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Global transfers of forest-based carbon units

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Abstract

The global market for forest-based carbon units is rapidly accelerating, yet tracking it is challenging. Here, we present a comprehensive global public accounting of forest-based carbon projects to assess cross-border transfers of forest-based carbon units. Cross-border carbon unit transfers - projects implemented in one country while carbon units are purchased and retired in another - are a way of achieving cost-effective global emissions reductions and can have many benefits. However, this spatial decoupling may also lead to unexpected negative socio-ecological impacts, such as inequitable distribution of benefits and revenues. We show empirically that the cross-border forest-based carbon market is largely being driven by purchases of carbon units from the global north, with projects being implemented in the Global South. Carbon units are largely being delivered in nations with low governance metrics and purchased in countries with high governance metrics. While we collated the most up to date and comprehensive database possible based on available information, our assessment exposes a lack of transparency in the global forest-based carbon market, and thus we call for a cohesive, publicly accessible database to track cross-border carbon unit flows. To improve transparency and consistency across the market, we provide a blueprint for unifying international, national, and voluntary forest-based carbon registries. At a time of rapid market expansion, this global perspective is essential to critically evaluate whether prevailing models of carbon trading are functioning as intended - or whether they risk entrenching existing global inequities.

Main

As the world scrambles to mitigate climate change on a planetary scale, the global carbon market is on the cusp of exploding. Already in 2025, worldwide annual revenues from carbon taxes and emissions trading systems topped USD 100 billion[1]. Carbon markets incentivise actions to remove atmospheric carbon by generating and trading carbon units through voluntary and non-voluntary markets. Within the global carbon market, forest-based carbon projects are an important subset of approaches where carbon is sequestered by protecting threatened forested areas, improving management of forests, or planting new trees on degraded landscapes[2,3]. Considering feasibility and social constraints, scientists estimate there is up to 195 million hectares available (2,225 TgCO2e per year total net mitigation potential) for reforestation globally[4]. Despite the potential benefits of forest-based carbon markets, there are an increasing number of examples showing that they can lead to unintended social, environmental, and economic consequences that can reverse progress towards the Sustainable Development Goals (SDGs)[5,6]. Understanding forest-based carbon and financial flows is essential, as transparency is critical for accountability and equitable outcomes, but these flows are often opaque and difficult to track.

Cross-border carbon unit transfers - carbon sequestration projects implemented in one country while carbon units are purchased and retired in another - are a way to increase market liquidity and reduce costs of carbon delivery (Fig. 1). However this process makes carbon accounting particularly complicated, especially when projects cross national borders because differences in accounting standards, regulatory frameworks, and data transparency hinder consistent tracking and verification. The

Clean Development Mechanism (CDM) established under the Kyoto Protocol was one of the first global carbon finance schemes that allowed for the trading of carbon units across borders - industrialised countries could buy carbon units from developing countries[7]. It facilitated lower-cost emissions reductions, and channelled investment to developing countries[7]. Other cross-border carbon unit transfer schemes have emerged including REDD++ - Reducing Emissions from Deforestation and forest Degradation[8] - and carbon start ups - companies who develop technologies, services, or market mechanisms to sequester carbon at scale[9–11]. Despite the economic benefits, this leads to spatial decoupling in the forest-based carbon market that can lead to unexpected negative socio-ecological impacts known as externalities - examples include land dispossession[12,13], unfair distribution of benefits[14], and uneven carbon pricing which can lead to carbon leakage - emissions shifting to countries with weaker climate policies instead of being reduced overall[15,16]. Unlike other carbon projects, forest-based carbon projects are tied to land, ecosystems, and communities, meaning their carbon outcomes are inseparable from social impacts and landscape-scale dynamics.

In 2021, the CDM was superseded by Article 6 of the Paris Agreement, enabling all countries to collaborate in achieving their Nationally Determined Contributions (NDCs) through trading in mitigation outcomes[17]. The key difference to the CDM being that Article 6 reflects a shift to a universal regime where all countries that have NDCs and can participate as both buyers and sellers of mitigation outcomes. This means that cross-boundary trade in carbon units will continue to expand with countries increasingly offsetting their emissions through sequestration in other collaborating countries. Already 80% of countries have signalled their intention to use Article 6 to achieve their NDC targets and 24% have started to engage with pilots and/or bilateral agreements[18]. The resulting cross-border trades may increase the challenge of effective governance of global carbon markets due to the complexity and uncertainty in global supply chains and international projects[19]. This is because governance systems, accountability mechanisms, and power relations are more uneven across jurisdictions, increasing the risks of land appropriation, unequal benefit-sharing, and ecological mismanagement[20]. In contrast, within-country trades operate under more unified regulatory frameworks and closer oversight, which generally reduces the likelihood and scale of such adverse outcomes[15,21,22]. At present there is limited understanding on the volume and geographic distribution of cross-border trades, constraining the ability to design and implement effective governance frameworks for international carbon markets.

