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Towards comprehensive blue carbon accounting in Vietnam

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Key messages

- The Government of Vietnam pays great attention to protecting mangrove ecosystems as they play a vital role in climate change mitigation. In 2024, the government issued Technical Guidelines for Biomass and Carbon Stock Estimation of Mangrove Forests (Decision No. 316/QD-LN-SXLN). These Guidelines aim to standardize estimates for biomass and carbon stock, and increase carbon storage from their restoration. This brief looks at required improvements to the Guidelines to help Vietnam join the blue carbon market.
- Better estimates of greenhouse gas (GHG) emissions from converted mangroves are needed to understand baseline emissions from anthropogenic disturbances in mangrove forests, as well as the impact of ending conversion of mangroves to other uses like aquaculture. To that end, better information on conversion and land-management practices is needed. This includes excavation depth for construction of aquaculture ponds and infrastructure development, nitrogen inputs for aquaculture production, and knowledge on crop types, drainage depth, and GHG budgets in mangroves converted to agriculture.
- Strategic alignment with established blue carbon standards—such as the Verified Carbon Standard (VCS) and the Gold Standard (GS) Framework—would enable Vietnam to harness the full potential of its mangrove ecosystems for high-integrity blue carbon crediting.
- Integrating remote sensing and machine learning techniques with species-level classification data can significantly enhance the accuracy and robustness of blue carbon accounting in mangrove ecosystems.

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Introduction

The total mangrove forest area in Vietnam in 2024 was 168,741.50 ha, accounting for 3% of the total forest area in Vietnam (Ministry of Agriculture and Environment 2025). Restoration efforts have reversed the national trend of net mangrove forest loss to forest gain in recent years. However, Vietnam continues to lose mangroves due to the expansion of aquaculture, agriculture, and infrastructure (Tran et al. 2024; Swails et al. 2025).

The estimated potential greenhouse gas (GHG) impact of CO_2 emissions from mangrove forest conversion in Vietnam over 10 years is 3,618,212 Mg CO_2. This estimate is based on net mangrove loss during recent decades. Protecting mangrove is thus critical for Vietnam to achieve its Nationally Determination Contribution target (Pham et al.2022).

An analysis of mangrove loss and expansion in the Mekong Delta, Vietnam revealed that CO_2 removals from gains in mangrove area did not offset CO_2 emissions from mangrove losses during 2016– 2024 (Swails et al. 2025). The Government of Vietnam is interested in exploring and engaging in the blue carbon market. However, it is hindered by the lack of its national measurement, reporting, and verification (MRV) system to quantify and measure blue carbon (Phamet al. 2022).

In 2024, to address these knowledge gaps, the government issued Decision No.316/QD-LN-SXLN – Technical Guidelines for Biomass and Carbon Stock Estimation of Mangrove Forests (hereafter, "Guidelines"). The Guidelines were developed by the Vietnam Administration of Forestry to establish a nationally consistent protocol for estimating carbon stocks in mangrove ecosystems. These aimed to align with the Intergovernmental Panel on Climate Change (IPCC) 2006 Guidelines for National Greenhouse Gas Inventories.

The Guidelines sought to enable standardized MRV across forest subcompartments, support REDD+ readiness, and contribute to Vietnam's national GHG inventory under the Paris Agreement. Specifically, they aimed to standardize the technique for biomass and carbon stock estimation of mangrove forests across Vietnam to help improve such estimates and increase carbon storage from their restoration. More than 10 provinces across Vietnam are applying the Guidelines to estimate mangrove carbon stocks. Stakeholders often perceive that applying the Guidelines on the ground would help Vietnam join the blue carbon market, but there is still much work to do for this to happen.

This brief discusses several technical improvements/refinements required to ensure the Guidelines can capture a precise picture of mangrove carbon stock based on international standards. It examines additional steps needed to move from this national inventory exercise to development of a robust accounting framework for blue carbon. It also evaluates the methodological robustness, completeness, and market relevance of the Guidelines. In addition, it assesses suitability of the Guidelines for international application, particularly in the context of project-scale blue carbon interventions targeting voluntary carbon markets or Article 6 cooperative approaches.

