophistication of these discussions, supported by improved monitoring capabilities, greater data availability, and rising expectations around transparency and environmental integrity.

¹ As indicated in the report *State of the Voluntary Carbon Market 2025*, published by Ecosystem Marketplace (Washington, DC: Ecosystem Marketplace, 2025), available at: <https://3298623.fs1.hubspotusercontent-na1.net/hubfs/3298623/SOVCM%202025/Ecosystem%20Marketplace%20State%20of%20the%20Voluntary%20Carbon%20Market%202025.pdf> (accessed April 3, 2026).

This evolving analytical landscape has prompted a new wave of empirical assessments and technical evaluations that are helping refine existing frameworks and identify opportunities to strengthen market architecture. Increasingly, attention has turned toward the systems that underpin market credibility, specially monitoring and verification mechanisms, data infrastructures, transparency tools, and financial integration platforms. At the same time, technological innovation has brought advances in digital monitoring, geospatial data systems, blockchain-based traceability, and financial infrastructure are beginning to reshape how environmental outcomes are measured, verified, and communicated.

Within this context, technological innovation is emerging as a central enabler of more robust and scalable carbon markets. Against this backdrop, this report explores the growing intersection between carbon markets and technological innovation, with a particular focus on the Amazonian context. By mapping emerging technologies, highlighting innovative initiatives, and examining evolving data and market infrastructures, it seeks to illuminate how technological solutions can strengthen integrity, improve transparency, and support the responsible scaling of carbon markets in forest regions.

In Brazil, this role extends beyond carbon markets narrowly defined. *Nature Techs* can already be understood as one of the strategic segments of the country's Nature-based Solutions (NbS) market, while also functioning as enabling infrastructure for other segments such as restoration, sociobioeconomy, regenerative agriculture, and bioeconomy value chains. In this sense, their relevance lies not only in improving environmental integrity, but also in making nature-linked assets more legible, comparable, and investable.



TERRITORY: THE FIRST STRUCTURE TO HIGH INTEGRITY CARBON PROJECTS

The generation of emissions-reduction credits presupposes, as a structural condition, the existence of land over which property or use rights are clearly defined, legally valid, and duly attributed to the project proponents. Because mitigation activities are implemented within a specific territory, only formal landowners, legitimate possessors, or holders of valid concessions can, in principle, develop emissions-reduction projects on a given area².

In the Amazon, however, this foundational assumption encounters significant structural constraints. The region has long been characterized by limited state presence, low levels of land titling, widespread tenure informality, and territorial instability. This context fuels land conflicts, overlapping claims, and uncertainty regarding rights of possession and use, all of which create substantial barriers to the certification of carbon projects. As a result, the risks of future legal challenges, credit invalidation, rising audit costs, reduced investment appetite, and heightened reputational exposure for developers, certifiers, and buyers are markedly increased.

Although land-tenure categories vary, recent guidance has increasingly recognized the need for rigorous prior due diligence that combines legal-technical expertise with localized territorial knowledge. Such diligence must enable the assessment of the legitimacy of ownership or use rights, since land-tenure uncertainty directly undermines both the environmental and legal integrity of mitigation outcomes.

² For further information on legally recognized instruments governing land tenure and ownership in the Brazilian Amazon, please refer to <https://amazoninvestor.org/best-practices-for-high-integrity-carbon-projects-in-brazilian-amazon/>.

Yet in complex land-tenure contexts like the Amazon, legal and territorial auditing is particularly costly, time-consuming, and technically demanding. Many municipalities encompass vast and remote areas with severe logistical constraints, limiting access to reliable and up-to-date information on land regimes. Verifying tenure legitimacy often requires historical reconstruction of land occupation, consultation with multiple land and environmental authorities, and direct engagement with multiple stakeholders, activities outside the primary scope of work for companies functioning as Validation and Verification Bodies (VVBs) in the context of origination projects.

These challenges are compounded by the limited integration and automation of land-tenure systems in Brazil, especially in the Amazon. Despite recent advances driven by decisions of the National Council of Justice aimed at digitizing and improving the interoperability of land registries, many notarial offices still rely on physical archives or incomplete digital records³. Moreover, inconsistencies between notarial records, environmental registries, territorial monitoring systems, and the methodological criteria adopted by different carbon standards undermine analytical coherence and heighten project complexity and legal risk. A cascade effect is then observed. The different certifiers adopt different methods for quantifying CO₂ removals, and the different developers adopt different databases for calculating variables such as land use. Public databases, commonly used, are credible and based on scientific publications; however, it is often not possible to understand the calculation performed and the extrapolations made, which contributes to the dispersion of results across the different registered carbon projects. The absence of integrated and reliable systems thus represents not merely an operational hurdle, but a structural constraint on the scalability and integrity of emissions-reduction projects in the Amazon.

In light of these structural limitations, the application of technologies to land-tenure and territorial analysis emerges as a strategic tool to mitigate risk, enhance due-diligence efficiency, and strengthen project integrity. Remote sensing, geospatial analysis, and territorial intelligence tools, such as the ones developed by Uirapuru, Terranalytics, TerrasApp and LandPrint Earth, enable the integration of land-use and land-cover data, deforestation histories, territorial overlaps, and occupation dynamics. This allows for the early identification of tenure inconsistencies and high-risk areas, even before on-the-ground fieldwork begins.

³ Until 2022, Brazil's public registry systems were officially tied to physical, paper-based records. With the enactment of Law No. 14,382/2022, the Electronic Public Registries System (Sistema Eletrônico de Registros Públicos – SERP) was created, establishing the mandatory adoption of electronic public registry systems. This transition is being implemented through an ongoing digitalization process, as set out in regulations issued by the National Council of Justice (CNJ), according to the information available at: <https://atos.cnj.jus.br/atos/detalhar/5696>.



When combined with cadastral and environmental databases, these technologies significantly expand the scope of remote territorial analysis and reduce reliance on exclusively in-person processes. In addition, digital platforms for document management, data interoperability, and automated auditing help consolidate information on chains of title, administrative authorizations, and evidence of legal compliance. This facilitates access to information, streamlines validation and verification processes for certifiers, auditors, and investors. Within emissions-reduction projects, the integration of such technological solutions promotes stronger alignment between land-tenure, environmental, and methodological data, reduces information asymmetries, and enhances transparency and traceability across environmental assets.

Here it is also important to recognize how the nature of tenure-related challenges varies across project types, and how the same set of technologies is required to interrogate different risk layers. Across REDD+, ARR, and IFM projects, the core technological toolkit remains largely consistent: remote sensing, cadastral cross-referencing, and geospatial intelligence. What differs is not the level of technological development, but the type of tenure risk that these tools are expected to surface and resolve.

In Conservation (REDD+) projects, tenure challenges tend to be most visible and structurally acute. These projects often cover large and remote areas where overlapping claims are common. The central question is whether the project proponent holds a formally valid and uncontested claim to the area, and whether this claim is sufficiently durable to support long-term conservation outcomes. In this context, territorial technologies play a critical role in identifying overlaps, inconsistencies, and areas of heightened legal risk at scale.

Platforms such as Uirapuru and Terranalytics are particularly well suited to the identification of structural tenure risks, especially in contexts such as REDD+ projects, where overlapping claims, fragmented land governance, and limited documentation are prevalent. By integrating cadastral records, environmental registries, and geospatial data, these tools enable the systematization of complex territorial information and support the early detection of inconsistencies related to ownership, possession, and land-use rights. Their primary contribution lies in reconstructing and organizing dispersed land-tenure data to inform legal due diligence and risk screening processes at scale.

In Restoration (ARR) projects, tenure conditions may appear more straightforward, particularly in areas classified as degraded land, such as former pasture or abandoned agricultural areas. However, the tenure inquiry shifts from control over existing forest cover to the legitimacy of land-use transformation. The key question becomes whether the proponent has the legal and environmental right to convert land use and claim carbon benefits from that transition. In the Amazon, this often requires demonstrating compliance with legal reserve and permanent preservation area requirements under the Forest Code, as well as reconstructing land-use history to substantiate degradation claims.

Terras App, plays a critical role in contexts where tenure analysis depends on cross-verification between legal, environmental, and land-use dimensions, which is particularly relevant for ARR projects. By integrating multiple datasets, including satellite imagery, land registries, and environmental compliance data, into a unified analytical environment, the platform allows for the validation of land-use history, verification of legal reserve and permanent preservation area requirements, and assessment of whether land-use transformations are consistent with regulatory frameworks. Its strength lies in enabling a dynamic and layered analysis of territorial compliance over time.

In Improved Forest Management (IFM) projects, tenure is often assumed to be more straightforward due to the presence of formal documentation, such as concessions, management plans, or private ownership titles. However, this apparent clarity can obscure a different and equally critical layer of risk. While documentation may be formally valid, it does not necessarily reflect who effectively occupies, manages, or holds customary rights over the land. Cases in the Amazon have demonstrated situations where projects were developed in public or collectively used areas based on formal or publicly available land data, without the knowledge or consent of the traditional communities responsible for managing those territories.

In this sense, the challenge in IFM is not the absence of data or less developed technological tools, but the need to interrogate whether formal tenure reflects legitimate, uncontested, and socially recognized rights, including customary and collective forms of land use. The role of technology, therefore, is not only to validate documentation, but to reveal potential discrepancies between formal records and territorial reality.

LandPrint Earth is particularly relevant in addressing traceability and transparency gaps across all project types, especially in cases where formal documentation exists but does not fully capture the complexity of territorial use and control, as often observed in IFM contexts. By connecting land-tenure, environmental, and production-related data into an integrated system, the platform enhances the traceability of environmental assets and supports the verification of their territorial origin. This is especially important for identifying discrepancies between formally registered rights and actual patterns of land occupation and use, including those involving customary or collective governance systems.

This distinction is fundamental. For buyers, auditors, and certifiers, the assessment can no longer be limited to verifying whether a title is formally valid; it must extend to evaluating whether that title reflects legitimate, uncontested, and socially recognized rights of use and control over the territory. Across project types, technology plays a central role in enabling this shift. Its function is mobilized to interrogate different layers of territorial risk, depending on the context. Rather than mapping onto specific project categories, these tools operate as a complementary analytical stack, collectively enabling a more granular, transparent, and context-sensitive understanding of land tenure, and, ultimately, a more robust assessment of project integrity in the Amazon.