Here, we examine current patterns of global forest-based carbon unit flows between countries by collating publicly available information on carbon projects. Our reliance on publicly available data is intentional because these are the same information sources on which policymakers and governments must currently rely on when making decisions. Although the dataset we use includes both voluntary and compliance-linked projects, most observed flows occur through voluntary markets. Voluntary markets are the most established and longest-running segment of the global carbon market, as such, patterns observed here offer an early indication of how cross-border trading dynamics may unfold as compliance-linked trading under Article 6 expands. We identify trends and opportunities for improving the

effectiveness, equity, and ecological impact of forest-based carbon projects on a global scale by addressing three key questions: (1) where are forest-based carbon units generated and where are they used; (2) what patterns characterise cross-border carbon unit flows; and (3) where do gaps in data availability limit transparency and accountability? By examining data availability, where, and how projects are implemented, decision-makers can identify gaps, adjust strategies, and foster policies that align with the objectives of data transparency, climate change mitigation, biodiversity conservation, and equity.

Global patterns of forest-based carbon flows

We identified 22 databases from which we collated a final sample of 15,368 forest-based carbon projects globally, which span carbon sequestration activity from 1999 - 2116 (future dates reflect ex-ante estimates of future sequestration timelines), and identified another three databases that were inaccessible (Tables S1 and S2). As our aim was to assess the transfer of forest-based carbon units across national borders, we only considered projects where the purchaser and implementer were in different countries.

We find that Europe purchases the most cross-border forest-based carbon projects (or 159.6 $MtCO_2$), followed by North America (71.8 $MtCO_2$), and Asia (22.0 $MtCO_2$) (Fig. 1). Carbon projects were mainly implemented in South America (103.6 $MtCO_2$), Asia (68.1 $MtCO_2$), and Africa (64.1 $MtCO_2$). The three largest cross-continent connections were South America to Europe (54.2 $MtCO_2$), Africa to Europe (51.4 $MtCO_2$), and Asia to Europe (43.9 $MtCO_2$).

At the country level, the USA purchased the largest amount of carbon units through forest-based carbon projects in other countries (66.1 $MtCO_2$) followed by the UK (54.6 $MtCO_2$), Germany (25.7 $MtCO_2$), Italy (22.2 $MtCO_2$), and Japan (14.4 $MtCO_2$) (Fig. 2). The most units were purchased from India (39.4 $MtCO_2$), followed by Colombia (33.8 $MtCO_2$), Peru (27.9 $MtCO_2$), Brazil (27.9 $MtCO_2$), and Australia (25.3 $MtCO_2$) (Fig. 2). The three largest cross country connections were Australia to the US (25.3 $MtCO_2$), Indonesia to the UK (15.1 $MtCO_2$), Peru to the UK (11.1 $MtCO_2$), Colombia to Brazil (10.8 $MtCO_2$), and Colombia to the US (10.5 $MtCO_2$).

Risk to the integrity of forest-based carbon projects

We find that the nations which produced and transferred the largest volume of carbon units through forest-based carbon projects are also those with mid to low scores for all Worldwide Governance Metrics[23] which measure control of corruption, government effectiveness, political stability, regulatory quality, rule of law, and voice and accountability (Fig. 3). With the exception of Australia, the majority of these countries being paid to sequester carbon in forests are located in Asia, South America, and Africa. Conversely, the nations that buy the largest volume of carbon through forest-based carbon projects are in the developed “Global North”, and those with relatively higher governance metrics (Fig. 3).

There are risks on both sides. The design and implementation of projects may privilege actors with greater financial and institutional capacity, potentially marginalising local communities and reducing their influence over project decisions[24,25]. At the same time there are many risks to forest-based carbon investors, including the project under-performing in terms of ecological outcomes[5], project persistence into the future[26], and social harms such as inequitable benefit-sharing or displacement of local people[6]. All of these can result in broader reputational risks, such as loss of credibility in unit quality and increased scrutiny from regulators, investors, and the public, that can impact carbon market actors financially in the longer term[27]. Investing in forest-based carbon projects in countries with relatively lower governance effectiveness has been shown to increase these risks[28–30].