The analysis draws on benchmark requirements outlined in the 2013 Wetland supplement to the IPCC guidelines, Verra's VCS Standard v4.7 and VM0033: Methodology for Tidal Wetland and Seagrass Restoration v2.1, and the Gold Standard's Principles and Requirements v2.1, Blue Carbon and Freshwater Wetlands Activity Requirement v1.0, and Sustainable Management of Mangroves methodology v1.0. For clarity and consistency, all Verra-related documents are referred to as the *VCS Standard*, and all Gold Standard-related documents as the *GS Framework* throughout the brief.

Blue carbon accounting

Mangrove ecosystems store large amounts of carbon in live vegetation, deadwood, litter, and soil. Anthropogenic activities affect carbon storage in these ecosystems and their emissions of non-CO_2 GHGs, including nitrous oxide (N_2O) and methane (CH_4). Such activities include mangrove forest degradation and conversion to other uses, as well as restoration of natural vegetation and hydrology in disturbed mangroves.

The IPCC developed guidelines for countries to report their GHG emissions to the United Nations Framework Convention on Climate Change. These data provide the basis to estimate GHG emissions and removals from land use and land-use change in mangroves for blue carbon accounting frameworks. Estimating emissions managed, converted, and restored in relation to mangroves requires information on the type and extent of anthropogenic activities in mangroves. It also requires emission factors (EF) to quantify GHG emissions and removals per unit area.

Chapter 4 of the 2013 Wetland supplement to the IPCC guidelines (Kennedy et al. 2014) provides default (global) Tier 1 EFs and procedures to quantify emissions and removals of CO_2 resulting from management of mangrove forests, their conversion for infrastructure, aquaculture, salt ponds, and agriculture, and mangrove restoration. It also provides guidance on quantifying emissions of N_2O from aquaculture production and changes in soil CH_4 fluxes in rewetted mangroves. Differences in environmental controls on GHG fluxes from vegetation and soils (e.g., management practices, soils and vegetation properties, hydrologic differences) may drive differences in net ecosystem GHG emissions. Consequently, countries are encouraged to develop Tier 2 (regional) EFs for GHG accounting.

Moving from national guidelines to a concrete and robust MRV system to help Vietnam take part in blue carbon market

Our review shows the Guidelines have provided an excellent foundation for Vietnam in quantifying mangrove biomass. Decision No. 316/QD-LN-SXLN will contribute to reducing uncertainty in CO_2 emissions and removals from forest management activities in mangroves (planting, thinning, harvesting, timber and fuelwood removal, charcoal production); vegetation removal and soil excavation for infrastructure, aquaculture, and salt pond development; and mangrove revegetation. Therefore, they represent a large and important step forward to achieving a robust blue carbon accounting framework in Vietnam.

The Guidelines reflect a technically sound, IPCC-consistent protocol well suited to national forest inventory objectives. However, several methodological omissions limit their applicability for compliance with carbon crediting frameworks. These frameworks require quantification of GHG fluxes beyond CO_2, statistical uncertainty treatment, and spatially explicit MRV frameworks. To serve as a foundation for carbon market participation, the methodology will require substantive upgrades in four key areas:

1. The guideline must expand to include full GHG fluxes – specifically CH_4 and N_2O emissions from saturated mangrove soils – as well as overlooked carbon pathways such as pneumatophore and fine root biomass, dissolved organic carbon (DOC) export, and sediment carbon burial.
2. Verification-ready methodologies require formal statistical treatment of uncertainty. The guideline lacks comprehensive tools for uncertainty analysis – such as error propagation techniques or Monte Carlo simulation – and does not define acceptable thresholds for error or confidence levels. This limits transparency and credibility under third-party audits.
3. The methodology must incorporate advanced spatial analytics, including LiDAR, UAV photogrammetry, and radar-based biomass mapping, to enable scalable and verifiable estimates across heterogeneous and dynamic mangrove landscapes.
4. The current approach lacks a feedback mechanism for updating biomass models or allometric equations based on new field data or regional ecological variability. Periodic recalibration is essential to maintain methodological accuracy and market integrity.