TECH SNAPSHOT



Uirapuru

[WEBSITE](#)

Uirapuru is a Brazilian platform focused on land-tenure, environmental, and territorial analysis, supporting the assessment of rural properties and areas of socio-environmental relevance. The initiative integrates geospatial data, land records, and environmental information to support legal due diligence and territorial risk assessments.

Terranalytics

[WEBSITE](#)

Terranalytics provides territorial intelligence and land-data management solutions, delivering customized analyses based on Brazilian spatial and cadastral datasets. Its work includes the systematization of land ownership, socio-environmental, and agrarian information, supporting the identification of land-tenure risks and informed decision-making in environmental and carbon-related projects.

Terras App

[WEBSITE](#)

Is a geospatial intelligence platform that integrates over 20 land-related datasets into a unified system, enabling analysis of rural properties across legal, environmental, and territorial dimensions in Brazil, with strong relevance for the Amazon. By combining satellite imagery, georeferenced data, and land registry information, Terras App enhances transparency and traceability in land governance, making it a valuable tool for carbon projects, supply chain monitoring, and sustainable land-use investments.

LandPrint Earth

[WEBSITE](#)

LandPrint Earth is a Platform focused on measuring, monitoring, and monetizing environmental quality across agricultural and natural landscapes. The platform integrates remote sensing technologies, laboratory analyses, farmer records, and in-field observations to track key ecological indicators, including biodiversity, carbon sequestration, water conservation, and soil health. Through dashboards and advanced analytics, it delivers personalized assessments and reports on the socio-environmental performance of land use and supply chains. By translating environmental quality into measurable, comparable, and verifiable indicators, the platform contributes to enhancing transparency and traceability across environmental assets, helping connect land-based interventions with broader financial and market infrastructure.



BUILDING GOVERNANCE AND BRIDGING THE EVIDENCE GAP

One of the central challenges observed in emission reduction projects, that has driven significant criticism of the voluntary carbon market in recent years, relates to weaknesses in data and evidence infrastructure, which directly undermine project governance and credibility. Under the current model, validation relies predominantly on static forms of evidence, such as technical reports, periodic audits, satellite imagery, and documentary records, which capture only temporal snapshots of project implementation.

This approach reveals a fundamental structural limitation. While emission reduction activities and governance processes unfold continuously and dynamically within the territory, their verification remains fragmented over time, difficult to access, and heavily mediated by intermediaries. As a result, the production, organization, and communication of evidence depend on lengthy audit cycles, limiting the ability to conduct independent, real-time assessments of what is actually being implemented. At the same time, core governance elements, including community participation, decision-making processes, and benefit-sharing, are often recorded in a declaratory manner, without mechanisms to track their execution over time.

These limitations generate significant technical and operational consequences. First, they create information asymmetries between project developers, standard-setters, and buyers: while developers retain privileged access to operational data, other actors rely on filtered, periodic information that is difficult to independently verify. Second, the absence of continuous evidence increases the risk of misalignment between what is reported and what occurs on the ground, making it harder to identify implementation gaps, operational deviations, or governance failures. Additionally, reliance on long audit cycles increases transaction costs and reduces system efficiency, making it less responsive to the dynamic nature of territories.

In this context, the core fragility lies not only in the methodological design of projects, but in the inability to demonstrate, in a continuous and verifiable manner, that reported activities are effectively being implemented, and that declared governance structures operate in practice. In other words, this reflects a systemic failure to translate dynamic, real-world processes into accessible, traceable, and verifiable evidence over time. This gap affects both private projects and community-based initiatives, albeit in different ways.

In private emission reduction projects, this gap primarily manifests as a challenge in demonstrating the effective execution of planned activities. Despite the existence of robust methodologies and formal validation frameworks, verification remains dependent on discrete evidence points, resulting in limited visibility between audit cycles. In practice, activities such as restoration, forest management, or territorial protection may be described and reported, but not continuously tracked in real time, creating a disconnect between planning, implementation, and verification. This disconnect is seen across project types, but closing the gap requires disparate technical solutions. This gap introduces a form of non-verifiable implementation risk, undermining confidence in the integrity of the credits generated.

In community-based projects, this structural gap becomes even more critical, as it affects the ability to demonstrate legitimate governance, effective participation and co-benefit generation. The State of the Voluntary Market 2025⁴ emphasizes that the voluntary market buyers tend to prefer credits generated from projects that provide environmental and social co-benefits. Elements such as Free, Prior and Informed Consent (FPIC), community participation, benefit-sharing, and decision-making processes are often included in project documentation, yet their verification remains largely limited to formal records. As a result, it becomes difficult to continuously and transparently assess who participated, how decisions were made, and whether benefits are being distributed as agreed. This creates risks of purely declaratory participation, weakens the verification of territorial legitimacy, and increases the likelihood of conflicts and external scrutiny.

In light of these challenges, simplifying processes, enhancing transparency, and expanding access to data emerge as key pillars for strengthening legitimacy and building integrity ecosystems in carbon markets. By reducing operational complexity and making information more accessible, these shifts bring project implementation closer to the capacity for verification by buyers, communities, and civil society. In this sense, the development of continuous, accessible, and verifiable evidence infrastructures represents a critical turning point for restoring trust and reinforcing the integrity of the voluntary carbon market. These same functions are increasingly relevant beyond carbon origination itself, as NbS and bioeconomy markets also depend on traceability, governance, impact verification, and lower transaction costs in order to attract capital and demand.

In response to these structural limitations, a new generation of technological solutions has emerged to enable continuous evidence generation and direct monitoring of activities on the ground. However, the nature of the evidence gap varies across project types. In conservation and reduced deforestation projects, where governance legitimacy is traditionally more challenging, tools that enable continuous documentation of FPIC processes and benefit-sharing mechanisms are essential to closing the information gap and rebuilding buyer confidence. In restoration projects, while governance remains important, the primary governance evidence gap is operational: technologies that enable continuous, field-level verification of planting, maintenance, and survival activities address the disconnect between project documentation and on-the-ground implementation. For improved forest management projects, the evidence challenge centers on demonstrating that harvesting practices have materially changed from the baseline regime. In this context, forestry monitoring applications such as Agerpoint, which leverage handheld, IoT-enabled devices for granular forest carbon measurement, can serve as verifiable evidence that management interventions are being operationalized as described.

⁴ As indicated in the report *State of the Voluntary Carbon Market 2025*, published by Ecosystem Marketplace (Washington, DC: Ecosystem Marketplace, 2025), available at: <https://3298623.fsl.hubspotusercontent-na1.net/hubfs/3298623/SOVCM%202025/Ecosystem%20Marketplace%20State%20of%20the%20Voluntary%20Carbon%20Market%202025.pdf> (accessed April 3, 2026).

Initiatives such as Working Trees, leverage mobile applications, georeferenced records, field-based imagery, and integration with remote sensing data to continuously document project implementation. These systems allow evidence to be generated directly at the point of activity and made available through accessible digital interfaces. Beyond the technical dimension of implementation, initiatives such as Tô no Mapa and Mapeo by Awana Digital enable participatory mapping and the generation of primary territorial data through community-led systems. These efforts capture not only land use and management practices, but also ecosystem resources, cultural practices, livelihoods, and local governance dynamics. By structuring data from the perspective of communities themselves, often within frameworks of data sovereignty and decentralized data management, these approaches expand the scope of evidence beyond carbon and more accurately reflect the socio-ecological complexity of Amazonian territories.

In this context, platforms such as Savimbo further strengthen this paradigm by enabling Indigenous and local communities to directly generate, control, and validate environmental data, while also linking these processes to financial flows associated with ecosystem services. By integrating community-led MRV, data sovereignty, and direct benefit-sharing mechanisms, such approaches reinforce the alignment between evidence generation and territorial governance, addressing longstanding gaps between formal project design and lived realities on the ground.

Complementarily, the Carbon Justice Standard advances this agenda by integrating a social integrity standard with a digital implementation platform. Through structured workflows, educational modules, and participatory MRV tools, it enables the continuous recording, monitoring, and verification of governance processes. This includes not only the operationalization of FPIC requirements, but also the incorporation of broader dimensions related to ecosystem services, cultural practices, and local governance systems. In doing so, it transforms governance into a continuous evidence infrastructure capable of demonstrating, over time, not only formal compliance, but also project legitimacy, territorial embeddedness, and contributions to multiple ecosystem values.

Taken together, these approaches signal a structural shift in carbon markets: from a model based on periodic assessments and static evidence to one grounded in continuous, territorially anchored, and socially embedded evidence systems. As these solutions progress and available data products increase, structural improvements will be made to these tools to reflect changing methodological requirements such as Verra's requirement for "precision FPIC" - identifying the most material contributions not the cheapest⁵. By enabling data to be generated, organized, and validated by multiple actors, these solutions make it possible to translate the complexity of territories into accessible interfaces through which stakeholders can directly and continuously monitor project implementation.

This ability to follow project execution "in the palm of one's hand" represents a fundamental shift in how the market operates. By reducing the distance between implementation and verification, these systems not only enhance transparency, but also rebuild the trust mechanisms that underpin demand for carbon credits, positioning continuous evidence as a core asset for integrity, traceability, and credibility.

⁵ According to informations available at: <https://verra.org/program-notice/verra-launches-version-5-of-the-vcs-program/>



Working Trees

[WEBSITE](#)

Is a digital monitoring platform designed to support the implementation and verification of silvopasture and agroforestry carbon projects through field-based data collection. The system integrates mobile applications, georeferenced records, and visual evidence to document project activities directly at the site of implementation. By structuring data flows from the ground to centralized interfaces, the platform enables continuous tracking of operational activities across project areas. In relation to evidence generation, it contributes to reducing reliance on periodic audits by enabling more frequent and location-specific data capture. This allows for greater visibility over project implementation between verification cycles.

Savimbo

[WEBSITE](#)

Indigenous-led platform that enables communities to directly generate, manage, and monetize environmental data and ecosystem services. The initiative combines community-based monitoring, digital tools, and decentralized governance structures to support data sovereignty and direct benefit-sharing mechanisms. Through its model, it allows Indigenous and local communities to collect georeferenced data, document territorial activities, and validate environmental outcomes using locally grounded knowledge systems. This information is then connected to financial flows, enabling direct payments for ecosystem services without reliance on intermediaries. It contributes to transforming MRV from a top-down, externally driven process into a bottom-up, community-embedded system. By aligning data generation with territorial governance and local participation, it strengthens the credibility, legitimacy, and continuity of evidence, particularly in complex socio-ecological contexts such as the Amazon.