Implications

The phenomenon of internationally traded forest-based carbon units is being upscaled through multiple driving forces. Article 6 of the Paris agreement is set to facilitate vast amounts of transfers through Internationally Transferred Mitigation Outcomes (ITMOs)[17], but this is just one driving force. Others include projects funded through private finance[27], environmental, social, and governance (ESG) requirements[31], carbon start up companies[32], and market drivers that favour cheap land[33]. We show that the forest-based carbon market is largely financed by the Global North - namely, Europe and North America, who are buying units in some form or another from the Global South - especially South America, Africa, and Asia. The Global South to North transfer of units reflect the original intent of carbon credit mechanisms such as the CDM to channel finance from wealthier to lower-income countries. Further, these patterns partly reflect structural differences in demand, as companies domiciled in the Global North face stronger regulatory pressures to purchase units, while those in the Global South in general face fewer such drivers. Developed nations funding forest-based carbon projects within the borders of nations with emerging economies can result in many benefits, including income for local people through job opportunities[34], direct payments to households or community funds from carbon credit revenues[35], and ecosystem co-benefits such as improved water regulation and erosion[36]. In many cases this may be a win-win where some nations gain economically while others benefit by reducing the cost of carbon sequestration. However, benefits vary and are often unclear, the negative impacts and externalities are often ignored, and the distribution of these benefits is often uneven, with different groups within countries experiencing divergent outcomes[37].

Concerns about the integrity of forest-based carbon projects[38–40] raise the question of whether internationally traded units face higher integrity risks than domestically traded units[41]. For example, governance challenges in forest-based carbon projects - particularly relating to accountability and social equity - are frequently reported, with concerns often amplified in internationally traded unit systems where oversight, grievance mechanisms, and benefit-sharing arrangements are more diffuse than domestic markets[41]. Under certain conditions, the patterns we reveal may contribute to entrenchment of climate injustice where the burden of not only climate change impacts but also mitigation falls on

countries that have historically contributed least to climate change. Crucially; however, this burden is often accompanied by financial transfers that may represent a net benefit[42]. As such, if carbon units were sourced domestically rather than traded internationally, some nations may lose access to the financial flows that cross-border markets provide, potentially reducing overall funding for conservation and mitigation in these regions[43]. The more pertinent equity question may therefore be not whether mitigation burdens fall on the Global South, but who within these countries receive the benefits and govern the process, and who bears the costs.

It is now well recognised that benefits from the forest-based carbon market tend to accrue disproportionately to multinational corporations, large intermediaries, and private investors, while local communities - who often bear the most direct opportunity costs and tenure risks - receive a smaller share of revenues[44]. Outcomes also vary considerably across countries and project types depending on governance quality, benefit-sharing arrangements, and the strength of community land rights[37]. Land tenure uncertainty can result in community displacement or loss of access to resources - especially when coupled with weak grievance mechanisms[45,46]. Additional equity concerns include opportunity costs for the Global South of foregoing development pathways (e.g., agriculture, resource extraction, infrastructure) in favor of land being locked into carbon sequestration rather than flexible, and locally-determined development priorities[47]. These structural asymmetries warrant scrutiny, as the cumulative effect may still entrench unequal distributions of costs and benefits. Equity concerns in the forest-based carbon market are not new[16,48] - but continue to be under appreciated and under evaluated.

There will be large implications for the winners and losers of this multi million dollar industry. Forest-based carbon projects must be founded on social, economic, and ecological dimensions and systems approaches, reconcile global targets and local objectives, and measure the rate of progress toward multiple and synergistic goals[49]. However, given the relative newness and limited regulation of the global forest-based carbon market empirical assessments of the full suite of impacts is needed. Our analysis maps the global transfers of forest-based carbon units, contributing empirical groundwork for a rapidly expanding market that currently operates with limited transparency and oversight

Data is essential for tracing transactions

The greatest challenge for tracking transboundary dynamics of the forest-based carbon market is the variability of reporting standards and norms across current databases. Leading databases include Verra's Verified Carbon Standard[50] – a voluntary crediting program for carbon projects; and the Climate Action Reserve[51] – a carbon credit registry for global carbon markets. Yet, these host only a small subset of the world's forest-based carbon projects[52] and the fragmented methodological landscape leads to heterogeneity in reporting. Standards-specific methodologies for quantifying integrity concepts such as additionality and permanence, result in inconsistency: a verified credit under Verra's Verified Carbon Standard may not represent the same mitigation outcome as one issued under the Climate

Action Reserve, and geography-specific standards complicate this further. Harmonising these definitions - for example determining what one tonne of CO_2 equivalent means across registries and what the externalities are - is therefore a challenge for any unified international framework.