Table 1 evaluates the Guidelines against internationally recognized methodologies, identifying alignment, limitations, and actionable recommendations based on emerging best practices in blue carbon accounting methodologies.

Furthermore, further refinement of GHG EFs for land uses in converted mangroves is also needed. This will permit full accounting of emissions from anthropogenic disturbances in mangrove forests, as well as understanding the impact of ending conversion of mangroves to other uses like aquaculture. This requires information on depth of extraction, biomass management in integrated mangrove – shrimp production systems, and N_2O emissions from aquaculture, as well as measurements of soil CO_2 fluxes and post-conversion biomass in drained agricultural systems, and CH_4 fluxes from mangrove rewetting. Further disaggregation of mangrove EF by soil type (mineral, organic) and hydrology (saline, brackish, freshwater) is also needed to refine GHG emissions and removals estimates, as these factors affect carbon storage and non-CO_2 emissions by mangrove soils.

Remote sensing techniques offer a cost-effective approach for blue carbon accounting (Malerba et al. 2023). Vietnam has made several attempts to quantify mangrove blue carbon using traditional and cutting-edge remote sensing technologies. Traditional approaches are often time consuming and costly. For their part, remote sensing approaches use a wide range of space-borne and airborne sensors, including multispectral and synthetic aperture radar (SAR) data combined with machine learning and artificial intelligence (AI) algorithms (Pham et al. 2019, Pham et al. 2020a,b)).

These advanced methods enable more robust and timely quantification of blue carbon components, including above-ground carbon (AGC), below-ground carbon, and soil organic carbon (SOC). Recent advances in Earth Observation and AI – such as computer visions and pattern recognition, and increased availability of free satellite data – are significantly enhancing the estimation of mangrove blue carbon from space (Pham et al. 2023).

The current Guidelines would benefit from several refinements to align the national inventory with international requirements (Table 2).