Tô no Mapa

[WEBSITE](#)

Is a Brazilian initiative focused on participatory territorial mapping led by traditional and local communities. Through community-driven data collection, the initiative generates primary information on land use, territorial boundaries, and socio-environmental dynamics, supporting the recognition of community territories and strengthening local governance. It contributes to evidence infrastructure by enabling the production of territorially grounded data that reflects local realities. This helps address gaps related to land tenure, territorial legitimacy, and community presence.

TECH SNAPSHOT



Mapeo

by **Awana Digital**[WEBSITE](#)

Co-develops decentralized digital tools with Indigenous peoples and local communities to support territorial governance, environmental monitoring, and the defense of human and environmental rights. In the context of evidence infrastructure, it contributes by enabling the continuous generation of territorially grounded data through community-led monitoring and mapping systems. Tools such as CoMapeo allow users to capture georeferenced data, images, and observations directly in the field, structuring primary evidence that reflects local realities and governance dynamics. By ensuring that data remains under community control, the model strengthens trust, reduces external dependencies, and addresses critical risks related to data extraction and asymmetries in information access.

Carbon Justice Standard

[WEBSITE](#)

Is an international framework designed to assess and operationalize social integrity in nature-based carbon projects, with a focus on community participation and rights-based approaches. The initiative incorporates a digital platform that integrates implementation workflows, educational modules, and participatory MRV tools. In relation to governance and evidence, it addresses a critical gap by enabling the continuous documentation of processes such as FPIC, decision-making, and benefit-sharing. By structuring these elements within a digital system, it moves beyond declaratory governance and introduces mechanisms for tracking implementation over time. Moreover, its approach extends beyond carbon metrics to include ecosystem services, cultural practices, and local governance systems, aligning evidence generation with the socio-ecological complexity of project territories.



BASELINE SCENARIOS AS THE TECHNICAL KEY FOR ENVIRONMENTAL INTEGRITY

Within the assessment of environmental integrity in emissions-reduction projects, a second structural point of friction emerges at the methodological level: the definition of the baseline scenario. While land-tenure uncertainty undermines the legitimacy of interventions at the territorial level, baseline construction directly conditions the measurement of additionality and, consequently, the credibility of claimed climate outcomes. According to the Integrity Council for the Voluntary Carbon Markets, the baseline represents the hypothetical situation that would occur in the absence of mitigation incentives, constructed using data intended to reflect the most likely land-use trajectories had the project not been implemented⁶.

The analysis of land-use history is a key variable in ARR, IFM, and REDD+ projects, as it is essential for defining both eligibility under different standards and methodologies, and the baseline, additionality, and robust quantification. Empirical research shows that deforestation rates used to establish baselines are typically derived from historical averages adjusted to regional reference data and then proportionally applied to project areas, generating deforestation-risk maps. These inputs are used to model a “without-project” scenario and a “with-project” scenario; the comparison between the two enables the estimation of avoided deforestation attributable to project activities, that is, additionality.

Technical innovation is already opening the door for more robust and defensible dynamic baselines. Geospatial embeddings are one such innovation, enabling large quantities of diverse data to be compressed, creating an forest “fingerprint” for the parcel. Unlike other geospatial data, embeddings consider the interaction of the data layers at play rather than simply noting layer’s changes independently. Organizations like Renoster are using Google’s AlphaEarth embeddings to more efficiently match control plots with project plots when constructing baselines.

⁶ As indicated in the report *State of the Voluntary Carbon Market 2025*, published by Ecosystem Marketplace (Washington, DC: Ecosystem Marketplace, 2025), available at: <https://3298623.fs1.hubspotusercontent-na1.net/hubfs/3298623/SOVCM%202025/Ecosystem%20Marketplace%20State%20of%20the%20Voluntary%20Carbon%20Market%202025.pdf> (accessed April 3, 2026).

⁷ <https://newsletter.cecil.earth/p/geospatial-embeddings>

⁸ <https://medium.com/google-earth/improved-forest-carbon-estimation-with-alphaearth-foundations-and-airborne-lidar-data-af2d93e94c55>

However, because the baseline is a theoretical and mathematical construction, and despite being grounded in historical deforestation data, it remains a probabilistic estimate rather than a directly observable measure. During project implementation, multiple exogenous variables, such as economic shifts, public policy changes, land-use pressures, or local social dynamics, may influence deforestation patterns without being fully captured by the models employed. This limits the precision with which emission reductions can be attributed to specific project interventions.

Thus, the baseline outcomes can be significantly influenced by the algorithms and technical assumptions used to generate risk maps, which vary across methodologies. As demonstrated in recent empirical studies, such methodological flexibility can lead to substantial variability in estimated results, with baselines differing by an order of magnitude across approaches, creating incentives to select methodologies that artificially maximize credit issuance. These findings have contributed to a broader debate regarding how methodological design can influence the credibility and comparability of reported mitigation outcomes.

Even where counterfactual approaches are applied, however, reliance on technical modeling and theoretical projections alone may still produce uncertainty regarding the volume of credits ultimately generated. Given this context, to generate more robust and accurate evidence of real project performance, methodological tools must move beyond exclusive reliance on forest carbon stock estimates. They should incorporate counterfactual analyses, observable spatial data, and explicit consideration of the socio-environmental dynamics associated with deforestation and forest degradation in the area.

In this context, complementing counterfactual instruments and territorial data with nationally or jurisdictionally defined baselines, periodically updated, and with regionally standardized carbon-stock default values can establish shared comparative parameters across certification bodies. Such harmonization would enhance predictability in credit estimates and reduce methodological dispersion. More frequent baseline updates, grounded in recent deforestation trends and informed by structurally comparable synthetic control areas or coupled human–natural systems models, could further improve accuracy.

⁹ According to the findings presented by West, T. A. P., Börner, J., Sills, E. O., and Kontoleon, A. (2020), voluntary REDD+ projects in the Brazilian Amazon have systematically overstated estimated emission reductions due to limitations in baseline construction and counterfactual assumptions. See: Overstated carbon emission reductions from voluntary REDD+ projects in the Brazilian Amazon, Proceedings of the National Academy of Sciences of the United States of America (PNAS), 117(39), 24188–24194. <https://doi.org/10.1073/pnas.2004334117>

¹⁰ As demonstrated by recent empirical research, methodological flexibility in the construction of deforestation baselines can produce substantial variation in estimated outcomes. According to West, T. A. P., Bomfim, B., and Haya, B. K. (2024), different baseline-setting approaches applied to the same contexts can yield results that vary by an order of magnitude, creating incentives to select methodologies that artificially inflate credit issuance. See: Methodological issues with deforestation baselines compromise the integrity of carbon offsets from REDD+, Global Environmental Change, 78, 102863. <https://doi.org/10.1016/j.gloenvcha.2024.102863>

¹¹ Even when counterfactual approaches are applied, uncertainty may persist due to the inherent reliance on technical modeling and theoretical projections. As discussed by West, T. A. P., Bomfim, B., and Haya, B. K. (2024), baseline-setting methodologies, whether historical, counterfactual, or hybrid, remain sensitive to modeling choices, assumptions, and data inputs, which can materially affect estimated credit volumes. See: Methodological issues with deforestation baselines compromise the integrity of carbon offsets from REDD+, Global Environmental Change, 78, 102863. <https://doi.org/10.1016/j.gloenvcha.2024.102863>

¹² This recommendation is consistent with the findings of West, T. A. P., Börner, J., Sills, E. O., and Kontoleon, A. (2020), who emphasize that greater consistency and comparability in emissions estimates can be achieved through the use of shared reference baselines and standardized parameters at broader spatial scales. The authors highlight that nationally or jurisdictionally defined baselines, periodically updated and grounded in observed deforestation trends, can reduce methodological dispersion across projects and certification bodies while improving the credibility of additionality claims. See: Overstated carbon emission reductions from voluntary REDD+ projects in the Brazilian Amazon, Proceedings of the National Academy of Sciences of the United States of America (PNAS), 117(39), 24188–24194. <https://doi.org/10.1073/pnas.2004334117>

Adopting these strategies would allow projects within the same region to apply comparable parameters for additionality accounting, while curbing disproportionate baseline inflation by anchoring estimates to jurisdiction-level emissions-reduction data. Beyond these measures, technological innovation is essential to overcoming the inherent limitations of approaches based solely on theoretical projections, thereby strengthening environmental integrity and the credibility of mitigation outcomes.

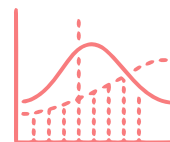
While the academic and policy debate has highlighted important limitations in baseline construction, it is equally necessary to acknowledge that methodological innovation within the carbon-market ecosystem is already taking place in practice. In fact, many existing methodologies have undergone successive revisions and are applying technological innovation, precisely to improve certainty, incorporate more refined spatial data, and better reflect the territorial dynamics that shape land use change and deforestation patterns in tropical forest regions.

A growing number of methodological frameworks already incorporate several of the improvements discussed in the literature, including shorter baseline update cycles as well as the incorporation of performance benchmarks on Agriculture, Forestry, and Other Land Use (AFOLU) sector methodologies, enhanced integration of remote sensing and geospatial data, and stronger consideration of jurisdictional and land-use governance dynamics. These developments indicate that parts of the methodological ecosystem are progressively adapting to the socio-ecological complexity of regions such as the Amazon, rather than remaining fixed in earlier analytical models.

Against this backdrop, a number of emerging certification systems are experimenting with approaches that attempt to translate these methodological improvements into operational practice. In this regard, initiatives such as Tero Carbon and Equitable Earth provide illustrative examples of how methodological evolution is already being implemented within the voluntary carbon market.

Rather than representing purely conceptual alternatives, these initiatives are developing certification frameworks and methodological approaches that explicitly seek to align carbon accounting with the legal, socio-environmental, and productive realities of the Amazon region. By integrating territorial governance considerations, more conservative accounting parameters, and more frequent methodological revisions, these frameworks contribute to a more context-sensitive and empirically grounded accounting of climate benefits.