Article 6.2 of the Paris Agreement recognises the need for a unified international registry that tracks internationally transferred mitigation outcomes - and provides guidance on how to do so[53]. However, the scope, rules, and accounting requirements of Article 6.2 markets differ fundamentally from those governing voluntary carbon markets, particularly with respect to corresponding adjustments, implementer country authorisation, and the prevention of double counting. As a result, datasets derived from voluntary market registries are not directly transferable to a United Nations Framework Convention on Climate Change (UNFCCC)-operated Article 6 registry. The proposed international registry will only track Article 6–authorised units. Rather than suggesting that voluntary units should automatically be incorporated into a UNFCCC registry, we frame our analysis as drawing lessons largely from the voluntary market that are essential for the design of future international databases. We propose a blueprint for unifying international, national, and voluntary forest-based carbon registries (Fig. 4). This blueprint is intended to support transparency and traceability across market segments, while allowing for differentiation between voluntary units, compliance units, and Article 6 - authorised mitigation outcomes where necessary. We define five core principles to guide the development of a unified forest-based carbon market data system, aligned with existing UNFCCC processes - 1. consistent data collection, 2. standardised data processing, 3. harmonised data reporting, 4. integrated data infrastructure, and 5. open and accessible data sharing. This blueprint aims to overcome key difficulties we experienced while collating forest-based carbon datasets including variable data standards (both in collection and reporting), limited access to regional or other databases, and limited API access.

Current data reporting practices are fragmented, have incomplete methodological detail, and are incompatible for syntheses. We found substantial gaps in data across projects, leading to their exclusion in our analysis. Even the units of carbon being reported were not consistently available, and when provided, were often presented in formats that were difficult to interpret. This limits accessibility for non-specialist stakeholders so there is an urgent need for the acceptance and use of a consistent accounting methodology and standards. Various forest-based carbon accounting standards disparately exist. Some - including the Warsaw Framework for REDD++[54], Verified Carbon Standard[50], the Natural Forest Standard[55], and Plan Vivo[56] - are project and/or crediting standards used in voluntary carbon markets to generate tradable units. Others - including the Greenhouse Gas Protocol[57] and ISO 14064[58] - provide accounting and reporting frameworks applicable to corporate greenhouse gas inventories and project quantification. Many of these draw from fundamental concepts within the CDM under the Kyoto Protocol[59], but have adapted over time. As voluntary and compliance markets increasingly interact with nationally determined contributions under the Paris Agreement, unresolved differences between these standards create risks of double counting, misaligned incentives, and reduced environmental integrity. Recent national restrictions on voluntary credit exports, such as Indonesia's temporary suspension of international voluntary carbon trading[60], illustrate the governance challenges that arise when voluntary

markets are insufficiently aligned with national accounting frameworks. There is a need for the international community to reconcile these to agree on a unified best practice.

Beyond carbon accounting, other elements that relate to the forest-based carbon market must also be reported on, including spatial data (specifically for project areal extents) - imperative for biodiversity assessments[52], whether safeguards for Indigenous and local community rights are implemented[61], the land and carbon tenure of the project[62], and governance and benefit-sharing arrangements[28]. These factors are uniquely relevant to the forest-based carbon market. The absence of this information limits broadscale assessments of outcomes and equity.

Governance and reporting standardsmust be established and upheld across countries and projects - coordinating this globally can likely only be achieved through an international organisation such as the UNFCCC. This is because international organisations have legitimacy that private standards lack. Global governance and reporting standards require scientific authority, political legitimacy, cross-border coordination, and alignment with national climate commitments. For these reasons these databases should be managed by or at least in conjunction with a trusted global authority that can oversee this evolving framework, which is expected to expand and eventually incorporate nature-based projects. The most effective is likely a hybrid governance structure that combines hierarchical oversight from international institutions such as the UNFCCC with network-based coordination among governments, private standards, and other market actors[63]. Many private companies and their standards have led to the integrity issues that the forest-based carbon market faces today[64,65]. Further, the UNFCCC is already globally connected with 195 member governments[66], and its Guidelines for National Greenhouse Gas Inventories being used to report under the UNFCCC and Paris Agreement and ensure methodological consistency across countries[67]. The UNFCCC has recently operationalized this role by approving its first-ever issuance of carbon units under the Paris Agreement, signaling the establishment of a centralised, UN-regulated global carbon market[68,69].

Well-supported back-end infrastructure is critical for ensuring the reliability, scalability, and security of forest-based carbon market data systems. We were forced to omit databases from our analysis due to their inaccessibility, in many cases due to technical issues such as broken web links, and lack of accessibility despite claims of open-access (see Table S2). Robust technical architecture, combined with regular maintenance and dedicated institutional support, enables consistent data integration, rapid processing, and long-term accessibility. Such infrastructure also facilitates interoperability between jurisdictions and platforms, a prerequisite for effective transboundary tracking and equitable market participation. Free and open access to carbon market data is essential for transparency, accountability, and equitable participation[70,71]. When data is publicly available, stakeholders - from local communities to international regulators - can verify claims, monitor outcomes, and ensure that benefits and responsibilities are distributed fairly. Open data fosters trust, reduces the risk of manipulation, and strengthens the overall integrity of the market. Beyond voluntary registries, some national and regional compliance and regulated offset markets have introduced registries and reporting requirements to

improve transparency[72–74]. These regulated markets offer instructive lessons: mandatory disclosure requirements, standardised reporting formats, and regulatory penalties for non-compliance have improved data availability in some jurisdictions. However, challenges around accessibility, standardisation, and independent verification persist even in well-resourced compliance markets - for example, Australia's Emissions Reduction Fund has faced ongoing scrutiny over the integrity and transparency of credited projects[75] - suggesting that regulation alone is insufficient.