Table 1. Comparison of carbon stock estimation approaches

Area of review	Decision No.316/QD-LN-SXLN	GS and VCS	Recommendations
Carbon pools and measurement scope	Includes five carbon pools – above-ground biomass (AGB), below-ground biomass (BGB), deadwood, litter, and soil organic carbon (SOC) – in alignment with IPCC Tier 2 standards. However, it omits measurement or modelling of non-CO_2 gases such as methane (CH_4) and nitrous oxide (N_2O), which are highly relevant in waterlogged mangrove soils. It also does not address carbon flows such as dissolved organic carbon (DOC) export or sediment accretion processes that contribute to long-term sequestration. While it provides flexibility to adapt scope based on project objectives, this creates ambiguity for market-standard applications, where conservative, comprehensive carbon accounting is required.	GS Framework and VCS Standard require comprehensive carbon pool coverage. This includes CH_4 and N_2O flux accounting, especially from anaerobic soil processes typical of saturated mangrove ecosystems. VCS Standard mandates treatment of DOC export and carbon burial through sediment accretion. Non-inclusion of these pools underrepresents the true greenhouse gas (GHG) flux and undermines environmental integrity. GS Framework further requires a justification if any pool is excluded and typically mandates conservative assumptions or default factors.	• Expand the guideline to include CH_4 and N_2O emissions from saturated soils using static chamber measurements, portable gas analysers, or modelled estimates calibrated with site-specific hydrology and salinity. • Integrate DOC export monitoring through water sampling and total organic carbon analysis, and include sediment core sampling for carbon burial assessments. This ensures compatibility with blue carbon crediting frameworks and enhances the environmental robustness of Vietnam's mangrove MRV systems.
Stratification and sampling design	EN_316 uses forest status maps to stratify plots by dominant species, origin (planted vs. natural), and age class. Sampling is random for large areas (≥2,000 ha) and typical case for smaller stands (<2,000 ha). While efficient for national inventories, this structure does not consider landscape-scale heterogeneity – such as tidal gradients, salinity zones, and hydrogeomorphic settings – which significantly affect carbon distribution. Sample size is calculated statistically, but edge effects and ecotones are not addressed. Absence of spatial uncertainty and non-random sampling in small areas may bias results.	VCS Standard and GS Framework require stratification not just by vegetation type but also by ecological and physical drivers. These include salinity, hydrological connectivity, soil type, and exposure to disturbance. Stratification must be spatially explicit, justified with data, and adaptable over time. Sampling design must be statistically robust and ground-truthed using recent, verified remote sensing layers. Small, non-contiguous patches must also be evaluated separately for eligibility and sampling intensity.	• Incorporate multi-criteria stratification based on ecological variables (e.g., salinity, tidal regime, sediment type) alongside species dominance. • Standardize typical-case sampling with minimum thresholds and justification for each stratum. Include provisions for edge zone analysis, adaptive sampling designs, and integration with high-resolution remote sensing tools (e.g., UAV, LiDAR) to capture fine-scale heterogeneity in carbon stocks. • Apply Monte Carlo simulation or other statistical validation techniques to assess representativeness and reduce sampling bias.
Allometric equations	Species-specific biomass equations included, but many lack disclosure on sample size, diameter at breast height (DBH) range, or error bounds. There is no guidance on choosing between multiple equations per species and no protocol for validation or recalibration.	Equations must be transparent, regionally validated, and statistically robust. Periodic recalibration expected.	• Enhance equation transparency, validate models regionally, and implement error propagation procedures. • Provide guidance for selecting the most appropriate equations. • Implement regional validation, periodic updates, and error propagation. Include local validation for shrub and Nypa species.

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Table 1. Continued

Area of review	Decision No.316/QD-LN-SXLN	GS and VCS	Recommendations
Plot design and field measurement protocols	Permanent circular, square or rectangular plots (100–500 m²) with standard procedures for measuring DBH, tree height, AGB and for collecting soil and litter data. However, the methodology lacks BGB coring, pneumatophore mapping, and formal training procedures. Additionally, quality assurance and control (QA/QC) are limited to data entry without systematic checks during fieldwork or estimation.	The GS Framework and VCS Standard require comprehensive, standardized field measurement protocols covering all relevant biomass components, including BGB, pneumatophores, and shrubs. Teams must be trained and QA/QC applied across the full data lifecycle.	• Expand measurement protocols to include BGB coring and pneumatophore mapping. • Introduce formal training, calibration sessions, and QA/QC at all workflow stages (fieldwork, entry, processing). Include checks like duplicate sampling and equipment validation.
Soil organic carbon (SOC)	SOC measured with Walkley-Black and combustion methods. Redox monitoring, CH_4/N_2O flux estimation, and soil-type stratification are missing. Rewetting dynamics are not addressed, limiting relevance to restored/saturated mangroves.	The GS Framework and VCS Standard require accounting for GHG fluxes from anaerobic conditions, including CH_4 and N_2O and CO2 (allochthonous SOC). Redox monitoring, differentiation of soil types, and consideration of SOC dynamics under rewetting are expected. GS Framework also requires stratification by soil properties, and robust monitoring protocols. VCS Standard requires field assessments for measuring SOC.	• Strengthen the methodology by incorporating redox potential. Include direct or modelled monitoring of CH_4 and N_2O. • Stratify SOC measurement by soil type (organic vs. mineral) and consider the influence of rewetting on carbon stability and GHG emissions.
Data management and analysis	Provides Excel templates and structured calculations, with average carbon stock assigned spatially. While this introduces a spatial dimension, the system lacks uncertainty propagation metadata documentation, and automation. Manual updates and no error thresholds limit auditability and carbon market alignment.	VCS Standard and the GS Framework require digital systems that ensure traceability, reproducibility, and transparency. This includes uncertainty propagation (e.g., Monte Carlo), metadata/ audit trails, and GIS/remote sensing integration. Error thresholds must be defined.	• Adopt uncertainty analysis tools, improve metadata practices, and transition to integrated digital systems. • Align uncertainty procedures with carbon standard expectations for transparent MRV.
Remote sensing and GIS integration	Uses satellite imagery for forest classification; no integration of remote sensing for biomass estimation or verification.	The VCS Standard and GS Framework call for integration of remote sensing tools (LiDAR, UAVs) for biomass estimation and monitoring. They require spatial validation and accuracy assessment.	• Integrate remote sensing into biomass estimation and verification processes. • Use high-resolution imagery, LiDAR or UAVs, and validation methods like ground-truthing and confusion matrices. • Ensure compatibility with MRV reporting systems.