As carbon accounting methodologies evolve to incorporate more dynamic and context-sensitive approaches, technological tools are becoming central to operationalizing these improvements at scale. Greater attention to these initiatives may therefore play an important role in informing the continued evolution of carbon-market methodologies toward more credible, territorially grounded, and scientifically robust frameworks for climate mitigation in the Amazon region.



Tero Carbon

[WEBSITE](#)

Tero Carbon is a Brazilian digital certification body focused on small- and medium-scale carbon projects, with methodologies specifically designed for Brazil's legal, land-tenure, and productive contexts. The initiative relies on digital tools for the registration, traceability, and verification of environmental assets, with the aim of lowering barriers to access certification.

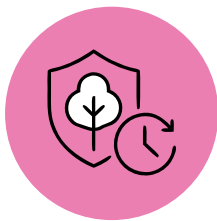
With respect to baseline scenarios, Tero Carbon advances methodologies that are more responsive to local realities, incorporating parameters aligned with Brazilian territorial and production dynamics. By operating at smaller scales and adopting shorter update cycles, the certifier seeks to reduce distortions associated with overly abstract baselines. Nevertheless, its approach remains dependent on methodological assumptions that require continuous validation and robust governance to ensure environmental integrity over time.

Equitable Earth

[WEBSITE](#)

Equitable Earth is an international certification standard for nature-based carbon projects, with a strong emphasis on initiatives led by local communities and Indigenous peoples. The standard integrates environmental, social, and governance criteria, aiming to align climate integrity with socio-environmental justice.

Regarding baseline scenarios, Equitable Earth proposes methodologies that combine technical modeling with social safeguards and more context-specific territorial analyses. The standard seeks to limit methodological arbitrariness through more conservative parameters, shorter validation cycles, and greater transparency around the assumptions underlying baseline construction, thereby strengthening both credibility and accountability in emissions-reduction claims.



STRENGTHENING PERMANENCE AND LONG-TERM CLIMATE INTEGRITY

Following the uncertainties associated with baseline construction and additionality estimation, a third central issue emerges in the debate on the environmental integrity of emissions-reduction projects: permanence. Permanence refers to the capacity of emissions reductions or removals to endure over time, ensuring that climate benefits are not reversed in the short or medium term after payments are made. According to the Science Based Targets initiative, permanence relates to “the longevity of a carbon reservoir and the stability of its stocks, considering the management regime and the disturbance environment in which it is embedded”¹³.

In forest-based projects, carbon sequestration and emissions-reduction activities are frequently exposed to external risks such as prolonged droughts, wildfires, extreme weather events, and anthropogenic pressures. These factors can undermine forest cover and, consequently, the stability of carbon stocks over time. As a result, it is not possible to guarantee with full certainty that mitigation activities will be sustained throughout the project lifetime, given that climatic shocks or human actions may threaten the permanence of achieved outcomes¹⁴.

Beyond environmental risks, economic and institutional challenges also play a decisive role. Empirical evidence indicates a recurring pattern in forest projects: once payments or financial incentives cease, conservation outcomes may be partially or fully reversed. This dynamic highlights the importance of designing mitigation models capable of maintaining conservation incentives and governance structures beyond the initial project cycle, thereby supporting more durable climate outcomes.

¹³ This definition highlights that permanence is not an absolute condition, but one that depends on both ecological dynamics and management practices over time. See: SBTi Glossary, 2025. Available at: <https://files.sciencebasedtargets.org/production/files/SBTi-Glossary.pdf>

¹⁴ This limitation is supported by empirical evidence showing that forest carbon offset outcomes remain vulnerable to both climatic disturbances and anthropogenic pressures over time. According to Coffield, S. R., Vo, C. D., Wang, J. A., Badgley, G., Goulden, M. L., Cullenward, D., Anderegg, W. R. L., and Randerson, J. T. (2022), remote sensing analyses of forest carbon offset projects in California demonstrate that climate-driven events and human activities can compromise long-term carbon storage, challenging assumptions of guaranteed. See: Climate-driven limits to future carbon storage in California’s wildland ecosystem, *Biology*, first published September 12, 2022. Available at: <https://doi.org/10.1111/gcb.16380>.

Depending on the methodological approach adopted, risks of non-permanence, and the social, physical, and economic drivers behind them, may or may not be internalized. To address these risks, most major carbon standards and registries employ buffer pools, whereby a share of issued credits is withheld as a reserve to compensate for potential future reversals. In this arrangement, buffer pools function as a risk-sharing mechanism that internalizes negative environmental externalities by allocating a portion of project-generated credits to cover cancellations or suspensions, thereby preserving the aggregate climate value of realized emissions reductions. These mechanisms represent an important institutional innovation within carbon markets, allowing permanence risks to be collectively managed across project portfolios.

At the same time, the scientific literature¹⁵ points to alternatives to the traditional logic of long-term permanence commitments. Research suggests that well-designed shorter permanence assessment periods can, under certain conditions, support the protection and expansion of carbon sinks. This approach emphasizes continuous flows of atmospheric carbon removal into short-term stocks which, through periodic renewal, active management, and recurring incentives, can deliver effective storage durability comparable to, or even exceeding, that of static long-term commitments. This perspective highlights the role of adaptive management and continuous stewardship in sustaining climate benefits over time.

Given the uncertainties surrounding permanence, particularly in forest projects exposed to climatic and anthropogenic risks, there has been significant progress in the deployment of continuous monitoring technologies to reduce information asymmetries and enhance early detection and response to reversal events. High-frequency remote sensing, near-real-time geospatial monitoring, and recurrent digital verification now make it possible to track forest-cover dynamics throughout the project cycle, strengthening transparency and traceability of carbon stocks. These technological developments are increasingly enabling permanence to be monitored as a dynamic process rather than a static assumption.

However, these technological developments do not eliminate permanence risks, they improve the capacity to anticipate, identify, and respond to emerging threats, such as deforestation pressures, land-use change trends, and illegal activities, thereby reducing the likelihood and potential magnitude of reversals. When combined with territorial governance and protection mechanisms, such systems enable a more proactive approach to risk management, in which permanence is supported through continuous monitoring, early warning signals, and timely intervention.

Initiatives such as PrevisIA exemplify this trend by applying predictive analytics, based on historic deforestation, satellite data and IA to anticipate deforestation risks and identify areas under heightened pressure before reversals occur. By supporting ex ante risk assessment and territorial intelligence, can strengthen the capacity of projects and jurisdictions to act preventively rather than react only after forest loss has taken place.

¹⁵ This approach is supported by the analysis of West, T. A. P., Börner, J., Sills, E. O., and Kontoleon, A. (2020), who demonstrate that baseline accuracy can be improved through more frequent updates grounded in observed deforestation trends and the use of structurally comparable control areas. The authors show that reliance on static historical averages increases estimation error, whereas approaches incorporating dynamic reference areas and counterfactual comparisons better reflect real-world deforestation dynamics. See: Overstated carbon emission reductions from voluntary REDD+ projects in the Brazilian Amazon, Proceedings of the National Academy of Sciences of the United States of America (PNAS), 117(39), 24188–24194. <https://doi.org/10.1073/pnas.2004334117>

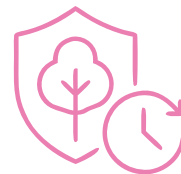
Beyond direct land-use threats, permanence risk also extends to the climatic knock-on effects that deforestation in non-project areas can have on project sites – and this dynamic has now been successfully modeled in the Amazon. Using AWS ParallelCluster, an open-source high-performance computing tool, researchers simulated how deforestation disrupts regional rainfall patterns, demonstrating that forest loss in one area can degrade downstream ecosystems through broken climatic feedback loops¹⁶. As models like these mature, project developers will be better equipped to incorporate endogenous Amazonian climate risks – such as shifting precipitation and tipping-point dynamics – into their permanence assessments and long-term project planning.

These predictive approaches are further strengthened when combined with instant monitoring and community-based alert systems. Rainforest Labs contributes by enabling the continuous generation of locally grounded environmental data, improving situational awareness over forest conditions and territorial dynamics. ForestLink complements this logic through real-time reporting systems that allow communities to transmit alerts on illegal activities directly from the field, thereby shortening the time between detection and response. Rainforest Defense, in turn, focuses on converting monitoring data and alerts into rapid territorial protection and enforcement actions, addressing one of the most critical dimensions of permanence: the ability to respond operationally to identified threats.

Taken together, these technological and governance-oriented innovations illustrate a broader shift in how permanence is being addressed within the carbon-market ecosystem. Rather than treating permanence as a static methodological assumption, these approaches frame it as a dynamic risk-management challenge shaped by anticipation, monitoring, territorial defense, and response capacity. In this sense, they help create the conditions under which permanence becomes more likely, aligning mitigation efforts with the ecological and governance realities of forest regions such as the Amazon.

¹⁶ More information available at: <https://aws.amazon.com/blogs/hpc/simulating-climate-risk-scenarios-for-the-amazon-rainforest/>

TECH SNAPSHOT



PrevisIA

[WEBSITE](#)

Is a predictive analytics platform developed by Imazon in Brazil to identify areas at high risk of deforestation using artificial intelligence and spatial modeling. The system integrates historical deforestation data, land-use dynamics, infrastructure proximity, and socio-environmental variables to generate short-term risk forecasts and identify emerging deforestation frontiers. It contributes by strengthening anticipatory capacity, enabling the identification of areas under heightened pressure before reversals occur, supporting preventive action and more efficient allocation of monitoring and enforcement resources.

ForestLink

[WEBSITE](#)

Is a real-time forest monitoring system designed to support community-based reporting of illegal activities in remote forest areas. Using offline-capable devices and satellite connectivity, the system enables local users to transmit alerts on deforestation, logging, or territorial invasions directly from the field to relevant authorities and stakeholders. It contributes by strengthening early detection and rapid reporting of anthropogenic risks that may lead to carbon reversals, linking local monitoring with external response mechanisms, and enhances the capacity to intervene before damage becomes irreversible.

Rainforest Labs

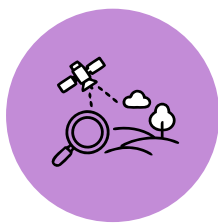
[WEBSITE](#)

Rainforest Labs develops digital tools to support community-based forest monitoring and the generation of primary environmental data. Its systems enable local actors to document land use, forest conditions, and territorial dynamics through participatory data collection and digital interfaces. Addressing permanence, it contributes by enabling continuous, locally generated data streams that can support the identification of changes in forest conditions over time.