Incentivising transparent reporting more broadly likely requires a combination of approaches: regulatory recognition and market access for projects that meet open data standards, reputational benefits for developers and buyers associated with verifiable high-integrity units, and financial penalties for non-disclosure or misreporting. Data sharing and transparency is an ongoing issue across science and industry[76,77]. Financial penalties have been shown to enhance carbon disclosure, with social media scrutiny amplifying the positive impact of penalties by increasing public pressure[78]. A final guiding principle for market development is that governance frameworks should integrate both incentives and enforcement, ensuring that certification is not merely symbolic but tied to market access, financial value, and regulatory recognition. Taken together, lessons from both voluntary and compliance markets suggest that open data is most effective when embedded within a governance framework that combines mandatory requirements, institutional enforcement, and positive incentives for participation.

Limitations and future research needs

Our analysis is limited by missing many projects globally due to accessibility issues (Table S2) and many projects are not reported in publicly accessible databases - either because they are not required to or they choose not to. While there may be existing governance mechanisms in some locations that have resulted in more data being available in some regions versus others - we do not account for this potential bias. Nevertheless, our dataset is the most comprehensive possible based on currently available information. This limitation compounds when project impacts cross jurisdictional boundaries altogether, such as through transnational agricultural displacement. There is a lack of understanding of how impacts could be exacerbated due to forest-based carbon projects crossing borders, such as transnational agricultural displacement[79–82]. With more understanding, these impacts could be accounted for in carbon monitoring, accounting, and reporting. Integrated assessment models that couple the global economy and land-use dynamics are one tool that can help quantify agricultural displacement dynamics by tracing how restoration finance and cross-border carbon markets influence trade, land-use change, and production systems across regions, allowing the indirect economic and environmental spillover effects to be quantified[83–85]. This is an area of active research.

Conclusion

While there are win-win scenarios and some nations benefit from cost-effective carbon sequestration, with little oversight of projects there is the potential for implementer nations to be disadvantaged in a

range of ways. Further, the current increase in private finance into restoration comes with risks, as private finance objectives in restoration often are misaligned with wider social and ecological objectives[86]. There are massive implications for the winners and losers for this expanding industry that the global trade in forest-based carbon units could exacerbate. Without harmonised databases populated by data collated through high-quality monitoring, reporting, and verification systems, it is nearly impossible to track the full suite of carbon flows across borders, identify where benefits and burdens are distributed, or ensure that market outcomes are functional and equitable. This lack of transparency allows the benefits and burdens of forest carbon projects to shift across regions without being properly recorded. Strengthening cross-border data infrastructure is therefore a prerequisite for both environmental integrity and equitable participation in the carbon market.

Methodology

Overview

Our aim was to create a comprehensive database of global forest-based carbon projects that cross the borders of another country using publicly available information. This involved searching for and downloading data from publicly available global and national databases, and subsetting based on forest-based carbon methodologies. Registries and databases were found through comprehensive Google searches, as well as cross-referencing registries mentioned in various carbon offset programs, lists, and articles. National registries were checked based on a list of countries with emission trading schemes[87].

Collating the database

To select only forest-based carbon projects we only included projects which contained one of our key words, namely: "REDD", "redd", "Forest", "forest", "FOREST", "Reforestation", "REFORESTATION", "reforestation", "Afforestation", "afforestation", "AFFORESTATION", "Deforestation", "deforestation", "DEFORESTATION", "Ecosystem Conversion", "ecosystem conversion", "ECOSYSTEM CONVERSION", "Peat Swamp", "peat swamp", "PEAT SWAMP", "Forestry", "forestry", "FORESTRY", "tree", "Tree", "trees", "TREES", "TREE", "forestation", "Forestation", "FORESTATION", "planting", "Planting", "PLANTATION", "mangrove", "Mangrove", "MANGROVE", "swamp-forest", "swamp forest", "SWAMP FOREST", "Swamp Forest", "Swamp forest", "wood", "Wood", "WOOD", "regeneration", "Regeneration", "REGENERATION", "regrowth", "Regrowth", "REGROWTH", "vegetation", "VEGETATION", "Vegetation", "seedling", "Seedling", "SEEDLING", "sapling", "Sapling", "SAPLING", "bosque", "Bosque", "BOSQUE", "forestal", "Forestal", "FORESTAL", "plantaciones forestales", "PLANTACIONES FORESTALES", "arbol", "Arbol", "ARBOL", "Agro-forestry", "agro-forestry", "AGRO-FORESTRY", "agroforestry", "Agroforestry", "AGROFORESTRY", "Plantation", "plantation", "PLANTATION", "woodland", "Woodland", "WOODLAND". We then further manually checked the included projects and removed any that were not relevant to forest-based carbon. We then further removed projects that did not contain a full set of data for our analysis; that was, purchaser and implementer country, carbon values, and project status.