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Table 1. Continued

Area of review	Decision No.316/QD-LN-SXLN	GS and VCS	Recommendations
Change detection and long-term monitoring	Supports repeated inventories but lacks minimum remeasurement intervals or event-triggered reassessments. No inter-cycle consistency measures.	Define remeasurement intervals, event-based monitoring, and verification consistency protocols.	Define clear monitoring intervals (e.g., 5 years) and QA protocols across measurement cycles to support continuity and comparability of data.

Table 2. Aligning Guidelines with international requirements

Current guideline	Areas for consideration
To estimate carbon fraction in dry biomass (CF), the Guidelines instruct stakeholders to use the default carbon fraction used for general dry biomass, harvested wood, and fuelwood is typically CF = 0.47.	The default value of the Guidelines refers to the IPCC 2006 guidelines for all tree parts. IPCC default CF for mangrove leaves and wood is 0.451 following the 2013 Wetlands Supplement. This means the estimation based on the Guidelines might be higher than the default CF instructed by IPCC. The Guidelines should adopt IPCC default value to ensure its global consistency and ensure Vietnam database aligns with IPCC requirements.
The Guidelines refer to the identification of carbon pools subject to carbon stock estimation as "*measurements focus only on the carbon in live trees (above-ground and below-ground) and soil organic carbon.*"	Although this instruction is correct, it is good practice to instead select pools for measurement based on the direction and magnitude of change in carbon stocks.
Data collection and carbon stock estimation of deadwood (standing and fallen): for fallen deadwood, the Guidelines refer to "Within the sub-plot, collect and weigh all fallen deadwood segments (including those of 10 or more cm in diameter)."	Collecting and weighing all pieces of deadwood in sub-plots could be challenging for large pieces of deadwood (e.g., sections of fallen trees). For large deadwood components, the volume measurement described immediately below is appropriate, but the volume of representative samples needs to be determined in the laboratory to determine deadwood density.
Data collection and carbon stock estimation of soil organic carbon: data collection to determine the content of organic carbon in mangrove soils must follow detailed procedures to ensure accuracy and compliance with IPCC guidelines.	These procedures are correct for determining the carbon content of soils. For determining soil carbon stocks, soil bulk density should also be measured. For this, the volume of the soil sample must be known. The Guidelines mention the laboratory procedures but are not clear about field sampling.
Analysis of dry biomass of trees, shrubs, litter, deadwood, palm, and low-lying vegetation: samples collected from the field, such as shrubs, litter, and deadwood, must be oven-dried and analysed in the laboratory to determine the dry weight. The equation for calculating dry weight is as follows: $\frac{\text{Dry weight}}{\text{Fresh weight}} \text{X } 100$	The density of deadwood is needed to estimate carbon in deadwood with volume measurements as described above in the field sampling. In that case, the volume of deadwood samples should be determined by calculating deadwood samples with regular shapes like discs or water displacement for irregularly shaped ones.