Rainforest Defense Company

[WEBSITE](#)

Rainforest Defense Company (RDC) is an organization focused on actively defending the highest-deforestation frontlines of the Brazilian Amazon against otherwise-certain forest destruction. It deploys a proactive defense model that combines intensive territorial monitoring, rapid response to incursions, and coordinated engagement with communities on both sides of deforestation frontlines to align local incentives with conservation and restoration outcomes. When successful in defending targeted areas, RDC generates high-integrity carbon credits derived from a combination of intact forest protection and restoration of adjacent degraded land. By integrating capital markets access, structured carbon finance, and on-the-ground enforcement capacity, RDC addresses one of the most critical dimensions of permanence: the operational ability to anticipate, detect, and respond to territorial threats before forest loss becomes irreversible.



MONITORING, REPORTING, AND VERIFICATION AS FOUNDATIONS OF CLIMATE INTEGRITY

Monitoring, Reporting, and Verification (MRV) encompasses the set of processes and technical instruments designed to track the implementation of emissions-reduction activities and to substantiate the effectiveness of the climate outcomes claimed in project documentation. In this sense, MRV serves as a foundational pillar supporting trust, transparency, and scalability in voluntary carbon markets, providing the technical foundation through which climate outcomes can be monitored, verified, and reliably communicated to a wide range of stakeholders.

Beyond validating baseline assumptions, MRV plays an essential role in substantiating the empirical information reported by project developers, by demonstrating outcomes actually delivered during implementation¹⁷. It is thus essential not only for quantifying emissions reductions, but also for documenting tangible evidence of forest conservation, enabling an assessment of whether methodological projections hold in practice.

¹⁷ According to Rotta Moro (2023), MRV systems in forest carbon projects include the monitoring of forest cover, biomass inventories, and the quantification of carbon stocks in line with predefined methodological frameworks. These elements are presented as core components for ensuring technical consistency, safeguarding rights, and supporting socio-environmental safeguards in REDD+ processes involving Indigenous Peoples and Quilombola communities. See: Forest Carbon Training Course in Indigenous and Quilombola Territories (Curso de formação sobre Carbono Florestal em territórios de povos indígenas e Quilombolas). Available at: <https://rottamoro.com.br/publicacoes/storage/2024/05/CARBONO-FLORESTAL-MANUAL-FINAL-1.pdf>

As expectations around data accuracy and accountability continue to evolve, MRV frameworks are undergoing continuous refinement and technological enhancement. Improvements in data quality, more frequent data collection, enhanced geospatial information, and broader accessibility of underlying evidence are progressively strengthening the capacity of these systems to document climate outcomes, contributing to more continuous verification processes, reinforcing confidence in reported results, and supporting the responsible expansion of voluntary carbon markets.

While the core MRV technologies, remote sensing, field-based data collection, continuous monitoring systems, are applied across REDD+, IFM, and ARR projects, the specific variables being monitored and the risks being addressed differ meaningfully by project type. Understanding these differences is essential for deploying technological solutions where they are most needed and for ensuring that MRV systems are calibrated to the actual risks each project type presents. Within this landscape, some solutions operate as transversal infrastructure relevant across all project types, while others are more specifically suited to the monitoring demands of a particular context¹⁸.

A foundational layer of MRV infrastructure serves all three project types by addressing shared needs: data integrity, continuous verification, and reduction of information asymmetries. Regen Network provides blockchain-based ecological monitoring infrastructure that enables the continuous recording and decentralized verification of field-based environmental data, creating auditable records accessible to multiple stakeholders throughout the project lifecycle regardless of project type. Shamba Network complements this by deploying remote sensing and cryptographic data oracles to ensure the integrity and traceability of climate and ecological data used in carbon accounting.

Beyond carbon metrics, these strategies also reflect the prices and values of the credits themselves. There is a growing recognition that land-use credits can command additional premiums when they demonstrably contribute to biodiversity conservation and ecosystem services, reinforcing the need for more robust and credible monitoring systems. As highlighted by Ecosystem Marketplace in the *State of the Voluntary Carbon Market 2025*¹⁹, value differentiation is increasingly tied not only to emissions outcomes, but also to measurable co-benefits such as biodiversity protection and ecosystem integrity. In this context, a growing range of tools is being deployed transversally, including environmental DNA (eDNA) tracking, community-based biodiversity monitoring, and remote sensing systems.

At the same time, innovative solutions are expanding the frontier of biodiversity monitoring across all project types. Organizations such as Rainforest Connection are advancing bioacoustic monitoring technologies that use AI-enabled sensors to capture and analyze forest soundscapes. These systems enable continuous, non-invasive monitoring of biodiversity while also tracking forest activities in real time. Importantly, this approach goes beyond ecological observation by supporting the detection of illegal activities such as logging and encroachment, thereby contributing to enforcement efforts and strengthening environmental governance, illustrating a shift toward multi-layered monitoring systems that combine different data sources and technologies to better capture ecological complexity.

¹⁸ As discussed by Christiansen, K. L. (2024), traditional MRV approaches in voluntary carbon markets often suffer from low data quality or infrequent data collection, limited availability of precise geospatial information, heavy reliance on episodic verification, and restricted public access to underlying evidence. These shortcomings undermine confidence in reported outcomes and act as structural constraints on market credibility, development, and scale. For more information, see: Christiansen, Kirstine Lund (2024). Relegitimising the voluntary carbon market: Visions of digital monitoring, reporting and verification. *Environment and Planning A*, 57(8), 1190–1205.

¹⁹ In the report *State of the Voluntary Carbon Market 2025*, published by Ecosystem Marketplace (Washington, DC: Ecosystem Marketplace, 2025), available at: <https://3298623.fs1.hubspotusercontent-na1.net/hubfs/3298623/SOVCM%202025/Ecosystem%20Marketplace%20State%20of%20the%20Voluntary%20Carbon%20Market%202025.pdf> (accessed April 3, 2026).

In REDD+ projects, MRV is primarily oriented toward detecting forest cover loss and verifying that deforestation has been avoided within and around the project boundary. The key challenge is spatial and temporal: ensuring that the absence of deforestation is continuously verifiable, not just at periodic audit points. At the jurisdictional level, Sylvera²⁰ through its Biomass Atlas, independently assesses jurisdictional REDD+ credits, as evidenced by its work in the State of Acre and elsewhere in the Amazon, providing high-capacity baseline generation that underpins project planning, carbon credit ratings, verification processes and most steps in between. Open Forest Protocol complements this through its open-source, blockchain-based MRV protocol, combining mobile data collection with a decentralized network of validators to create tamper-resistant, publicly accessible evidence of forest conservation outcomes throughout the project lifecycle.

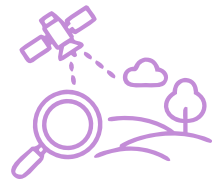
In IFM projects, MRV must go beyond forest cover to track whether harvesting activities comply with approved management plans, in terms of volumes, species, and spatial extent. As documented in cases such as Brazil's Operation Greenwashing²¹, approved management plans can serve as cover for illegal extraction, making compliance monitoring as critical as forest cover monitoring. This requires tools capable of cross-referencing harvesting authorizations from systems such as SINAFLOR with satellite-derived canopy data, detecting discrepancies between declared and actual extraction volumes. In this context, monitoring initiatives that document activities as they are effectively carried out within project territories represent a critical differentiator in ensuring high-integrity carbon outcomes, such as Rainforest Connection's acoustic detection of chainsaw activity, that provides an independent and continuous verification layer that periodic audits or satellite imagery alone cannot replicate.

In ARR projects, MRV shifts toward verifying the establishment and survival of restored vegetation, tracking biomass accumulation over time, and demonstrating that land-use change has actually occurred. This requires different data layers, including soil carbon measurement, species composition monitoring, and land-use history validation that complement but differ from the forest-cover-centered approaches used in REDD+ and IFM. Re.Seed addresses this directly by integrating field data, satellite imagery, and digital records to track restoration activities through a bottom-up approach, where local actors collect real-time observations using mobile devices, incorporating local knowledge into operational processes and strengthening data reliability through shorter monitoring cycles particularly well suited to the iterative nature of restoration.

Taken together, these technological developments signal a broader shift in how MRV is being operationalized across all project types, from periodic, document-based approaches toward continuous, data-driven systems calibrated to the specific risks each project presents. By enabling higher-frequency monitoring, multi-source data integration, and enhanced transparency, these solutions expand the evidentiary basis of carbon accounting, reduce information asymmetries, and advance MRV toward a more auditable and credible model aligned with contemporary standards of environmental integrity.

²⁰ More information available at: <https://www.sc.com/en/press-release/standard-chartered-and-brazilian-state-of-acre-to-bring-high-integrity-carbon-credits-to-market-to-support-forest-conservation/>

²¹ Operation Greenwashing was launched by the Brazilian Federal Police on June 5, 2024 – World Environment Day – to dismantle a criminal organization suspected of selling approximately R\$ 180 million in carbon credits derived from illegally occupied public lands in the Legal Amazon. The investigation revealed a decade-long scheme of land fraud originating in Lábrea, Amazonas, involving the duplication and falsification of land titles and the unauthorized insertion of false data into Brazil's Land Management System (SIGEF), with the participation of public servants and technical officers. The operation resulted in five preventive arrest warrants, 76 search and seizure orders, and the seizure of R\$ 1.6 billion, spanning the states of Rondônia, Amazonas, Mato Grosso, Paraná, Ceará, and São Paulo. Among the illegal activities identified were the harvesting of over one million cubic meters of timber in protected areas, the issuance of fraudulent environmental licenses, and the generation of carbon credits over grilagem areas – illustrating how formally registered land management activities can serve as cover for large-scale environmental crime. See: Polícia Federal, "PF deflagra Operação Greenwashing para investigar venda irregular de créditos de carbono," June 5, 2024. Available at: <https://www.gov.br/pf/pt-br/assuntos/noticias/2024/06/pf-deflagra-operacao-greenwashing-para-investigar-venda-irregular-de-creditos-de-carbono> (accessed April 2026).