We included only projects that crossed an international border. We regarded a project as having crossed an international border when a project's "implementer country" was in a different country than the "purchaser country" (Fig. 1). Duplicates were removed. This resulted in 11 publicly available carbon registries which collate data at the global level, and 4 at the national level (Table S1). Our analysis was limited to data drawn from public data sources. Several databases and registries were present online, but data was not viewable, was not available for download, or otherwise had limited access (Table S2).

Aligning carbon values

We standardised each registry to reflect the sum of credit volume in tonnes of carbon. Several registries and projects reported carbon volume as units, as an annum emissions reduction, or with another metric. We considered carbon units/volumes retrospectively. We excluded cases where projects had a registration date, but not a commencement date, or where no carbon values were reported.

Risk analysis

We visualised cross-boarder forest-based carbon trading relationships based on governance indicators by representing pair-wise aggregate volumes of implementer-purchaser trade volume. Specifically, governance indicators from the World Bank Group include government effectiveness (Fig. 3), voice and accountability, political stability, government effectiveness, regulatory quality, rule of law, and control of corruption[23] (SM 1). We also created versions standardised by GDP per capita of the implementer country[88] (SM 1).

All data processing and analyses were carried out in R[89].

Declarations

Code availability

R code and data developed for and used in this analysis is available via GitHub at https://github.com/BIOSFERE-Lab/carboncrossingborders.

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Competing interests

The authors declare no competing interests.

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Figures

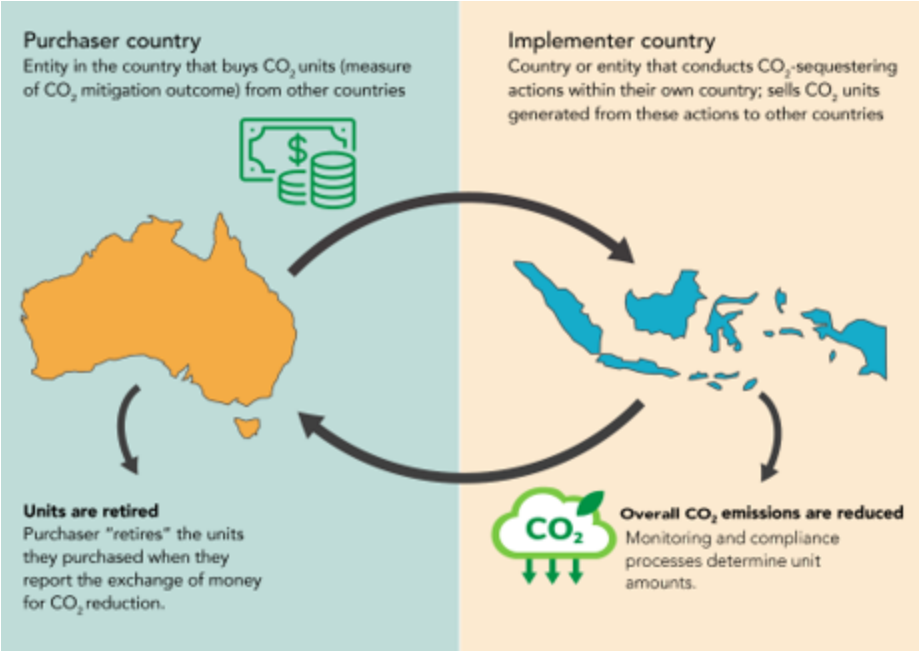


Figure 1

Conceptual diagram of cross-border carbon unit transfer terminology. Projects implemented in one country while carbon units are purchased and retired in another are a way for fueling the global carbon market. We note that retirement is mandatory in compliance markets but not in voluntary markets.