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Table 2. Continued

Current guideline	Areas for consideration
Based on mangrove species, select the appropriate AGB estimation equation in Appendix A1. If the species does not have a specific biomass estimation equation in Appendix A1 or if the species is unidentified, use the general equation: AGB = 0.251* ρ *DBH1.32.46 (ρ is the wood density –tons dry matter per m3 fresh volume – and DBH is measured in cm.	**For large-scale mangrove AGB estimates:** data fusion techniques that integrate optical approaches such as Sentinel-2 Multispectral Imager (MSI) and Sentinel-1 SAR sensors can significantly enhance estimation accuracy at 10 m spatial resolution in Vietnam (Pham et al. 2017, 2020a, 2020b).
Soil organic carbon (SOC) Mangrove soil carbon stock is calculated by multiplying the dry bulk density (BD) by the total carbon (TC) content (%) at a depth interval. BD (g cm-3) = [dry mass (g)] / [wet sample volume (cm3)]Soil carbon stock (Mg TC ha-1) = BD (g cm-3) * TC (%) * depth interval (cm)	Soil cores should be collected at a depth of at least 100 cm in undisturbed areas, specifically at the centre of each sampling plot at the lowest tidal level within the mudflat. An Eijkelkamp gouge auger is recommended for this purpose. Soil core samples should be sectioned into the following layers from the surface (0–15 cm, 15–30 cm, 30–50 cm, and 50–100 cm) as recommended by Kauffman and Donato (2012). **For large-scale SOC estimates:** application of multispectral remote sensing data such as Sentinel-2 MSI, combined with advanced decision-tree ensemble learning algorithms, can improve estimation of mangrove soil carbon stocks at 10 m spatial resolution (Pham et al. 2021).

Conclusion

The Guidelines mark a major milestone in strengthening Vietnam's blue carbon accounting framework, providing a critical foundation for standardized methodologies, robust data management, and alignment with international carbon market requirements. They provide a rigorous national protocol to estimate mangrove carbon stocks, aligned with international GHG accounting norms at the Tier 2 level. Their structure and parameters are appropriate for domestic MRV systems and could be extended to support REDD+ baselines and jurisdictional-level reporting.

However, enhancements are needed for the Guidelines to function as a credible framework within national and international carbon markets, especially those recognizing blue carbon methodologies. These enhancements include integration of non-CO_2 GHG accounting, formal uncertainty analysis, spatial monitoring protocols, and conformance with crediting programme requirements. As written, the Guidelines should be considered a baseline technical framework that requires methodological overlay or augmentation to achieve market-level rigour.

To advance blue carbon initiatives, more refined estimates of greenhouse gas (GHG) emissions from converted mangrove areas are essential. This includes improving our understanding of baseline emissions resulting from anthropogenic disturbances, such as the conversion of mangroves to aquaculture or agricultural land. Accurate accounting requires detailed data on land-use conversion and management practices—for example, excavation depths for aquaculture pond construction, infrastructure development, nitrogen inputs in aquaculture systems, crop types, drainage depths, and GHG budgets in converted agricultural lands.

Equally important is the need to reduce uncertainty around GHG emissions and removals associated with mangrove restoration activities. Reliable data on carbon sequestration rates in vegetation and soils, as well as the extent and effectiveness of rewetting in degraded mangrove systems, are critical to improving estimates of net GHG emission reductions. These improvements are vital to enhancing the credibility and effectiveness of blue carbon accounting and ensuring alignment with international climate reporting and carbon market standards.

Strategic alignment with VCS Standard and GS Framework would also enable Vietnam to leverage its mangrove ecosystems for high-integrity blue carbon crediting and secure greater access to climate finance under Article 6 and the voluntary carbon market.

By integrating AI-based tools, Vietnam can strengthen its capacity to generate credible carbon data, optimize resource allocation, and scale up participation in both compliance and voluntary carbon markets.

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