Shamba Network

[WEBSITE](#)

Shamba Network is an initiative focused on building digital infrastructure for the monitoring, reporting, and verification (MRV) of climate and ecological data, leveraging remote sensing technologies, cryptography, and blockchain-based data oracles. Its model is designed to ensure the integrity and traceability of information used in accounting for carbon emissions and removals, with a strong emphasis on long-term data reliability. Within the MRV context, Shamba Network operates as a technical layer for data validation and integrity, transforming observable environmental data into verifiable and auditable records. This approach helps reduce information asymmetries and mitigates risks related to data manipulation or inconsistency, particularly in projects that require continuous monitoring and heightened transparency.

Rainforest Connection (RFCx)

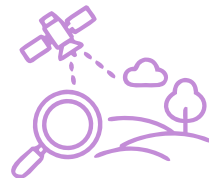
[WEBSITE](#)

Is a technology-driven organization that deploys AI-enabled bioacoustic sensors to monitor forest ecosystems in real time. Its system captures soundscape data from the forests and processes it through machine learning models to identify biodiversity patterns and detect specific acoustic signatures, including species presence and human activities, enabling continuous, non-invasive biodiversity monitoring while also supporting the detection of illegal activities such as logging, mining, or encroachment. The platform integrates hardware (field-deployed sensors), cloud-based analytics, and user-facing dashboards, allowing stakeholders to access near real-time environmental intelligence, strengthening systems by providing additional layers of evidence on ecological outcomes and forest integrity. Its approach enhances transparency, supports enforcement mechanisms, and contributes to more credible and accountable project implementation, particularly in high-risk and remote forest regions.

Re.Seed

[WEBSITE](#)

Re.Seed is a platform that integrates digital MRV, financial incentives, and proprietary methodologies for carbon and ecosystem-services projects, with a particular focus on smallholder farmers and agricultural value chains. The initiative combines field data, satellite imagery, and digital records to track production, structuring evidence directly from the field through a bottom-up approach, where data is collected by local actors using mobile devices, integrating real-time observations, visual records, and contextual validation, incorporating local knowledge into operational processes and strengthening data reliability. Distinguishes itself through shorter monitoring cycles and a strong emphasis on empirical evidence tied to local productive activities.



Open Forest Protocol

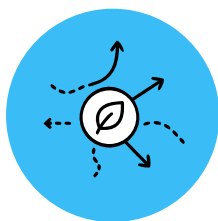
[WEBSITE](#)

Is an open-source, blockchain-based MRV protocol designed to enable decentralized, transparent, and verifiable data generation for forest-based projects. The system combines mobile data collection tools with a distributed network of validators, allowing field-level evidence to be captured, verified, and immutably recorded. By structuring data flows across decentralized nodes, OFP creates auditable and tamper-resistant data environments that support end-to-end traceability throughout the project lifecycle. It represents a shift from closed, intermediary-dependent validation systems toward open, interoperable, and publicly accessible evidence architectures. By prioritizing continuous data collection and transparent audit trails, the protocol reduces reliance on episodic verification cycles and enhances the accessibility of project-level information for multiple stakeholders, including buyers, validators, and civil society.

Sylvera

[WEBSITE](#)

Sylvera's Biomass Atlas is a global forest biomass data product that quantifies aboveground biomass density and canopy height at 30-meter resolution annually from 2000 to present. Built on over \$10 million in proprietary multi-scale LiDAR field campaigns spanning 250,000+ hectares across five continents, it achieves project-area errors below 10% for projects over 400 hectares, enabling project developers, registries, and governments to establish defensible carbon baselines and verify forest carbon stocks in hours rather than months. In Brazil, Sylvera is working with the State of Acre to independently assess forest carbon credits and support jurisdictional REDD+ programmes that meet the highest integrity standards. Sylvera The product also powers Sylvera's independent carbon credit ratings while functioning as a standalone data layer accessible to all market participants for verification, monitoring, and due diligence.



ADDRESSING LEAKAGE TO STRENGTHEN CLIMATE INTEGRITY

If earlier debates highlighted frictions related to territory, time, and methodological constraints, leakage exposes an additional layer of risk: the challenge of ensuring that project-scale carbon interventions are aligned with broader spatial, economic, and productive dynamics. Even where an emissions-reduction project successfully curbs deforestation or emissions within its defined boundaries, there remains a risk that these same activities generate adverse environmental impacts beyond the project area by displacing or intensifying anthropogenic pressures in adjacent territories. This phenomenon, known as leakage, constitutes a negative externality, as it leads to an unanticipated loss of net emissions-reduction benefits²².

Leakage can manifest in multiple ways. One form occurs when emissions-generating activities are not truly halted, but rather displaced outside the project boundary, affecting connected areas, undermining ecosystem services, and generating upstream or downstream emissions along the relevant value chains²³. Another form arises when project outcomes indirectly alter local or regional economic dynamics, potentially influencing land-use decisions that were not fully anticipated in the baseline scenario, such as shifts in the supply of goods, services, or development opportunities²⁴.

²² This definition of leakage is consistent with the conceptual framework developed by Aukland, L., Moura Costa, P., and Brown, S. (2003), who describe leakage as the displacement or intensification of emissions-generating activities outside project boundaries as a consequence of project implementation, resulting in a net loss of anticipated emissions-reduction benefits. See: Aukland, L., Costa, P. M., & Brown, S. (2003). A conceptual framework and its application for addressing leakage: the case of avoided deforestation. *Climate Policy*, 3(2), 123–136. <https://doi.org/10.3763/cpol.2003.0316>

²³ See: Aukland, L., Costa, P. M., & Brown, S. (2003). A conceptual framework and its application for addressing leakage: the case of avoided deforestation. *Climate Policy*, 3(2), 123–136. <https://doi.org/10.3763/cpol.2003.0316>

²⁴ See: Aukland, L., Costa, P. M., & Brown, S. (2003). A conceptual framework and its application for addressing leakage: the case of avoided deforestation. *Climate Policy*, 3(2), 123–136. <https://doi.org/10.3763/cpol.2003.0316>

As highlighted in the scientific literature²⁵, the use of standardized leakage factors across many methodologies has been the subject of ongoing discussion regarding their ability to capture the full diversity of territorial dynamics. This challenge is compounded by the fact that leakage assessment is not incentive-neutral: identifying higher leakage levels directly reduces the volume of credits issued, potentially discouraging more rigorous or conservative analyses. For this reason, recent debates increasingly emphasize the importance of improving methodological transparency and refining leakage estimation approaches in order to strengthen the credibility of project outcomes.

Leakage dynamics are typically linked to activities that were not anticipated or incorporated into the initial calculations of baselines, additionality, and permanence, making leakage intrinsically connected to how these parameters are constructed. This relationship highlights the importance of integrating broader territorial and economic dynamics into project design. When potential drivers of displacement or intensified deforestation are identified early in the project design phase, leakage can be mitigated or even prevented from the outset through territorial planning, socio-economic engagement, and a more robust definition of project areas of influence²⁶.

Given the inherent challenges of measuring leakage exclusively at the project scale, there is growing attention to the role of regional monitoring technologies, integrated spatial analysis, and supply-chain traceability as complementary tools for detecting and mitigating this risk. Unlike traditional approaches centered on fixed project boundaries and default leakage values, these technologies enable the observation of broader territorial dynamics, capturing deforestation displacement, indirect land-use change, and spillover effects associated with project activities.

Territorial monitoring systems, such as those referenced in the MRV section, supported by high-resolution satellite data and geospatial platforms, do not treat leakage as a standalone analytical category, but they play a critical role in observing land-use dynamics beyond project boundaries, enabling the identification of patterns consistent with pressure displacement over time. By providing temporal and spatial granularity, these tools allow for the detection of emerging trends and shifts in land-use dynamics, although they do not, on their own, establish causal attribution between project interventions and observed changes.

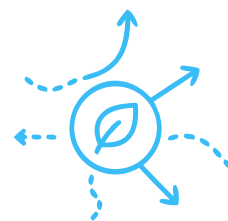
Geospatial analytics platforms further enhance this layer by translating complex environmental datasets into accessible, decision-ready insights. Initiatives such as TransparenC integrate satellite imagery, in-situ data, and automated analytics to generate dashboards, reports, and real-time monitoring interfaces. By making territorial dynamics more visible and interpretable, these tools strengthen the capacity of stakeholders to identify patterns associated with displacement, improving transparency and responsiveness in leakage-related assessments.

²⁵ This concern is supported by Gill-Wiehl, A., Kammen, D. M., and Haya, B. K. (2023), who demonstrate that the use of standardized or default leakage factors across offset methodologies often lacks robust empirical grounding, becoming a significant source of uncertainty and systematic over-crediting. Although their analysis focuses on cookstove offset methodologies, the findings are directly relevant to broader offset markets, including land-use and forest-based projects, where methodological defaults may obscure real displacement effects. See: Pervasive over-crediting from cookstove offset methodologies, *Nature Sustainability, Analysis*. <https://doi.org/10.1038/s41893-023-01259-6>

²⁶ See: Aukland, L., Costa, P. M., & Brown, S. (2003). A conceptual framework and its application for addressing leakage: the case of avoided deforestation. *Climate Policy*, 3(2), 123–136. <https://doi.org/10.3763/cpol.2003.0316>

In parallel, supply-chain traceability infrastructures offer a complementary and increasingly relevant lens into leakage dynamics by focusing on the economic drivers underlying land-use change. Platforms such as AmaChains Carbon enable the tracking of production flows, commodity movements, and environmental indicators across value chains. By linking shifts in supply and demand to territorial outcomes, these approaches make it possible to infer patterns of pressure displacement associated with project interventions, particularly in regions characterized by interconnected production systems.

In this context, supply-chain traceability significantly strengthens the empirical basis for its identification. When combined with spatial data, temporal analysis, and project-level impact assessments, these systems allow for the triangulation of evidence, connecting changes in production geographies with land-use dynamics and enabling a more informed and systemic assessment of leakage risks. As such, leakage analysis increasingly depends not on a single methodological approach, but on the integration of multiple analytical layers capable of capturing the complex interactions between territory, economy, and governance.