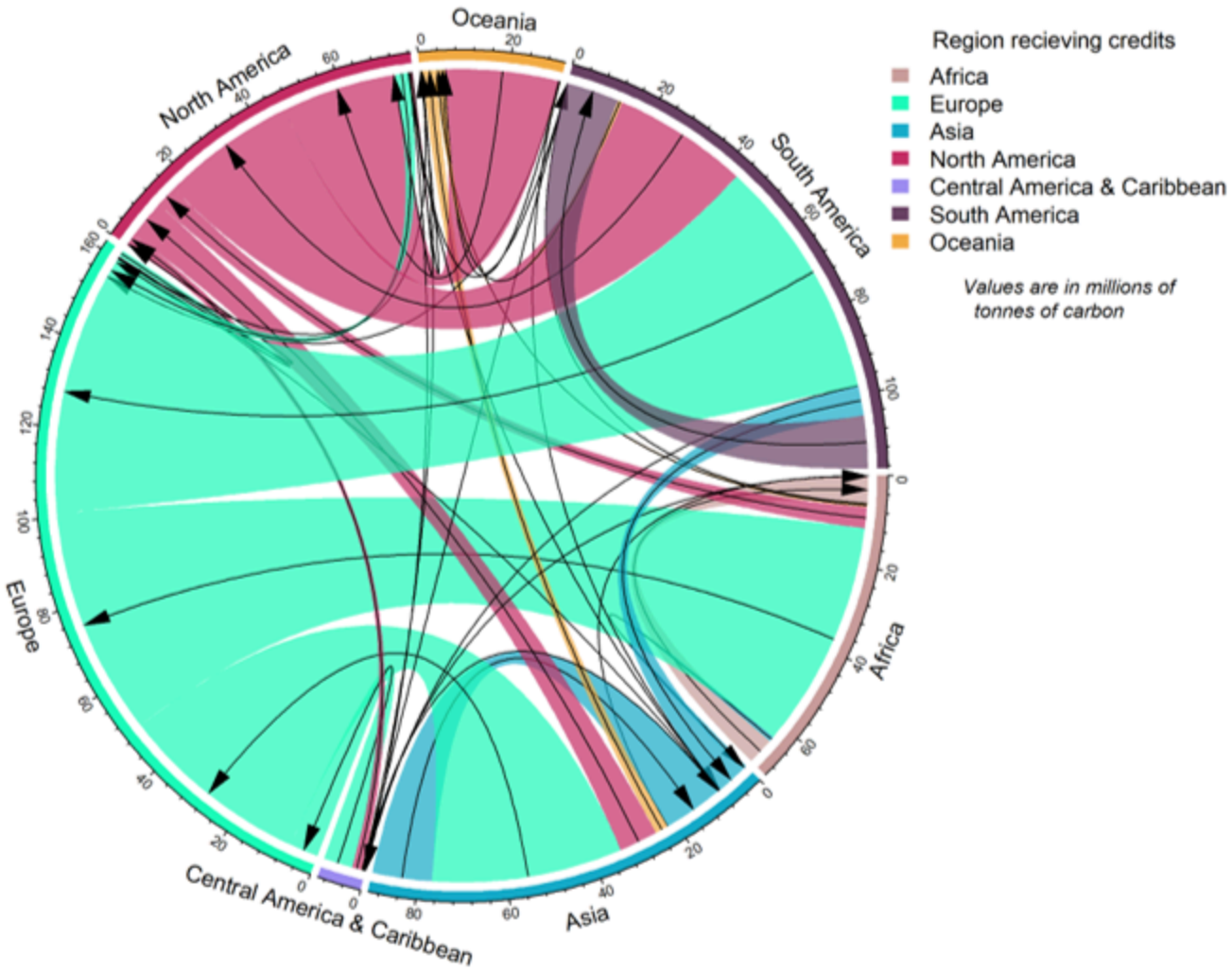


Figure 2

Transfer of forest-based carbon units between continents. Chord diagram showing the transfer of forest-based carbon units between continents, units are in tonnes of carbon. Arrows begin where the project is being implemented and end in the region where the country is buying (or retiring) the carbon unit. Flows within the same continent occur when crossing a country's border.



Figure 3

Transfer of forest-based carbon units between countries and continents. Arrows indicate the transfer of forest-based carbon units between continents, units are in tonnes of carbon. Arrows start where the unit is being transferred from (or country carbon is being retired in) and ends in the country buying the unit (or funding the project). The project coordinates are rarely provided so the arrow origins are country centroids.



Figure 4

Government effectiveness of implementer and purchaser countries for forest-based carbon units. Points represent individual projects, government effectiveness values are from the Worldwide

Governance Indicators for the year 2025 (World Bank 2025) (for full suite of metrics assessed see SM 1). Project volume size is represented by bubbles, and the continent of the seller is represented in: pink, Africa; blue, Asia; purple, Central America & Caribbean; light green, Europe; red, North America; orange, Oceania; dark purple, South America.