AmaChains Carbon

[WEBSITE](#)

AmaChains Carbon is an Amazon-based platform that leverages blockchain technology to enable supply-chain traceability, carbon accounting, and environmental data integration. By connecting territorial, economic, and environmental information, the platform allows for the tracking of production flows and their relationship to land-use dynamics. It contributes by making visible the economic dimension of land-use change, enabling the identification of indirect pressures on areas beyond project boundaries. By linking shifts in production geographies to territorial outcomes, the platform strengthens the analytical capacity to infer displacement patterns along value chains.

TransparenC

[WEBSITE](#)

TransparenC is an AI-powered geospatial analytics platform designed to simplify the analysis, visualization, and communication of environmental data for carbon and nature-based projects. By integrating satellite imagery, in-situ data, and multiple data layers, the platform enables the generation of interactive dashboards, automated reports, and real-time monitoring tools. It enhances the visibility and interpretability of territorial dynamics by transforming complex geospatial data into accessible insights, supporting the identification of patterns consistent with pressure displacement, strengthening transparency, stakeholder engagement, and the ability to respond to emerging risks.



ACCESS TO INFORMATION, TRANSPARENCY, AND DATA INFRASTRUCTURE

Beyond the technical parameters that define emissions reductions, such as additionality, leakage, and permanence, the credibility and scalability of the Voluntary Carbon Market (VCM) also depend on the quality of its information. While additionality, leakage, and permanence occupy a central place in technical debates on emissions-reduction projects, the ability of markets to generate trust ultimately relies on robust systems for transparency, data accessibility, and traceable environmental accounting. Among these, the development of robust systems for access to information and transparency plays a particularly important role in strengthening credit traceability and supporting the consolidation of a market capable of meaningfully contributing to ambitious climate goals and avoiding double counting. In this context, transparency and qualified access to information assume a strategic role, not only for buyer confidence, but also for public governance and the social legitimacy of these instruments.

One of the VCM's core challenges relates to the ongoing development of robust, standardized, and interoperable systems capable of continuously and coherently tracking the full life cycle of credits, from issuance and transfer to final retirement. Operationally, this need manifests at multiple levels. Information essential to assessing environmental and social integrity, such as land use and land cover, additionality, leakage, permanence, socio-environmental safeguards, and land-tenure status, is not always available in fully integrated, real-time, auditable, or comparable formats across projects, methodologies, and registries. Moreover, post-issuance tracking can vary across registries and systems, sometimes limiting clear identification of ownership, transaction histories, declared uses, and retirement status. Addressing these information gaps has therefore become a central priority for strengthening transparency and consistency across carbon-market actors.

Against this backdrop, technological innovation emerges as a key vector for mitigating these weaknesses, particularly solutions focused on data integration, qualification, and standardization. Platforms capable of unifying information from multiple registries, methodologies, and monitoring systems, while providing reliable data on issuance, transfer, and retirement, become central to reducing information asymmetries and enhancing market transparency. In this regard, blockchain-based technologies have attracted particular attention. By operating through distributed, immutable, and verifiable ledgers, blockchain provides a digital infrastructure for transparent record-keeping that is resilient to unilateral alteration. This architecture enables independent third-party verification, with each block validated in a decentralized manner, strengthening the credibility of recorded data. Such systems can be applied to a range of environmentally relevant functions, including asset traceability, tokenization of environmental assets, crypto-financial instruments, decentralized autonomous organizations, and environmental protocols.

In parallel, the use of blockchain to decentralized MRV infrastructures, such as Open Forest Protocol and Regen Network, demonstrates how these technological architectures are being operationalized to enhance transparency and data accessibility at the project level. By anchoring field-based evidence, georeferenced data, and monitoring records within verifiable digital systems, these initiatives contribute to strengthening auditability and traceability across the lifecycle of environmental assets, reinforcing broader transparency objectives by enabling continuous, distributed, and independently verifiable access to environmental information. In carbon markets specifically, decentralized ledgers could link each credit to a structured set of verifiable metadata, covering project origin, source registry, applied methodology, monitoring data, independent verification outcomes, transaction history, and retirement status. This design enables continuous audit trails accessible to regulators, certifiers, investors, buyers, and civil society alike.

As noted by Christiansen²⁷, blockchain can also facilitate efficient exchange of information tokens without intermediaries, integrating data on land tenure, socio-environmental safeguards, implementation evidence, georeferenced information, impact assessments, and MRV processes. The potential is further expanded through the use of non-fungible tokens (NFTs) differentiated by the carbon content associated with specific trees or forest assets, allowing finer-grained valuation and a more direct link between physical environmental assets and their digital representations²⁸.

Moreover, even where not yet fully operationalized, blockchain offers the technical capacity to permanently lock or burn NFTs, removing them from circulation and helping prevent double counting, thereby reinforcing environmental integrity. Permanence risks, for example, could be partially mitigated by integrating blockchain systems with independent, up-to-date data sources such as satellite imagery and geospatial information that continuously track vegetation cover and detect land-use change²⁹.

²⁷ For more information see: Christiansen, K. L. (2025). Relegitimising the voluntary carbon market: Visions of digital monitoring, reporting and verification. *Environment and Planning A: Economy and Space*, 57(8), 1190-1205. <https://doi.org/10.1177/0308518X241278937>.

²⁸ For more information see: Christiansen, K. L. (2025). Relegitimising the voluntary carbon market: Visions of digital monitoring, reporting and verification. *Environment and Planning A: Economy and Space*, 57(8), 1190-1205. <https://doi.org/10.1177/0308518X241278937>.

²⁹ For more information see: Christiansen, K. L. (2025). Relegitimising the voluntary carbon market: Visions of digital monitoring, reporting and verification. *Environment and Planning A: Economy and Space*, 57(8), 1190-1205. <https://doi.org/10.1177/0308518X241278937>.

Similarly, consolidating and cross-checking multiple validated data sources can support more robust additionality assessments by incorporating commodity price signals, regional deforestation drivers, remote sensing, and territorial dynamics, enhancing analytical rigor and reliability. Blockchain applications may also strengthen community participation by enabling tools for territorial monitoring, forest-cover tracking, transparent transaction records, and evidence of community engagement and consent. These mechanisms can increase transparency in benefit-sharing and protect collective rights, particularly in contexts of heightened socio-environmental vulnerability.

Crucially, blockchain should be understood as a complement to, rather than a replacement for, existing systems, especially in complex settings such as the Amazon. By enhancing traceability, interoperability, and transparency, these technologies offer a promising pathway to reinforce carbon-market integrity, improve access to information, and better align projects, registries, buyers, and public policies within an ecosystem that demands ever-higher standards of climate credibility.

Importantly, these functions are no longer merely theoretical. They are already being operationalized through digital infrastructures such as Climate Action Data Trust and KLIMA protocol, which exemplify approaches to this challenge. While some solutions operate as institutional integration layers connecting registries, buyers, and financial systems, others provide native blockchain infrastructures for end-to-end environmental asset traceability. What they share is a response to the growing need to reduce information asymmetries, ensure accounting uniqueness, strengthen audit trails, and build market confidence, by offering clearer mechanisms to track issuance, transfer, and retirement of carbon credits. In doing so, they help align projects, registries, buyers, and public policy within a carbon-market ecosystem that increasingly demands transparency, integrity, and verifiable climate impact.

TECH SNAPSHOT



Climate Action Data Trust

[WEBSITE](#)

The Climate Action Data Trust (CAD Trust) is an international initiative aimed at building a global digital data infrastructure for carbon credits, designed to integrate information from multiple registries, standards, and certification systems. CAD Trust operates as a centralized data layer that consolidates information on projects, issued units, transfers, and retirements, using unique identifiers to prevent overlaps and inconsistencies across otherwise fragmented systems. By promoting interoperability among registries and providing a consolidated view of credit status, CAD Trust directly addresses risks of double counting, opacity, and informational fragmentation. In doing so, it strengthens transparency, improves access to information, builds market confidence, and supports the overall integrity of carbon markets.

KLIMA protocol

[WEBSITE](#)

While CAD is a read-only platform, KLIMA protocol operationalizes data transparency through blockchain where it actually tokenizes, prices, and retires credits on-chain, creating a unified venue across registry sources. The core mechanism works through a bridging process: verified carbon credits from established standards like Verra's VCS or Gold Standard are brought onto a blockchain, where they are locked or cancelled at the source registry and re-issued as digital tokens on-chain. This creates a single on-chain environment where credits from multiple registries coexist as tokenized assets.



STRENGTHENING FINANCIAL INFRASTRUCTURE FOR SCALABLE CARBON MARKETS

If transparency and traceability are prerequisites for integrity, their continued development also plays an important role in enabling greater market liquidity, efficiency, and scale. As carbon markets evolve, strengthening information infrastructure becomes essential not only for access to reliable data, but also for facilitating more efficient participation by institutional buyers that rely on standardized, auditable, and legally robust processes.

We currently observe significant transactions of Nature-Based Solutions (NBS) carbon credits in Brazil, executed through public tenders and the over-the-counter market. Examples include Profloresta+, carried out by the Nature Investment Lab, whose secretariat is led by Climate Ventures, and the partnership between global technology companies and specific market players. These spot transactions are characterized by a deep and long-standing relationship between buyers and project developers. For the carbon market to achieve maturity, scale, and carbon credit to become a commodity, technological innovation in financial systems is also necessary.

Beyond informational considerations, another important dimension relates to the ongoing integration of carbon credits into broader financial systems. At present, credits are gradually being incorporated as economic assets, though their integration into conventional mechanisms of trading, financing, and risk management remains in development. In practice, carbon credits are increasingly interacting with core financial infrastructures such as banking systems, credit instruments, structured finance operations, and regulated financial markets.

As these connections deepen, the potential for carbon credits to function as investable assets becomes more visible. Expanding their compatibility with financial systems can increase their attractiveness to financial institutions, facilitate institutional investor participation, and strengthen market liquidity, ultimately supporting the mobilization of capital at scales aligned with global climate objectives. Furthermore, the formalization of carbon credits as financial assets and their demystification is urgent. The lack of clarity on this matter gives rise to potential fraud and jeopardizes the resurgence of the new, high-integrity market. Efforts to develop clearer standards for risk classification, pricing mechanisms, and interoperability with financial infrastructure are therefore gaining momentum, helping to position carbon credits more clearly within the broader landscape of environmental and financial assets.

In response, a growing set of innovative initiatives has emerged to enhance the economic functionality of carbon credits by aligning them more closely with traditional financial market dynamics. These approaches seek to structure credits as more standardized, traceable assets compatible with banking systems, trading platforms, and investment instruments. By incorporating digital traceability, standardized attributes, integration with financial infrastructure, and greater clarity around risk allocation and guarantees, such initiatives contribute to strengthening market infrastructure, increasing liquidity, and enabling broader participation by banks, funds, and institutional investors. In this sense, the responsible financialization of carbon credits, when coupled with robust environmental, social, and methodological safeguards, can play a meaningful role in enhancing scale, efficiency, and long-term credibility in carbon markets.

Within this evolving landscape, initiatives such as Carbonplace, Triangle Digital, and The Landbanking Group illustrate distinct innovation strategies aimed at strengthening market infrastructure. Together, they signal a broader convergence between carbon markets and conventional finance, pointing toward pathways to expand liquidity, predictability, and scale, while reinforcing the structural conditions necessary for credible and durable climate finance. By integrating digital traceability, financial interoperability, and standardized asset structures, these emerging infrastructures help position carbon credits not only as environmental instruments, but increasingly as investable climate assets capable of mobilizing capital across institutional and financial ecosystems. As these systems mature and converge with established financial architectures, they have the potential to strengthen market confidence, facilitate greater capital flows toward climate mitigation, and support the long-term development of carbon markets aligned with the scale and urgency of global climate goals.



Carbonplace

[WEBSITE](#)

Carbonplace is a digital market infrastructure designed to enable the trading, settlement, and custody of carbon credits within an environment aligned with international banking standards. The platform operates as an integration layer connecting buyers, sellers, carbon registries, and financial institutions, allowing portfolio visualization, transaction execution, and real-time tracking of credit status within a single interface. Its architecture prioritizes regulatory compliance, operational security, auditable transaction trails, and interoperability with existing financial systems. By directly addressing liquidity constraints and institutional trust gaps in the voluntary carbon market, Carbonplace brings carbon credits closer to conventional financial infrastructure. By reducing transactional frictions and simplifying access, trading, and retirement processes, it contributes to greater market scale, efficiency, and credibility.

Triangle Digital

[WEBSITE](#)

Triangle Digital is a climate technology company developing digital infrastructures for monitoring, reporting, and verification (dMRV), with a focus on transforming carbon credits into regulated asset class for collateral, lent and structured products, with issuance and qualified custody, compatible with financial and regulatory systems. The platform integrates operational, environmental, and economic data to create digital twins of environmental assets, automating data collection, traceability, and compliance with high integrity frameworks for nature assets. Triangle connects with registries and certification systems, enabling the issuance of auditable credits that are ready for use in financial instruments, including sustainable loans and corporate reporting. By structuring credits with greater predictability and auditability, it acts as a bridge between carbon projects and the financial system, expanding the economic functionality of credits and facilitating their integration into financing and investment operations.

The Landbanking Group

[WEBSITE](#)

The Landbanking Group is a company that has developed a proprietary methodology for the assessment, measurement, and monetization of natural capital assets, including carbon, biodiversity, water, and ecosystem services, with a strong orientation toward financial markets. Through land-tenure analysis, remote sensing data, and standardized metrics, The Landbanking Group generates measurable units of natural capital that can be recognized, priced, and used as the basis for financial instruments. This approach enables environmental assets to be converted into verifiable collateral for credit, investment, and financing operations. By advancing the structured financialization of environmental assets, The Landbanking Group addresses one of the core limitations of carbon markets: limited compatibility with traditional financial systems. By offering standardized, risk-oriented metrics linked to economic value, it enhances liquidity, predictability, and the attractiveness of carbon credits and related assets for banks and institutional investors.

TECHNOLOGY AS A PILLAR FOR INTEGRITY AND SCALE IN AMAZONIAN CARBON MARKETS

Recent debates surrounding voluntary carbon markets do not introduce fundamentally new problems; rather, they bring long-standing structural challenges into sharper focus. Issues related to land tenure, baseline construction, additionality, permanence, leakage, monitoring, double counting, and transparency not only generate technical debate, but also influence the market's ability to operate with predictability, trust, and scale. This report has examined these issues through the intersection between carbon markets and technological innovation, highlighting how emerging digital tools, monitoring systems, and data infrastructures are beginning to address many of these challenges in practice.

Taken together, these factors help explain why voluntary carbon markets have faced difficulties in attracting institutional capital, increasing liquidity, and consolidating themselves as effective instruments of climate finance. Methodological uncertainties affect credit credibility; gaps in monitoring and verification reduce confidence in reported outcomes; and limitations in transparency, traceability, and market infrastructure constrain the broader economic functionality of carbon credits. Recognizing these challenges is important, but it is equally essential to acknowledge that a growing ecosystem of technological solutions is actively working on those gaps to improve how carbon markets operate.

In Brazil, the strategic importance of these solutions is likely to extend well beyond carbon markets in the narrow sense. As NbS and bioeconomy markets move toward greater financial structuring and scale, technologies that improve traceability, monitoring, integrity, and comparability will become increasingly central. *Nature Techs* should therefore be understood not only as technical support tools, but as core market infrastructure that can help translate nature-based value into assets that are more visible, credible, and finance-ready.

It is precisely at this juncture that the convergence between emissions-reduction projects and technological innovation becomes strategically important. The initiatives highlighted in this analysis demonstrate that new technological approaches are already helping address key sources of risk and uncertainty. Technologies such as high-frequency monitoring, digital MRV systems, blockchain-based traceability, and financial integration platforms are beginning to strengthen how climate outcomes are measured, verified, and communicated. In doing so, they help reduce information asymmetries, strengthen auditability, and improve the reliability of environmental assets.

TECH STACK

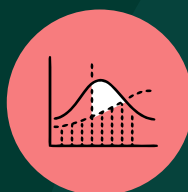
TECHNOLOGIES
WORKING TOGETHER TO
ENSURE INTEGRITY, FROM
TERRITORY TO MARKET.



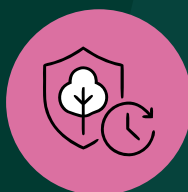
Territory: the First
Structure to High Integrity
Carbon Projects



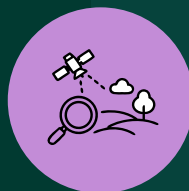
Building Governance and
Bridging the Evidence
Gap



Baseline Scenarios as the
Technical Key for
Environmental Integrity



Strengthening
Permanence and Long-
Term Climate Integrity



Monitoring, Reporting,
and Verification as
Foundations of
Climate Integrity



Addressing Leakage to
Strengthen Climate
Integrity



Access to Information,
Transparency, and Data
Infrastructure



Strengthening Financial
Infrastructure for
Scalable Carbon Markets



High-Integrity Carbon Projects

Carbon projects designed to
deliver credible, measurable,
and long-term climate impact.

These solutions are no longer theoretical. They are already being implemented across different segments of the carbon-market ecosystem, contributing to improvements in transparency, traceability, and operational efficiency. This evolution is increasingly reflected in initiatives such as the Climate Ventures' Onda Verde program and the Nature Tech Collective, which highlight the growing emergence of digital and data-driven technologies designed to address complex environmental and socio-economic challenges. While identifying, supporting, and showcasing these innovations, such platforms play a catalytic role in accelerating the development of solutions that strengthen climate integrity, environmental monitoring, and sustainable development.

Onda Verde Platform by Climate Ventures

[WEBSITE](#)

is a digital infrastructure designed to map, connect, and activate actors within the low-carbon and green economy ecosystem in Brazil and beyond. Built on a standardized taxonomy and a curated database of climate solutions, the platform functions as a **matchmaking and market intelligence tool**, connecting solution providers (e.g., climate tech companies, project developers, NGOs) with demand-side actors such as corporations, investors, and governments seeking decarbonization pathways. It helps address a key market failure: the **fragmentation of information and lack of coordination among stakeholders** working on climate and nature-based solutions. The data generated through the platform contributes to ecosystem-level intelligence, supporting strategic decision-making, policy design, and investment allocation in the green economy, playing a critical role in **reducing transaction costs, increasing visibility of solutions, and accelerating the deployment of climate technologies**.



Scan to open the website

Nature Tech Directory by Nature Tech Collective

[WEBSITE](#)

is a digital platform developed by *Nature Tech* Collective to map and organize organizations, tools, and innovations supporting nature-based solutions and environmental markets. Currently in a preview phase, the platform combines **structured data and AI-assisted capabilities** to enhance the discoverability and classification of ecosystem actors. It aggregates global initiatives while also incorporating curated datasets, including region-specific information such as organizations operating in the Amazon. By centralizing fragmented information into a single interface, the Directory functions as a **shared infrastructure for ecosystem intelligence**, supporting navigation across technologies, actors, and solution types.



Scan to open the website

Airtable

As part of this research, we co-developed, in collaboration with *Nature Tech* Collective (NTC), a mapping of nature tech solutions relevant to strengthening integrity in ecosystem services in the Amazon region. The mapping brings together a diverse set of initiatives across the technology landscape, supporting greater visibility and ecosystem understanding. This mapping is available through the following Airtable:



Scan to open the website

By highlighting these initiatives and the technologies they help catalyze, this report seeks to contribute to greater visibility for the growing ecosystem of digital and technological solutions that are reshaping how integrity, transparency, and accountability are operationalized in carbon markets. In doing so, it points to practical pathways through which technological innovation can strengthen environmental credibility while enabling carbon markets to scale in a responsible and durable manner. In the Amazonian context in particular, technological innovation can play a pivotal role in bridging environmental integrity and market scale. By enabling more robust monitoring systems, interoperable data infrastructures, enhanced traceability, and stronger integration with financial mechanisms, technology has the potential to transform trust into investment and translate climate commitments into tangible flows, unlocking the scale of climate finance required to protect one of the planet's most critical ecosystems.

Help us map the ecosystem!

This report is part of an ongoing effort to better understand and connect the landscape of technologies supporting integrity in nature markets. If your organization develops or applies technology solutions relevant to forest conservation, carbon markets, or ecosystem services and is not yet featured in key ecosystem platforms, we encourage you to submit your information:

[ONDA VERDE](#)[NATURE TECH DIRECTORY](#)

Contributing to this shared resource helps strengthen transparency, coordination, and informed decision-making across the ecosystem.