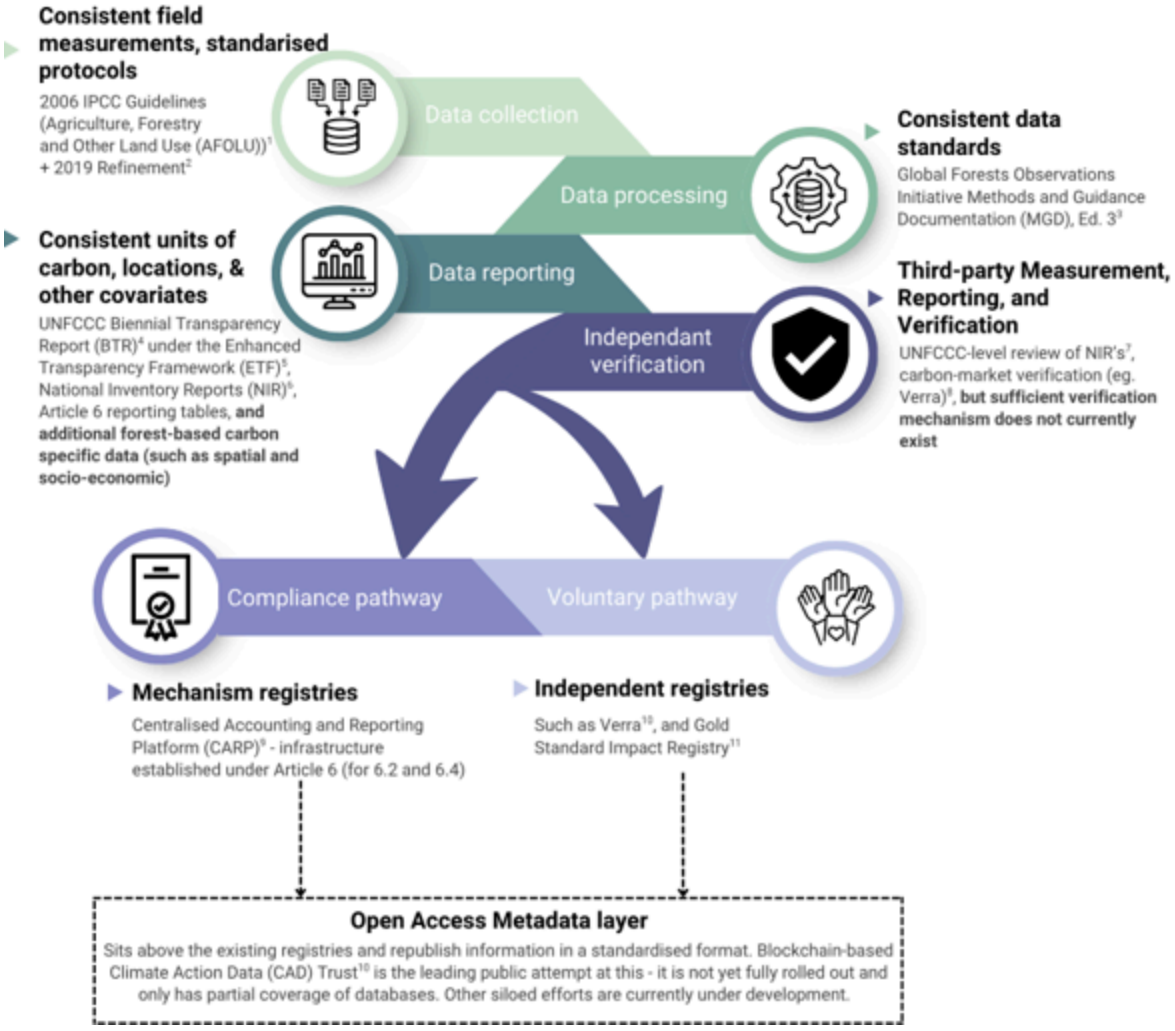


Figure 5

Blueprint to achieve an enduring and effective global repository - or metadata layer - of the forest-based carbon market. Steps to support transparency, consistency, and effectiveness and leading example of protocols or initiatives. Both compliance and voluntary driven registries should feed into an open access metadata layer. 1. https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html, 2. https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html, 3. https://www.reddcompass.org/mgd/resources/GFOI-MGD-3.1-en.pdf, 4. https://unfccc.int/biennial-transparency-reports, 5. https://unfccc.int/sites/default/files/resource/Enhanced%20Transparency%20Framework.pdf, 6. https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review/reporting-and-review-under-the-paris-agreement/national-inventory-reports, 7. https://unfccc.int/reporting-and-review, 8. https://verra.org/validation-verification/, 9. https://unfccc.int/process-and-meetings/the-paris-

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